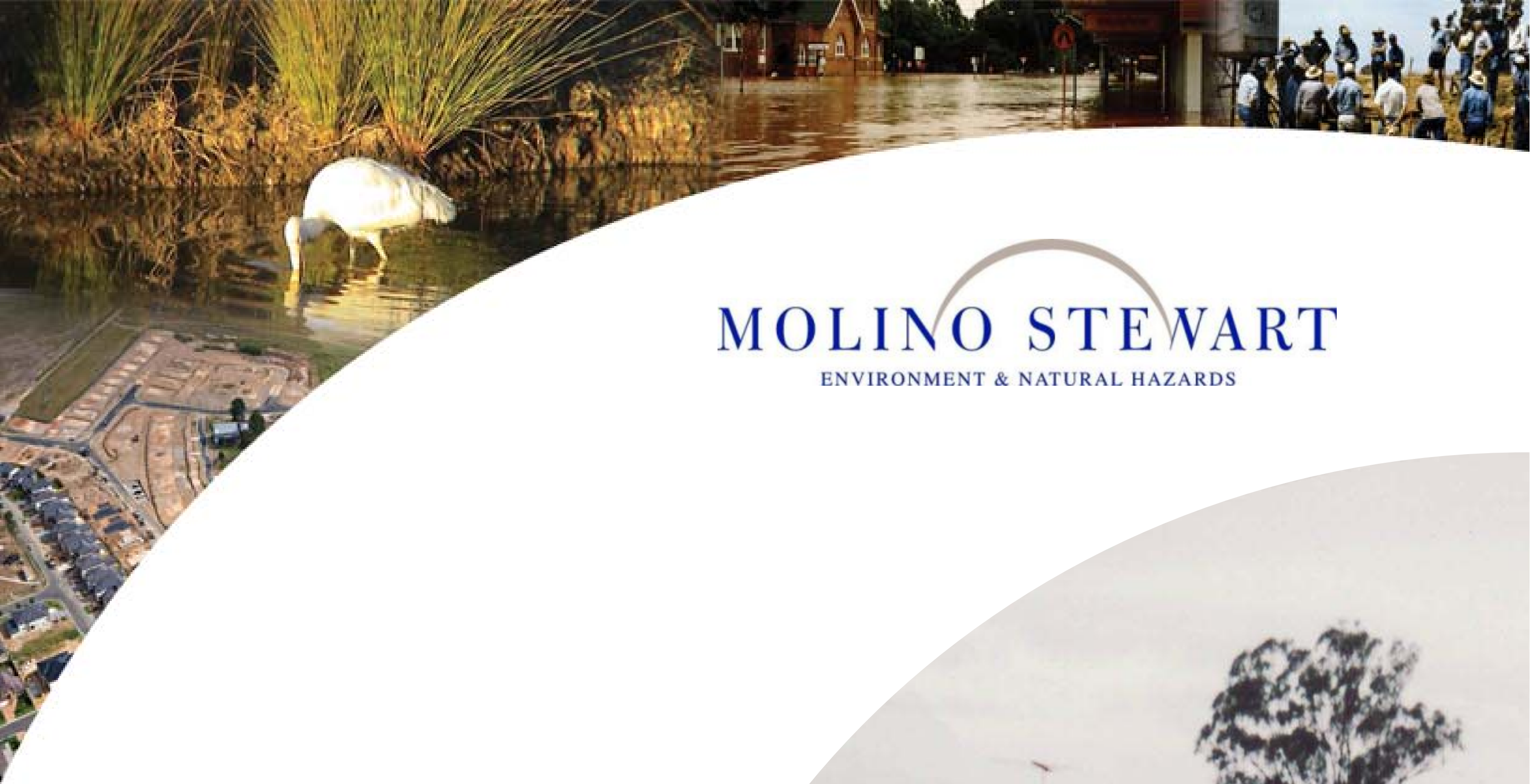

MOLINO STEWART
ENVIRONMENT & NATURAL HAZARDS

Infrastructure New South Wales

# Hawkesbury-Nepean Flood Damages Assessment: Final Report

# Hawkesbury-Nepean Flood Damages Assessment

FINAL REPORT

for

Infrastructure NSW

by

Molino Stewart Pty Ltd

ACN 067 774 332

SEPTEMBER 2012

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# DOCUMENT CONTROL

| | |
|---|---|
| ***Document Reference*** | 0528 HN_Flood_Damages_Report_Draft v1.3.docx |
| ***Project*** | Hawkesbury-Nepean Flood Damages Assessment |
| ***Document Type*** | Draft |
| ***Author*** | Tim Morrison; Steven Molino |

## REVISION HISTORY

| *Date* | Version | Name | Comments |
|---|---|---|---|
| *15/06/2012* | Ver 1.1 | Tim Morrison | First draft for internal review |
| *26/06/2012* | Ver 1.2 | Tim Morrison | Revised Draft |
| *27/06/2012* | Ver 1.3 | Steven Molino | Draft Report for client review |
| *11/07/2012* | Ver 1.4 | Steven Molino | Final Report incorporating INSW comments |
| *26/07/2012* | Ver 1.6 | Steven Molino | Final Report with additional information in Section 4.1 |

## DOCUMENT APPROVAL

| | |
|---|---|
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# EXECUTIVE SUMMARY

Infrastructure NSW has decided as part of its development of the 20 year State Infrastructure Strategy to review the issue of whether there is benefit in investigating the provision of flood mitigation capacity at Warragamba Dam.

This report sets out a preliminary investigation which draws heavily on previous work, particularly the 1995 Warragamba Flood Mitigation Dam EIS. However, since the 1995 EIS was produced, a number of changes have occurred in development on the floodplain, data availability and flood damage estimation techniques. These updates are reflected in the methodology for this project.

The flood damages in the Hawkesbury-Nepean Valley have been calculated under existing conditions and conditions if a 23m raising of Warragamba Dam were undertaken for flood mitigation.

The largest flood in living memory to have occurred in the Valley reached 15.0m above sea level at Windsor in 1961 and has about a 1 in 40 chance of occurring again in any year. The largest flood recorded in the Valley occurred in 1867 and reached 19.3m at Windsor and has roughly a 1 in 200 chance of occurring in any year. This is a similar probability to some of the floods in Victoria in early 2011. There is sedimentary evidence of even bigger floods having occurred before the arrival of Europeans. By way of comparison, some of the 2011 Queensland floods have been reported to have had a 1 in 1,000 chance of occurrence per year. A flood with that probability would reach 21.7m above sea level. Many of the houses built in the Valley up until the mid 1990s have floor levels at 16m and much older houses are even lower

A repeat of the 1867 flood, which was roughly equivalent to a 1 in 200 year event, would flood about 7,000 homes and cause significant structural damage to about 1,200 of them. It would flood more than 1,600 businesses and cause approximately $3 billion in damages. At least 26,000 people would occupy the buildings exposed to flooding and more than 50,000 people would have to evacuate from the Valley because of the risks associated with isolation and further rises in river levels.

Numerous flood mitigation strategies were investigated in the 1990s including structural works such as river straightening, levees, dredging and flood storages. Of these, a flood mitigation dam at Warragamba was found to be the most cost effective and have the least environmental impacts. Other options such as alternative spillway gate operation were found to have minimal flood mitigation benefit. Modifying assets in the floodplain including houses and infrastructure to make them less susceptible to flooding were found to be only worthwhile for new development or redevelopments. There have been significant investments in improved emergency planning to reduce risk to lives but significant life and property risks remain.

Were a flood mitigation dam to proceed with an additional 23 m of air space, the cost of the 1867 flood would be reduced to less than $200 million dollars and place less than 1,000 people at risk.

When the full range of floods and their probabilities are considered, the average annual damages of flooding is the Valley is expected to be in the order of $70 million. This estimate does not include the cost of complete building failure, which in a repeat of the 1867 flood may be the outcome for more than 1,200 homes. Should development within the valley continue, as is planned, then these flood damages will increase.

A 23m raising of Warragamba Dam to provide flood mitigation would reduce the annual average damages to less than $20m. When these annualised damages are reduced to a present value using a 7% discount rate and a 50 year benefit period, the total benefits of constructing the mitigation dam are estimated to be approximately $760 million.

In addition to the tangible benefits, there are a range of intangible benefits that have not been included in the benefit cost ratio. These include reducing:

- the population at risk, with the average number of at risk people per year reducing from 560 to 50.

- the probability of mass evacuations would reduce from about a 1 in 100 chance per year to less than 1 in 800.
- untreated sewage discharging into the River for weeks from about a 1 in 500 chance per year at Penrith and a 1 in 100 chance per year at Richmond and Windsor to less than a 1 in 1,000 chance per year at both of these locations.
- the number of commercial and industrial premises that are flooded in a repeat of the 1867 flood from more than 1,600 to less than 100. Many flood businesses are unlikely to recover after the flood and will go into liquidation, it is also likely that many of the employees will also reside in the valley and are likely to lose their job as a result.

Dam construction cost estimates from 1995 were inflated to December 2011 dollars and it was estimated that the 23m concrete raising of Warragamba Dam would cost $411 million. Using a conservative payment schedule over five years would result in a present cost of $346 million and a benefit cost ratio of 2.2.

In an extreme flood, with a probability similar to some of the 2011 Queensland floods, damages could exceed $8 billion, which would create a significant cash flow and balance sheet problem for the state economy.

An average annual insurance premium of more than $1,000 would need to be paid by each of the 19,000 households below the PMF just to cover their own flood losses, excluding the cost of rebuilding dwellings which fail structurally.

Sensitivity analyses using lower benefits, higher costs and various discount rates suggest that the project is likely to have a benefit cost ratio of greater than 1.0. When building failures are accounted for in the cost of damages the benefit cost ratio is estimated to exceed 3.0. These are summarised in the table on the following pages.

The economic worth of the project will increase if committed and planned development above the current planning level in the floodplain proceeds. Conversely, the reduced flood damages and other benefits will be eroded should future development be permitted below the current planning level after the mitigation dam is built. However the additional development would carry other benefits which would need to be weighed up against the reduction in flood damage benefits.

The dam would also deliver some significant intangible social, economic and environmental benefits because of the reduced risk of extended failure of critical electricity, sewerage and other assets. It would also have some intangible costs including the periodic, temporary flooding of up to 75km$^2$ of national parks and wilderness areas in the Blue Mountains World Heritage Area upstream of the dam, increased durations of minor flooding downstream which could have environmental impacts and construction impacts on Warragamba Village and surrounding areas during its 5 year construction.

This project represents a ‘first pass’ at calculating the benefits of a mitigation dam. Due to the timing constraints, a number of assumptions have been made and data has limited the precision of many of the calculations. Should a flood mitigation dam be investigated further, it is recommended that data and modelling be updated to provide more accurate estimates of the likely costs and benefits.

*Summary of Economic Evaluations*

| ***Scenario – 23m flood mitigation airspace provided by raising Warragamba Dam in mass concrete*** | **Damage estimation method** | **Existing Flood Damages NPV ($m 2011)** | **Mitigated Flood Damages NPV ($m)** | **Assumed period of mitigation benefit (yrs)** | **Dam Cost Estimation method** | **Mitigation Dam Cost ($m)** | **Dam Cost NPV over 5 years ($m)** | **Discount rate** | **Benefit-Cost Ratio** |
|---|---|---|---|---|---|---|---|---|---|
| *Base Case* | *Estimate using 1995 EIS methods but which accounts for changes in development plus CPI since 1990s.* | 1,041 | 281 | 50 | *1995 Dam construction cost escalated by CPI. Assumes 6 equal payments with first on Day 1.* | 411 | 349 | 7% | 2.2 |
| *Sensitivity 1: Low damage with high construction costs* | *Low estimate which simply inflates the 1995 EIS damages using CPI and ignores increased development on floodplain* | 895 | 248 | 50 | *1995 Dam construction cost escalated by 2 (Deloitte) and a further 50% Assumes 6 equal payments with first on Day 1.* | 741 | 630 | 7% | 1.03 |
| *Sensitivity 2: Base case damages plus building failure with most construction costs later in construction schedule than in base case* | *Base case plus additional damages to account for replacement of failed residential buildings ($250,000 per building)* | 1,157 | 310 | 50 | *1995 Dam construction cost escalated by CPI. NPV estimated from expenditure schedule used in the 1995 EIS* | 411 | 271 | 7% | 3.1 |

| *Scenario – 23m flood mitigation airspace provided by raising Warragamba Dam in mass concrete* | Damage estimation method | Existing Flood Damages NPV ($m 2011) | Mitigated Flood Damages NPV ($m) | Assumed period of mitigation benefit (yrs) | Dam Cost Estimation method | Mitigation Dam Cost ($m) | Dam Cost NPV over 5 years ($m) | Discount rate | Benefit-Cost Ratio |
|---|---|---|---|---|---|---|---|---|---|
| *Sensitivity 3: Applying 4% discount rate to Base Case Damages and Dam cost* | *Estimate using 1995 EIS methods but which accounts for changes in development plus CPI since 1990s.* | 1,582 | 426 | 50 | *1995 Dam construction cost escalated by CPI. Assumes 6 equal payments with first on Day 1.* | 411 | 373 | 4% | 3.1 |
| *Sensitivity 4: Applying 11% discount rate to Base Case Damages and Dam cost* | *Estimate using 1995 EIS methods but which accounts for changes in development plus CPI since 1990s.* | 706 | 190 | 50 | *1995 Dam construction cost escalated by CPI. Assumes 6 equal payments with first on Day 1.* | 411 | 321 | 11% | 1.6 |

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# 1 INTRODUCTION

## 1.1 PROJECT BACKGROUND

Warragamba Dam is the largest concrete dam in Australia and supplies the majority of Sydney's drinking water supply. Downstream of the dam, in the Hawkesbury-Nepean floodplain, significant development has occurred that will be flooded in large rainfall events.

The Hawkesbury-Nepean is arguably one of the most over-developed and at risk floodplains in Australia. A repeat of the 1867 flood in the Valley is expected to flood around 7,000 homes of which 1,000 would be likely to fail. The SES has plans to evacuate more than 60,000 people in an extreme flood.

The upgrade of Warragamba Dam to incorporate flood mitigation was proposed and investigated in the early 1990's. These investigations culminated in a comprehensive Environmental Impact Statement in 1995 (1995 EIS), data from which showed a significant reduction in flood extents could be achieved.

The State Government decided not to proceed with the mitigation dam but rather construct a side-spillway to ensure the existing dam's structural integrity in large floods. It was proposed to manage the residual flood risks downstream through town planning and emergency planning and the upgrading of evacuation routes to provide more time for evacuation. The 1997 Warragamba Dam Auxiliary Spillway EIS (1997 EIS) updated the previous flood damages work completed in the 1995 EIS.

Infrastructure NSW is again looking at the feasibility of a Warragamba Flood Mitigation Dam. One of the initial steps in this feasibility assessment is estimating the benefits which would be delivered by providing flood mitigation. These benefits will be a reduction in flood damages which will include both tangible economic benefits as well as intangible, but measurable, benefits (such as reduced risk to life).

## 1.2 THE HAWKESBURY-NEPEAN CATCHMENT

The Hawkesbury-Nepean Catchment covers approximately 21,000 square kilometres. It falls on the eastern side of the Great Dividing Range and almost completely surrounds the Sydney Basin. The headwaters of the catchment lie almost 50 km south of Goulburn, almost 10 km to the west of Lithgow and as far north as Newcastle (Figure 1). Approximately 9,050 square kilometres of the catchment is upstream of Warragamba Dam.

The catchment upstream of Warragamba Dam lies within the Southern Highlands and the Blue Mountains and the terrain is relatively mountainous with river channels in deep gorges. The Nattai, Wollondilly, Coxs and Kowmung rivers drain this part of the catchment and flow into the Warragamba River which is completely flooded by Lake Burragorang, the reservoir formed by Warragamba Dam. .

A few kilometres below the Dam, the Warragamba River flows into the Nepean River which itself has a catchment of about 2,000 square kilometres upstream of their junction. The confluence of the two rivers is in the Nepean Gorge. The Nepean River widens out into a wide channel with a broad floodplain at Regentville, less than 2 km upstream of the M4 Motorway Bridge. The river flows past Penrith, Richmond and then Windsor, where the river virtually reaches sea level.

Downstream of Windsor, the river flows back into a deep gorge at Sackville and continues to wind its way through the gorge until it reaches the estuary mouth downstream of Brooklyn. It is about 100km by river from Windsor to Brooklyn.

## 1.3 FLOODING IN THE VALLEY

During a flood upstream of Warragamba Dam, the water is generally confined to the deep gorges that are relatively un-developed. Below Warragamba Dam and the Nepean Gorge, the floodwaters can spread out across the

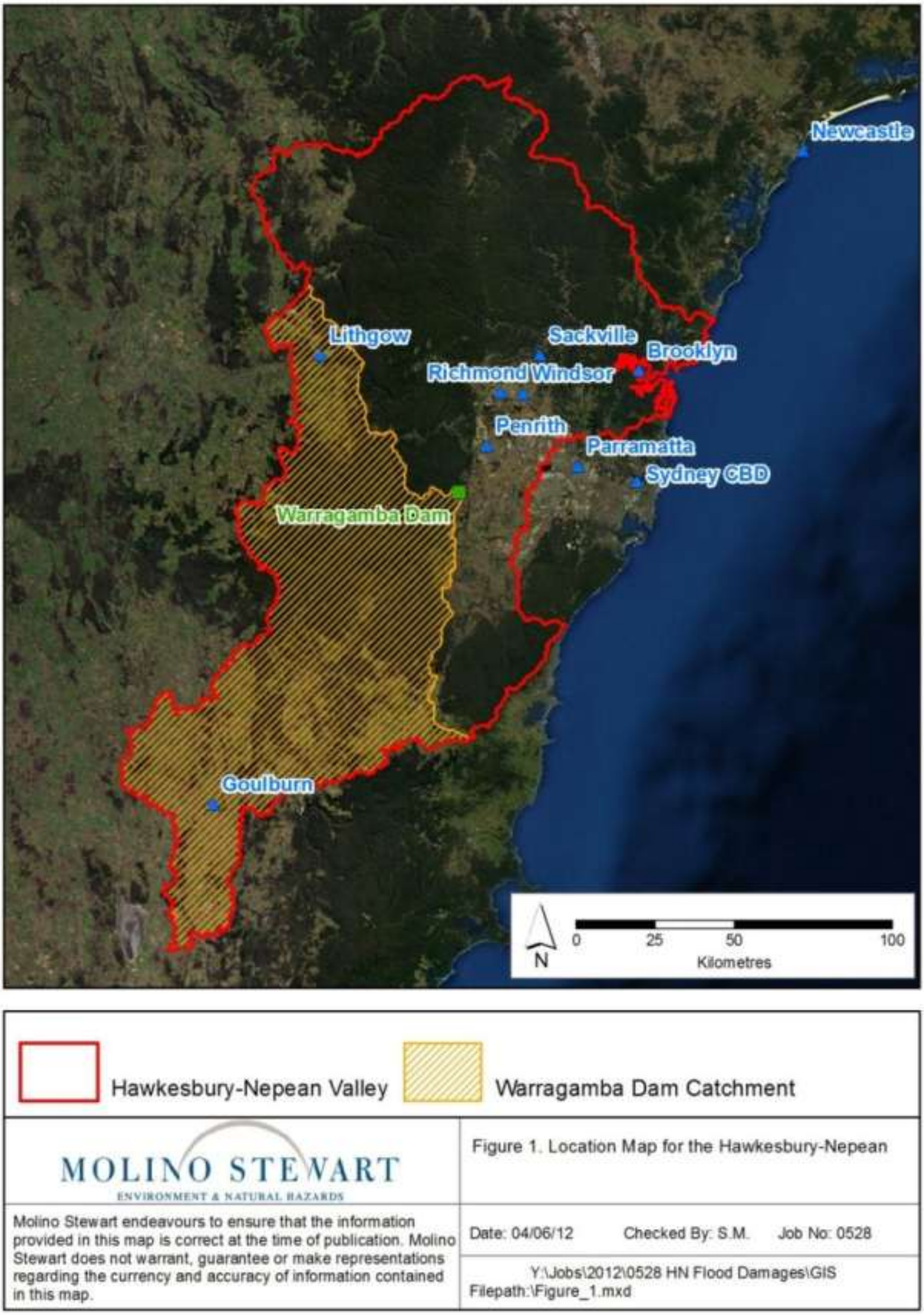


*Figure 1 Hawkesbury Nepean Catchment*

floodplain, inundating large sections of Penrith and Emu Plains and Richmond and Windsor. When the floodwaters reach Sackville, the River has reached sea level and the floodwaters which have spread out over the floodplain need to pass through the narrower gorge. These two effects combine to cause the floodwaters to flow out of the floodplain much more slowly than they are flowing in. The floodplain around Richmond and Windsor can therefore fill to quite extraordinary depths. This type of flooding is roughly analogous to a bathtub where the inflow from the tap is far greater than the outflow from the drain plug.

This then causes floodwaters to flow back up the River's tributaries, particularly South, Rickabys and Eastern creeks. This causes further inundation around Richmond and Windsor as well as several other suburbs, including Bligh Park, McGraths Hill, Riverstone, Marsden Park and Londonderry. It takes several days for this ponded water to flow out to sea.

Downstream of Sackville, the flow rate is decreased and the flooding is confined to the lower levels of the gorge, the area is mostly undeveloped, however low lying caravan parks and access roads as well as some isolated houses can become inundated. By the time a flood reaches Brooklyn, it has almost no impacts.

The largest flood on record in the Hawkesbury-Nepean Valley occurred in 1867 when the river level reached 19.3m AHD at Windsor. This essentially means that the water level was 19.2m above mean sea level compared to the normal river level at Windsor which is less than 0.5m above sea level. This flood is estimated to have about a 1 in 200 chance of occurrence in any year (1 in 170 at Penrith and 1 in 220 at Windsor).

Analysis of sediment 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 500 chance of occurrence in any year. Such a flood would reach 20.2m AHD at Windsor.

The Probable Maximum Flood (PMF), which is the largest flood that could theoretically occur, would reach a level of approximately 26.3m AHD. Figure 2 shows the extent of a flood similar to the 1867 flood and also the extent of the PMF. Table 1 outlines the history of recorded floods in the Valley.

