NSW STATE EMERGENCY SERVICE

FLOOD HAZARD AND RISK IN NEW SOUTH WALES

Supporting Document to the NSW State Flood Plan

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PART 1 - THE FLOOD THREAT IN NSW

1.1 GENERAL

1.1.1 Floods occur frequently in New South Wales. In terms of average annual dollar damage to infrastructure, property and production, and probably also in terms of deaths and injuries to human beings, flooding constitutes the most serious natural hazard faced by the community in this state.

1.1.2 Both East Coast Lows and Flooding are identified in the 12 hazards identified in the NSW State Level Emergency Risk Assessment that pose significant risk to NSW, both with an assessed risk rating of Extreme.

1.1.3 In an average year, a small number of deaths are recorded during floods within the state, and occasionally there are multiple deaths in an individual flood episode. There have been several flood events in the state's history in which more than twenty people have died. One flood at Gundagai in 1852 caused the deaths of 89 people and the floods on the Hunter River and in the state's north-west in 1955 also resulted in a large death toll. Nationally between 1788 and 2013 some 2400 people died as a consequence of floods (1).

1.1.4 In terms of total economic costs incurred by floods, damage and disruption caused by flooding is estimated to cost Australia around $550 million a year as at 2001 (2). In years of unusually severe flooding, the total cost may be two to four or more times this value as was the case in 1954, 1955, 1956, 1974, 1975, 1976, 1984, 1990, 1998, 2000, 2001, 2007, 2010-2011 and 2012. The Australian Business Roundtable claims the 2010-11 Queensland floods alone had a total economic cost of $14.1 billion in 2015 dollars, including social costs. Even during periods of drought there have been significant and costly episodes of flooding. In NSW, the average damage from flooding in coastal and inland urban centres is around $200 million a year.

1.1.5 Substantial community assets are exposed to the flood threat. More than 160,000 urban residential properties in Australia are believed to be at risk of inundation in 1% AEP (Annual Exceedance Probability) flood events, with approximately 55,000 of these in NSW as at 2006. To these numbers an unknown but large number of rural properties must be added which are similarly exposed (3). While more than 100,000 buildings in NSW are at risk of flooding.

1.1.6 It has been estimated that the total potential damage exposure from flooding in the state, in terms of all assets exposed (private and public, residential, commercial, industrial, agricultural, infrastructural and other), may approximate $50 billion as at 2006 (3).

1.1.7 Even low-level floods, which occur relatively frequently in the state's flood liable areas, usually cause some damage and result in economic losses and inconvenience. Floods reaching high levels are less common but invariably have more serious consequences and affect more property, more infrastructural assets and more people.

a. Many floods necessitate the evacuation of people to safety. There are areas from which evacuation is a relatively common occurrence, and cases in which entire communities (including whole towns and suburbs) have had to be evacuated.

1.1.8 Extreme floods are rare but can be catastrophic in their impacts. In this context it should be noted that very few flood prone areas in New South Wales have experienced floods of severities approaching Probable Maximum Flood (PMF) proportions since European settlement, although some events of 0.5-0.8 PMF have occurred during the very short period of flood records in the state, for example Wollongong in 1984 (4).

1.1.9 Floods much higher than have been experienced in recorded history should be expected to occur at some stage in the future. It is these very severe floods which are the most likely to result in great damage, risk to human life on a substantial scale and the evacuation of large numbers of people. Such floods will be more dangerous in terms of depth and velocity conditions than lesser ones, and they will be outside the experience of floodplain communities. As a result, people cannot be expected to know how to deal with them.

1.1.10 Floods occurring in the future which are of equal magnitude to the worst previously recorded in European history are likely to be more severe in their impacts than those earlier floods due to the growth in population and economic activity in flood liable areas. For example, a flood on the Hawkesbury-Nepean River equal to the size of the flood of 1867 (between 0.5% and 0.2% AEP) would flood approximately 12000 properties. A flood of this magnitude would also necessitate the evacuation of more than 90,000 people and cause much more serious damage than occurred in 1867 (5).

