IMPACTS OF CLIMATE CHANGE ON NATURAL HAZARDS PROFILE

NEW ENGLAND/NORTH WEST REGION

December 2010

NSW GOVERNMENT | Environment, Climate Change & Water

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- Bureau of Meteorology (BoM)
- University of Wollongong (UoW).

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- Only some meteorological and climatological hazards are covered. Other natural hazards such as landslide and earthquake are not covered.
- This profile is not a comprehensive description of the current state of natural hazards.
- Some projections currently involve a considerable degree of uncertainty.

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1 Introduction

The New England/North West region experiences recurring, costly and significant natural hazards potentially impacting upon public safety, private property, infrastructure integrity and the insurance sector. This profile provides emergency management agencies with information on:

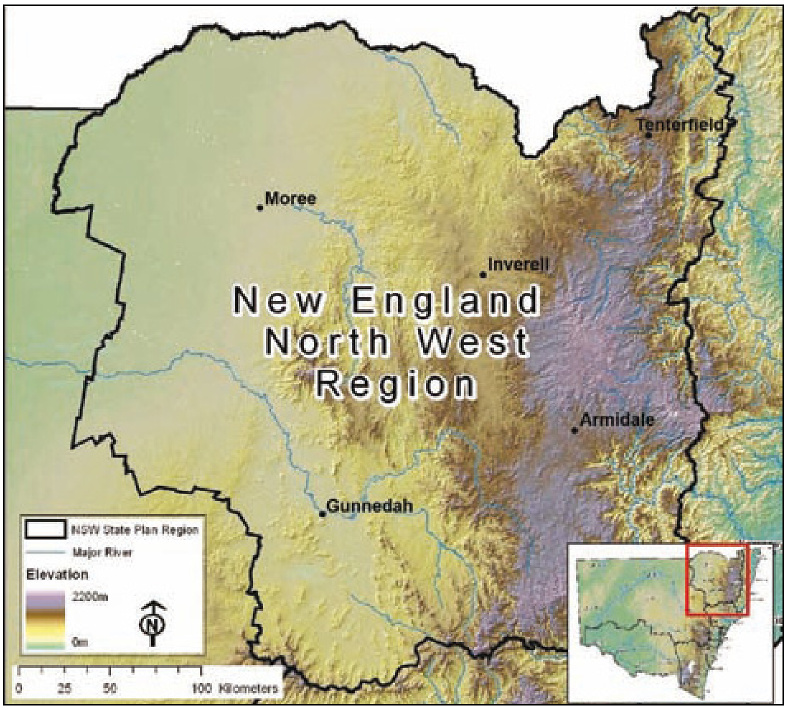
- the following natural hazards to which the New England/North West region is exposed:

  1. Fire
  2. Flash flooding
  3. Riverine flooding
  4. Hail
  5. Wind
  6. Lightning
  7. Heatwave

- projections of how these natural hazards may change into the future due to climate change.

The New England/North West region, shown in Figure 1, extends from Glen Innes and Armidale on the New England Tablelands in the north-east, through Inverell and Tamworth in the centre, and further inland to Moree and Narrabri on the north-western plains. It covers 98,600 km^2, includes 14 local government areas (LGAs) and encompasses the Peel Emergency Management District (EMD).

Figure 1: Map of the New England/North West region



2 Current climate and natural hazards of the New England/North West region

2.1 Current climate

The climate of the New England/North West region varies from temperate in the tablelands where summers are warm and winters are cool, to hot and semi-arid in the far north-west, while much of the centre of the region is subhumid. Average annual rainfall is moderate at about 700 mm, and it ranges from about 1200 mm per year on the tablelands to less than 600 mm per year in the west. Rainfall events are greatest in summer, with falls comparatively uniformly distributed across the other seasons. Runoff follows a similar seasonal pattern to rainfall, but runoff is almost four times higher on the tablelands than it is in the west of the region.