*Table 1 Flood History*

| ***Chance per year*** | **Penrith (m AHD)** | **Windsor (m AHD)** | **When occurred** |
|---|---|---|---|
| *1 in 5* | 20.1 | 11.1 | 1992, 1986, 1975, 1956, 1952 & 11 other times |
| *1 in 30* | 23.9 | 13.3-14.5 | 1990, 1978, 1964, 1956 & 12 other times (8 times 1806-1819) |
| *1 in 40* | 24.4 | 15.0 | 1961, 1799 |
| *1 in 100* | 26.0 | 17.2 | Not occurred |
| *1 in 200* | 26.9 | 18.6 | 1867 |
| *1 in 500* | 27.6 | 20.3 | At least once before 1788 |
| *1 in 1,000* | 28.5 | 21.7 | No record |
| *PMF* | 32.1 | 26.4 | No record |

To place these probabilities in context, some of the rivers in Victoria which flooded in 2011 experienced floods with a 1 in 200 chance of occurrence while some catchments in Queensland experienced floods in 2011 that have been reported to have had about a 1 in 1,000 chance of occurrence.

The second largest recorded flood in the Valley was in 1799 and it reached 15.3m AHD. The third largest, and the largest in living memory, was in 1961 and it peaked at 15.1m AHD at Windsor. The most recent floods to have overtopped the river banks were in 1990 (13.4m AHD) and 1992 (11m AHD). There have been 14 floods in excess of 14m AHD recorded on the river, of which eight occurred within the 20 years between 1799 and 1819.

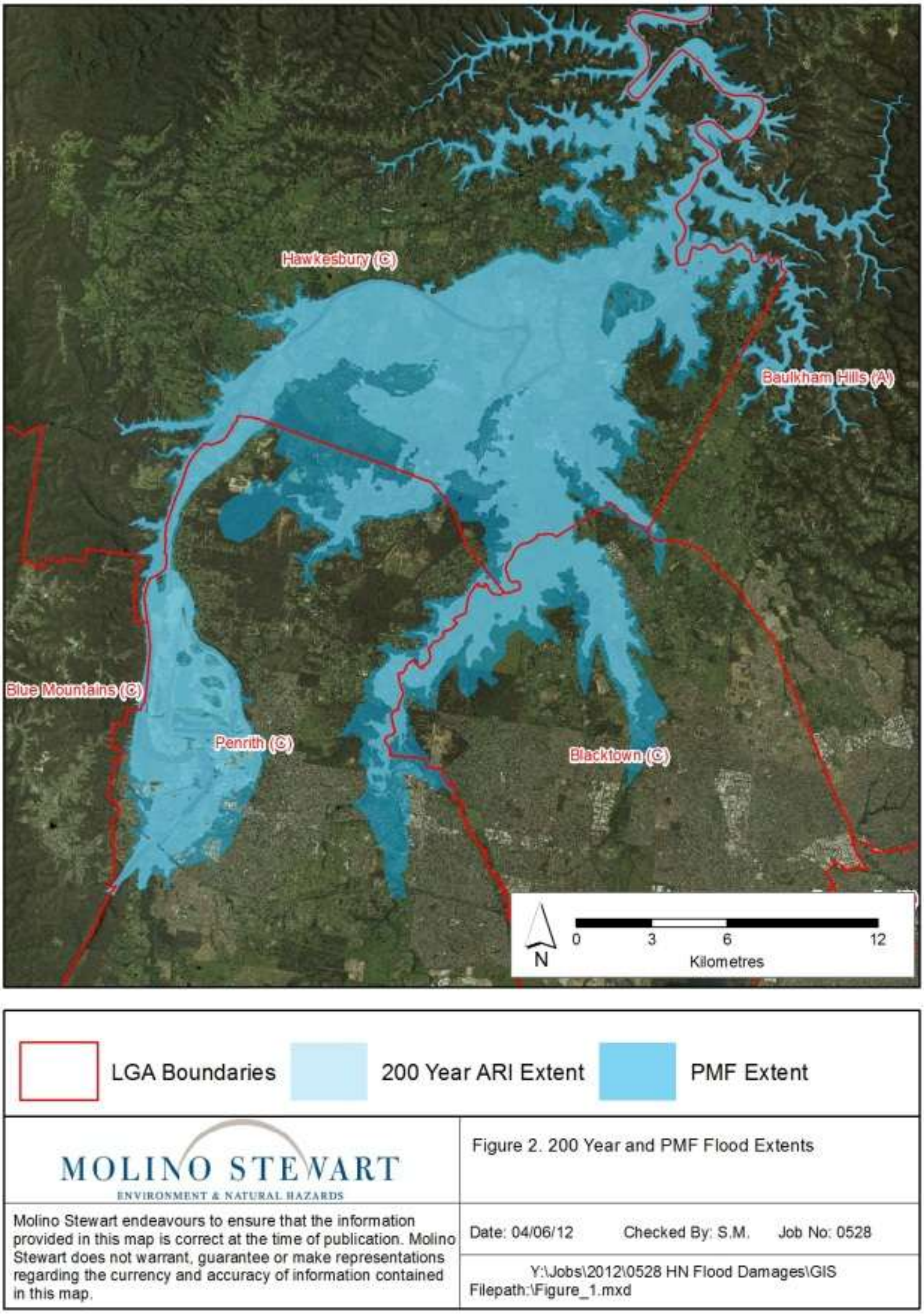


*Figure 2: Flood Extents*

## 1.4 DEVELOPMENT HISTORY

The devastating floods in the early days of the Colony moved Governor Macquarie to order that development should not take place on the low lying floodplains. To encourage development on the high ground he established the five Macquarie towns of Richmond, Windsor, Pitt Town, Wilberforce and Castlereagh. Little did he realise that all of Richmond and Windsor, most of Pitt Town and much of Wilberforce can be completely overwhelmed by floodwaters.

There are some older buildings on the Windsor floodplain which are constructed with floors as low as 11m AHD but most homes are built above 14m AHD. In the 1970s 16m AHD was adopted as the minimum floor level for new dwellings in the belief that this corresponded to the 1 in 100 year average recurrence interval (ARI) level at Windsor. Similar building controls were imposed elsewhere along the river and its tributaries.

Following the Warragamba Dam flood safety investigations in the 1990s, councils revised their minimum floor levels upwards to align with the new understanding of the 1 in 100 ARI flood level which is 17.2m AHD at Windsor. Some set their minimum habitable floor levels at the 1 in 100 ARI level while others added a freeboard of up to 0.5m on top of that.

Since that time development has continued in the Valley (see Figure 4 and Figure 5). There has been considerable infill development as well as some new subdivisions. In some instances evacuation and life safety considerations have constrained or prevented new subdivision but planning controls have generally permitted infill development without consideration of flood risk to life. In some suburbs, detached dwellings on quarter acre blocks have been replaced by several townhouses placed on that same block.

New urban development continues with houses built with a floor level at the current 1 in 100 ARI level could expect to be flooded to almost ceiling level in a repeat of the 1867 flood. Further development is planned (Figure 6).

The SES has developed a comprehensive flood emergency response plan for the Valley which caters for the evacuation of more than 60,000 who could be overwhelmed or isolated by floodwaters but recent studies suggest the number could be closer to 90,000 people.

A particular challenge with implementing the plan is that many of the evacuation routes have low points below the level of the premises which need to be evacuated. Despite hundreds of millions of dollars having been spent raising sections of these evacuation routes it would still be necessary to order people to evacuate long before they can see any threat to their buildings or their lives. Failure to evacuate in a repeat of the 1867 flood could result in significant loss of life.

Along with the urban development and rural residential development which has taken place in the Valley, there has also been a corresponding increment in utilities, infrastructure and essential services to meet the needs of the increased population.

While all of the service providers have taken flood risks into consideration in their planning and design, many have not thought about the implications of a flood larger than the 1 in 100 year ARI event. This has resulted in assets which are vulnerable to considerable damage in larger floods and the potential extended loss of service to many people who would otherwise not be affected by the flooding.

## 1.5 THIS REPORT

This report builds upon earlier work done for the Warragamba Dam EISs and subsequent investigations undertaken for NSW government agencies and local councils. It provides a more up to date estimate of the impacts and costs of flooding (flood damages) in the Valley and the potential reduction that could be achieved by flood mitigation capacity at Warragamba Dam.

Chapter 2 sets out how the flood damages were estimated and Chapter 3 summarises those estimates. Chapter 4 sets out the estimated damages were flood mitigation in place and Chapter 5 provides a preliminary economic analysis of flood mitigation. Conclusions and recommendations are provided in Chapter 6.

# 2 FLOOD DAMAGE ASSESSMENT

## 2.1 FLOOD DAMAGES

### 2.1.1 Damage Categories

Flood damages can be loosely divided into four categories, made up of a combination of two variables. The first variable is whether the damage is direct or indirect, where direct damage is defined as that which results from contact with the flood waters and indirect damage that which occurs as a consequence of the direct damages. The second variable is whether the damage is tangible or intangible, where tangible damage is defined as that which is able to be easily given a dollar value while intangible damages are those which are more difficult to value. Table 2 shows how the two variables interact to create the four categories and provides some examples of each.

The method of calculating flood damages varies between the four damage categories but within each category it will also vary between different types of development as each will be affected in different ways by a flood.

### 2.1.2 Stage Damage Curves

The majority of the tangible direct flood damages are in residential, commercial and industrial developments. Typically these are calculated using stage damage curves. A stage damage curve represents the cost per square metre of floor area for a given depth of inundation.

The stage damage curve is typically linear with a number of steps, these steps represent thresholds where large additional damages take place. For example, once flood waters exceed the height of a standard table, then additional damage will occur as most residents place their contents on tables to prevent flood damage.

There are also given depths at which it is assumed that a building will have considerable structural damage or is likely to fail. Building failure is not limited to a structural collapse but may also be damage such that major repairs or demolition are required after the flood.

Figure 3 is a typical set of stage damage curves for residential buildings.

### 2.1.3 General Approach

The flood damages for the Hawkesbury-Nepean have been previously calculated a number of times, most recently in 1997. In these assessments the tangible damages have been calculated for the different development types discussed in Section 2.2. Since these calculations were made, a number of changes to the floodplain have occurred, particularly in developing new residential, commercial and industrial buildings. Additionally, as construction methods and contents have changed, the stage damage curves have changed.

Updated stage damage curves have been used for the residential and commercial and industrial development types because there has been a significant increase in the vulnerability and value of building contents. However, for many of the other types of development there have been no significant changes on the floodplain and re-calculation of the damages would be inefficient for a preliminary study such as this. For these development types the Consumer Price Index (CPI) increase from December 1997 to December 2011 was applied to account for inflation over that time. If it was warranted, additional adjustments were made to account for changes in the magnitude of development. These have been documented as part of Section 2.2.

Indirect tangible damages are generally calculated as a proportion of direct damages. These will generally range from around 10% to over 150% depending on the development type and the scale of flooding. As part of the 1995 EIS, a literature review was undertaken to determine the most appropriate means of estimating indirect tangible damages for each development type. Generally those same methods have been applied for this study.

*Table 2 Flood Damage Categories*

| | Direct | Indirect |
|---|---|---|
| **Tangible** | Direct Tangible<br>Damage to buildings and contents<br>Loss of plant or stock<br>Damage to infrastructure | Indirect Tangible<br>Clean-up costs<br>Alternative accommodation<br>Lost production and profit |
| **Intangible** | Direct Intangible<br>Loss of life<br>Loss of memorabilia<br>Damage to heritage items | Indirect Intangible<br>Increased stress and anxiety<br>Increased illness<br>Loss of business confidence |

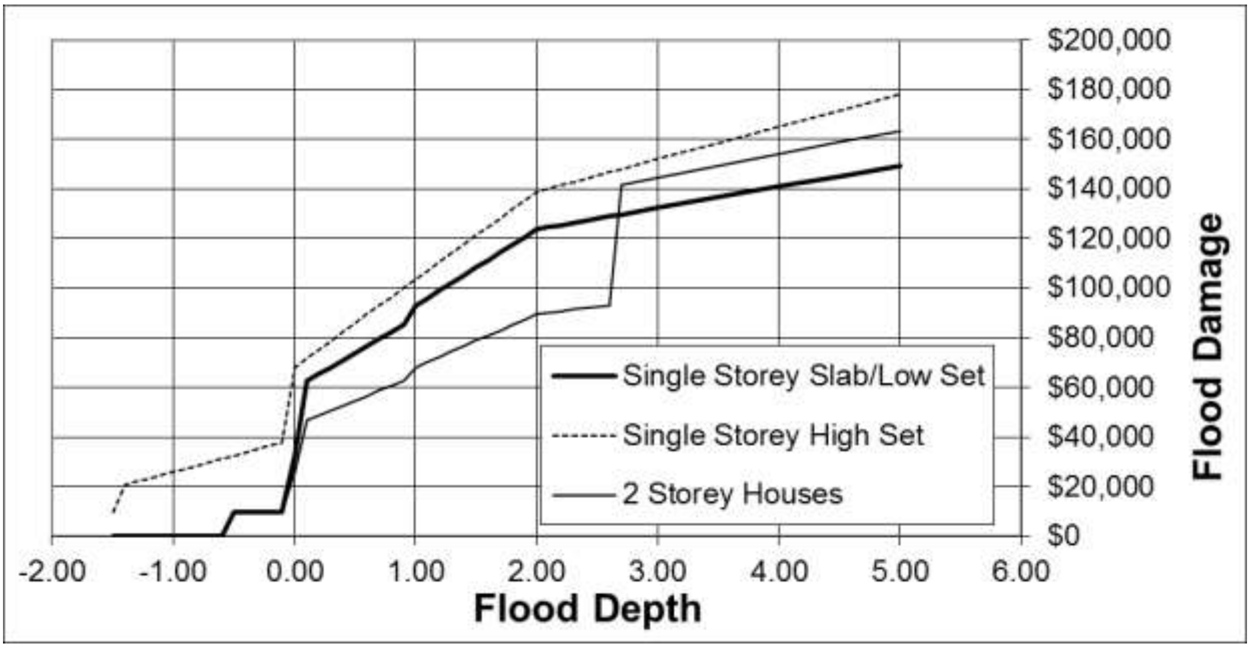


*Figure 3 Typical Residential Stage Damage Curve (Extract from the OEH standard residential calculator with default values applied)*

For details about original damage estimation methodologies the original EISs should be referred to. The following sections focus mainly on the methodologies used to update the damage estimates.

### 2.1.4 Data Sources

The data for this project has been derived from a number of sources as follows.

#### a) ANUFLOOD Location and Elevation Data

The ANUFLOOD Flood Damages program was previously used to calculate flood damages within the Hawkesbury-Nepean Valley in the 1990s. The program relied upon a database of property information that was gathered by two methods.

The first involved field surveys of urban areas by university students in 1988. The students logged information about building type, size, condition and use and estimated co-ordinates and floor levels from maps and survey benchmarks. By comparison to the data currently available, these data have low precision, however, the ANUFLOOD data is the only near-complete geo-referenced property database for the Hawkesbury-Nepean floodplain and includes more than 20,000 buildings. Therefore these data were used as a starting point for the commercial, industrial and residential flood damage estimates.

The second method involved logging rural residential properties by reviewing topographic maps of the floodplain. This dataset has since been mislaid within government but was never particularly accurate because the topographic maps were based on airphotos from the 1970s and it was difficult to interpret from the maps whether building were houses, let alone what floor level they had baed on contour intervals of up to 10m.

The ANUFLOOD software itself was not utilised as there are more powerful computer programs now available. For this study ArcGIS and WaterRIDE were used to undertake the tasks previously performed by ANUFLOOD as well as other, more advanced, analyses.

#### b) Google Earth and Street View for New Properties

Google Earth, including its ‘street view’, was used to locate all of the additional residential properties and calculate their size and assess whether each new property was one or two storeys. While the Google Earth software utilises a number of satellite images, a January 2009 image was predominately the latest available image in the catchment. Additionally, the Google Street data was predominately collected in late 2009.

#### c) Elevation Data

Recent Airborne Laser Survey (ALS) data was provided by the Sydney Catchment Authority for the majority of the floodplain. These data are highly accurate, however they were provided to the nearest metre and are therefore not very precise. It is believed that the raw ALS data would have sub metre precision, however it was not available within the timeframe of this project and it is considered that the data available would be accurate overall.

Additionally, where there were gaps in the ALS data, the freely available Shuttle Radar Topography Mission (SRTM) elevation data were applied, it was found that these data aligned to the ALS Data and were therefore acceptable for use.

#### d) Flood Model Data

Flood modelling data has been provided by Penrith City Council and Hawkesbury City Council for the Hawkesbury Nepean. In particular, time series flood extents and velocities were provided in WaterRIDE native formats and used to extract peak flood surfaces for the design events. The combined flood extents cover the floodplain from Regentville to Sackville.

#### e) Stage-Damage Curves

Two stage damage curves have been applied in this assessment. For the residential properties the Office of Environment and Heritage’s standard residential flood damage calculator was used with its embedded stage damage curve. This is based on the

Residential Flood Damages guideline within the New South Wales Floodplain Development Manual. The second stage damage curve applied was based upon the Worley Parsons (2008) stage curve for commercial and industrial properties. This is based upon a range of literature and community surveys and has been widely used in Floodplain Risk Management Studies and Plans in NSW.

These provide more realistic estimates of building contents damage than the stage damage curves used in the 1990s and which were thought to underestimate damages even then. This is explained further in Section 2.2.1.

### f) Existing Studies

A variety of published literature has been used in the production of this report. These sources include:

- Mitchell McCotter (1995) 'Warragamba Flood Mitigation Dam EIS', prepared for Sydney Water and the NSW Government
- Hawkesbury-Nepean Flood Management Advisory Committee (1997) 'Achieving a Hawkesbury-Nepean Floodplain Management Strategy'
- Mitchell McCotter (1996) 'Proposed Warragamba Auxiliary Spillway EIS', prepared for Sydney Water
- Molino Stewart (1997) 'Hawkesbury-Nepean River Impacts of Flooding on Communities and Infrastructure'
- Molino Stewart (2012) 'Hawkesbury Nepean Flooding Impacts Review', prepared for NSW SES

## 2.1.5 Assumptions and Limitations

- The data used in ANUFLOOD was created before GPS recording was available. This has meant that each point is not necessarily marking the centre of each house, but is frequently offset, sometimes by up to 50 m. On sloping land this may mean the depth of inundation for those houses is over or under estimated, depending on the position of the data point relative to the house.
- Similarly, the floor level estimates in the ANUFLOOD dataset were based on field estimates of floor heights above ground levels which were estimated from surveyed benchmarks. There is likely to be inaccuracies in these estimated levels but there is no reason to suspect that they would consistently underestimate or overestimate floor levels.
- The floor levels of new urban residential dwellings and all of the rural residential dwellings were estimated by assuming a height above the ALS level for the location of the dwelling. New urban residential floors were assumed to be 300 mm above ground level and rural residential floors 500 mm.
- All residential properties were categorised as either; small, medium or large. Small houses were assumed to 150 m$^2$, medium 240 m$^2$ and large houses 300m$^2$. House sizes were categorised as the damages calculator does not have the functionality to have a size for each individual house. While some houses will be under-estimated in size, and therefore damage, it is expected that some houses will be over-estimated and therefore the overall damages will remain accurate.
- For the vast majority of properties, the SCA ALS data has been used to estimate the ground height. While the collected data would generally be accurate to within 100 mm, the data which has been provided is only reported to the nearest metre. This will lead to both over and underestimations of individual house floor heights, but it is expected that this will still be accurate across the catchment. Where the ALS data was not available, the less accurate SRTM data was utilised, checking of this data where it overlapped with the ALS showed that it still remained fairly accurate, with no consistent over or under estimation.
- The stage-damage curves used make a number of assumptions regarding the cost of repairs and replacing house and commercial/industrial contents. In reality these may be greater or smaller than those estimated by the stage-damage curves. This study has applied industry best practice stage-damage curves and is expected to be as accurate as possible.
- The residential and commercial and industrial stage-damage curve do not take into account the cost of completely replacing a failed building and therefore may underestimate damages, particularly

in the more extreme events where building failure is likely to be widespread.

- The developed proportions of new commercial and industrial land have been estimated using aerial imagery. It has been assumed that 53% of commercial and industrial areas are buildings' floor space which contributes to flood damages. The remainder is roads, parking and open space. This number has been derived by checking approximately 5% of the new commercial and industrial land areas and floor areas within the GIS.
- It has not been possible to estimate the number of commercial and industrial premises now affected by flooding without undertaking a similar ground level survey as was undertaken in 1988. Suffice to say that there are considerably more businesses affected than 25 years ago.
- Where there has been no change in the level of development, it is assumed that the cost of flood damages (other than commercial, industrial and residential) has increased at the same rate as the CPI index. The value utilised for December 2011 is 179.40 and December 1997 is 120.00.
- Flood modelling data which was available for this study only covered the floodplain between Regentville and Sackville. This covers the vast majority of development but there is some development upstream and downstream of these locations which would make a small contribution to flood damages. Also there were no flood surfaces available for the Penrith floodplain below the 1 in 100 year ARI event. This means that there is a slight underestimate of residential, commercial and industrial damages due to the exclusion of these areas and events.
- The flood model provided for the Penrith floodplain conformed to a 2008 configuration of the proposed Penrith Lakes Scheme finished form. There have been other proposed finished forms for Penrith Lakes since that time but as no decision has been made as to what final form it would take, it was determined that the 2008 model would be adequate for the purposes of this investigation.
- Flood modelling assumes that Warragamba Dam will not fail in any flood but that the auxiliary spillway will operate in floods exceed a 1 in 500 year ARI event.
- Damage estimates are for the amount of development on the floodplain in 2011. Should that increase in the future, as is planned, then flood damages will increase.

## 2.2 ASSET CATEGORIES

### 2.2.1 Residential Properties

Residential properties are single dwelling houses, duplexes, town houses and apartment complexes. Residential damage includes the structural damage to the building as well as damage to the contents of the building.

The majority of the urban residential buildings within the floodplain were located by field survey in 1988. Rural residential buildings were generally identified from orthophoto or topographic maps in 1992 although the photographic bases for the maps generally dated from the 1970s. The 1988 field survey data was available digitally for this study and was imported into a geographic information system (GIS). The other data had been mislaid over time.

It was known that additional development had occurred since the previous data was collected and so additional residences were located using recent aerial images (see Figure 4 and Figure 5). This same method was also used to log all rural residential buildings as the older data had been lost and there were new homes built since. These dwellings were digitised and added to the GIS. The size of the new buildings was estimated using aerial images and the GIS and the number of storeys determined using Google Street View.

The areas downstream of Sackville were not included because of time and budget constraints, the limited flood model data available for that section of the River and the minor contribution to total losses that these properties make.