1.2 FLOOD PRODUCING WEATHER SYSTEMS

1.2.1 There are many different types and origins of flood-producing weather systems and different parts of the state are affected by different kinds of weather activity in different seasons of the year. The state's flood-producing mechanisms are complex and there is no single clear-cut flood season. Rather, different regions have general tendencies towards flooding at particular times of the year. As a rule, the northern parts of the state have more frequent flooding during the summer and autumn months than at other times while the south experiences most of its flooding in winter and spring.

1.2.2 The heavy rain which produces flooding in New South Wales may come from any of the following kinds of weather system:

Inland Troughs

a. Inland troughs, often within an associated low pressure cell, that direct moist air from the tropical north of the Australian continent, have been responsible for several of the most severe floods in inland northern and central NSW and the Hunter Valley. A few such systems have also extended further south to cause floods in the Murrumbidgee catchment.

b. Troughs are an elongated area of low pressure, but are not closed, like low pressure cells. On synoptic charts they typically appear as “U”, or trough, shaped isobars.

c. Examples of significant historical flooding as a consequence include:

- February 1955 – record flooding in the Hunter, Gwydir, Namoi, Macquarie and Castlereagh and major flooding along the Macintyre and Darling Rivers.
- January 1971 to February 1971 - major flooding along the Macintyre, Gwydir, Culgoa, Hunter and Darling Rivers. Gunnedah experienced its 4th highest flood.
- August 1974 – major flooding along the Murrumbidgee and Lachlan rivers. Wagga Wagga experienced its 3rd highest flood. As the system moved eastwards major flooding also developed in the Nepean Hawkesbury and Shoalhaven catchments.
- April 1990 – record flooding at Nyngan and major flooding along the Castlereagh, Lachlan, Macquarie, Darling, Paroo, Warrego and Namoi Rivers.
- February 1992 – major flooding in the Bogan, Hunter, Nepean Hawkesbury, Namoi and Moruya catchments.
- November 2000 – major flooding along the Namoi, Gwydir, Macintyre, Macquarie and Darling Rivers.
- September 2010 to February 2011 – Strong La Nina conditions caused significantly higher than average rainfall and widespread flooding in central and eastern Australia, especially in the Murrumbidgee, Castlereagh and Lachlan catchments (4).
- March 2011 - Significant flooding occurred in far northern NSW, Wagga Wagga, and the Darling basin, with flash flooding across south eastern NSW in March 2011 (6).
- February to March 2012 – widespread flooding across south eastern NSW including major flooding of the Murrumbidgee River near Gundagai, Wagga Wagga and rural localities downstream, major flooding in the Darling Basin and the Lachlan River (7).

Tropical and Ex-Tropical Cyclones

d. Most damage from tropical cyclones affecting Australia’s east coast occurs in coastal areas of northern and central Queensland. Occasionally, however, the severe effects of a cyclone extend further south into north eastern NSW. One of the worst was a very severe tropical cyclone which struck northern NSW on 20 February 1954. This storm had lost little of its intensity when it struck NSW, causing widespread flooding and 26 deaths.

e. Usually tropical cyclones lose some of their intensity when they reach the cooler southern waters and are labelled “ex-tropical”.

f. Such systems generally cause flooding in New South Wales only a small number of times in a decade, but on occasions the flooding is very severe.

g. Examples of historical flooding as a consequence include:

- February 1954 'TC137' – category 1 Tropical Cyclone caused record major flooding at Murwillumbah and Lismore. Major flooding was experienced along the NSW coast down to the lower Hunter.
- January 1974 Tropical Cyclone Wanda – major flooding in the Tweed, Richmond Wilsons and Clarence catchments. A weakening Cyclone Wanda crossed the Queensland coast on 24 January about 150 kilometres north of Brisbane. It caused massive flooding in Brisbane.
- March 1974 Ex-Tropical Cyclone Zoe – major flooding along the NSW coast from the Tweed to the Macleay with near record major flooding at Lismore.
- February 1990 Tropical Cyclone Nancy – crossed the NSW Coast near Byron Bay as a category 2 cyclone before moving seaward again. Flooding occurred along the NSW coast from the Tweed to the Georges with major flooding in the Manning, Hunter and Hastings catchments. Five people drowned in northern NSW.
- January 2013 – Ex-Tropical Cyclone Oswald caused severe flooding along the coast, with the Clarence catchment reaching record flood peaks at Grafton and Ulmarra. Effects were exacerbated by storm surge exceeding 0.59m. Significant coastal erosion and some inundation of foreshore areas were experienced (8).
- March 2017 – Ex-Tropical Cyclone Debbie caused severe flooding in northern NSW. Record flooding was experienced in Murwillumbah and major flooding occurred on the Tweed, Brunswick and Richmond/Wilsons catchments. Moderate flooding occurred on the Clarence, Bellinger and Upper Macintyre catchments.

East Coast Lows

h. Cyclones which develop outside the tropics are called extra-tropical cyclones or, when developing off the NSW coast, "East Coast Lows". They are about the same size as tropical cyclones but occur further south and are usually not quite as intense. Most major riverine floods along the NSW coast have been caused by East Coast Lows. Some East Coast Lows, for example, August 1949 and February 1956, were inland lows before moving off the NSW coast. The heavy rainfall from these systems often extends west of the Great Dividing Range to produce major flooding along the Macquarie (particularly Bathurst) and Lachlan Rivers. Occasionally flooding also occurs in the upper Murrumbidgee catchment, including the Queanbeyan and Molonglo Rivers.

i. East Coast Lows also produce gale force winds, storm surges, dangerous surf conditions and coastal erosion.

j. Examples of historical flooding as a consequence include:

- June 1867 – Damaging floods were reported from the Hunter in the north to Moruya in the south and the Macquarie and Murrumbidgee in the west. The Hawkesbury-Nepean River system flooded to record levels, and is estimated to be between a 1 in 200 (0.5%) and 1 in 500 (0.2%) chance per year flood at Windsor. Over 30 fatalities were associated with the weather event (9).
- August 1949 – major flooding in the Macleay, Hunter, Hastings and Gwydir catchments. At Kempsey, 6 lives were lost, 35 houses were destroyed, 300 houses were uninhabitable and 2000 people were left homeless. The damage bill in the Macleay Valley alone exceeded $200 million, in 2015 dollar values.
- June 1950 – major flooding in the Clarence, Bellinger, Nambucca, Macleay, Hastings, Manning, Hunter and Macintyre catchments. Record flooding was experienced along the Bellinger and Nambucca Rivers.
- February 1956 - this was an inland low before moving off the NSW coast. Major flooding in the Macintyre, Namoi, Gwydir, Bellinger, Nambucca, Nepean Hawkesbury, Georges and Shoalhaven catchments. The Georges River at Liverpool had its 5th highest flood – the level was over 1 metre higher than the major 1986 and 1988 floods.
- March 1978 – major flooding in the Tweed, Manning, Hunter and Nepean Hawkesbury catchments. Taree experienced its 2nd highest flood.
- August 1986 – major flooding on the Hawkesbury-Nepean and Georges Rivers.
- March 2001 – major flooding in the Bellinger, Nambucca, Clarence, Macleay, Manning and Lower Hunter catchments.
- June 2007 – a series of five East Coast lows within the month caused flooding in the Hunter, Georges, Myall, Tuggerah Lakes, Wyong, Lake Macquarie, Hawkesbury Nepean and Karuah catchments. The most severe storm occurred on the 8th and 9th of June. Flooding affected Singleton, Maitland, Raymond Terrace, Newcastle, Lake Macquarie and Wyong, with several thousand properties experiencing flood inundation. In Maitland 4000 people were evacuated. Eight people died as a consequence of flooding, with many more rescued from critical conditions.
- April 2015 – a severe East Coast Low developed in a surface trough off the Hunter coast system causing very heavy rain and strong winds in the Hunter, Sydney, and Illawarra regions over subsequent days, contributing to widespread flooding. Major flooding occurred in the Paterson, Williams and Hunter Rivers. Flooding along Myall Creek was estimated as being 1m higher than a 0.2% AEP event. Three people died

as a consequence of flooding in Dungog, several houses were destroyed and over 70 dwellings were inundated.