2.2 Natural hazards

Some examples of recent significant natural events experienced in the New England/North West region are shown in Table 1.

Table 1: Recent significant natural events in the New England/North West region

Event	Date	Estimated damage/cost*
Severe storms	29 September 1996	$104 million (cost)
Severe thunderstorm	21 January 1997	$49 million (cost)
Severe storm	19 January 2000	–
Flooding	10 December 2004	–

* Emergency Management Australia estimates (EMA 2009) – cost is original dollar values.

It should be noted that in most cases the above phenomena were not unprecedented and were less intense than the highest magnitude events possible under present climatic conditions.

This section provides more detail on the storms of 29 September 1996 and the flooding on 10 December 2004, to demonstrate the kinds of impacts that recent significant natural hazards have had on the New England/North West region.

On 29 September 1996, severe storms produced hail 8 cm in diameter through parts of the region with winds reaching speeds of up to 157 km/h in Armidale. An intense band of hail 2 km wide and extending for 15 km left a trail of ice 10–20 cm deep, causing severe damage to more than 1000 buildings and moderate damage to more than 3000 others in Tamworth alone. Roof damage was the most widespread impact, with many cars and crops also battered in the storm. Severe instability that day also led to the development of three tornadoes in the region.

Many townships in the region are close to rivers and streams and have suffered serious past flooding, particularly in 1955 and 1976. The experience of floods has led to construction of levees, and local government manages over 40 km of levees protecting Walcha, Tamworth, Wee Waa, Mungindi and other centres in the region. The local impact of flooding varies with terrain and is influenced by human-made structures such as roads, embankments, bridges and culverts. On the headwaters of the rivers and creeks within the region, flood levels depend on peak stream flows and the warning time is generally short. In the western areas of the region that are dominated by floodplains, warnings can be given earlier but floods tend to stay near peak levels for long periods of time. Flooding can be a major problem for many weeks in some areas.

On 10 December 2004, floods affecting Moree and Narrabri claimed three lives, isolated 266 properties and caused millions of dollars worth of damage. Rain moved south from the Gulf of Carpentaria and falls of more than 150 mm were common, with Narrabri recording 200 mm on 9 December 2004. The subsequently swollen Namoi River isolated Wee Waa with a flood peak of 7.19 m, and the NSW Government made Natural Disaster declarations for the Narrabri, Gunnedah, Liverpool Plains, Gwydir and Moree LGAs.

3 Projected changes to climate and natural hazards in the New England/North West region

The following section details projected changes to climate and the frequency and intensity of natural hazards in the New England/North West region out to 2050. Projections for significant fire and weather-related hazards in the New England/North West region are based on those developed for the *NSW Climate Impact Profile: the impacts of climate change on the biophysical environment of New South Wales* (DECCW 2010). The *NSW Climate Impact Profile* projections were developed using current global climate model data provided by the Climate Change Research Centre at the University of New South Wales. Further research will be undertaken to improve the accuracy of these projections in subsequent years.

3.1 Projected changes to climate

Daily maximum temperatures in the New England/North West region are projected to increase over all seasons by 1–3°C, with the greatest increase during winter and spring (2–3°C). Nights are also projected to be warmer, with mean minimum temperatures likely to increase by 2–3°C in the east of the region, and by 1–2°C in the west.

Rainfall is projected to increase in all seasons except winter, when it is expected to decrease by 10–20%. The projected increase in spring, summer and autumn is 5–20% but higher evaporation is projected to create drier conditions, with winter and spring projected to be the driest.

Evaporation is likely to increase throughout the year, especially in spring when a 10–20% increase is likely in the east, grading to a 20–50% increase in the west. Moderate increases are likely in summer and autumn, and in winter increases of 5–10% are projected for the east and 10–20% for the west. Overall water balance is likely to remain similar to what it is at present, but with some redistribution of runoff likely to produce substantial increases in summer and a substantial decrease during spring and winter. Despite the potential for drier conditions due to increased evaporation, flood-producing rainfall events are likely to increase both in frequency and intensity.