A total of 21,142 residential buildings within the floodplain were located. This is nearly 5,000 more dwellings than previously estimated. The work in the 1990s used a computer program called ANUFlood to estimate residential damages using stage damage curves which were built into the program. The 1995 EIS suggested that this may have grossly underestimated residential building damages because the values of contents were based on surveys which dated back to the 1974 Brisbane flood.

Subsequent studies by Risk Frontiers at Macquarie University found that residential damages are far greater than had been estimated by ANUFlood. The NSW Government has since issued a standard calculator to be used in estimating residential flood damages which has a much more realistic and up to date set of residential stage damage curves which accounts for significant quantities of high value electronic goods in homes today.

For this assessment, the rural residential properties have been combined with urban residential properties. All residential damages have been calculated using the Office of Environment and Heritage's standard Residential Flood Damage Calculator (OEH, 2012). The size of the properties has been divided into three categories for use in the calculator:

- Small: assumed 150 $m^2$ floor plan area
- Medium: assumed 240 $m^2$ floor plan area
- Large: assumed 300 $m^2$ floor plan area

It should be noted that the calculator does not make allowance for the cost of replacing buildings that have failed. Therefore it is expected that the damage estimates are potentially on the low side for a floodplain such as the Hawkesbury Nepean where significant flood depths and, in some locations, velocities, could see many homes destroyed by floodwaters. A sensitivity analysis was undertaken by making an additional allowance for the reconstruction of severely damaged homes.

ANUFlood had previously been used to estimate whether buildings would be structurally damaged. This time an inbuilt hazard function in WaterRIDE calculated peak depth and velocity combinations to determine whether building failure was likely. From the results it would appear that WaterRIDE estimates buildings to be more robust that ANUFlood had done.

Indirect damages were previously estimated in two parts. The first part was a percentage of the direct damages with the percentage being higher for more extreme floods. Those percentages were maintained for this study. The second part was based on the cost of temporary accommodation for properties which were evacuated and the duration of evacuation. Evacuation duration was estimated to depend on whether the building was isolated, flooded or structurally damaged by floodwaters and how widespread the flooding would be.

The same durations for absence were used as previously but it was assumed that alternative accommodation would cost $375 per week which is about equivalent to CPI being applied to previous alternative accommodation estimates.

### 2.2.2 Commercial & Industrial Properties

Commercial and industrial properties are all other properties not used as residential dwellings, including major public buildings such as hospitals and schools as well as private hospitals, schools, nursing homes and child care facilities.

Commercial and industrial development was also catalogued through field survey in 1988 and this information was imported into the GIS for this project.

A recent airphoto was compared to a 1988 airphoto to identify areas new commercial and industrial development since then. An estimated additional 143 hectares of commercial and industrial floor space has been added to the floodplain since 1988 (see Figure 4 and Figure 5).

The original commercial and industrial damages were calculated using stage damage curves built into ANUFlood. For this assessment the flood damages from the 1997 EIS were used for the commercial and industrial areas that were developed at that time and then inflated using the CPI. The damages for the additional areas were calculated using the WaterRIDE Floodplain Manager software, utilising the Worley Parsons Industrial and Commercial Damage Curves, which are derived from Water Studies (1992). These values were then inflated using CPI to December 2011 values.

Indirect damages were calculated as a percentage of direct damages with the percentage increasing for more extreme and widespread flooding as was done in 1997.

### 2.2.3 Caravans

There are many caravan parks along the Hawkesbury River, particularly downstream of Pitt Town. Many are small facilities used only at weekends or holiday times.

In the 1997 EIS, caravan flood damage costs were developed using Smith et al. (1990). The following assumptions were made:

- all caravans were family holiday style units, 5 to 6 metres long
- temporary sites were 50 per cent occupied
- there would be no opportunity to remove vans or contents, so actual damages would equal potential damages
- caravan damages were increased by 20 per cent to allow for facilities provided by the caravan park such as amenities and laundries

In the 1997 EIS total damages for caravans were relatively minor thus more detailed investigations were not warranted.

In this assessment the caravan damages from the 1997 EIS have been inflated using the CPI.

### 2.2.4 Motor Vehicles

When the original damage estimates were undertaken a comprehensive flood emergency plan for the Valley did not exist and it was assumed that in the larger floods most motor vehicles would suffer some flood damage and half would be written off. The degree of damage was estimated based on the depth of flooding at the home where it was usually parked.

Today, there is a plan to evacuate, by motor vehicle, all residents at risk and so even in the larger floods the proportion of cars which remain in the floodplain is likely to be much less than assumed in previous studies. However, because of the increase in electronics in vehicles in the past 20 years, it is more likely that a car that suffers any above floor flooding will be written off. Additionally, the number of vehicles per capita has increased by over 13% during this time. Therefore it is believed that our estimates are conservatively low.

In a flood, it is expected that the residents and persons at commercial and industrial sites will evacuate using their vehicles. Previous studies by Molino Stewart, using the SES Timeline Evacuation Model, have estimated the number of vehicles that are likely to be unsuccessful in a flood with the same rate of rise as a PMF event (Molino Stewart, 2012).

Despite all of these changes, motor vehicles make a very minor contribution to the total damages. For this study the 1997 estimates were simply inflated by CPI.

### 2.2.5 Agriculture

Non-urban areas of the floodplain are mainly used for agriculture.

Direct agricultural damages are caused by the inundation of farm plant and improvements, loss of livestock, damage to livestock fodder reserves and loss of crops in production. Indirect damages include loss of production during re-establishment of the enterprise after flooding.

In the 1997 EIS flood damages per hectare were calculated from the value of plant and improvements used in agricultural production and gross margin data for each activity. Gross margin is the sale price of produce minus production and transport costs. The flood damages are an average year cost for the planting and harvesting seasons. They included some production costs but excluded harvesting and transport costs.

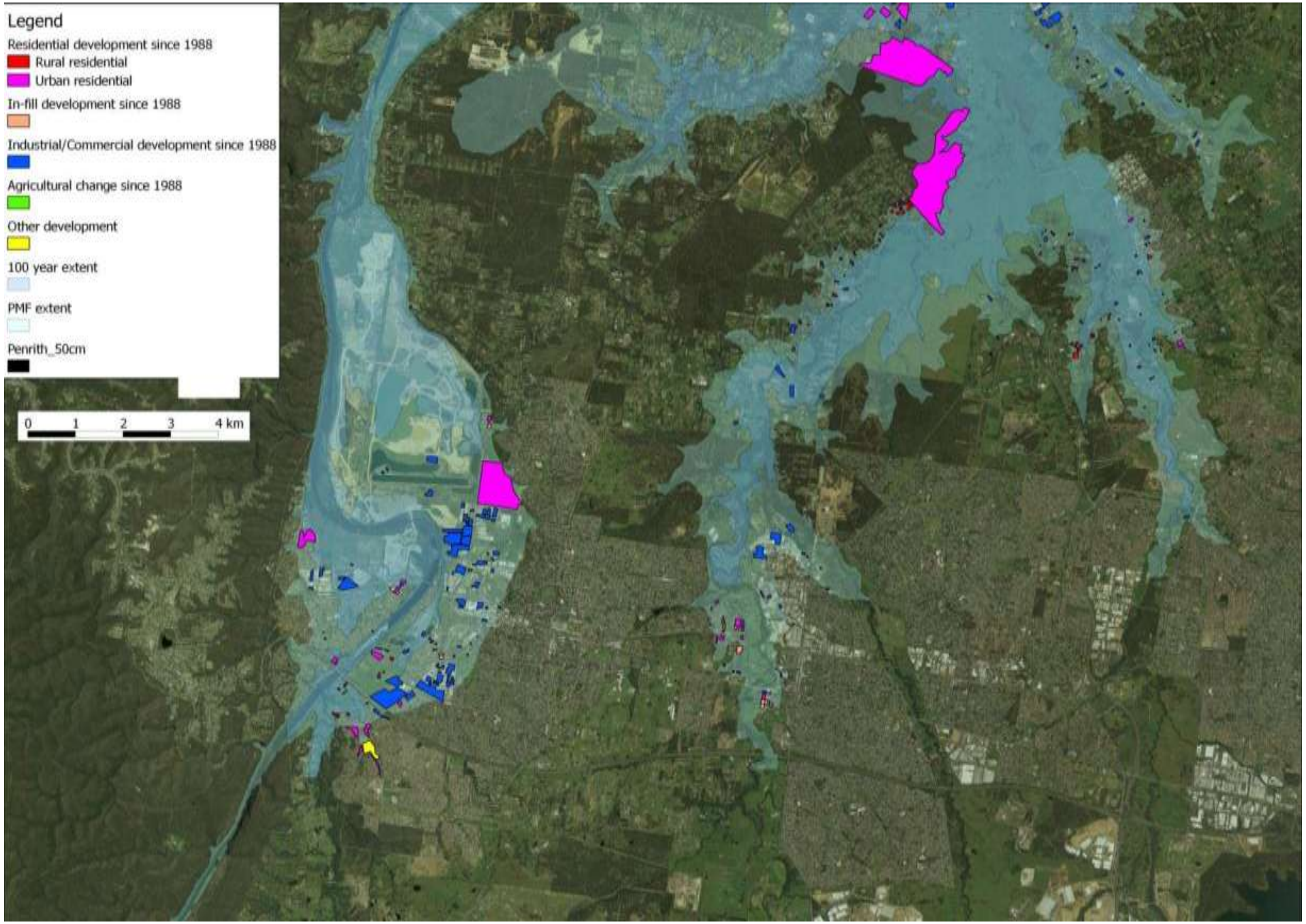


*Figure 4 Changes to Rural and Urban Development since 1988 (Southern Extent including Emu Plains, Penrith, St Marys and Riverstone)*

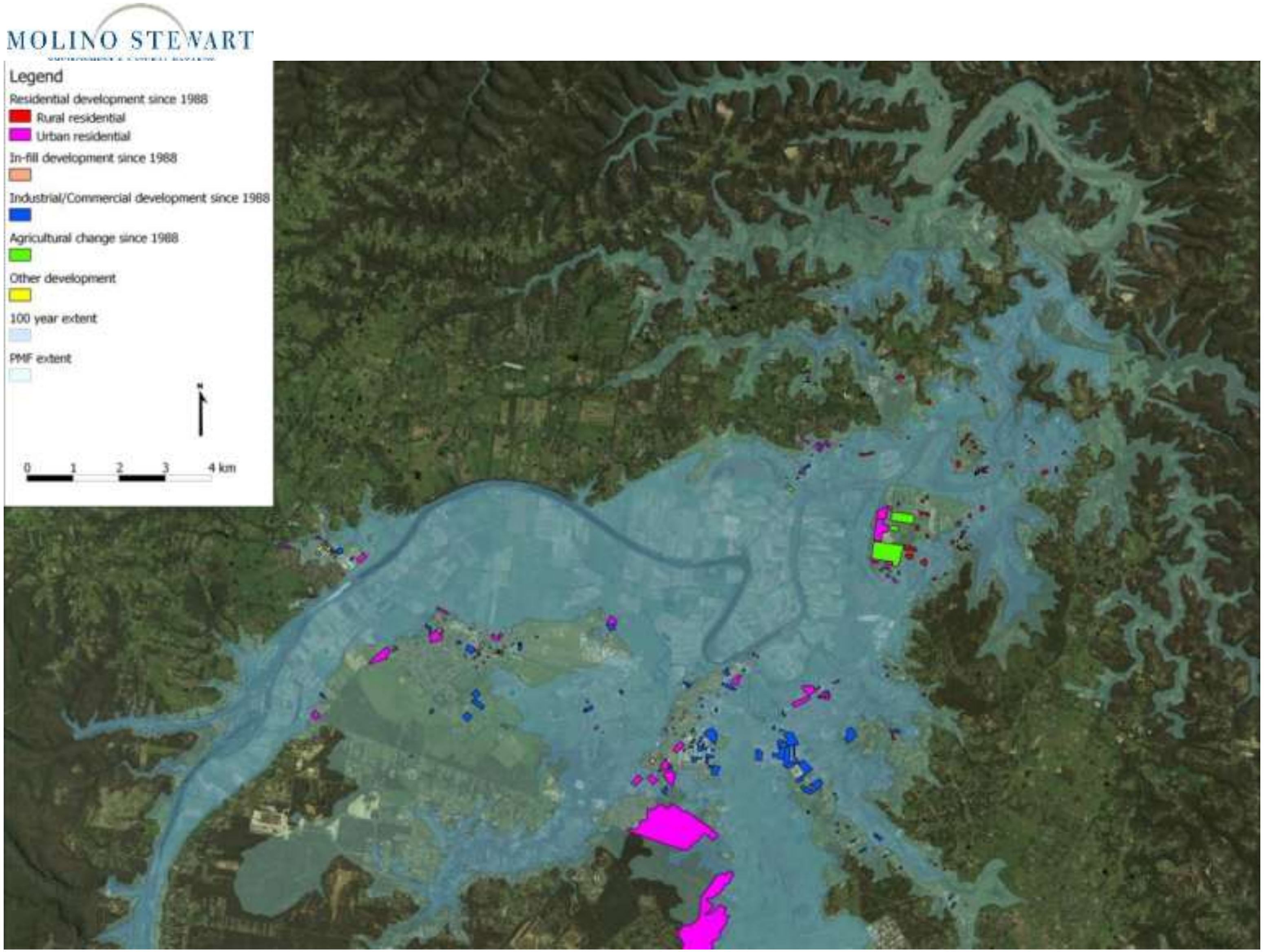


*Figure 5 Changes to Rural and Urban Development since 1988 (Northern Extent including Richmond and Windsor)*

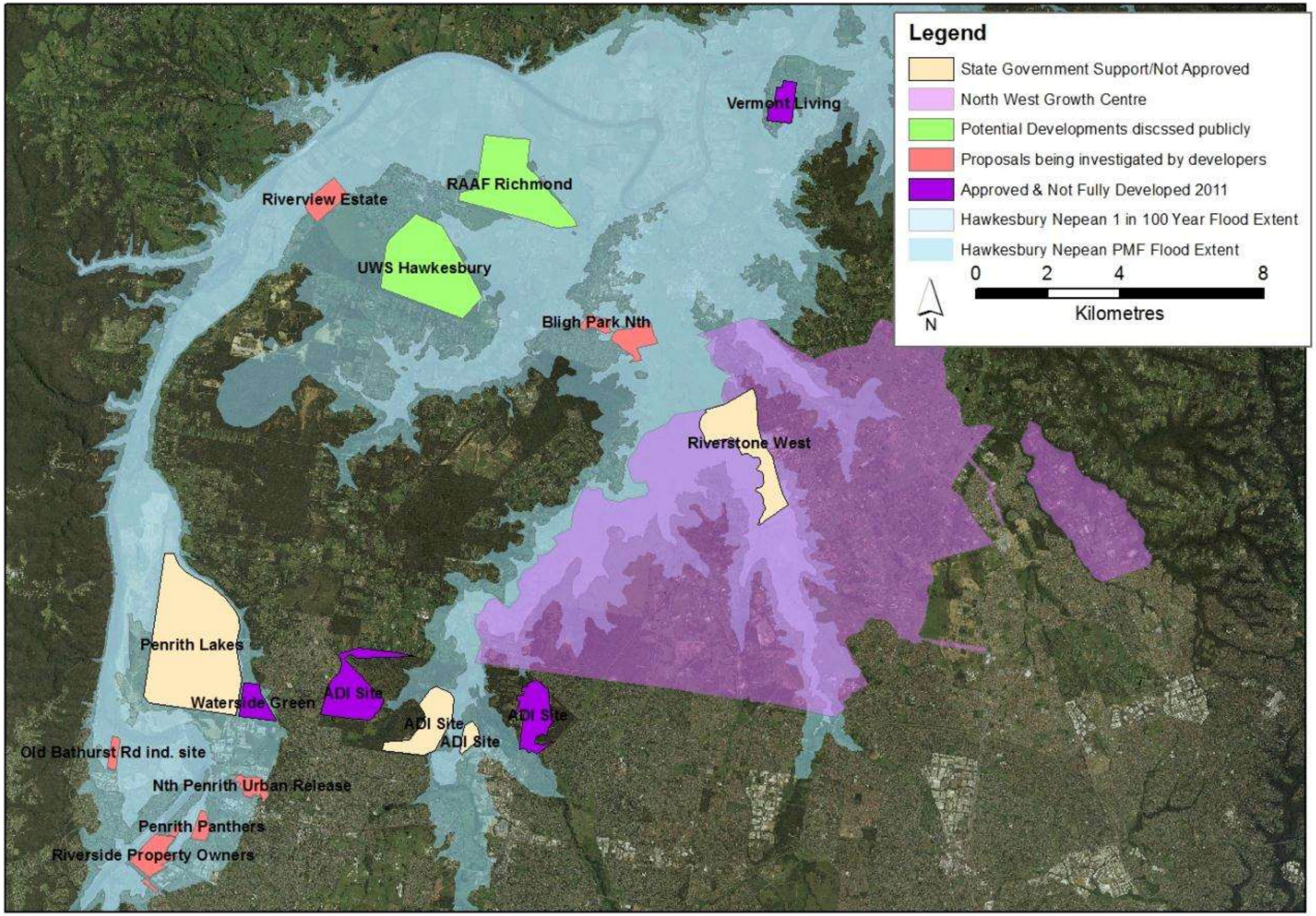


*Figure 6 Future Development*

Since this time, the value of plant and equipment in the floodplain is likely to have increased, however the total agricultural area and output is likely to have decreased. There have also been changes in the type of agricultural production on the floodplain. Some of this was clear from airphotos (see Figure 4 and Figure 5). The level at which these have occurred is difficult to estimate and, given the small contribution of these damages to the overall total, it was considered not worth more detailed analysis for this project.

In this assessment agricultural damages from the 1997 EIS have been applied and updated using the CPI.

### 2.2.6 Roads & Bridges

There are numerous urban communities throughout the valley, surrounded by intensive agriculture. They are connected by a network of roads including a state highway and two motorways (see Figure 7).

The three principal roads crossing flood-affected areas are the M4 (Western Motorway), State Highway 44 (Great Western Highway) and the M7 (Westlink). The M4 Motorway parallels the Highway and provides a link from Sydney to the Blue Mountains and western parts of NSW that by-passes urban settlements in the western suburbs. The M7 connects the M2 at Blacktown, the M4 at Eastern Creek and the M5 at Casula.

The Great Western Highway is the major road transport link between Sydney and its western suburbs. Regional links through the area connect Singleton to Campbelltown, Parramatta to Lithgow, and Liverpool to Richmond.

The main transport routes affected by moderate to extreme flooding are the roads crossing the Windsor/Richmond/Castlereagh area. They include:

- Richmond/Blacktown Road
- Windsor Road
- Castlereagh Road
- Bells Line of Road
- Putty Road

Some of these cross the Hawkesbury-Nepean River. Hawkesbury Road crosses at Yarramundi Bridge south of Richmond and Bells Line of Road links Richmond and Lithgow via Richmond Bridge. Windsor Road crosses the river at Windsor Bridge just north of Windsor and continues north as the Putty Road to Singleton. In the Penrith area the M4 Motorway crosses the river on the Regentville Bridge and the Great Western Highway crosses on Victoria Bridge.

Roads may be damaged by flooding in two ways. Where water velocities are high they may be scoured or undermined, with damaged sections requiring subsequent reconstruction. Bridge approaches and sections of road along river banks are particularly susceptible to this type of damage. Roads may also be damaged by traffic loadings. When flood waters are deep and the period of inundation is long, the subgrade under roads may become saturated. In this state they are weak and significant traffic loads may cause the pavement to fail. It may take several days after flooding before a road can return to full strength.

Flood damage to bridges depends on the structural design of each bridge. North Richmond, Windsor and Yarramundi bridges were designed to be submerged. Victoria and Regentville bridges were intended to be above design flood levels. They could potentially fail if overtopped in more extreme flood events. Bridges can also be damaged by erosion around abutments, which can remove structural support and lead to the collapse of the bridge. Damage can occur from debris striking the bridge structure.

In the 1997 EIS total lengths of main, rural and arterial roads in the study area were measured from 1:4,000 orthophotomaps. Residential roads were estimated from the number of properties in urban areas and an average length of road per property which was calculated from three sample suburbs.

Since the 1997 EIS data were collected, additional roads and bridges have been constructed to service the additional houses and commercial areas, it has been estimated that this has increased the total road lengths within the floodplain by approximately 10%

In this assessment roads and bridges damages have been calculated by inflating the 1997 estimates by the CPI and adding an additional 10% to account for new road infrastructure.

### 2.2.7 Railways

The study area is crossed by the Main Western Railway, which runs through Penrith and Emu Plains, and the Blacktown to Richmond line which joins the main Western line at Blacktown. Both lines are electrified and are major commuter routes serving the western suburbs and Blue Mountains areas, and the North West Sector respectively.

The main Western line also serves western NSW and is part of the rail link to Western Australia. The line crosses the Nepean River on a rail bridge adjacent to Victoria Bridge (see Figure 8).

Floods with a 1 in 10 chance of occurrence per year can disrupt traffic on both lines. Traffic can be suspended for between 10 and 24 hours due to the effects of water on signalling, communications and power facilities.

In the 1997 EIS it was assumed that:

- rolling stock trapped in the affected area would be moved to higher ground and would not be damaged by rising flood waters;
- Signalling, electrical assets and stations would be damaged by floodwaters;
- 20% of overtopped sections of the Western Line would be scoured. This is because the line acts as a control across the floodplain and is perpendicular to the direction of flow;
- only the section of the Richmond Line between Richmond and Mulgrave would be subject to scouring as the remainder of the line is in a low velocity area. It was assumed that 10% of the inundated length of this line would scour;
- the rail bridge over the river would fail when flood waters exceed 28m AHD.

Direct damages to rail were based on the cost of replacing or repairing the damaged assets listed above.

Failure of the rail bridge and scour of the rail embankment (the embankment washing away) at Penrith would severely disrupt commuter services from the Blue Mountains and wheat and coal exports from Western NSW for about six months.

Indirect rail damages included the loss of revenue from commuter rail ticket sales and the cost of diverting exports via Port Kembla and Newcastle.

In this assessment, damages have been calculated using the 1997 EIS damages inflated to the December 2011 value, using the CPI. This is likely to underestimate the damages because of the increase in passenger numbers and coal freight.

### 2.2.8 Water & Sewerage

Sydney Water supplies Sydney, the Blue Mountains and the Illawarra Region. Most of this water comes from the Hawkesbury-Nepean river system.

There has not been a significant increase in major water supply infrastructure in the floodplain since 1997 (see Figure 9).