- June 2016 - an intense East Coast Low stretched along the entire NSW coast and over three days brought widespread rainfall, damaging winds and flash flooding to the Northern and Southern coastal regions, Sydney Northern Beaches and South West Metropolitan region. There was major flooding in the Georges River which reached its highest level in thirty years. As a result of the storm, two people lost their lives. Approximately 600 houses and 130 business were directly impacted, the major impact occurred in central Picton, where 81 out of approximately 128 businesses were significantly damaged. Significant coastal erosion occurred along several stretches of beach, including Collaroy. In 2016, the Insurance Council of Australia estimated the costs of the storm to be over $304million in NSW (10).

Cold Fronts

k. Cold fronts themselves are a relatively poor source of moisture. However, when they interact with the warmer air in the Tasman Sea, they provide a trigger for rain. Moisture for these systems is fed in from the Coral and Tasman seas. Widespread rainfall often results from these cold fronts, particularly during May to October, although the amount of rain is variable. The cumulative effect of several fronts over the winter period can often lead to major flooding along the Macquarie, Lachlan, Murrumbidgee and Murray Rivers, as the catchments can become increasingly saturated from relatively modest rainfall totals.

l. Examples of historical flooding as a consequence include:

- June 1952 - record major flooding at Forbes (Lachlan) and major flooding in the Macquarie, Murrumbidgee and Upper Murray catchments.
- October 1975 – major flooding occurred along the Lachlan, Murrumbidgee and Murray Rivers. Flood levels along the lower Murray River at Echuca were the highest for nearly 60 years (6th highest flood) during this flood.
- October 1993 - major flooding along the Murray and Lachlan Rivers. Widespread major flooding occurred in northern Victoria, including record flooding at Benalla.
- June to October 2016 – a successive series of five cold fronts and inland troughs brought rainfall to large areas of inland NSW. River systems were affected in the following regions: Central West, Far West, Lachlan, Macquarie, Murray, Murrumbidgee, Namoi, North West, Southern Highlands. There was major flooding on the following rivers: Barwon/Darling, Bell, Bogan, Lachlan, Macquarie and Murrumbidgee. The Lachlan River reached 11.9m at the Nanami Gauge on 24 September 2016 (the largest flood event since the 1974 flood on the

Lachlan River). In the Lachlan LGA, 200 people were evacuated. In the Forbes LGA, 1000 people were evacuated.

Deep Easterly Flow and Surface Trough

m. Deep easterly flow, in combination with a surface trough and/or upper low pressure system, brings in moisture from the Pacific Ocean or Tasman Sea to the NSW coast. The area where the trough line touches the coast is where the heaviest rain is likely to occur.

n. Examples of historical flooding as a consequence include:

- August 1998 – major flooding at Wollongong. This event, which came one week after a major east coast low, caused Warragamba Dam to fill and spill.
- June 2005 – major flooding in the Tweed, Brunswick and Wilsons (Lismore) catchments. Record major local flooding occurred in parts of the Brunswick and Tweed catchments, with over 500 millimetres of rain falling over a 48 hour period in some parts.

Thunderstorms

o. Unlike the other flood producing weather systems described, the scale of thunderstorms on their own is relatively small and usually leads to local flash flooding, rather than major widespread main river flooding. However, large scale flood producing weather systems can also generate thunderstorms which will typically result in much higher local rainfall totals than the regional average.

p. Thunderstorm activity occurs frequently in New South Wales, especially during the months from October to March.

q. For NSW it is estimated that about half of flash flooding is due to thunderstorms alone. The other half is caused by major flood producing weather systems (that may also have embedded thunderstorms) where local flash flooding develops ahead of riverine flooding.

r. Occasionally thunderstorms bands are very slow moving, so that one area receives prolonged heavy rainfall. Alternatively, successive thunderstorms may move over the same area, called the "train" effect, which can lead to high rainfall totals that have resulted in local flash flooding as well as main river flooding. E.g. November 2008 major flood along the Peel River at Tamworth.