Patterns of the El Niño–Southern Oscillation (ENSO) cycle and other climatic influences may be modified by global warming and this is an active area of research. Although large uncertainties exist regarding the future interactions of ENSO and other climatic influences, El Niño years experienced in the region are likely to continue to result in an increased probability of lower than average rainfall and become hotter. La Niña years experienced in the region are likely to continue to result in an increased probability of higher than average rainfall and become warmer, with storms producing heavy downpours likely to become more frequent.

3.2 Projected changes to natural hazards

The current resolution of global climate models means that relatively large damaging weather events such as ECLs are currently not captured. The Department of Environment, Climate Change and Water (DECCW) is leading a multi-institutional research initiative called the Eastern Seaboard Climate

Change Initiative (ESCCI) to address specific research gaps. The first priority of ESCCI is to establish an ECL project to improve future projections.

In addition, little information is available for small scale, short-lived damaging weather events such as severe thunderstorms which are not adequately captured in the resolution of climate models so that a low level of confidence is associated with any projections of extreme winds. Further research is required to improve projections for changes to flood-producing rainfall events. Studies of triggering events such as severe thunderstorms, ex-tropical cyclones and troughs, and broad scale weather systems resulting in flooding, currently do not provide enough certainty for projections of frequency and intensity. The impacts of flooding at specific locations may have been assessed in flood investigations; however, many of the impacts of climate change on flood behaviour are yet to be investigated in detail. The exposure of individual locations to flooding and the associated impacts on flooding due to climate change are quite specific and need to be addressed by flood investigations in particular catchments and locations.

More detailed high resolution (spatial and temporal) information on future climate is required to improve certainty of projections of significant fire hazards. Understanding future changes to El Niño frequency and intensity is also a key research need, as is research on ignitions (lightning and human), and changes in moisture and elevated carbon dioxide levels on vegetation, as the degree to which vegetation fuel characteristics will change and affect fire regimes is unknown.

Further research on all climate variables is ongoing and will be reviewed by the Intergovernmental Panel on Climate Change (IPCC) in the development of its Fifth Assessment Report (due for finalisation in 2014). This material will be reviewed following its release.

3.2.1 Fire (*see Table 2*)

The frequency of very high or extreme fire-risk days is projected to increase in the New England/North West region and across New South Wales. Increases in temperature, evaporation and high fire-risk days are likely to influence fire frequency and intensity across the region, and the fire season is likely to be extended.

Fire frequency likely to increase

Fire frequency in the New England/North West region is highly variable. It can be absent for more than 50 years about the plains, slopes and tablelands, with return periods of 20–50 years common in forest/woodlands; and 5–20 years in wet forests in eastern parts. Out to 2050, fire frequency is likely to increase across the majority of the region but the fire return period is likely to remain largely within current ranges. A decrease in fire frequency is possible in the west due to the lower availability of herbaceous fuels, and changes in farming practices are likely to further reduce fire in cropping lands. These projections are regarded as conservative however, and may require revision after further research on the effect of climate change on the frequency and intensity of ENSO, ignition rates, and fuel accumulation.

Weather conditions conducive to large, intense fires to increase

The conditions conducive to large and intense fires, such as prolonged drought, days of high temperature and wind speed, and low humidity, are anticipated to increase out to 2050. At the same time, the incidence of prolonged wet periods across successive years in the west and parts of the tablelands may decrease. However, a much better understanding of future changes to the frequency and intensity of El Niño, ignition rates and fuel accumulation is needed to project the extent of the changes.

Length of fire season likely to increase

Peak fire dangers in the New England/North West currently are reached during summer in the west of the region, and spring–summer in the east. Changes out to 2050 project possible extensions both forward into spring in the west, and back into late summer in the east.