There are eight Sewerage Treatment Plants (STPs) potentially affected by flooding. They are St Marys, Penrith, North Richmond, Richmond, McGraths Hills, South Windsor, Riverstone and Quakers Hill (see Figure 10). Several of these have had significant upgrades since 1997 and since they, by necessity, are at low points in the floodplain, they are very susceptible to flood damage.

In this assessment water and sewerage damages have been calculated using the 1997 EIS damages inflated using CPI and then multiplied by 1.5 to principally account for the additional sewerage assets.

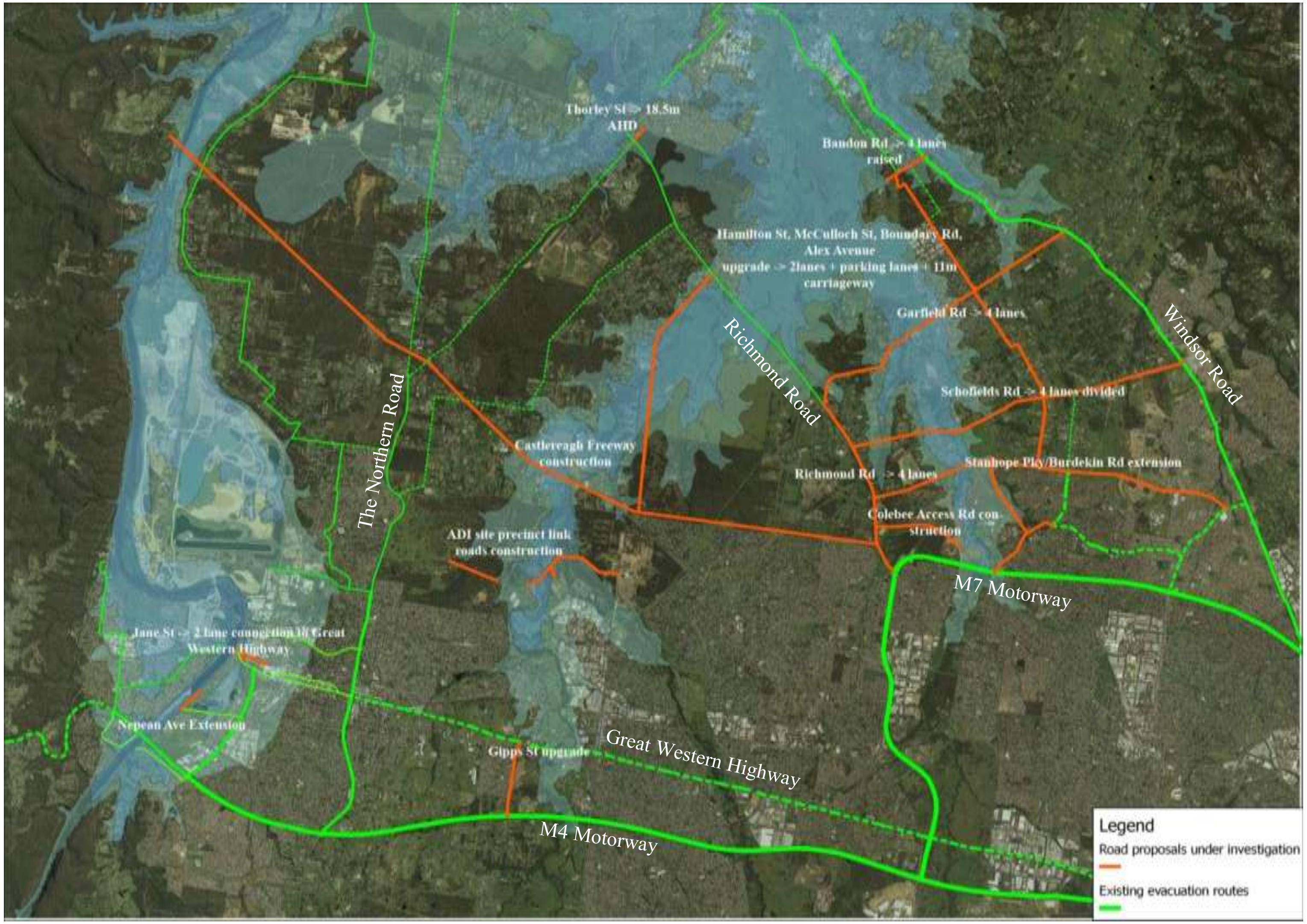


*Figure 7 Evacuation Routes and Future Road Proposals*

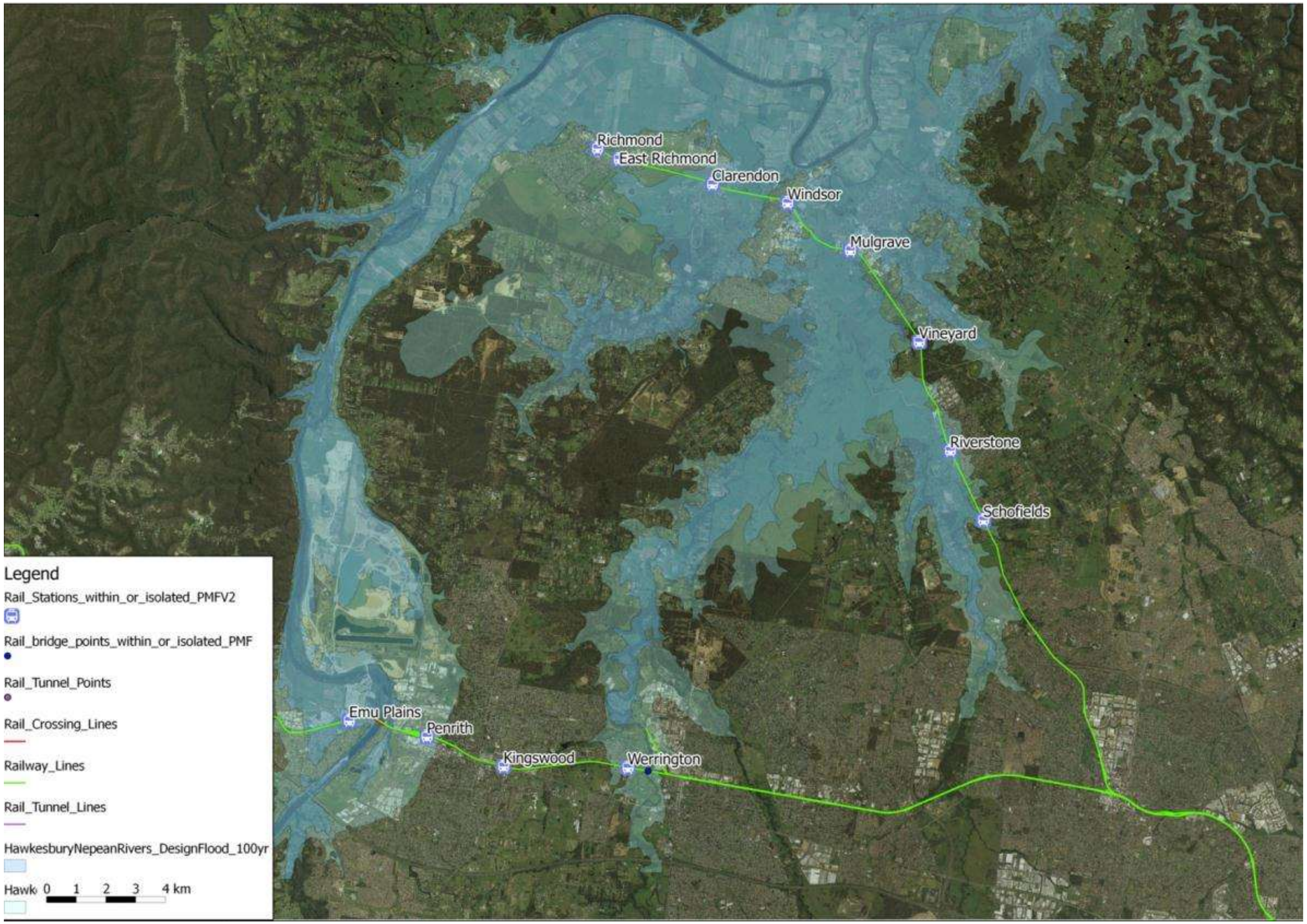


*Figure 8 Rail infrastructure located on the floodplain*

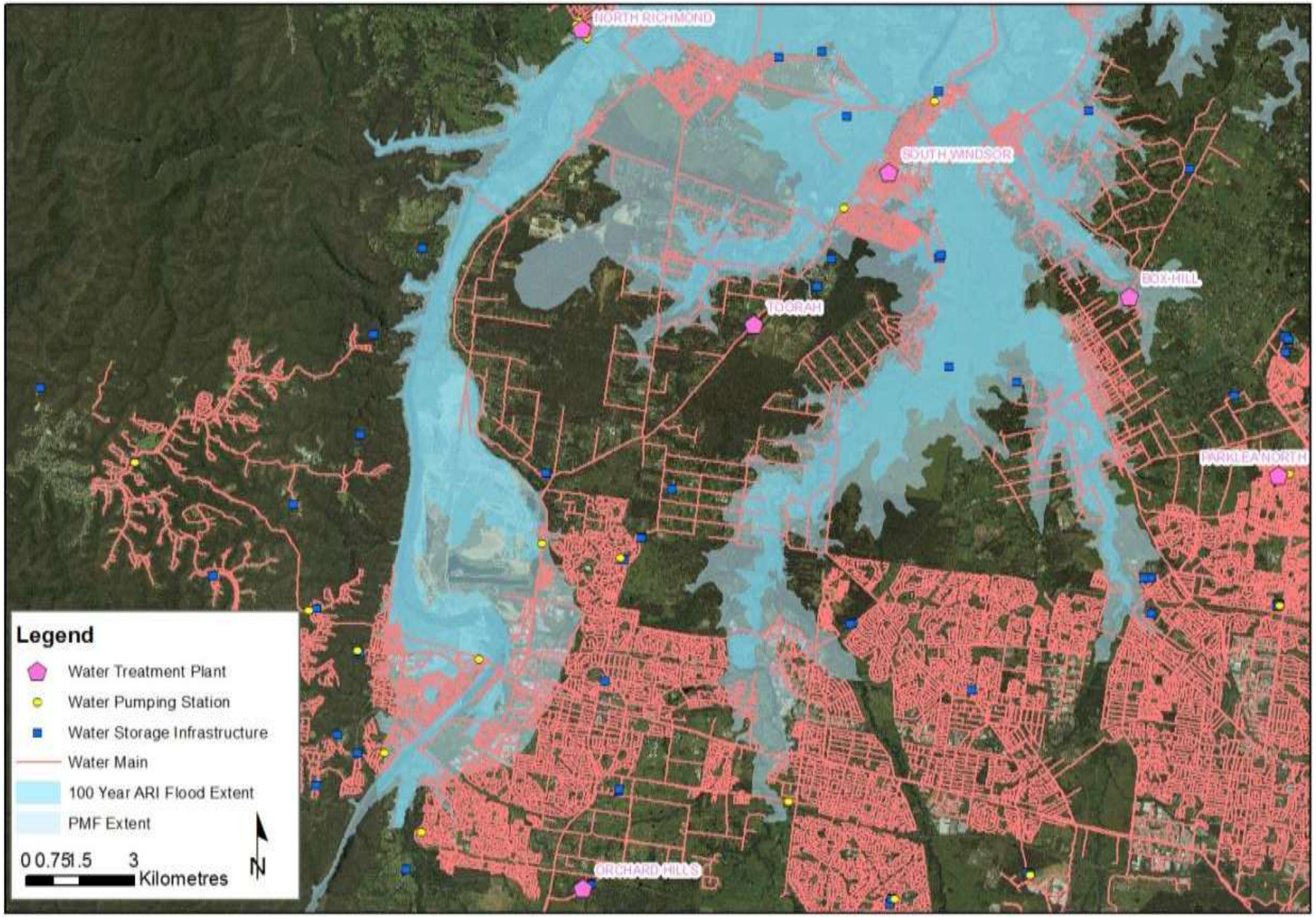


*Figure 9 Sydney Water Potable Water Network*

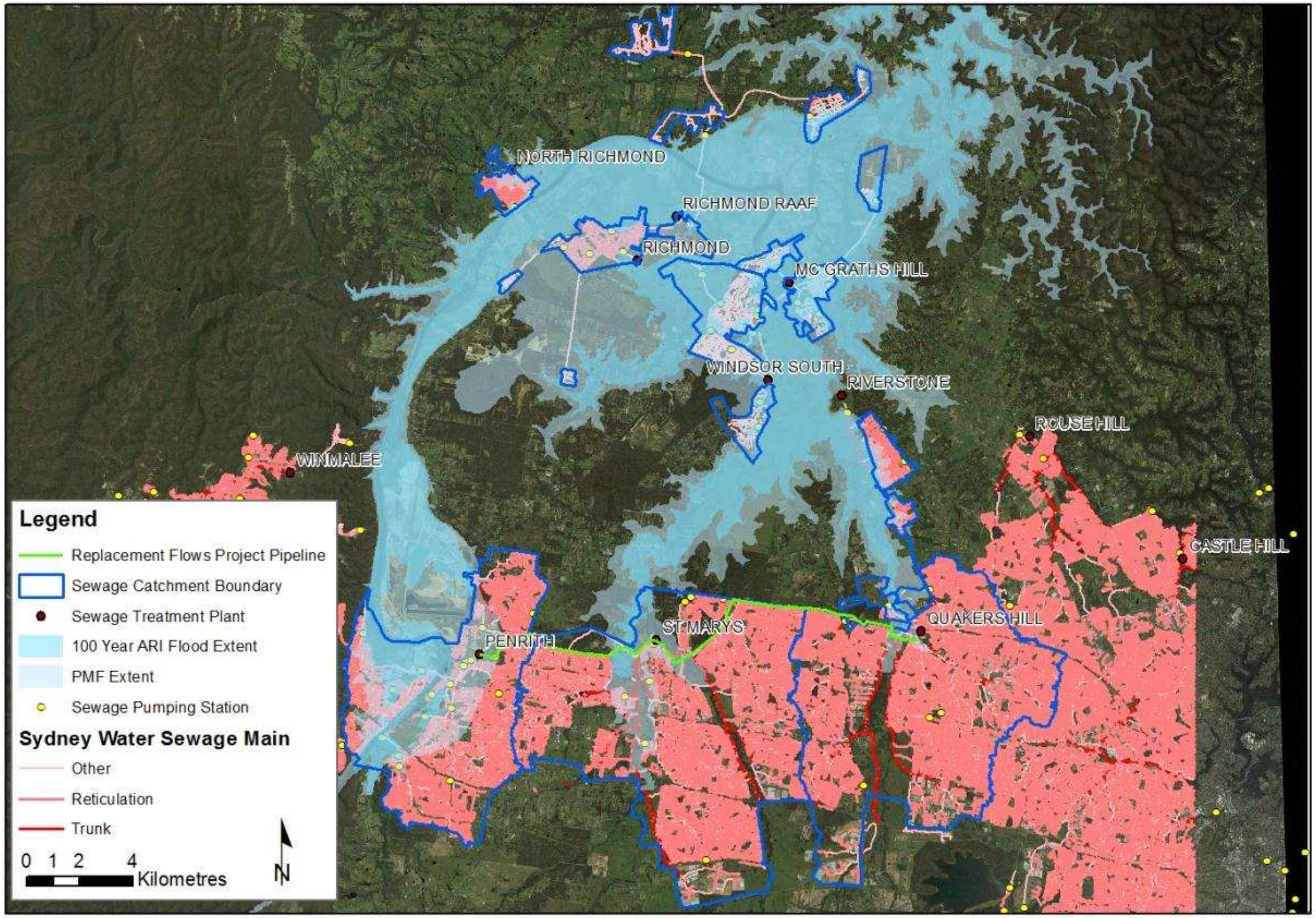


*Figure 10 Sydney Water, Hawkesbury City Council and ADF Sewerage Infrastructure*

### 2.2.9 Electricity

Five TransGrid high voltage transmission lines cross the river or its floodplain:

- Eraring to Kemps Creek double circuit 500kV line (line No. 5A1/5A2)
- Sydney West to Central Coast double circuit 330kV line (25/26)
- Sydney West to Sydney North 330kV line (20)
- Sydney North to Kemps Creek 330kV line (14)
- Bayswater to Sydney West double circuit 330kV line (31/32)

All these lines are supported on steel lattice towers and supply regional substations. Only part of Vineyard regional substation is potentially affected in the more extreme floods.

Endeavour Energy has numerous lower voltage transmission and distribution lines which cross the floodplain and several substations which are at risk of flooding.

In the 1997 EIS flood damages were provided by the Electricity Transmission Authority and Prospect Electricity. In this assessment direct damages have been calculated using the 1997 EIS damages inflated by the CPI.

Indirect damages are potentially more significant because of the tens of thousands of non-flooded customers who could be without power should substations or transmission lines be damaged. Most of these customers are outside of the floodplain. In more severe floods power outages could last for weeks or months.

Because there has been a significant increase in the number of customers supplied by the vulnerable assets, indirect electricity damages have been recalculated for this study.

This has been calculated by inflating the 1997 estimates of the sale price per KWh, which was calculated in 1992 as the revenue of the electricity supplier, and multiplying this by the current number of residences affected (both flooded and non-flooded residences without power) and the estimated time that the residents would be in alternative accommodation.

The reason that the sale price of electricity was used rather than the suppliers profit margin is that in NSW most electricity is supplied from generators in NSW and so the loss of electricity sales will be felt throughout the economy right back to the primary producers.

The value of the unsupplied electricity to the customers who are not flooded is an additional indirect cost. It was treated as an intangible damage because each KWh can be used for a number of different purposes and therefore have a different value to different customers. There is currently not enough data to quantify its value and so the damage was quantified as the number of unsupplied, non-flooded premises.

### 2.2.10 Telephone

The telecommunications market has changed significantly since the 1990s. The technology has also radically changed with greater use of digital technology and fibre optic cables as well as much greater use of mobile phones, other mobile devices and the internet. The telecommunications companies were less forthcoming with information about their systems than Telstra was in the 1990s and much of the flood impact assessment for telecommunications has been based on earlier investigations.

These advances also mean a greater number of towers and infrastructure in the floodplain, however the extent of infrastructure development is unknown. Known infrastructure is presented in Figure 11.

Due to the ambiguity around the changes in telecommunications infrastructure in the Valley, the damage calculations have been estimated by inflating the 1997 EIS damages using CPI.

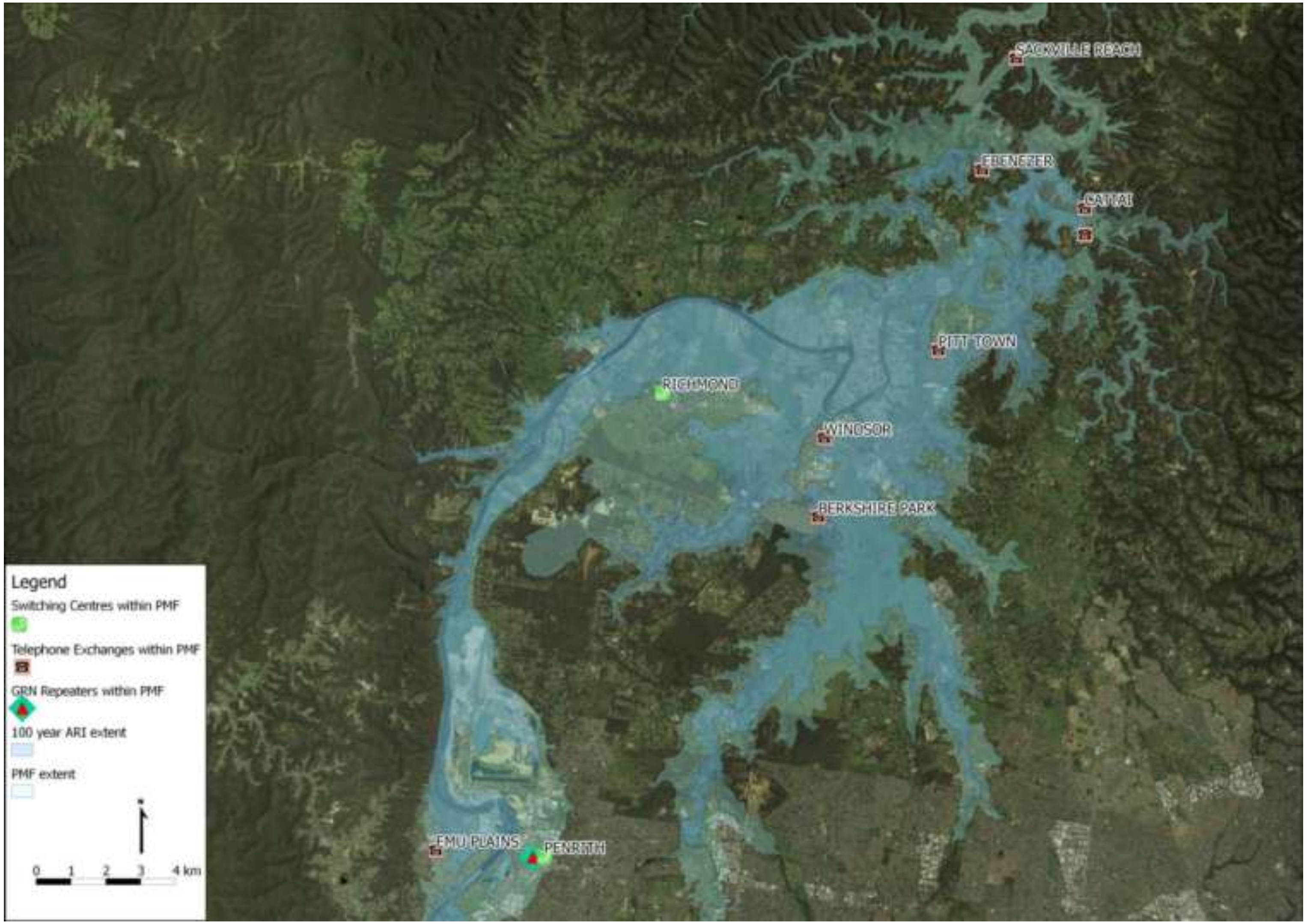


*Figure 11 Terrestrial Telecommunications infrastructure on the floodplain*

### 2.2.11 Gas & Oil

The natural gas supply to Sydney, Wollongong, the Central Coast and Newcastle comes by transmission pipeline from South Australia via Wilton. The line runs north east from Wilton to Windsor before crossing the Hawkesbury River downstream of Wisemans Ferry. The line lies below the bed of the river and is covered by rock ballast to protect it from scouring.