1.3 CAUSES AND TYPES OF FLOODING

1.3.1 Flooding may be defined, in an emergency management context, as an overflowing or influx of water from its normal confines onto land not usually submerged, threatening human life, property or activity. In the New South Wales context there are four potential mechanisms which may cause flooding (10):

a. Heavy rainfalls, which cause the banks of rivers and creeks to be overtopped, result in overflows from lakes, detention basins and

stormwater drains, cause local overland flooding, or result in releases or spills from dams. Heavy falls of rain constitute by far the most common cause of flooding in the state.

b. Storm surges, which are temporary raisings of sea level above the astronomical tide. These are caused by deep low-pressure systems located off the coast and result in sea water invading low-lying areas along the coast. This flood mechanism is relatively uncommon, but its effects are usually exacerbated by 'rainfall' flooding occurring at the same time or soon afterwards and caused by the same weather system.

c. Tsunami, resulting from undersea earthquakes, landslides, meteorite impacts or volcanic activity. The arrangements for the emergency management of tsunami are contained in the State Tsunami Emergency Sub Plan.

d. Dam failure, which is very rare but can be catastrophic in its consequences. It may cause flooding in excess of PMF proportions and inundate areas well above the limits of floodplains.

1.4 DAM FAILURE FLOODING

1.4.1 This flood-producing mechanism is extremely rare except for the case of very small farm dams whose failure causes only limited and very localised flooding. Several dams and detention basins in New South Wales have been identified as high risk due to a range of factors but including that their spillway capacities are insufficient to pass their design floods. Hence, during very severe floods their walls may be overtopped leading to a credible chance of failure. Such severe flooding, however, should be recognised as being rare and that dam owners have programs in place to enhance dams so that they can safely pass their design floods.

1.4.2 Other high risk dams include a limited number which are known to lack structural integrity and could fail because of piping (internal erosion of the wall) or because of severe earthquake activity. Such failures could occur in the absence of heavy rain and are known as 'sunny day' modes of failure. A list of prescribed dams is included as Schedule 1 of the *Dams Safety Act 1978* (NSW).

1.4.3 Failures of dam operating equipment may also occur, including failures of gates or spillway operating mechanisms. In some such cases, sudden and unplanned releases may result and cause flooding downstream.

1.5 CHARACTERISTICS OF FLOODING IN NSW

1.5.1 Flash flooding eventuates very soon after the rain which causes it and initially occurs in the same area in the form of overland flooding. It can also occur anywhere in the state when the intensity of the rainfall overwhelms natural or artificial drainage systems. Such flooding commonly occurs from stormwater drains in built-up areas, on the headwaters of rivers and on short creeks. Less frequently, it happens over large areas of the state's inland.

1.5.2 Flash flooding is especially a problem in the larger urban areas of Sydney, Newcastle, the Central Coast and Wollongong and in near-coastal environments where communities have developed on and immediately below steep escarpments (such as at Coffs Harbour). Flash flooding also occurs when urban drainage systems are overwhelmed by intense rainfall and roads become "rivers" with flooding occurring at their low points. In steeply-sloping areas such flooding can have dangerously high flow velocities. In the low-lying, flat, western parts of the state, the results of local overland flooding from heavy rain can last for long periods with virtually no flow of water towards main rivers.

1.5.3 'Riverine' flooding differs in characteristics between the coastal and inland areas of the state. Most of the coastal streams are short and of relatively steep gradient, floods rise quickly, flows can be of high velocity and inundation even on the low-lying floodplains near the coast proper usually lasts only for days. On the very extensive Murray-Darling River system west of the Great Dividing Range, floods downstream of the headwaters reaches rise and travel relatively slowly. Flooding can occur long after heavy rain and at great distances from the location of the rainfall. Vast areas of land can be inundated for weeks or months on end, and flood waters can take months to evaporate or travel out of the state. They can travel for long periods virtually as large lakes.

1.5.4 Flooding on the lower reaches of coastal streams and around the lakes along the coast can be worsened by tidal conditions and storm surges.