Very high to extreme fire danger days per year to increase

Historically, the New England/North West region experiences more than 10 very high to extreme fire danger days per year on the tablelands and more than 30 further inland. These are projected to increase by 10–50% out to 2050. Potential days for prescribed burning (days when fire danger levels are moderate to high) are currently more than 110 days per year in the west, scaling down to more than 60 days per year on the tablelands and in the east. Such days are projected to decline by up to 10% in the west, but increase by up to 5% in the east. This projection is based on the number of days where the Forest Fire Danger Index is potentially appropriate. Actual suitable days will also depend on fuel moisture, forecasts of unfavourable weather and other safety considerations.

Changes to fuel availability uncertain

Projections of fuel availability are regarded at this time as highly speculative, and major research is required to determine the future effects of changes in moisture levels and elevated carbon dioxide levels on fire regimes. Future changes in fuel availability are the least certain of all the fire hazard indicators. Projected decreases in available moisture out to 2050 will possibly reduce litter and grass fuels. Also, there is a possible tendency for increased plant woody cover in woodlands due to higher carbon dioxide levels, tending to decrease herbaceous fuel and flammability. Projected decreases in available moisture could reduce litter and grass fuels in parts of the region, and possible changes to rainfall patterns could increase the presence of crop stubble.

3.2.2 Wind (*see Table 3*)

High winds in the New England/North West region are associated with a number of climatic systems including severe thunderstorms and frontal systems, occasionally ex-tropical cyclones, but very rarely do ECLs affect this inland area.

Changes to frequency of ECLs uncertain

Existing information on present day thunderstorm frequency is tied to those storms that generate hail, of which there are about 11 that affect the New England/North West region annually. However, a larger number of thunderstorms produce severe winds that can be in excess of 90 km/h. Severe thunderstorms occur mostly from November through to March. Projections of wind speeds associated with severe thunderstorms out to 2050 are currently unavailable, as these weather events are not adequately covered by climate models.

Changes to frequency of severe thunderstorms uncertain

The incidence of tropical and ex-tropical cyclones producing severe winds in the New England/North West region is historically low, although northern parts of the region especially can be affected by cyclones in southern Queensland. Future changes are largely unknown. Studies have concluded that no significant change is likely in overall tropical cyclone numbers out to 2050, but there could be an increase in the proportion of categories 3–5 systems depending on changes in sea surface temperatures (SST) and upper atmosphere circulation.

Changes to incidence of gales and frontal systems uncertain

The incidence of gales and frontal systems in the New England/North West region is currently low, and some projected changes indicate a likely decline in the frequency of westerly gales as the winter westerly belt moves south. However, further development of daily wind speed modelling is required to improve the level of confidence for extreme wind speed projections.

3.2.3 Hail (*see Table 4*)

Changes to frequency of hail days uncertain

The New England/North West region is affected by 11 hail-producing thunderstorms per year on average. These storms are more common in the tablelands to the east. Between 1990 and 2007, about 29 were recorded near Armidale, but only two further inland near Moree. The hail season lasts from October through to February, with the highest frequency in November and December. Further development of climatic models is required for projections of future frequency and intensity.

3.2.4 Lightning (*see Table 5*)

Changes to lightning frequency uncertain

The New England/North West region currently has an average of 25–30 days per year which experience thunder, with a frequency of lightning strikes of 1–3 per km^2 per year. They are more prevalent in the south and west of the region. They are summer dominant, but can occur at any time of year. Projections under climate change are mostly unknown, but some studies have suggested a 5–6% change in global lightning frequency for every 1°C of global temperature change and a possible increase in high based (dry) thunderstorms.

3.2.5 Flash flooding (*see Table 6*)

Incidence of flash flooding may increase

Flash flooding results from storms of relatively short duration and high intensity, with water both rising and flowing quickly. Current incidence is variable depending on location, but the risk is expected to increase with changing community profiles in urban areas and potential increases in the intensity of these storms.

Urban parts of some areas are protected from riverine flooding by levee systems; however, the urban areas behind levees often rely upon stormwater drainage systems through the levee to reduce the impacts of flash flooding. Any increase in the intensity or frequency of flash flood events could result in impacts on the consequences of flash flooding on the local community.