Caltex Oil Australia Pty Limited has a petroleum products pipeline which crosses the eastern part of the study area. The pipeline delivers gasoline, distillate and jet fuel from the Kurnell Refinery to Newcastle.

At Plumpton there is a remotely operated pump station. From Plumpton the line extends north west along the gas pipeline easement and consists of a 300mm diameter steel pipe buried about one metre below the surface.

The Sydney to Newcastle Gas Pipeline and the Caltex Oil Pipeline would be susceptible to flood damage at the Hawkesbury River crossing. Erosion of the river banks or the bed itself could rupture the pipes or destroy a 400 to 600 metre section of each pipeline.

In the 1990s the then owner of the gas pipeline, AGL, suggested that this might be a possibility in extreme floods. More recently, the current owners, Jemena, advised that even in the most extreme floods it would be unlikely that this line would be lost.

In the absence of greater certainty, this report used the gas and oil damages calculated in 1997 and inflated them using the CPI.

### 2.2.12 Sand & Gravel

The Nepean/Hawkesbury floodplain is the main source of sand and gravel for Sydney's construction industry.

The gravels and sands are obtained from deposits either adjacent to the river or, in the case of sand, within the river channel.

The Penrith Lakes Scheme is the largest sand and gravel quarry in Australia, is operated by three shareholders, Boral, Holcim and Hanson (Heidelberg) and supplies over 50% of the Sydney market with sand and aggregate.

Quarry activities will cease in the near future and planning for the remediation of the Penrith Lakes site is well underway.

In 1992, data on damage costs for the industry were obtained from Pioneer Concrete, Boral and the Quarry Masters Association. The Quarry Masters Association provided details on the value of all other extractive industries including the major CSR Readymix facility at Penrith Lakes and several smaller operations. Since the 1992 data was collected, the quarrying component and associated plant of the Penrith Lakes Scheme has been significantly reduced.

In this assessment damages have been calculated as 50% of the 1997 EIS damages and inflated using CPI.

### 2.2.13 Defence

Previously there had been two Defence facilities at risk: the RAAF base at Richmond and the St Marys munitions filling factory.

The latter has since closed and is being redeveloped for housing.

Richmond Air Base remains a principal transport facility for the RAAF and has developed into a large establishment with several hundred buildings..

In the 1997 EIS, likely damages at Richmond were assessed for all major buildings. Allowances were made in the damage assessment for building failure and the loss of aircraft which would be in maintenance and not able to be flown out.

In this report, damages to defence have been calculated by subtracting the St Marys munitions factory damages from the 1997 EIS values and then inflating using CPI.

### 2.2.14 Erosion

Erosion and sedimentation occurs after rainfall or flooding events. Soil and sediment is washed into rivers, creeks and streams, and can clog stormwater drains.

Large amounts of sediment are moved during floods. Erosion of material in one location results in sedimentation in another. Damage to the river channel and floodplain caused by erosion and sedimentation can be substantial.

Types of damage which may occur include:

- collapse or undermining of river banks through erosion, which may then threaten structures such as houses, bridges, weirs, buried pipelines and roads
- erosion of local areas in the floodplain, particularly at points of hydraulic control, such as road formations
- clean-up costs for deposited materials

In the 1997 EIS damage estimates from erosion and sedimentation were only indicative due to a lack of available information. For estimation purposes, damages were assumed to be 2.2% of total direct damages for all events.

In this assessment damages have been calculated using the 1997 values updated with the current CPI.

### 2.2.15 Emergency Services

During and after a flood there would be an increased demand for emergency services.

These services include:

- Police
- Ambulance
- Fire Brigade
- State Emergency Service
- possibly the armed forces

In the 1997 EIS it was reasoned that these services are provided for emergencies such as flooding and their cost is committed anyway. There are emergency service facilities in the floodplain which are impacted by flooding (see Figure 12 ) but damage to these is accounted for in the commercial and industrial damage estimates.

Indirect damages for emergency services were assessed as the cost of mobilising these services in a flood. In 1997 this was estimated as a cost per flood affected property with the cost per property decreasing as the number of affected properties increased. For this study the indirect emergency service costs for residential premises were calculated by inflating the 1997 cost per affected residence using the CPI and multiplying by the new total number of residences. To account for the contribution of new commercial premises the 1997 estimates for commercial premises were inflated by CPI and multiplied by 1.25.

## 2.3 INTANGIBLE DAMAGES

Although it is not realistic to place a monetary value on intangible damages, it is desirable to quantify them in some way if that is possible.

Some effort was made in the 1995 EIS to estimate some intangibles such as loss of life, illnesses, loss of pets, loss of memorabilia and business failures. Each was calculated as a function of the number of residential and commercial properties flooded and the scale of flooding.

Research in the past decade suggests that some of the relationships which were previously widely used to calculate such impacts were too simplistic. They could significantly underestimate or overestimate these losses. For this preliminary study we have decided to quantify the number of buildings affected by flooding and the number of people living and working on the floodplain. This gives a sense of the intangible personal losses which may ensue including loss of life, illness and injury, loss of pets and memorabilia and financial hardship.

We have estimated the number of flooded commercial and industrial buildings and the number of non-flooded properties which will not be supplied with electricity as these provides a sense of the impacts on individuals and the local economy.

The volumes of raw sewage likely to be discharged to the river after the flood have also been estimated to give a sense of the environmental impacts of flooding.

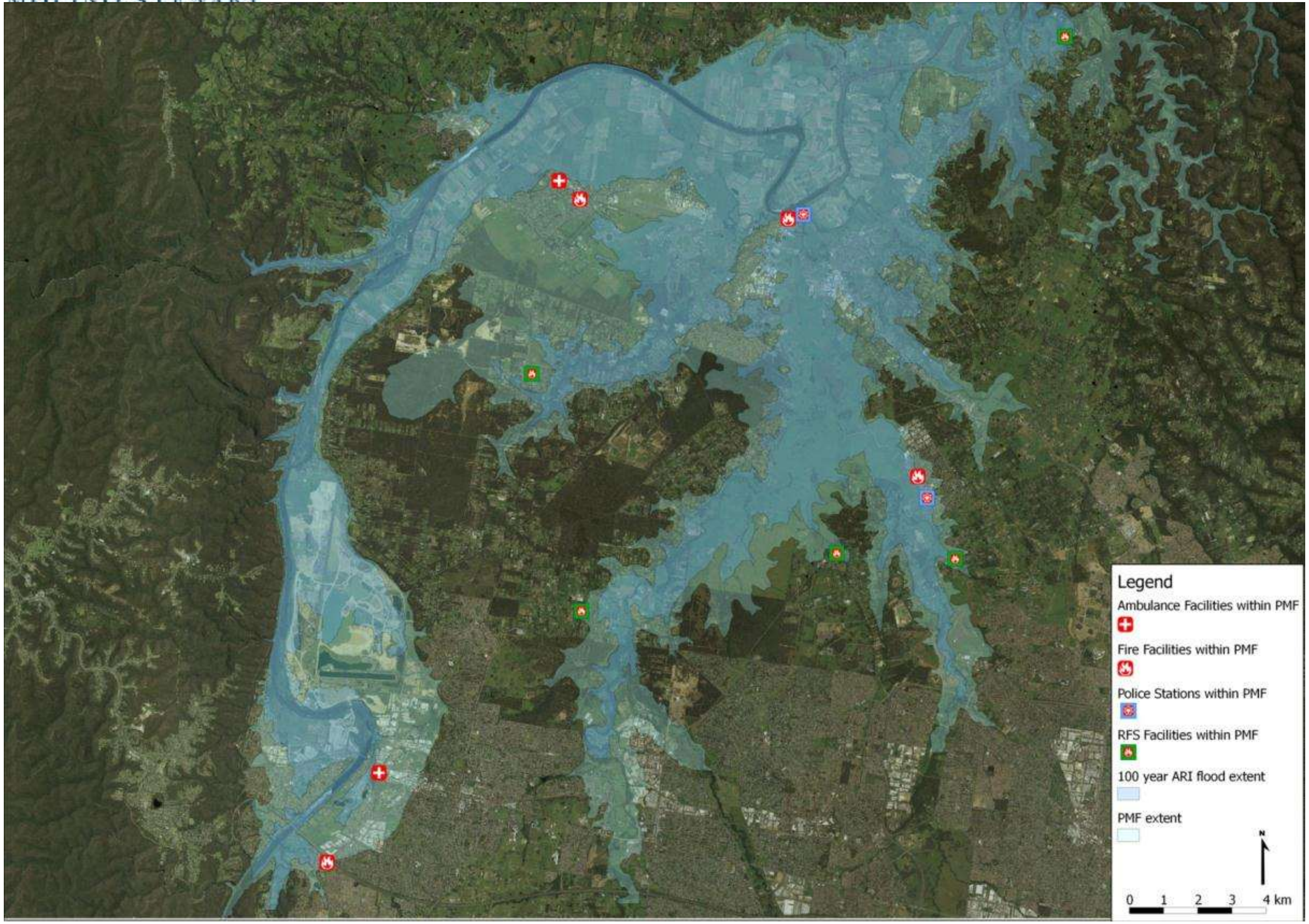


*Figure 12 Emergency Service facilities located on the floodplain*

# 3 HAWKESBURY NEPEAN FLOOD DAMAGES

## 3.1 DIRECT TANGIBLE DAMAGES

The direct flood damages for each category are summarised per event in Table 3. As would be expected, agricultural and road damages dominate in the smaller events. For larger events, the greatest direct damages will be to residential properties, followed by commercial/industrial development. These represent around two thirds of the direct damage. Water, sewerage, electricity and defence infrastructure. are all significant contributors to the total direct damages.

A repeat of the 1867 flood could be expected to flood nearly 7,000 homes, structurally damaging 1,200 of them and causing total direct damages in the order of $1.7 billion. This compares to the 2011 Brisbane River flood in which more than 20,000 homes were flooded and it cost Brisbane City Council more than $440 million in infrastructure repairs.

Of special consideration is the number of residential properties affected by each event. These are summarised in Table 5. It can be seen that progressively larger events will result in more properties that have above ground and above floor flooding. Similarly, the number of buildings likely to suffer significant structural damage will increase markedly as the floods become more severe.

For economic analyses the total damages in each event are reduced to average annual damages (AAD) which takes into account the probability of the damages being repeated over a long period of time. This is discussed further in Section 3.3 and is used for the economic analyses in Chapter 5.

However, it is also worth considering the financial implications of flood damages on individuals. Research suggests that there is a 'threshold of affordability' of flood damages that households can afford to recover from over time (Hawkesbury Nepean Floodplain Management Steering Committee, 2006). This varies greatly between households depending on household incomes, whether renting or owning, years remaining of mortgage, age of occupants and the time after purchase that the flood occurs. The research suggests than an average value of about $60,000 was the threshold of affordability in 2001 dollars. Inflating this by CPI to December 2011 dollars results in a threshold of approximately $80,0000. Table 5 includes an estimate of the number of properties that would suffer damages to a greater value than $80,000 dollars. It shows that were a repeat of the 1867 flood to occur (1 in 200 year event) than approximately 5,000 residences would not be able to afford the cost of the flood damages.

Residential flood insurance was generally not available in Australia prior to 2007 but is now being offered by insurance companies to residents of the Hawkesbury Nepean Valley. While insurance would be one way in which households could mitigate their risk of unaffordable flood losses, the affordability of premiums is also a consideration. The AAD for residential direct and indirect damages alone is about $20 million. This would require an average annual insurance premium of more than $1,000 to be paid by each of the 19,000 households below the PMF just to cover the flood losses let alone the insurance companies' administrative and reinsurance costs.

It should also be noted that these damage estimates exclude the cost of rebuilding dwellings which fail structurally. Were those costs included then the number of households unable to afford the flood damages and the cost of insurance premiums would increase substantially.

## 3.2 INDIRECT TANGIBLE DAMAGES

The indirect flood damages for each category are summarised per event in Table 4. As with direct damages, the greatest indirect damages in larger events will be to residential properties followed by commercial and industrial properties. Agriculture and infrastructure categories contribute greater proportions in smaller events.

*Table 3 Direct Damages ($m 2011)*

| Category | Event (1 in x Years) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 5 | 10 | 20 | 50 | 100 | 200 | 500 | 1000 | PMF |
| *Residential* | 0.0 | 5.3 | 23.9 | 35.7 | 469.4 | 820.7 | 1309.1 | 1874.5 | 2830.2 |
| *Caravans* | 0.0 | 0.0 | 3.9 | 7.8 | 11.3 | 12.8 | 14.2 | 15.5 | 15.9 |
| *Commercial Industrial* | 0.5 | 1.5 | 4.4 | 74.1 | 320.2 | 496.7 | 741.7 | 1161.0 | 1725.3 |
| *Motor Vehicles* | 0.0 | 0.3 | 0.7 | 1.4 | 8.0 | 9.5 | 46.4 | 75.5 | 147.0 |
| *Agriculture* | 18.4 | 23.5 | 30.0 | 36.0 | 42.8 | 46.0 | 55.4 | 60.0 | 71.9 |
| *Roads & Bridges* | 7.3 | 8.3 | 9.8 | 12.4 | 15.6 | 18.4 | 22.5 | 35.1 | 44.6 |
| *Railways* | 0.0 | 0.3 | 4.4 | 17.4 | 24.7 | 30.7 | 41.4 | 51.7 | 94.8 |
| *Water & Sewage* | 1.5 | 2.0 | 7.7 | 16.9 | 27.4 | 81.6 | 181.3 | 220.2 | 559.0 |
| *Electricity* | 0.7 | 2.4 | 7.0 | 12.8 | 28.1 | 37.5 | 49.4 | 83.0 | 178.7 |
| *Telephone* | 0.0 | 0.0 | 0.2 | 1.7 | 5.1 | 10.1 | 22.3 | 23.9 | 64.8 |
| *Gas & Oil* | 0.0 | 0.0 | 0.0 | 0.3 | 3.8 | 5.8 | 10.1 | 11.3 | 17.0 |
| *Sand & Gravel* | 0.0 | 0.9 | 2.0 | 2.6 | 7.6 | 17.5 | 28.3 | 51.1 | 74.1 |
| *Defence* | 0.0 | 0.0 | 0.0 | 0.0 | 5.1 | 141.2 | 502.6 | 651.1 | 727.0 |
| *Erosion* | 0.7 | 1.2 | 2.3 | 5.5 | 12.4 | 23.2 | 44.7 | 67.0 | 112.3 |
| *Emergency Services* | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| ***Total*** | **29.1** | **45.8** | **96.3** | **224.5** | **981.4** | **1751.8** | **3069.4** | **4380.8** | **6662.6** |

*Table 4 Indirect Damages ($m 2011)*

| Category | Event (1 in x Years) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 5 | 10 | 20 | 50 | 100 | 200 | 500 | 1000 | PMF |
| *Residential* | 0.0 | 0.8 | 3.6 | 5.3 | 170.4 | 300.9 | 533.7 | 787.1 | 1297.8 |
| *Caravans* | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| *Commercial Industrial* | 0.3 | 0.7 | 2.0 | 37.1 | 373.7 | 641.2 | 1112.4 | 1741.3 | 2587.8 |
| *Motor Vehicles* | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| *Agriculture* | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| *Roads & Bridges* | 6.9 | 7.7 | 8.6 | 6.6 | 6.6 | 7.1 | 7.1 | 7.5 | 6.6 |
| *Railways* | 0.0 | 0.0 | 0.0 | 0.3 | 0.5 | 9.2 | 14.3 | 7.5 | 137.4 |
| *Water & Sewage* | 0.0 | 0.0 | 0.0 | 0.3 | 0.8 | 1.5 | 2.6 | 6.4 | 10.0 |
| *Electricity* | 0.0 | 0.0 | 0.0 | 0.1 | 1.0 | 19.9 | 42.5 | 42.5 | 65.5 |
| *Telephone* | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.3 | 4.1 |
| *Gas & Oil* | 0.0 | 0.0 | 0.0 | 0.2 | 69.4 | 79.6 | 83.9 | 86.6 | 90.4 |
| *Sand & Gravel* | 0.0 | 0.4 | 1.0 | 1.4 | 11.1 | 26.3 | 42.4 | 76.6 | 111.2 |
| *Defence* | 0.0 | 0.0 | 0.0 | 0.0 | 5.1 | 141.3 | 501.6 | 675.5 | 835.4 |
| *Erosion* | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| *Emergency Services* | 0.0 | 0.0 | 0.0 | 0.2 | 1.7 | 37.2 | 74.8 | 74.8 | 94.1 |
| ***Total*** | **7.3** | **9.6** | **15.3** | **51.4** | **640.2** | **1264.2** | **2415.2** | **3506.1** | **5240.1** |

*Table 5 Residential Flooding Summary*

| | Properties with Above Ground Flooding | Properties with Above Floor Flooding* | Buildings Likely to Fail* | Dwellings* with more than $80,000 dollars of damage |
|---|---|---|---|---|
| *1 in 5* | 70 | 0 | 0 | 0 |
| *1 in 10* | 136 | 48 | 0 | 35 |
| *1 in 20* | 451 | 249 | 0 | 129 |
| *1 in 50* | 6,26 | 361 | 0 | 190 |
| *1 in 100* | 4,825 | 3,977 | 628 | 3,174 |
| *1 in 200* | 7,664 | 6,931 | 1,258 | 5,344 |
| *1 in 500* | 12,071 | 10,710 | 3,779 | 8,820 |
| *1 in 1,000* | 14,969 | 14,160 | 6,464 | 12,748 |
| *PMF* | 19,376 | 19,015 | 15,516 | 18,250 |

*Note:

- Properties with above floor flooding are a subset of properties with above ground flooding
- Buildings likely to fail are a subset of those properties with above floor flooding
- Dwellings with more than $80,000 are a subset of buildings with above floor flooding.

The electricity sector becomes a more significant contributor to indirect tangible damages because of the large number of unsupplied customers outside of the flood zone. Similarly, the loss of the rail bridge at Penrith would make the indirect railway damages jump considerably.

## 3.3 TOTAL TANGIBLE DAMAGES

Table 6 shows the total damages for flooding per event as well as the annual average damage. The annual average damage (AAD) is a method of summarising the flood damage given the probabilities for certain events to occur. The AAD is essentially the average cost per year of flooding over a long period of time. AAD also reveals which sized floods are likely to make the largest contribution to total flood damages over a long period of time.

The AAD is equal to the area under the probability – damage curve which accounts for a continuum of flood probabilities from the most common up to the PMF. The contribution to AAD listed in the table for each flood represents the area under the curve for a band of floods centred around that event and is not the product of the probability multiplied by the damage for each event. It is indicative of which range of events make the greatest contribution to AAD.

Table 6 shows that total tangible damages could exceed $3 billion in a repeat of the 1867 flood and approach $8 billion if a more extreme event were to occur. A single damage bill of this magnitude is likely to create significant cashflow and balance sheet problems for the state economy.

The annual average damages would be about $70 million. That is, on average tangible flood damages in the Valley will cost $70m each and every year. Generally it is the floods greater than the 1 in 50 year ARI event which have a larger contribution to the AAD.

## 3.4 INTANGIBLE DAMAGES

The intangible damages for flooding within the Hawkesbury Nepean valley were considered in the Proposed Warragamba Flood Mitigation Dam EIS (1995), the Warragamba Dam Spillway EIS and subsequent work undertaken by Molino Stewart for the Hawkesbury-Nepean Flood Management Advisory Committee and most recently for the NSW State Emergency Services.

*Table 6 Event total damage and AAD*

| *Event* | Event Damage ($m 2011) | Contribution to Annual Average Damage ($m 2011) |
|---|---|---|
| *1 in 5* | 36 | 5.5 |
| *1 in 10* | 55 | 4.6 |
| *1 in 20* | 112 | 4.1 |
| *1 in 50* | 276 | 5.8 |
| *1 in 100* | 1,622 | 9.5 |
| *1 in 200* | 3,016 | 11.6 |
| *1 in 500* | 5,485 | 12.8 |
| *1 in 1000* | 7,887 | 6.9 |
| *PMF* | 11,903 | 9.8 |
| *Total AAD* | | **70.3** |

The majority of the intangible damages, both direct and indirect, are proportional to the number of buildings flooded. Some others bear a different relationship to direct flood damages.

Previous studies attempted to quantify many of the intangible damages however it was considered outside of the scope of this study. Instead, key quantifications have been determined and the various intangible damages which are proportional to those are listed.

Appendix A provides a summary of incremental flood impacts on people and major infrastructure and is derived from recent work for the NSW SES.

### 3.4.1 Population at Risk

The Population at Risk (PAR) are those who live and work on the floodplain and are likely to be directly affected by a flood. The number of fatalities, injuries and illness can be expected to be proportional to the PAR although those proportions may increase as the flood magnitude increases.

The population at risk can be calculated in two separate ways. Firstly, by considering the whole population within the floodplain and secondly, by considering those who are likely to fail to evacuate during a flood.

The numbers calculated in this study are not precise numbers, nor are they estimates of the number of lives that will be lost. The intention is to provide some sense of the scale of the human risk dimension of Hawkesbury Nepean Flooding.

#### a) Calculation by population within the floodplain

By multiplying the number of residences within the floodplain by the average dwelling occupancy rate (2.9 per residence from the 2006 census) we can determine the number of residents within the floodplain. Those working within the floodplain can be counted for by multiplying the number of commercial and industrial premises by an average number of employees. Currently, the SES evacuation modelling assumes 2 vehicles per commercial or industrial premise, therefore 2 employees per premise has been applied. The population at risk is presented in Table 7.

Table 7 Population at Risk

| *Event* | Residents | Commercial and Industrial Persons |
|---|---|---|
| *1 in 5* | 203 | 0 |
| *1 in 10* | 394 | 0 |
| *1 in 20* | 1,308 | 0 |
| *1 in 50* | 1,815 | 596 |
| *1 in 100* | 13,993 | 1,986 |
| *1 in 200* | 22,226 | 3,710 |
| *1 in 500* | 35,006 | 5,206 |
| *1 in 1,000* | 43,410 | 8,694 |
| *PMF* | 56,190 | 12,212 |

#### b) Calculation by those unable to Evacuate

Molino Stewart, commissioned by the SES, has previously undertaken detailed evacuation modelling of the entire Hawkesbury-Nepean floodplain using the SES Timeline Evacuation Model, the standard model used within NSW. This modelling used an event with the highest theoretical rate of rise and assumes that the entire at-risk community is evacuated, including those isolated by flooding.