1.6 FLOOD FREQUENCY

1.6.1 Long-term flood records indicate that flooding in New South Wales is highly irregular in the temporal sense. Long periods can occur with little flooding at all, but sequences of frequent and severe floods on individual rivers have also been experienced. In many parts of the state the latter half of the nineteenth century produced repeated flooding, some of the events very serious, while the first half of the twentieth century saw relatively few floods in most areas.

1.6.2 Frequent flooding occurred in many regions in the 1950s, including the Murrumbidgee River and the Hunter valley, which experienced half of the most serious floods in its recorded history between 1949 and 1956. The early and middle 1970s also saw frequent and widespread flooding, some of it severe. In general, the period since 1950 has been one of more frequent flooding in New South Wales than the period between 1900 and 1950.

1.6.3 Variations in flood frequency may be related to values of the Southern Oscillation Index (SOI). Strong and persistent negative levels (El Niño) can indicate a higher likelihood of drought conditions and below-average rainfall, which would translate to lower than average occurrence of flooding in eastern Australia. Strong and persistent positive levels (La Niña) tend to be associated with low pressure troughs and heavier winter, spring and early summer rainfall and more frequent flooding (11).

1.6.4 The five wettest years on record have all occurred during periods of La Niña and virtually all major widespread floods have occurred in years when La Niña conditions have prevailed (1955, 1974, 2000, 2010, 2011) (12). There is also a

strong correlation between the transition from negative to positive SOIs and major floods occurring in NSW.

1.6.5 There are, however, other factors that influence rainfall. Floods can occur during El Niño periods and droughts have occurred during periods of La Niña. However, the chance of having floods during El Niño periods is less than during La Niña periods. Such floods are typically smaller events due to the prevailing dry conditions (12).

1.6.6 Very strong and prolonged El Nino conditions were observed between 1982-83 and 1997-98, which was accompanied by drought. Recent prolonged La Nina events include 1973-74, 1988-89, 1998-2000, and 2010-12 (12). The La Nina conditions between 2010 and 2012 were one of the strongest on record, causing record rainfall and widespread flooding across Australia (11).

1.6.7 Major floods are listed for each NSW SES region on the NSW SES website.

1.7 IMPACTS OF CLIMATE CHANGE

1.7.1 Climate change modelling suggests that there are likely to be little change in average annual rainfall across the state by 2030, with large seasonal differences (13) (14). Autumn rainfall is projected to increase across the entire state. The southern and north-west areas are projected to also have increases in summer rainfall, and the north east increasing rainfall is projected for spring (14). Extreme rainfall events are projected to increase in frequency (15), which may lead to an increase in flood frequency. However, evidence for this trend is inconsistent (15).

1.7.2 The frequency of coastal flooding may increase as a consequence of sea level rise and the potential increased frequency of storm surge events (13), particularly as the events coincide (15) (16).

1.7.3 Risks to population and infrastructure are likely to increase as a consequence of sea level rise and the increased severity and frequency of storms and coastal flooding. This may be further exacerbated by the increase in population and associated pressure placed on floodplain development (17).

1.8 THE CONSEQUENCES OF FLOODING

1.8.1 The negative impacts of flooding are numerous and a wide range of actions is necessary if individuals and communities are to minimise the damage and inconvenience which floods can bring. The consequences of flooding can include:

a. Loss of life;

b. Damage to property, farmland, infrastructure and roads due to inundation;

c. Isolation of properties and/or communities due to the flooding of access roads, with the additional risk of secondary emergencies and the threat of dangerous animals seeking refuge and;

d. Indirect effects as a consequence of infrastructure damage or disruption of essential services and ongoing psychological issues.

1.8.2 The consequences may be exacerbated by communities' or community members' vulnerability.

1.8.3 Such consequences of flooding can necessitate emergency management actions such as warning, evacuation, resupply, rescue and property protection.

1.8.4 Floods also bring many benefits. Their positive impacts include the triggering of environmental processes which benefit native plants, fish and animals, often with consequent economic benefits.

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