Further research will be needed to provide more specific information on the potential scale of changes to these flood-producing rainfall events. The proposed ECL project will assist in addressing some of the research gaps as ECLs can contribute to flooding in eastern parts of the region, although severe thunderstorms are the main causes of flash flooding.

3.2.6 Riverine flooding (*see Table 7*)

Incidence of riverine flooding likely to increase

Vulnerability and exposure to riverine flooding varies significantly with location, but will increase with any increase in development within communities and any increase in exposure to flood-producing storm events. However, the increase in flood levels due to an increase in exposure to flood-producing rainfall events will depend on the catchment conditions (including soil moisture and water levels in reservoirs such as Split Rock, Chaffey, Keepit and Copeton) before each flood event. Therefore for the same flood-producing rainfall, drier soils and lower reservoir levels will result in lower flood impacts than wetter conditions with higher reservoir levels. The antecedent (relative wetness) catchment conditions are likely to change from current conditions because of altered seasonal rainfall patterns. Given the complex role of changes in catchment conditions, the degree to which climate change will alter the frequency or intensity of major floods cannot yet be determined.

Further research will be needed to provide more specific advice on the potential scale of changes to the significant rainfall events that produce floods and how seasonal changes will impact on likely antecedent catchment conditions. The proposed ECL project will assist in addressing some of the research gaps as ECLs can contribute to flooding in eastern parts of the region, particularly when combined with trough systems, which are among the current main causes of riverine flooding, along with fairly rare ex-tropical cyclones.

3.2.7 Heatwaves (*see Table 8*)

Heatwaves have the potential to cause a significant number of human casualties, particularly among the elderly and very young. Heatwaves have accounted for more deaths in Australia than any other natural hazard. The definition of heatwaves used in this assessment is at least three consecutive days with maximum temperatures above the 90th percentile for the month.

In the New England/North West region, the frequency of heatwaves has historically been consistent across the main centres of the region. In the period 1979–2008, there were 36 spring and 32 summer heatwave events at Tamworth; while for Moree the figures were 32 spring and 34 summer. Both centres show a high coincidence of dates and have exhibited increased frequency over time, with 44% of events occurring in the 9 years since 2000.

Frequency and intensity of heatwaves to increase

Heatwaves are projected to become more severe because of higher temperatures as a result of climate change. They are also likely to become more frequent, but projections are dependent on mid-latitude circulation patterns.

Table 2: New England/North West fire hazard indicators

Indicator	Current conditions	Projected change (to 2050)	Status of research
Frequency range	Highly variable. Fire is often absent (no fire >50 years) from remnant and modified vegetation on the plains, slopes and tablelands. Fire cycles of 20–50 years are common in dry forest/woodlands (e.g. Pilliga). Fire cycles 5–20 years common in wet forests (eastern margins). Irregular fire in land used for cropping (stubble burning and unplanned ignitions).	Increased frequency of fire likely but the fire cycle will remain largely within these ranges. Possible decline in fire in the west due to lower availability of herbaceous fuels. Changes in farming practices (less stubble burning) will further reduce fire in cropping lands.	Some detailed analyses of current fire regimes are available for this region (e.g. Pilliga and eastern forest estate). More detailed high resolution (spatial and temporal) information on future climate required. Understanding future changes to ENSO frequency and intensity is a key research need. Research on ignitions (lightning and human) is required.
Season of peak fire danger	Summer in the west (e.g. Pilliga/Kaputar). Spring–summer in the east.	Possible extension into spring in the west and late summer in the east.	See above.
Potential days for prescribed burning **(i.e. average annual days of moderate – high fire danger)**	>110 days in the west. >60 days on tablelands and east.	Projected decline (1–10%) in west. Projected increase (1–5%) in east.	See above.
Average number of days (per annum) of very high – extreme fire danger	<10 on tablelands. >30 inland.	A 10–50% increase is possible.	See above.