This cannot be broken down into event specific numbers as the SES will evacuate entire sectors at given threshold levels rather than progressively evacuate smaller areas as they become inundated. This is due to evacuation routes being cut before the sectors are inundated, leaving residents isolated.

Table 8 shows the population at risk as calculated by those who are unable to evacuate per sector. Table 8 shows a total of 92,893 will be attempting to evacuate in a large flood. It should be noted that this varies significantly from the estimated population at risk when considering those residential and commercial properties that would be flooded

This is due to a number of reasons, firstly, this is based upon sector wide evacuations and may include houses that are not inundated and additionally the SES evacuation data is based off estimates from Geoscience Australia's NEXIS dataset (uses geocoded addresses) rather than the ANU Flood and Molino Stewart developed database. Molino Stewart (2012) documented a number of problems with these data and recommended that these numbers be considered approximate values only.

Table 8 Population at risk who are unable to evacuate

| *Sector* | Those able to evacuate | Those Unable to Evacuate |
|---|---|---|
| *Emu Plains* | 7,548 | 5,479 |
| *Penrith South* | 844 | 0 |
| *Penrith (via Mulgoa Road)* | 3,572 | 1,842 |
| *Penrith (via The Northern Road)* | 9,560 | 2,127 |
| *Penrith North* | 3,628 | 1,324 |
| *Penrith South* | 844 | 0 |
| *Richmond and Richmond Lowlands* | 14,017 | 480 |
| *Bligh Park and Windsor Downs* | 7,299 | 1,358 |
| *Windsor* | 9,333 | 3,749 |
| *McGraths Hill* | 3,365 | 880 |
| *North Richmond* | 2,847 | 0 |
| *Pitt Town* | 2,038 | 0 |
| *Oakville/Cattai* | 1,780 | 0 |
| *Yarramundi* | 1,892 | 0 |
| *Wilberforce* | 2,326 | 218 |
| *Colo River* | 0 | 1,885 |
| *Webbs Creek* | 0 | 429 |
| *McDonald River* | 0 | 2,231 |
| ***Total*** | **70,891** | **22,002** |

### 3.4.2 Intangible Damages Proportional to PAR

#### a) Pets and Memorabilia

Pets are generally considered as another member of the family and previous studies have shown that approximately one in three residences have a cat and one in three residences have a dog. While most of those who evacuate are likely to take their pets with them, it is highly likely that many pets will be stranded and overwhelmed by flood waters or lost.

Similarly, it is likely that memorabilia such as photo albums, awards etc. that have a high sentimental value will be taken with those residents that evacuate. However it is likely that in a larger sized event, much memorabilia would be lost.

#### b) Fatalities

The number of fatalities directly attributable to flooding, by drowning, electrocution and accidents is mainly a function of water velocity and depth, particularly along transport routes. Other contributing factors include warnings, the preparedness of the community, the vulnerability of the population and temperature.

Various studies have been undertaken over the years to estimate the number of fatalities as a proportion of PAR but no reliable, simple relationship has been identified.

About 90% of flood fatalities in Australia in recent decades are a result of people deliberately entering floodwaters. However, the recent Queensland floods resulted in about one third of the nearly 40 fatalities being caused by people being swept from their homes. This shows that extreme flood events with little warning can have very different fatality consequences to other floods.

There are methods available for placing a value on human life but these are not universally accepted. Since it is not realistic to put a figure on the number of lives which could be lost in floods in the Valley is was decided for this study to quantify risk to life in terms of population at risk and no attempt was made to put a monetary value on flood risk to life.

#### c) Health Effects

Direct contact with flood waters can cause some residents to suffer illness, injury or possibly death. Far more widespread, however, is the trauma and stress which arises from being evacuated, losing property, cleaning up and having to cope with severely disrupted living conditions. This can lead to the onset of stress induced illnesses, the aggravation of existing illnesses and in some cases premature death.

These damages vary with the number of people exposed, the velocity and depth of flood waters and the extent of community preparedness.

There is also a linkage between stressful events such as floods, and ill health. The degree to which flooding affects the health of those inundated depends on flood preparedness, personal experience, the extent of flooding and a range of individual family and social factors influencing peoples' ability to cope.

It is recognised that flood-induced stress may also cause premature death but it is not possible to place a realistic figure on this.

### 3.4.3 Intangible Socio-Economic Damages

#### a) Business Liquidations

If a commercial or industrial building undergoes significant inundation, structural damage or both as a result of a flood, it is likely that many of the businesses that operate out of the building will not be able to recover after the flood and will need to be liquidated.

Research in the US shows that approximately 30% of businesses go out of business following a natural disaster. It is likely that most of the employees of these businesses reside within the Hawkesbury Valley and are likely to lose their job as a result of the business failure. Table 9 shows the number of commercial and industrial premises that would flood under different events with the 1988 level of development. Unfortunately no data was available to update these numbers but it does provide a lower bound for what would be the expected commercial and industrial premises affected.

*Table 9 Commercial Premises Flooded (1988 Development)*

| *Event* | Flooded | Failed |
|---|---|---|
| *1 in 5* | 24 | 0 |
| *1 in 10* | 36 | 0 |
| *1 in 20* | 102 | 0 |
| *1 in 50* | 298 | 5 |
| *1 in 100* | 993 | 7 |
| *1 in 200* | 1,633 | 10 |
| *1 in 500* | 2,558 | 58 |
| *1 in 1000* | 2,809 | 108 |
| *PMF* | 3,428 | 482 |

#### b) Loss of Utility Services

Intangible utility damages are the losses of amenity suffered by residential customers and the loss of production suffered by commercial and industrial customers whose occupied properties cannot be supplied with essential utility services. These are expressed as the total number of customer days unsupplied.

Flooding, particularly extreme flood events, would mean that services would be lost for long periods to people inside and outside of flood-affected zones.

Water supply would be maintained to all areas but restrictions would apply. This can be measured as total customer days on water restrictions.

It has been assumed that there would be no loss of sewerage services. Customers will continue to use their sewerage facilities but the sewage may not receive treatment before being discharged to the river.

Of all of the utility services which may be disrupted by flooding, electricity supplies may suffer some of the greatest disruptions, be unsupplied to the greatest number of customers outside of the floodplain and have the greatest impact if not supplied. These numbers have not be recalculated for this study but Table 10 is taken from a recent report to the NSW SES which gives an inundation of the number of premises who will want electricity but will not be able to be supplied.

In estimating intangible damages for all utilities, flood-affected properties were not counted for the period they were expected to be vacant.

### 3.4.4 Environmental Damages

#### a) Terrestrial Ecosystems

Flooding could significantly damage terrestrial ecosystems. Remnant native vegetation on the floodplain has high conservation significance because the Cumberland Plain has been extensively cleared. A major flood could damage remaining areas by uprooting or undermining trees and other vegetation, depositing silt and other debris, introducing weeds, removing native seed sources required for regeneration and depleting native fauna populations.

The ability of the vegetation in the Hawkesbury-Nepean Floodplain to recover after an extreme flood would be inhibited because:

- sediment and other debris would be deposited by flood waters
- weeds may be transported into the area by floodwaters
- there would be a paucity of nearby seed sources for natural regeneration
- surviving faunal populations may not be sufficient to recolonise these areas

#### b) Water Quality

Although flood levels may be little different to natural conditions, the water quality is likely to change significantly. Agricultural and urban development has increased the amount of sediments and pollutants entering the river.

Chemicals and other pollutants will be released from flooded industrial and utility establishments and gas and oil can enter the river environs where supply mains are ruptured. Although the quantities of pollutants released will be significant, they will be small relative to the volume of flood waters. They are therefore not considered to have a significant environmental cost.

However untreated sewage discharging to the river will be a significant long term pollution problem following extreme floods. Plants will fail and may take many months to be brought back into service.

Table 11 shows how long it would take to restore each STP following a flood and Table 12 provides an indication of how many megalitres of untreated sewage could be discharged to the River for many months.

*Table 10: Premises without electricity 2010*

| ***Transmission Substation*** | **Flood Level (m AHD)** | **Days without power supply** | **Total premises** | **Total premises not flooded** |
|---|---|---|---|---|
| *Hawkesbury* | 13.6 | 2 | <1,100* | <200* |
| | 15.7 | 2 | <700* | <3,000* |
| | 17.4 | 14 | 3,600 | 2,400 |
| | 18.2 | 14 | 3,600 | 2,100 |
| | 19 | 14 | 10,200 | 5,900 |
| | | 2 | 25,900 | 20,300 |
| | 19.6 | 14 | 10,200 | 5,400 |
| | | 2 | 25,900 | 19,200 |
| | 20 | 90 | 36,100 | 23,800 |
| | 22.1 | 90 | 36,100 | 20,800 |
| | 26.1 | 180 | 36,100 | 12,700 |
| *Penrith* | 24.9 | 2 | 6,200 | 6,000 |
| | 26.3 | 14 | 6,200 | 4,900 |
| | | 2 | 13,700 | 12,300 |
| | 27 | 90 | 30,639 | 26,875 |
| | 29 | 90 | 30,639 | 25,612 |
| | 33.8 | 90 | 30,639 | 19,498 |

Table 11: *Restoration of Treatment Plants*

| Sewage Treatment Plant | Flood Level (m AHD) | Time For Restoration (Days) | |
|---|---|---|---|
| | | Operations | To achieve Pre-flood effluent standards |
| Penrith | 26 | 5 | 30 |
| | 31 | 90-180 | 180 |
| St Marys | 20 | 42 | 60 |
| | 25 | CR | CR |
| North Richmond | 22 | 14 | 90 |
| | 25 | CR | CR |
| Richmond | 20 | 0 | 14 |
| | 25 | 0 | 180-365 |
| Riverstone | 26 | 0 | 0 |
| Quakers Hill | 26 | 42 | 60 |
| McGraths Hill | 14 | 90 | 150 |
| | 20 | CR | CR |
| South Windsor | 20 | 90 | 150 |
| | 26 | CR | CR |

*CR:complete rebuild required*

Table 12: *ML of untreated or partially treated effluent*

| Sewage Treatment Plant | Flood Level (m AHD) | Daily flows (ML) | Time to meet effluent standard (Days) | Volume of untreated or partially treated discharges (ML) |
|---|---|---|---|---|
| Penrith | 26 | 21 | 30 | 630 |
| | 31 | 21 | 180 | 3,780 |
| St Marys | 20 | 33 | 60 | 1,980 |
| | 25 | 33 | 360 | 11,880 |
| North Richmond | 22 | 0.5 | 90 | 45 |
| | 25 | 0.5 | 360 | 180 |
| Quakers Hill | 26 | 42 | 60 | 2,520 |

# 4 FLOOD MITIGATION

## 4.1 MITIGATION OPTIONS

### 4.1.1 Alternative Strategies

When flood mitigation for the Valley was first investigated in the early 1990s, several broad strategies and specific options were identified and investigated to a level of detail that allowed unviable options to be eliminated and the others to be investigated further. Many of these, and some additional options, were again reviewed in 1997 as part of the investigations of the Hawkesbury-Nepean Flood Management Advisory Committee.

Six groups of strategies were considered:

- *non structural strategies*: these do not alter flood levels but reduce the effects of flooding;
- *asset modifications*. These remove vulnerable assets from the floodplain or make them more flood resistant;
- *floodplain works*: localised physical works in the floodplain could be used to divert floodwaters from properties;
- *drainage strategies*: these lower flood levels by assisting floodwaters to escape from the floodplain;
- *flood detention strategies*: these temporarily store floodwaters on contributing rivers and thereby lower peak levels downstream; and
- *combined strategies:* these combine some of the above approaches.

The following summarises the assessment, and in some cases implementation, of these options

#### a) Non- structural strategies

These included:

- Flood insurance –neither cost effective nor practical
- Flood emergency planning – NSW government has invested heavily in improvements to evacuation infrastructure, improved emergency planning and community education
- Town planning - local councils have been encouraged to develop comprehensive floodplain risk management plans. None have done so although all have revised minimum floor levels for new development. This will only mitigate impacts on new development

#### b) Asset modifications

- Property purchase – neither cost effective nor practical
- House raising – many buildings are not suitable for this and risk to life would not be significantly reduced for those which are raised
- Flood resistant buildings – Australian Building Codes Board has draft standard on exhibition but this will only mitigate impacts on new development
- Relocation of infrastructure – not always practical or affordable. Some electricity infrastructure has been recently relocated to a more flood prone area contrary to best practice.
- Reconstruction of infrastructure – some sewerage and electricity infrastructure has been reconstructed to be less flood prone

#### c) Floodplain Works

- Levees – would need to be several metres high to exclude 1867 flood, would have significant visual impacts, require demolition of many existing buildings and would increase flooding of buildings outside of the levees. Possibly beneficial in a few selected locations where such impacts are less.
- Deflection walls – could reduce flood velocities in some selected locations. Localised benefits only.

#### d) Drainage Strategies

- Dredging – dredging the river bed between Sackville and Wisemans Ferry by 10m would reduce 1867 flood level at Windsor by 2.3m but have no benefits at Penrith. Would require removal and disposal of 20-30 million cubic metres of dredged materials. Was estimated in 1995 to cost more than $350m and would have ongoing costs to prevent resilting.

- River straightening – 23km of meanders between Sackville and Wisemans Ferry could be removed by excavating about 50 million cubic metres of ridgelines. This would lower the 1867 flood by about 1.1m and was estimated to cost $730m in 1995.

### e) Flood Detention Strategies

- Upstream Dams – dry detention dams on the Wollondilly River and Coxs River upstream of Lake Burragorang could detain enough floodwater to reduce the 1867 flood to about 15m at Windsor. These were estimated to cost about $500m in 1995 but would have a more significant impact on the Blue Mountains World Heritage Area than mitigation storage at Warragamba Dam
- Downstream Dams – flood mitigation dams on the Nepean, Grose or Colo rivers were all investigated. They would reduce the 1867 flood by between 0m and 0.7m but each would require a new dam in an environmentally sensitive area.
- Change Gate Operation – changing the operation of the spillway gates on Warragamba Dam may be able to slightly mitigate the more frequent floods but would have negligible impact on the 1867 flood. It would reduce the time for emergency response and also run the risk of reducing the secure water supply yield of the Dam.
- Deplete Warragamba Storage – Lowering the full supply level by 12m to current spillway crest would reduce the Dam's water supply storage capacity by 40%. To bring the 1867 flood level down to 16m AHD at Windsor, 90% of the Dam's water storage capacity would be lost.
- Warragamba Wall Raising – identified as the most cost effective flood detention strategy with the least environmental impacts. Carried through for more detailed investigations.

### f) Composite Strategies

It was perceived that composite options combining some of the above strategies could potentially give a better outcome than any one strategy on its own.

It became apparent that a combined strategy would not overcome the major limitations of any of the individual strategies but would have total costs and impacts greater than any strategy considered on its own.

## 4.1.2 Warragamba Mitigation Dam Options

The 1995 EIS presented a number of options for building mitigation capacity into Warragamba Dam. The summary details for these are presented in Table *13* with each option being described in terms of the height of mitigation airspace which could be provided above full supply level.

The 15 m option required the construction of an auxiliary spillway in order to pass the PMF while the other options would pass the PMF without a spillway. Since the EIS was produced, the auxiliary spillway has been constructed and it is expected that the 15 metre option would therefore have a lower cost and therefore an increased benefit cost ratio to that which is presented in Table *13*.

Based upon the benefit cost ratios, the 1995 EIS chose the 23 m option as the preferred option and presented detailed analysis only for this option. This information was required for this assessment, and so only the 23 m option was assessed for flood damages at that time.

This has meant that only the mitigated flood levels for the 23m option have been available for this study and are discussed in this section. It is expected that the other options would have a similar change in benefit cost ratio as the 23 m option has and the 23m option would remain the optimal mitigation option.

Table 13: Mitigation Options (1995 EIS)

| *Option* | Construction Type | Flood level at Windsor Bridge (m AHD) | | | Benefit Cost Ratio(1995 EIS) |
|---|---|---|---|---|---|
| | | 1 in 20 year ARI Flood | 1 in 200 year ARI Flood | PMF | |
| **No Mitigation (without Spillway)** | N/A | 13.7 | 19.2 | 28.9 | N/A |
| **15 Metre Option** | Rock Stabilised Concrete Raising | 11.5 | 16.0 | 24.3 | 1.0 |
| **23 Metre Option** | Mass Concrete Raising | 10.4 | 14.8 | 22.5 | 1.7 |
| **30 Metre Option** | Mass Concrete Raising | 10.4 | 14.0 | 21.9 | 1.2 |
| **35 Metre Option** | Concrete Faced Rockfill | 10.4 | 14.0 | 19.4 | 1.1 |

## 4.2 CHANGES IN FLOODING

### 4.2.1 Reduction in Downstream Flood Levels

The reduction in flood levels for a 1995 EIS 23m option equivalent mitigation dam are presented in Table 14 for Penrith and Table 15 for Windsor. The reduction in flood levels varies between the two locations and from event to event. This is due to the different hydraulic conditions upstream at Penrith and downstream and Windsor and the behaviour of different size floods.

### 4.2.2 Increase in downstream flood durations

While a flood mitigation dam will reduce the downstream flood levels for a given flood event, the same volume of flood water must eventually be discharged down the river. This is achieved by releasing water from the dam for a longer time at a lower rate than would occur were the mitigation dam not there.

This is illustrated in Figure 13 which has been scanned from the 1995 EIS and compares the flows at Warragamba Dam without a dam, with the current dam operating under the current H14 operating rules and with a mitigation dam in place. It illustrates the impact of flood mitigation on the 1978 flood.

This will also mean that the duration of flows below 11m AHD at Windsor will be increased with the operation of a mitigation dam. Figure 14 which has also been scanned from the 1995 EIS summarises the impacts of a mitigation dam on downstream flood levels and durations.

*Table 14 Reduction in Flood Levels - Penrith*

| | Existing Dam with Spillway | Mitigation Dam |
|---|---|---|
| *1 in 5 Year* | 20.1 | 17.9 |
| *1 in 10 Year* | 21.6 | 18.5 |
| *1 in 20 Year* | 23.3 | 19.2 |
| *1 in 50 Year* | 24.8 | 20.2 |
| *1 in 100 Year* | 26.0 | 21.2 |
| *1 in 200 Year* | 26.9 | 22.5 |
| *1 in 500 Year* | 27.6 | 24.7 |
| *1 in 1000 Year* | 28.5 | 26.1 |
| *PMF* | 32.1 | 28.4 |

*Table 15 Reduction in Flood Levels - Windsor*

| | Existing Dam with Spillway | Mitigation Dam |
|---|---|---|
| *1 in 5 Year* | 11.1 | 8.6 |
| *1 in 10 Year* | 12.3 | 9.3 |
| *1 in 20 Year* | 13.7 | 10.4 |
| *1 in 50 Year* | 15.6 | 11.5 |
| *1 in 100 Year* | 17.2 | 12.8 |
| *1 in 200 Year* | 18.6 | 14.4 |
| *1 in 500 Year* | 20.3 | 16.4 |
| *1 in 1000 Year* | 21.7 | 19.9 |
| *PMF* | 26.4 | 22.5 |

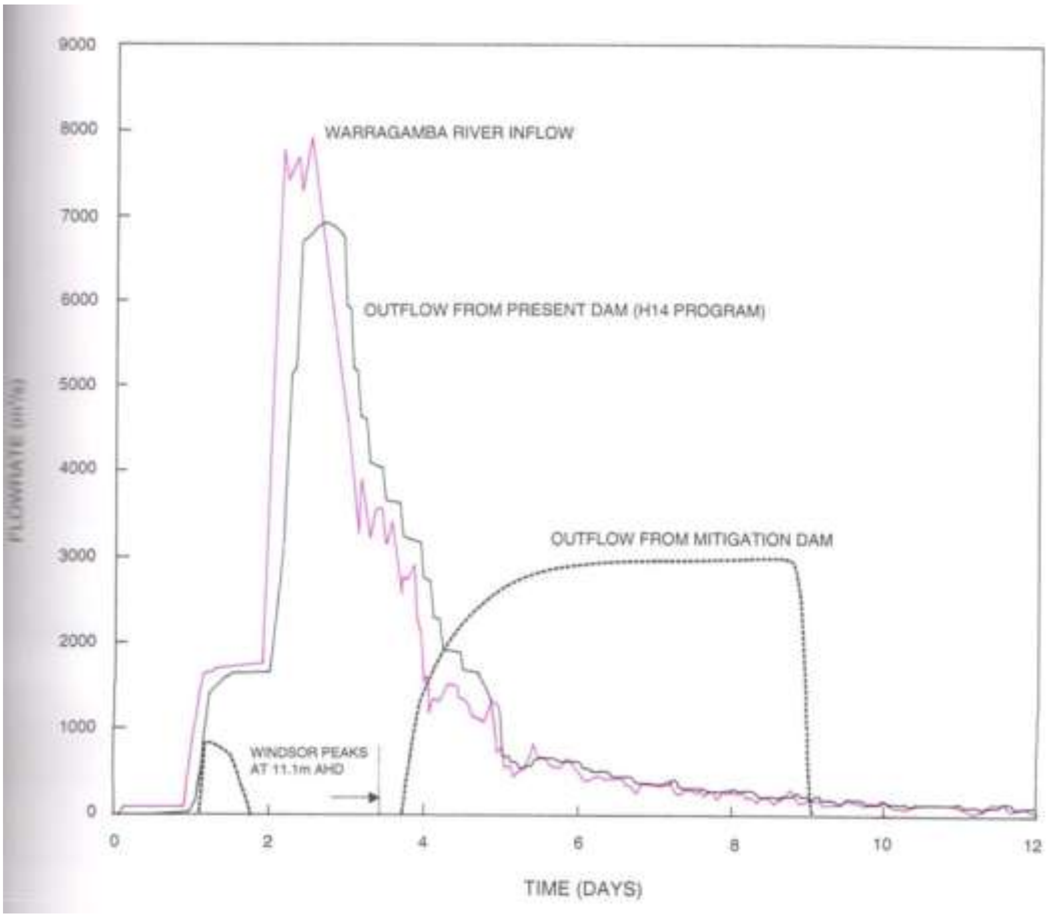


*Figure 13: Comparison of flood flows*

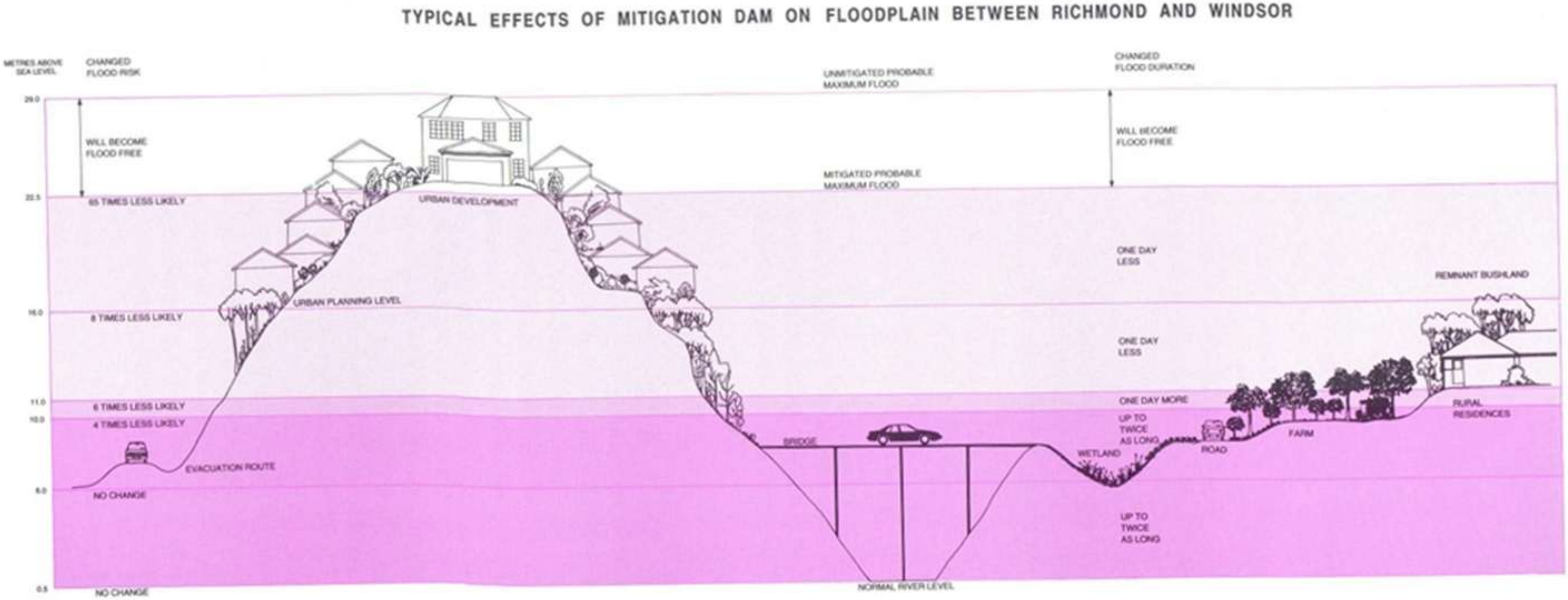


*Figure 14: Impacts of mitigation on Downstream levels and durations*

### 4.2.3 Change in Downstream ARIs

Another way to look at the way mitigation changes flooding downstream, is to consider how it changes the probability of a particular flood level being reached.