Indicator	Current conditions	Projected change (to 2050)	Status of research
Weather conditions conducive to large, intense fires	Prolonged drought. Days of high temperature and wind speed, plus low humidity. Prolonged wet periods across successive years in the west and parts of the tablelands.	The incidence of these conditions may increase. The incidence of these conditions may decrease.	Detailed analyses of weather conditions associated with large fires are available for this region. Projection models (remote sensing based) of fire severity are available for some forested regions (eastern only). Future trends – see above.
Influence of runoff on water availability (average seasonal trends)	Highest in summer and lowest in spring.	A major increase in summer and major decrease in winter–spring is projected (prior to fire season).	See above.
Fuel	Herbaceous/grassy fuels prominent in the west and tablelands. This fuel component also important in woodlands and forests. Predominantly litter fuels in sclerophyll woodlands/forests. Crops and crop stubble.	Projected decrease in available moisture could reduce the mass and availability of herbaceous grass fuels throughout the region. Possible tendency for increased plant woody cover (e.g. shrubs, cypress) in woodlands due to elevated CO_2 effects on plant growth. This would tend to decrease herbaceous fuel and therefore flammability. Projected decreases in available moisture could reduce litter and grass fuels in forest/woodland remnants in eastern slopes/tableland fringe. Possible change to summer cropping due to rainfall seasonality changes. More crop stubble present.	Major research effort required to resolve future effects of changes in moisture and elevated CO_2 on plant growth, litter accession, decomposition, plus overall changes to vegetation structure (cover and woody/herbaceous plant balance). Projections are currently highly speculative and the degree to which vegetation fuel characteristics will change and affect fire regimes is unknown.

Table 3: New England/North West wind hazard indicators

Meteorological source	Indicator	Current conditions	Status of research
East Coast Low	**Frequency**	Can impact the tablelands in the east of the region, but rarely damaging in inland areas.	
Severe thunderstorm	**Frequency**	Storms with severe winds affect the New England/North West region approximately eleven times per year, predominantly on the slopes and tablelands.	Research is currently limited to only a couple of studies for NSW: Schuster *et al*. 2005; Leslie *et al*. 2007. CSIRO (2007a) states that severe thunderstorms are not adequately captured by the resolution of the climate models. Future work to improve these models is therefore required to improve projections for extreme winds associated with severe thunderstorms.
	Intensity	Severe thunderstorms can produce wind gusts of 90 km/h or greater.	There is currently no published work on observed trends in intensity. Future research is required to develop models capable of resolving these relatively small scale phenomena and therefore providing future projections.
	Seasonality	November through March.	
Ex-tropical cyclone	**Frequency**	Low – only a few recorded crossings into NSW of decaying cyclones from the Pacific or the Gulf of Carpentaria.	No significant change in East Coast cyclone numbers projected to 2050 (Abbs *et al*. 2006; Leslie *et al*. 2007; Walsh *et al*. 2004). Likely to be highly dependant on the level of emissions and the magnitude of SST changes and upper atmosphere circulation changes.
	Intensity	Severe winds can result from these low frequency events.	Increase in proportion of categories 3–5 systems in the modelling studies above. These studies do not provide, with any certainty, projections for the frequency and intensity of systems over NSW latitudes. Likely to be highly dependant on SST and upper atmosphere circulation changes.

Meteorological source	Indicator	Current conditions	Status of research
Gales and frontal systems		Low.	Only a small number of models provide daily wind speed data from which extremes can be estimated. Therefore further development is required to improve the level of confidence associated with any extreme wind speed projections. Several models indicate a likely decline in the frequency of westerly gales as the winter westerly belt moves further south.

Table 4: New England/North West hail hazard indicators

Indicator	Current conditions	Status of research
Frequency	The New England/North West region experiences on average 11 thunderstorms with hail per year, with ~2 per year producing hail with a diameter of at least 5 cm. These are more common in the tablelands to the east, with ~29 within 25 km of Armidale between 1990 and 2007, but only 2 near Moree. Schuster *et al*. (2005) reported a decline of 30% in the number of hailstorms affecting Sydney in the period 1989–2002 compared with 1953–1988. Kuleshov *et al*. (2002) found no such decline.	The CSIRO Mark 3.5 model for Special Report on Emissions Scenarios (SRES) A2 scenario suggests a significant increase in hail days over the Sydney area; an increase of around 6 hail days per year by 2070 (CSIRO 2007a). Research is currently limited to only a couple of studies for NSW: Schuster *et al*. 2005; Leslie *et al*. 2007; Niall and Walsh, 2005. CSIRO (2007a) states that severe thunderstorms are not adequately captured by the resolution of the climate models. Future work to improve these models is therefore required to improve projections for extreme winds associated with severe thunderstorms.
Intensity	Severe thunderstorms can produce hail over 2 cm in diameter. The largest hail in this region from 1990–2007 was 8.5 cm in Inverell on 25 October 1993. A hailstorm on 29 September 1996 caused >$100 m damage.	There is currently no published work on observed trends in intensity. Future research is required to develop models capable of resolving these relatively small scale phenomena and therefore providing future projections.
Seasonality	The hail season lasts from October to February, with highest frequency in November and December.	

Table 5: New England/North West lightning hazard indicators

Indicator	Current conditions	Status of research
Frequency	Average lightning strike in the New England area is 25–30 thunder days per year (Kuleshov *et al*. 2002); higher in the south-west.	Currently no research for the Australian region of expected changes to lightning under enhanced greenhouse conditions. Some studies such as Price and Rind (1992) have suggested a 5–6% change in global lightning frequency for every 1°C global temperature change. US studies have also indicated that there may be an increase in high based (dry) thunderstorm activity. The regional scale effects on lightning for NSW are unclear.
Intensity/scale	Average of 1–3 per km^2 per year (ground flash).	
Distribution	More prevalent in the south and west.	
Seasonality	Summer dominant but can occur at any time of the year.	

Table 6: New England/North West flash flooding hazard indicators

Meteorological source	Indicator	Current conditions	Status of research
All types of relatively short duration storms	**Vulnerability of people and property to above floor flooding in urban areas where no specific flood warnings are able to be provided and flooding rises and can flow quickly**	Varies significantly with exposure of specific locations or communities to flooding. Can be derived from a range of weather events including thunderstorms and occasionally ECLs in the east of the catchment. Expected to increase with the increase in scale of development or flood-producing rainfall events.	Research needs to be undertaken to provide more specific advice on potential scale of changes to these flood-producing rainfall events.
	Exposure	Significant, widespread exposure varying with location. May increase with any changes to density or scale of development and any increase in exposure to flood-producing storm events discussed below. The exposure levels of individual locations to flooding are quite specific and need to be addressed by flood investigations in specific catchments and locations. Studies have been undertaken to examine existing risks in many areas but other areas remain unstudied.	Assessment of climate change impacts of flood-producing rainfall events is necessary for specific locations. Research needs to be undertaken to provide more specific advice on potential scale of changes to these flood-producing rainfall events.

Meteorological source	Indicator	Current conditions	Status of research
East Coast Low	**Frequency**	Average of 10 per year.	Very limited literature: McInnes *et al*. 1992; Hennessy *et al*. 2004; Abbs and McInnes 2004. These studies are yet to give a consistent projection for changes to ECLs beyond 2050. The proposed ECL research project is the first priority for the ESCCI and is designed to address this research gap.
	Intensity	Very few have severe impacts beyond coastal regions; however, some can impact the tablelands in the east, particularly when combined with other rain-causing events.	
	Seasonality	Autumn through spring. Winter dominant.	No change likely as they require a strong temperature gradient between a cold land surface and warm inshore SST for development.
Ex-tropical cyclone	**Frequency**	Low – only a few recorded crossings into NSW of decaying cyclones from the Pacific or the Gulf of Carpentaria.	Likely to be highly dependant on SST changes and upper atmosphere circulation changes. Abbs *et al*. 2006; Leslie *et al*. 2007; Walsh *et al*. 2004. No significant change in East Coast cyclone numbers projected to 2050.