The reduction of levels has been used to calculate what the mitigated levels would be equivalent to in an unmitigated situation. These are presented in Table 16. For example, the mitigated 1 in 100 year event would be roughly equivalent to a current (unmitigated) 1 in 8 year event.

Conversely the ARI in an unmitigated situation have been calculated and are presented in Table 17. For example, the levels reached by a current 1 in 100 year event would only be reached by a 1 in 964 year event at Penrith.

### 4.2.4 Increase in upstream flood levels and durations

The detention of floodwaters upstream of Warragamba Dam will inevitably result in an increase in the depth and duration of water levels being above full supply level in Lake Burragorang.

Figure 15 is scanned from the 1995 EIS and summarises how a mitigation would increase the depth and duration of upstream flooding.

The upstream areas are mostly forested, generally within national parks and some are declared wilderness areas. Since 1995, the Blue Mountains World Heritage Area has been declared and includes most of the areas which would be inundated above full supply level.

*Table 16 Unmitigated ARI equivalent*

| *Unmitigated ARI* | Penrith Equivalent ARI (1 in X years) | Windsor Equivalent ARI (1 in X years) |
|---|---|---|
| *1 in 5 Year* | < 5 | < 5 |
| *1 in 10 Year* | < 5 | < 5 |
| *1 in 20 Year* | < 5 | < 5 |
| *1 in 50 Year* | 5 | 8 |
| *1 in 100 Year* | 9 | 14 |
| *1 in 200 Year* | 15 | 31 |
| *1 in 500 Year* | 48 | 75 |
| *1 in 1000 Year* | 111 | 150 |
| *PMF* | 950 | 17,851 |

*Table 17 Mitigated ARI equivalent*

| *Unmitigated ARI* | Penrith Mitigated ARI (1 in X years) | Windsor Mitigated ARI (1 in X years) |
|---|---|---|
| *1 in 5 Year* | 47 | 39 |
| *1 in 10 Year* | 130 | 42 |
| *1 in 20 Year* | 323 | 156 |
| *1 in 50 Year* | 536 | 380 |
| *1 in 100 Year* | 964 | 767 |
| *1 in 200 Year* | 35,435 | 16,065 |
| *1 in 500 Year* | 61,260 | 48,347 |
| *1 in 1000 Year* | N/A | 82,783 |
| *PMF* | N/A | N/A |

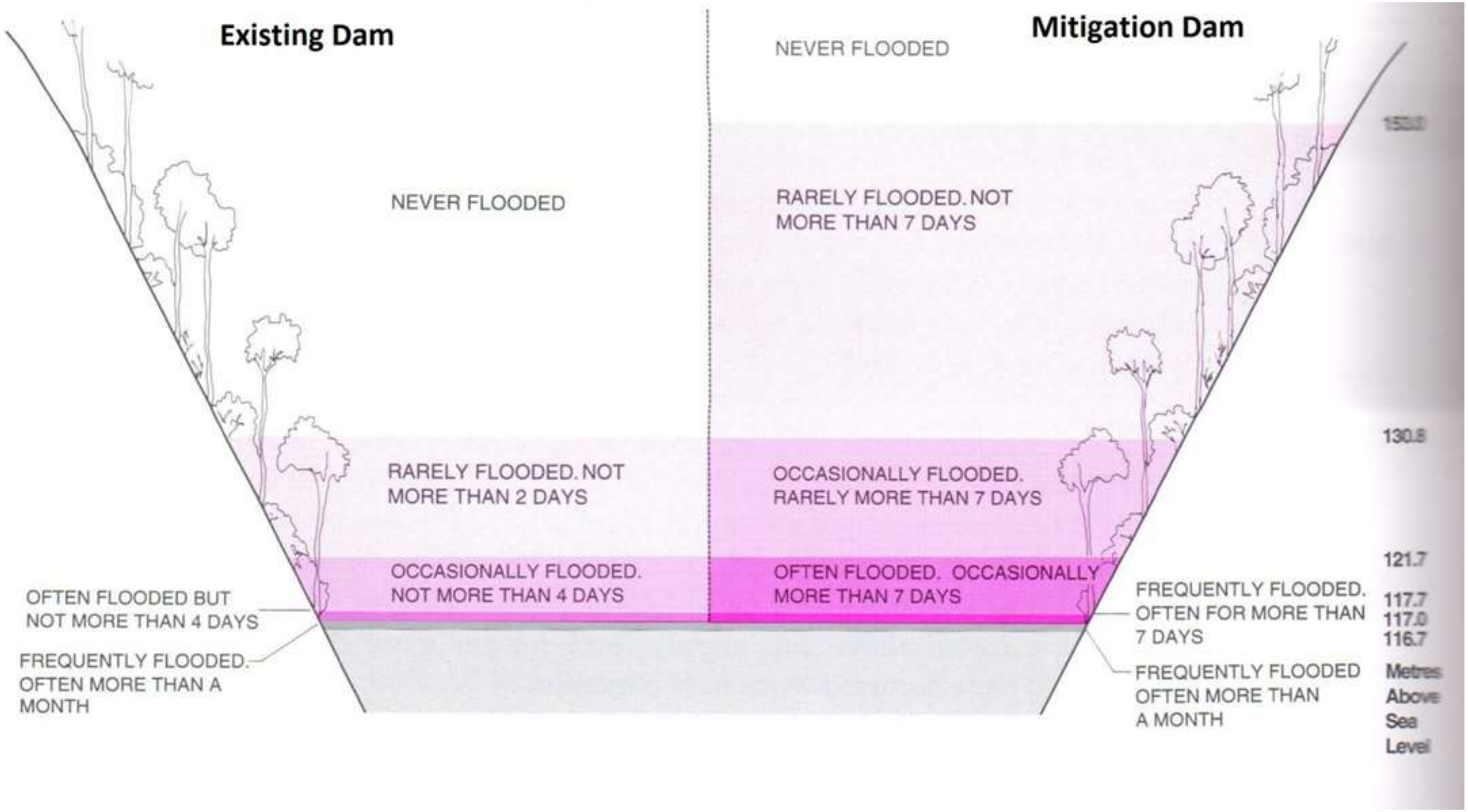


*Figure 15: Impact on upstream flood levels*

## 4.3 CHANGES IN DAMAGES

### 4.3.1 Tangible Damages

The reduction in tangible damages has been calculated by plotting an event based damage curve from the unmitigated dam (presented in Table 6) and interpolating along this line based upon the results presented in Table 16. For example, the 1 in 100 Year mitigated event would have equivalent damage of an unmitigated 1 in 8 year event. The mitigated damages are presented in Table 18.

Figure 16 illustrates this graphically where the top line is the damage curve for the current dam and the bottom line the damage curve for the mitigation dam. It can be seen that the mitigated damages are orders of magnitude less for the events smaller than the 1 in 500 Year (0.200% AEP) and still significantly less for the larger events.

The areas under each curve are the AADs for each dam respectively. Therefore the brown area represents the AAD of a mitigation dam and the blue area represents the reduction in AAD (tangible benefits) provided by flood mitigation.

The mitigation dam would reduce tangible AAD by $51.4m.

Table 18 Mitigation Dam Flood Damages

| *Event* | Event Damage ($m 2011) | Contribution to Annual Average Damage ($m 2011) |
|---|---|---|
| *1 in 5* | 14.2 | 2.1 |
| *1 in 10* | 20.4 | 1.7 |
| *1 in 20* | 30.2 | 1.3 |
| *1 in 50* | 42.7 | 1.1 |
| *1 in 100* | 75.4 | 0.6 |
| *1 in 200* | 172.2 | 0.6 |
| *1 in 500* | 948.8 | 1.7 |
| *1 in 1000* | 5,155.4 | 3.1 |
| *PMF* | 8,570.4 | 6.8 |
| *Total AAD* | | 19.0 |

### 4.3.2 Intangible Damages

#### a) Population At Risk

For the current 1 in 1,000 year event, it would be mitigated to approximately a 100 year event, meaning that the population at risk would be approximately 16,000 as opposed to 52,000 with the current dam. Similarly, the PMF would be reduced to approximately a 1 in 1,000 year event, which implies that approximately the PAR would be approximately 52,000 instead of 68,000.

*Table 19 Mitigation Dam PAR*

| *Event* | Residents | Persons at Commercial and Industrial premises |
|---|---|---|
| *1 in 5* | 0 | 0 |
| *1 in 10* | 0 | 0 |
| *1 in 20* | 0 | 0 |
| *1 in 50* | 203 | 0 |
| *1 in 100* | 318 | 0 |
| *1 in 200* | 760 | 0 |
| *1 in 500* | 1,629 | 377 |
| *1 in 1,000* | 12,288 | 1,791 |
| *PMF* | 38,452 | 6,636 |

#### b) Environmental Damages

Downstream of the dam it is likely that the mitigation dam will reduce damage on environmentally sensitive areas that are not tolerant to flood waters, this includes any ecologically endangered communities, such as any remnant Cumberland Plain Woodland. Additionally, the mitigated floods will reduce the volume and time that untreated sewage discharges into the river due to flooded sewage treatment plants. These have not been quantified in this assessment, however they were examined at length during the 1995 EIS and it is expected the benefits of mitigation will have only increased since then.

### 4.3.3 Intangible Costs

#### a) Increased Duration of Minor Flooding

It is expected that the mitigation dam will increase the length of time that the river is in minor flood conditions both downstream of the dam and periodically increase the level upstream of the dam. This will occur on the recession limb of a flood, as the water that is stored within the mitigation dam is drained

This is exemplified by Figure 17 which shows the simulated water level at Windsor Bridge for a 58 day period in early 1956 for both the existing dam and 23 m option mitigation dam. During a repeat of this event under existing conditions the bridge would be closed on three occasions for about 3 days each time. With the mitigation dam in place, the bridge would have been closed only once but for about 16 days continuously.

This is also likely to result in the lower lying agricultural land on the floodplain being inundated for longer than would otherwise be the case.

### 4.3.4 Potential Environmental Impacts

The changes to the hydrology of the river are likely to have an impact on the ecology of the river and downstream estuary as well as the area upstream of the dam that falls in the elevation between the current storage level and the mitigation dam crest level.

These effects were discussed at length in the 1995 EIS and summarised as:

- Potential sedimentation will increase in the estuarine section of the river (downstream of Windsor)
- Potential increase in bank erosion at lower levels, decrease in erosion at higher levels
- Decreased flushing of saline water from the estuary, however longer periods of low salt conditions
- Potential impacts on aquatic ecology primarily due to changes to flow, depth and morphology regimes.
- Up to 75 square kilometres upstream of the dam may be affected by increased flooding, the exact nature of the impacts are unknown.

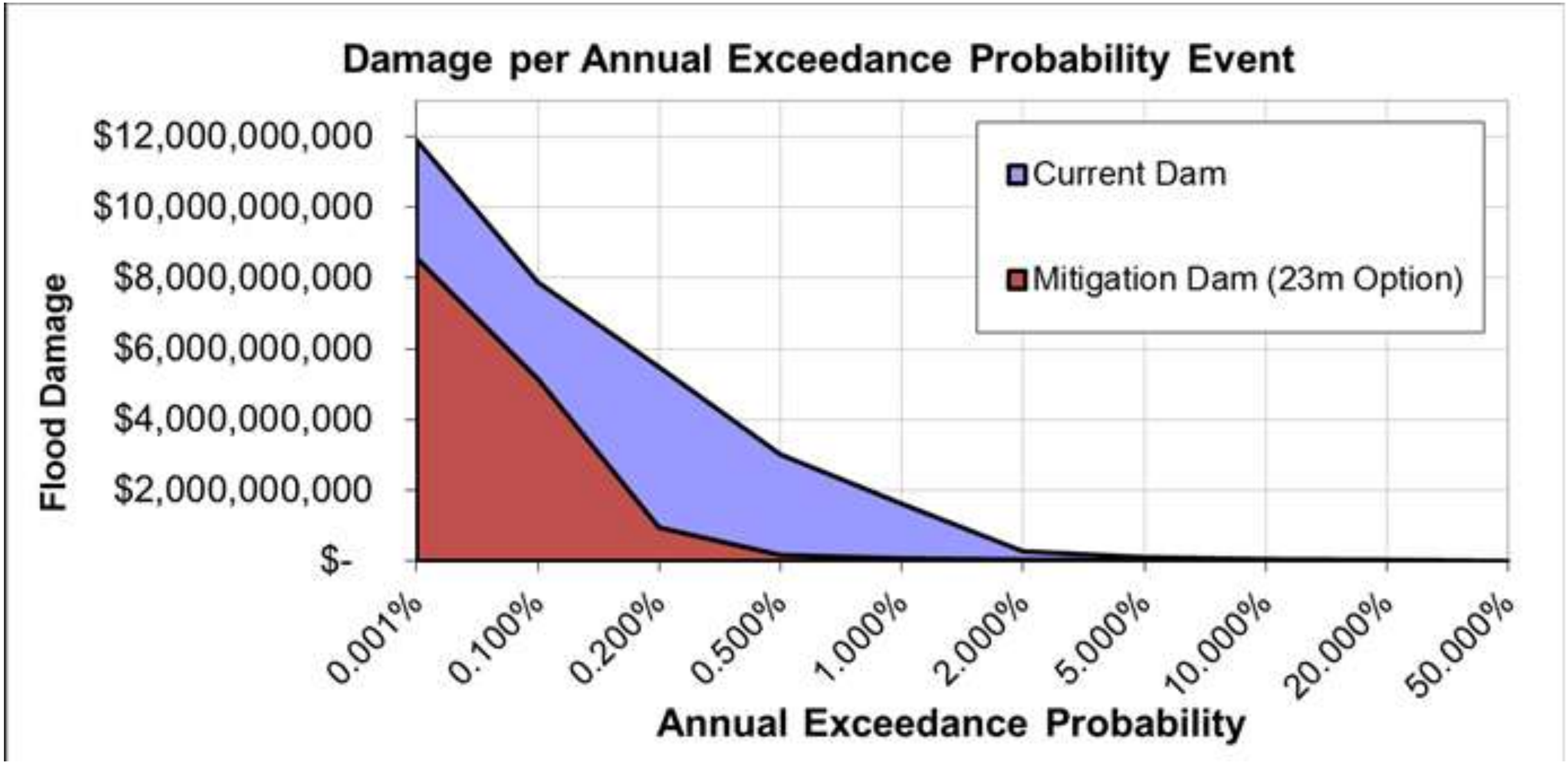


*Figure 16: Changes in tangible flood damages*

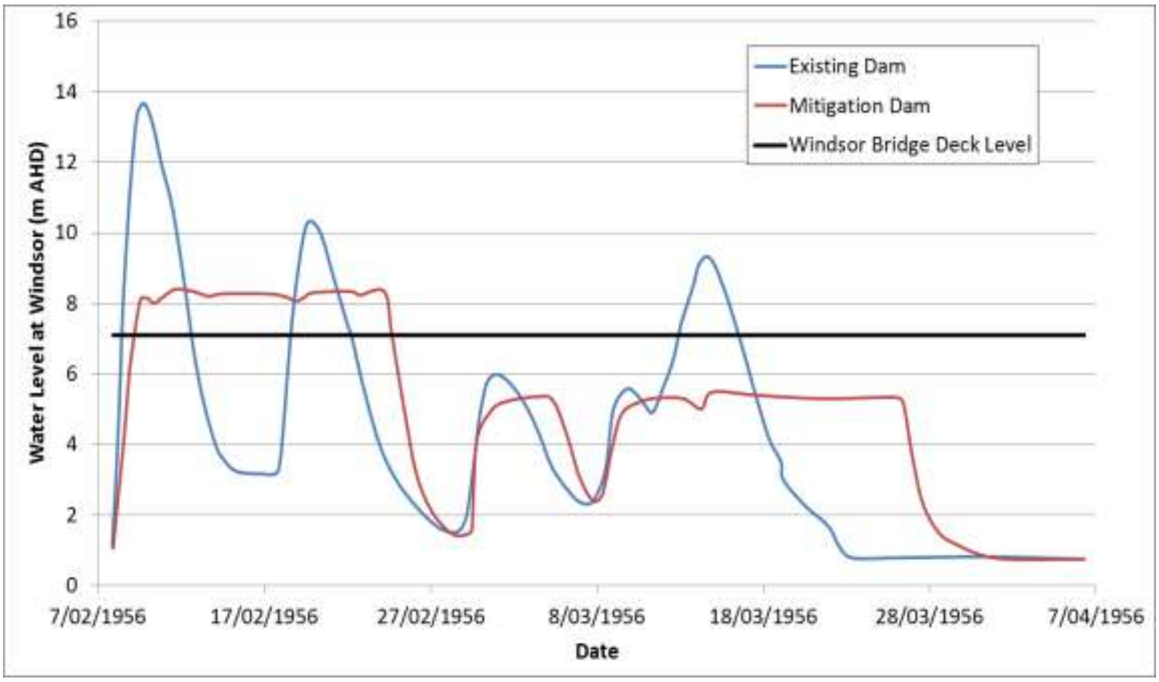


*Figure 17. Simulated Water Level at Windsor Bridge, 1956. Extracted from the 1995 EIS.*

# 5 PRELIMINARY ECONOMIC ANALYSIS

## 5.1 MITIGATION DAM BENEFITS

Standard practice in flood damage economic analyses is to determine the Net Present Value (NPV) of the AAD to determine a present day value of flood damages which can be compared to a present day cost of mitigation options. OEH (2012) recommends a period of 50 years and NSW Treasury recommends real discount rates of 4, 7 and 11 per cent be considered.

While many of the costs and benefits have been explicitly escalated at CPI to calculate present day values, the economic analysis, which is done in real terms, keeps AAD constant into the future.

For this assessment we have applied the 7 per cent discount rate for a 50 year period and used the 4 and 11 per cent discount rates in sensitivity analyses.

The AAD under the existing case are $70.3 million and with a mitigation dam in place are $19.0. At a 7 per cent discount rate over 50 years the NPV of tangible damages with the existing dam are $1,041 million. Using the same methodology the NPV of tangible damages with a flood mitigation dam are calculated as $280 million. The NPV of the tangible benefits of the flood mitigation dam is the difference in the NPV of flood damages, which is $761 million.

In additional to these tangible benefits, there are also intangible benefits. For example:

- The number of people at risk during a repeat of the 1867 flood would be reduced from about 26,000 people to less than 1,000 people.
- The average number of people at risk from flooding each year would reduce from 560 to 50 (calculated on the same basis as tangible AAD).
- Other intangible losses such as loss of life, injury, illness, loss of memorabilia and loss of pets is likely to reduce proportionally to the reduction in people at risk.
- The probability of having to mass evacuate 50,000 people or more would reduce from about a 1 in 100 chance per year to less than a 1 in 800 chance year.
- The probability of more than 10,000 non-flooded premises being without electricity for two weeks would reduce for about 1 in 200 chance to less than a 1 in 1,000 chance per year.
- The probability of more than 50,000 non-flooded premises being without electricity for three months would reduce for about 1 in 500 chance to much less than a 1 in 1,000 chance per year.
- The probability of untreated sewage being discharged to the River from several sewerage treatment plants for weeks would reduce from about a 1 in 500 chance per at Penrith and a 1 in 100 chance per year at Richmond and Windsor to less than a 1 in 1,000 chance per year in both locations.

## 5.2 DAM COSTS

The 1995 EIS estimated that the option to raise Warragamba Dam 23m in mass concrete to provide flood mitigation would cost a total of $243 million. This cost estimate was based on detailed preliminary designs by NSW Public Works.

At the time, there was no auxiliary spillway around Warragamba Dam to enable it to safely pass the PMF but a 23m mass concrete raising would not only provide downstream flood mitigation but it would also make the dam PMF safe. In order to determine the additional cost of providing flood mitigation in 1995, the cost of an auxiliary spillway was subtracted from the total dam cost. The construction costs were applied over a five year construction period and the present value of the mitigation costs determined. The estimated construction program and resultant payment schedule is not presented in the 1995 EIS and was not available for this study.

For this assessment, the 1995 total estimate ($243 million) was taken and inflated by CPI (1.6) to provide a 2011 total cost, this resulted in $411 million. This total cost was used because the auxiliary spillway is now built and is a sunk cost so a 23m raising of the dam would not provide any dam safety benefit as it would have in 1995.

The total $411 million cost was assumed to be spread across a five year construction period with six equal payments with the first payment made on day one. This resulted in a present value of approximately $350 million.

## 5.3 OTHER COSTS

As explained in Chapter 4, the changes brought about by flood mitigation do come with some other costs, most of which are intangible. This includes:

- Increased risk of periodic, temporary inundation of 75km$^2$ of national parks, wilderness areas and Blue Mountains World Heritage Area above Warragamba Dam's full supply level
- Longer durations of minor flood levels downstream resulting in:
  - Low lying agricultural land being under water for longer
  - Low roads and bridges being closed for longer
  - Potential increased sedimentation in the River downstream of Windsor
  - Potential increase in bank erosion at lower levels
  - Longer periods of low salt conditions in the estuary
  - Potential impacts on aquatic ecology primarily due to changes to flow, depth and morphology regimes.

In addition, there will be the environmental and socio-economic impacts on Warragamba Village and surrounding areas during the five years of dam construction.

## 5.4 ECONOMIC WORTH

The benefit cost ratio can then be calculated as the total benefits divided by the total costs. For this project the benefit cost ratio is 2.2. This has been summarised in Table 20. It is generally considered that a benefit cost ratio greater than one implies that a project is economically worthwhile.

## 5.5 SENSITIVITY ANALYSES

A number of sensitivity analyses have been undertaken in order to determine how robust the results of the economic evaluations are. The results of the sensitivity analyses are summarised in Table 20 and explained in the following sections.

### 5.5.1 Sensitivity 1

This was undertaken to see how lower than expected flood damages and higher than expected dam costs would affect the results.

The flood damages were calculated using the 1995 EIS estimates and inflating by CPI only. This does not take into account the increased value and vulnerability of house and business contents across the floodplain nor the substantial new development on the floodplain since 1992.

Additionally, the cost of the dam was inflated by two based on some preliminary construction inflation indices provided by Deloitte and then increased by a further 50% to allow for potential underestimates in the original cost.

Taking all of these factors into account, the resulting benefit cost ratio is 1.03.

### 5.5.2 Sensitivity 2

This analysis examined whether the base case analysis was underestimating the damages and overestimating the costs.

The flood damages were increased by adding an additional cost of $250,000 per house for replacing failed homes.

The dam construction costs were held at $411 million but the present value of the constructions costs was decreased to reflect the apparent payment scheduled used in the 1995 EIS.

The resulting benefit cost ratio was 3.1

### 5.5.3 Sensitivity 3

The discount rate for the present value of the flood damages and the construction cost of the dam were changed to 4%. The result was an increase the present value of the flood damages and the dam construction, which results in a benefit cost ratio of 3.1.

### 5.5.4 Sensitivity 4

A discount rate 11% was applied. The result was a decrease in the present value of both the flood damages and the dam construction, which results in a benefit cost ratio of 1.6

## 5.6 DISCUSSION

The preliminary economic assessment suggests that a 23m mass concrete raising of Warragamba Dam to provide flood mitigation is economically worthwhile. The analysis is sensitive to assumptions regarding flood damages, construction costs and discount rates but even significant unfavourable changes in these assumptions suggest that it would still be economically worthwhile.

Furthermore, should planned development above the current planning level continue in the Valley, then the benefits will increase over time. This has not been accounted for in the preceding analyses.

Conversely, should a mitigation dam be built and then the planning levels in the Valley be lowered to allow for further urban development below the current planning level, the flood damage reduction benefits of the flood mitigation dam would be eroded and this would need to be considered against the benefits of the additional development.

While the analyses demonstrate that a flood mitigation dam would be worthwhile on purely economic considerations, the intangible benefits and costs also need to be considered in determining the overall worth of proceeding with the project.

Table 20 Benefit Cost Ratios for the base case and sensitivity scenarios tested.

| Scenario – 23m flood mitigation airspace provided by raising Warragamba Dam in mass concrete | Damage estimation method | Existing Flood Damages NPV ($m 2011) | Mitigated Flood Damages NPV ($m) | Assumed period of mitigation benefit (yrs) | Dam Cost Estimation method | Mitigation Dam Cost ($m) | Dam Cost NPV over 5 years ($m) | Discount rate | Benefit-Cost Ratio |
|---|---|---|---|---|---|---|---|---|---|
| Base Case | Estimate using 1995 EIS methods but which accounts for changes in development plus CPI since 1990s. | 1,041 | 281 | 50 | 1995 Dam construction cost escalated by CPI. Assumes 6 equal payments with first on Day 1. | 411 | 349 | 7% | 2.2 |
| Sensitivity 1: Low damage with high construction costs | Low estimate which simply inflates the 1995 EIS damages using CPI and ignores increased development on floodplain | 895 | 248 | 50 | 1995 Dam construction cost escalated by 2 (Deloitte) and a further 50% Assumes 6 equal payments with first on Day 1. | 741 | 630 | 7% | 1.03 |
| Sensitivity 2: Base case damages plus building failure with most construction costs later in construction schedule than in base case | Base case plus additional damages to account for replacement of failed residential buildings ($250,000 per building) | 1,157 | 310 | 50 | 1995 Dam construction cost escalated by CPI. NPV estimated from expenditure schedule used in the 1995 EIS | 411 | 271 | 7% | 3.1 |

| ***Scenario – 23m flood mitigation airspace provided by raising Warragamba Dam in mass concrete*** | **Damage estimation method** | **Existing Flood Damages NPV ($m 2011)** | **Mitigated Flood Damages NPV ($m)** | **Assumed period of mitigation benefit (yrs)** | **Dam Cost Estimation method** | **Mitigation Dam Cost ($m)** | **Dam Cost NPV over 5 years ($m)** | **Discount rate** | **Benefit-Cost Ratio** |
|---|---|---|---|---|---|---|---|---|---|
| *Sensitivity 3: Applying 4% discount rate to Base Case Damages and Dam cost* | *Estimate using 1995 EIS methods but which accounts for changes in development plus CPI since 1990s.* | 1,582 | 426 | 50 | *1995 Dam construction cost escalated by CPI. Assumes 6 equal payments with first on Day 1.* | 411 | 373 | 4% | 3.1 |
| *Sensitivity 4: Applying 11% discount rate to Base Case Damages and Dam cost* | *Estimate using 1995 EIS methods but which accounts for changes in development plus CPI since 1990s.* | 706 | 190 | 50 | *1995 Dam construction cost escalated by CPI. Assumes 6 equal payments with first on Day 1.* | 411 | 321 | 11% | 1.6 |

# 6 CONCLUSIONS AND RECOMMENDATIONS

This preliminary investigation has confirmed that a flood mitigation dam at Warragamba would:

- significantly reduce flood risks in the Hawkesbury Nepean Valley
- significantly reduce the damages caused by major floods ranging up to the largest flood on record and beyond
- provide economic benefits well in excess of the cost of dam construction
- significantly reduce the risk to life and deliver other intangible social, economic and environmental benefits
- increase the risk of periodic, temporary inundation of natural areas upstream of the dam
- increase the duration of minor flood flows in the river downstream of the dam which would have social, economic and environmental impacts
- have local social, economic and environmental impacts on Warragamba Village and surrounding areas during its construction

It is recommended that should a decision be made to investigate a Warragamba Flood Mitigation Dam further that:

- flood modelling be updated using:
  - current rainfall and runoff estimation techniques
  - current dam gate and auxiliary spillway configurations and operating rules
  - the latest and most accurate floodplain survey data
  - modern two dimensional flood modelling for the entire river length below the Dam
- built asset databases be updated to accurately reflect current conditions
- committed and planned future development be included in flood damage estimates
- building failure and replacement costs be included in damage estimates
- the environmental effects of changed flood levels upstream of the dam and changed flow regimes downstream be investigated further.

# REFERENCES

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# APPENDIX A – INTANGIBLE DAMAGES SUMMARY

Intangible Consequences of Flooding at Penrith and Emu Plains

| RIVER LEVEL (m AHD) | CHANCE PER YEAR 1 IN | INCREMENTAL CONSEQUENCES |
|---|---|---|
| 15 | usual level | nil |
| 21 | 7 | • A few low lying homes flood, evacuation necessary |
| 22 | 12 | • First of the sewage pumping stations fail and raw sewage overflows to river for 3 days |
| 24 | 32 | • Up to 340 homes flooded and 15 of the flooded homes fail<br>• Up to 950 people needing temporary accommodation for about 1 week and about 45 people for at least three months<br>• Penrith sewage treatment plant starts flooding.<br>• Electricity supply to Cranebrook cut and 6,400 non-flooded properties without power for 2 days. |
| 24.5 | 35 | • Up to 450 homes flooded of which 25 flooded homes fail<br>• Up to 1,250 people needing temporary accommodation for about 5 weeks and 75 people for three to six months<br>• Emu Plains substation flooded. No electricity to 5,500 non-flooded properties for 2 days.<br>• Emu Plains telephone system reliant upon battery power for first six hours then mobile generator power for 2 days<br>• Reduction in service for some mobile phone customers |

| RIVER LEVEL (m AHD) | CHANCE PER YEAR 1 IN | INCREMENTAL CONSEQUENCES |
|---|---|---|
| 26 | 100<br>River breaks its banks | • A total of more than 2,000 homes now flooded of which about 300 homes fail<br>• Up to 5,000 people needing temporary accommodation for about 5 weeks and up to 900 for three to six months<br>• Up to 5,000 people who may need to evacuate from Emu Plains if floodwater continue to rise will not be able to because their evacuation route has been cut and they will not have had sufficient warning time to escape before it does.<br>• Penrith electricity substation shuts down and 7,100 additional non-flooded properties without power for two days and 4,900 without power for 14 days.<br>• 190 private hospital and nursing home beds evacuated and 130 reliant upon emergency generator power for two days<br>• Telephone system for Emu Plains and Penrith reliant upon emergency battery and generator power for two days<br>• Penrith Sewage Treatment Plant damaged. One week shut down with 630 ML of untreated sewage discharged. |
| 27 | 200 | • Up to 2,600 homes flooded of which almost 1,000 homes fail<br>• Up to 4,600 people needing temporary accommodation for about three to six months and a further 3,000 for 12 months<br>• Penrith electricity substation damaged and more than 26,800 non-flooded properties without power for three months<br>• 130 nursing home beds reliant upon emergency generator power for three months<br>• Telephone system in Emu Plains and Penrith reliant upon emergency battery and generator power for three months.<br>• Sewage pumping stations and treatment plant reliant upon emergency generators to keep them operational for three months |

| RIVER LEVEL (m AHD) | CHANCE PER YEAR 1 IN | INCREMENTAL CONSEQUENCES |
|---|---|---|
| 28 | 900 | • Up to 3,200 homes flooded of which 1,850 homes fail<br>• Up to 3,900 people needing temporary accommodation for about three to six months and 5,400 for 12 months<br>• Retirement Village evacuated including 49 nursing home beds<br>• Penrith electricity substation severely damaged and a total of 26,000 non-flooded properties without power for up to three months<br>• Governor Philip Hospital will have to rely upon emergency generator power for up to 3 months<br>• Telephone system for 047 area code east of Lapstone reliant upon emergency battery and generator power for up to 3 months<br>• Victoria Bridge (Great Western Highway) fails taking out rail, gas, telephone, water and sewage lines across the river as well as cutting major road access.<br>• No rail passenger service across Nepean River for 6 months<br>• Rail Freight from west of Nepean River (principally wheat and coal) will need to be transported via long routes to Newcastle and Port Kembla for at least 6 months<br>• No gas supply west of river for three months<br>• Possible reductions in telephone services in and out of Sydney<br>• Raw sewage from any occupied dwellings in Emu Plains discharged to river for three months<br>• Sewage pumping stations and Penrith treatment plant reliant upon emergency generators to keep them operational for three months |

| RIVER LEVEL (m AHD) | CHANCE PER YEAR 1 IN | INCREMENTAL CONSEQUENCES |
|---|---|---|
| 31 | 20,000 | • More than 4,000 homes now flooded of which 2,000 fail<br>• Up to 6,000 people needing temporary accommodation for about three to six months and 6,000 for 12 months<br>• Penrith electricity substation destroyed and a total of 25,000 non-flooded properties without power for 3 to 6 months<br>• Governor Philip Hospital will have to rely upon emergency generator power for up to 6 months<br>• Telephone system for Penrith and Emu Plains fails due to flooding of Penrith Switching Centre. Up to one month to restore system then reliant upon emergency battery and generator power for up to 5 more months.<br>• Penrith Sewage Treatment Plant severely damaged. At least 3 months to repair with untreated sewage being discharged to river. A further three months until licensed effluent standards can be achieved. About 3,800ML of untreated or partially treated sewage discharged to the River. |
| 32 | 100,000 | • Up to a total of 7,200 homes flooded and 5,000 of the flooded homes fail<br>• Up to 6,400 people needing temporary accommodation for about three to six months and 14,500 for 12 months |

Intangible Consequence of Flooding at Richmond-Windsor

| RIVER LEVEL AT WINDSOR (m AHD) | CHANCE PER YEAR 1 IN | INCREMENTAL CONSEQUENCES |
|---|---|---|
| 0.5-1.0 | normal tidal range | nil |
| 7 | 3 | * River breaks its banks<br>* North Richmond and Windsor bridges close. Yarramundi Bridge already closed |
| 12.5 | 10 | * 250 rural dwellings flooded<br>* at least 750 people evacuated and needing temporary accommodation for one week |
| 13 | 14 | * Up to 500 homes flooded<br>* Up to 300 people needing temporary accommodation for two days and 1,200 for about one week<br>* Richmond, McGraths Hill, Riverstone and South Windsor sewerage systems virtually non functional due to loss of pumping stations. Raw sewage discharged to river for 2 days |
| 14 | 22 | * Over 1,000 homes flooded<br>* At least 5,600 people evacuated including the whole of McGraths Hill and Mulgrave<br>* Up to 2,800 people requiring temporary accommodation for 2 days and 2,800 people for one week<br>* electricity supply to 200 properties north of River shut down for 2 days<br>* Telephone system north of the river will have to rely on battery or generator power for up to 2 days<br>* St John of God Hospital at North Richmond will have to rely upon emergency generator power for 2 days<br>* McGraths Hill Sewage Treatment Plant Damaged. Untreated sewage discharged to River for 3 months and further 3 months to achieve required effluent quality<br>* One Pumping station for Quakers Hill Sewerage System fails and raw sewage overflows into Eastern Creek |

| RIVER LEVEL AT WINDSOR (m AHD) | CHANCE PER YEAR 1 IN | INCREMENTAL CONSEQUENCES |
|---|---|---|
| 16 | 60 | * Up to 2,300 homes flooded of which 550 homes fail<br>* The whole of Bligh Park and Pitt Town would have been evacuated even if their homes have not flooded.<br>* 33,000 people needing temporary accommodation for two weeks, 6,500 for about five weeks and 1,500 for three to six months<br>* Hawkesbury District Hospital and Richmond Community Nursing Home evacuated<br>* 6,500 properties would lose telephone services due to flooding of exchanges but this would be in evacuated areas |
| 17.2 | 100 | * Up to 3,300 homes flooded of which 850 homes fail<br>* The whole of Windsor and most of Richmond , Bligh Park and Windsor Downs would need to be evacuated including homes which might not flood<br>* About 30,200 people needing temporary accommodation for about two weeks, 6,700 for five weeks and 2,400 for three to six months<br>* Potential for 3,800 people who are meant to evacuate from Windsor not being able to because their evacuation route has been cut.<br>* 2,400 premises supplied by Windsor substation which are not flooded are without power for up to two weeks but most of these have probably been evacuated |

| RIVER LEVEL AT WINDSOR (m AHD) | CHANCE PER YEAR 1 IN | INCREMENTAL CONSEQUENCES |
|---|---|---|
| 18.6 | 200 | * Up to 8,500 homes flooded and 900 homes fail<br>* 15,600 people needing temporary accommodation for about two weeks, 21,300 for five weeks and 2,500 for three to six months<br>* Major sewage pumping station in St Marys Sewerage System flooded and half of system's sewage discharging untreated to South Creek for about one week<br>* Electricity supply into Hawkesbury Transmission Substation cut. 20,300 non-flooded properties without power for two days, many (but by no means all) of these have been evacuated<br>* Telephone system in whole area with 45 prefixes would be reliant upon emergency battery and generator power for two days. Continued operation of generator at Richmond terminal exchange critical to operation of entire system<br>* Significant reduction in mobile telephone service<br>* All sewerage systems reliant upon emergency generators for two days<br>* Possible rupture of gas and oil pipelines at Hawkesbury River crossing (Jemena does not believe so). 36,000 residential and commercial gas users at Newcastle and Central Coast without gas supply for 5 months. Petroleum products transported by road for 12 months. |

| RIVER LEVEL AT WINDSOR (m AHD) | CHANCE PER YEAR 1 IN | INCREMENTAL CONSEQUENCES |
|---|---|---|
| 20.1 | 500 | * Up to 11,100 homes flooded of which 1,900 fail<br>* 2,000 people needing temporary accommodation for about 3 months, 25,800 for 6 months and 5,300 for six to 12 months<br>* Hawkesbury Transmission substation flooded and substantial damage to transmission lines. 23,800 non-flooded properties without power for up to 3 months<br>* St John of God Hospital will have to rely upon emergency generator power for up to 3 months<br>* Telephone system for entire area with phone numbers beginning with 45 reliant upon emergency generator power for up to 3 months<br>* Significant disruption to mobile phone system unless towers in electricity supply area can be provided with emergency generator power for up to 3 months.<br>* Richmond, South Windsor and St Marys sewage treatment plants damaged. 3 months to get South Windsor operational and 6 weeks to get St Marys Operational with untreated sewage being discharged to river. Twice that time to achieve licensed effluent standards. Richmond would take 2 weeks to achieve effluent standards<br>* Almost 200 hospital and nursing home beds reliant upon emergency generators for power supply for up to 3 months<br>* North Richmond Sewage Treatment Plant shuts down and raw sewage discharged to river for 2 days<br>* McGraths Hill Sewage Treatment Plant severely damaged. 12 months to rebuild and get fully operational. |
| 22 | 1,500 | * Up to 18,000 homes flooded and up to 7,800 of the flooded homes fail<br>* 28,560 needing temporary accommodation for 6 months and 21,840 for 6 to 12 months<br>* Hawkesbury Transmission Substation significantly damaged. No electricity to 20,800 non-flooded properties for 3 months or more<br>* Richmond Switching Centre damaged and no terrestrial telephone service to whole of area with numbers beginning with 45 for 2 weeks after which it would be reliant upon emergency generator power for 3 months or more.<br>* North Richmond Sewage Treatment plant damaged. 2 weeks to become fully operational and 3 months to achieve effluent standards. |
| 25 | 15,000 | * St Marys, North Richmond, and Richmond Sewage Treatment Plants need total reconstruction and 12 months to |

| RIVER LEVEL AT WINDSOR (m AHD) | CHANCE PER YEAR 1 IN | INCREMENTAL CONSEQUENCES |
|---|---|---|
| | | be fully operational. St Marys and North Richmond have significant parts of their catchments which would not be affected by flooding and raw sewage would be discharged until the plants were operational. |
| 26.4 | 100,000 | * Up to 21,300 homes flooded of which 18,000 fail<br>* 9,200 for 6 months and 50,400 for 6 to 12 months<br>* South Windsor Sewage Treatment Plant needs 12 months to be completely rebuilt. Quakers Hill Sewage Treatment Plant damaged. 6 weeks to become operational and another 3 weeks to achieve effluent standards. |

# APPENDIX B - GLOSSARY

**ALLUVIAL** - Deposited by river processes.

**ANNUAL EXCEEDANCE PROBABILITY (AEP) -** The likelihood of a flood being exceeded in any given year. For example, a flood with an AEP of 1 in 100 has a 1 in 100 chance of being exceeded in any given year.

**AUSTRALIAN HEIGHT DATUM (AHD)** - The standard reference level used to express the relative elevation of different features. A height given in metres AHD is essentially the height above sea level.

**BACKWATER** - An area inundated by water from a river but outside the general flow of the river.

**BANKFULL** - The condition of a river when flow is so great that no river banks are exposed.

**BENEFIT COST RATIO (BCR) -** The ratio of the benefits derived from a project to the costs of constructing and operating the project.

**CATCHMENT** - The land surface area that drains into a reservoir or to a specific point in a river system.

**DAM -** A structure across a river which impounds water.

**DESIGN FLOOD** - A flood where the levels at all points along the river have the same chance of occurrence. It is estimated using hydrologic and hydraulic computer models.

**ENVIRONMENTAL IMPACT STATEMENT (EIS)** - A formal description of a project and an assessment of its likely impact on the physical, social and economic environment. It includes an evaluation of alternatives and a justification of the project. The EIS is used as a vehicle to facilitate public comment and as the basis for analysing the project when seeking approval under relevant legislation.

**FLOODPLAIN** - That part of a river valley, adjacent to the river channel, over which a river flows in times of flood.

**FREEBOARD** - The vertical height between the maximum flood level in a reservoir and the crest of a dam wall.

**FULL SUPPLY LEVEL (FSL) -** The water level in a reservoir when it is at its full water supply storage capacity. It only rises above this level during floods and the excess water is discharged from the reservoir.

**HYDROGRAPH** - A graph showing the variation over time of water levels or flow.

**MEGALITRE (ML)** - One million litres.

**NET PRESENT VALUE** - The net difference between the present day value of future benefits and the present day value of future costs.

**PLANNING LEVEL** - The level above which local government permits urban development. This level varies from location to location.

**POTABLE WATER** - Water of a quality suitable for human consumption.

**PROBABLE MAXIMUM FLOOD (PMF)** - The largest flood likely to occur.

**REACH -** Section of a river between bends.

**RESERVOIR** - A body of stored water. Often refers to water stored behind a dam but can refer to water stored by a tank, pit or bund.

**RIVERINE** - Of or pertaining to a river.

**SCOURING** - Erosion of materials by the passage of water.

**SPILLWAY** - A channel to convey overflow water from a reservoir to the downstream watercourse in a controlled manner.