Meteorological source	Indicator	Current conditions	Status of research
	Intensity	Heavy rainfall can result from these low frequency events.	Likely to be highly dependant on SST changes and upper atmosphere circulation changes. Increase in proportion of categories 3–5 systems in the modelling studies above. These studies do not provide, with any certainty, projections for the frequency and intensity of systems over NSW latitudes.
Severe thunderstorm	**Frequency**	On average, severe thunderstorms produce flash flooding several times per storm season though the location of impact within the region would vary.	Limited to only a couple of studies for NSW: Schuster *et al*. 2005; Leslie *et al*. 2007. CSIRO (2007a) states that severe thunderstorms are not adequately captured by the resolution of the climate models. Future projections for extreme winds associated with severe thunderstorms are therefore currently unavailable.
	Intensity	On average, severe thunderstorms produce flash flooding several times per storm season.	There is no published work on observed trends in intensity. Models are currently unable to resolve these relatively small scale phenomena and are therefore unable to provide future projections.
	Seasonality	Late spring through to autumn. Summer dominant.	

Table 7: New England/North West riverine flooding hazard indicators

Meteorological source	Indicator	Current conditions	Status of research
All types of relatively short duration storms	**Vulnerability of people and property to above floor flooding from rivers**	Varies significantly with exposure of specific locations or communities to flooding. Can be derived from a wide range of weather events including thunderstorms and troughs. Expected to increase with the increase in scale of development or flood-producing rainfall events.	Research needs to be undertaken to provide more specific advice on potential scale of changes to these flood-producing rainfall events and potential changes to likely antecedent conditions within catchments.
	Exposure	Significant, widespread but varies with location. Expected to increase with the increase in scale of development or flood-producing rainfall events. The exposure levels of individual locations to flooding are quite specific and need to be addressed by flood investigations in specific catchments and locations. Studies have been undertaken to examine existing risks in many areas but other areas remain unstudied.	Assessment of climate change impacts of flood-producing rainfall events is necessary for specific locations. Research needs to be undertaken to provide more specific advice on the potential scale of changes to flood-producing rainfall events and potential changes to likely antecedent conditions within catchments.

Meteorological source	Indicator	Current conditions	Status of research
East Coast Low	**Frequency**	Average of 10 per year.	Very limited literature: McInnes *et al*. 1992; Hennessy *et al*. 2004; Abbs and McInnes 2004. These studies are yet to give a consistent projection for changes to ECLs beyond 2050. The proposed ECL research project is the first priority for the ESCCI and is designed to address this research gap.
	Intensity	Very few have severe impacts beyond coastal regions; however, some can impact the tablelands in the east, particularly when combined with other rain-causing events such as troughs.	
	Seasonality	Autumn through spring. Winter dominant.	No change likely as they require a strong temperature gradient between a cold land surface and warm inshore SST for development.
Ex-tropical cyclone	**Frequency**	Low – only a few recorded crossings into NSW of decaying cyclones from the Pacific or the Gulf of Carpentaria.	Likely to be highly dependant on SST changes and upper atmosphere circulation changes. Abbs *et al*. 2006; Leslie *et al*. 2007; Walsh *et al*. 2004.
	Intensity	Heavy rains can result from these low frequency events.	Likely to be highly dependant on SST changes and upper atmosphere circulation changes. Increase in proportion of categories 3–5 systems in the modelling studies above. These studies do not provide, with any certainty, projections for the frequency and intensity of systems over NSW latitudes.
Trough systems	**Frequency**	Unknown.	Unaware of any Australian research on how trough systems will respond to enhanced greenhouse gas conditions. This is an obvious research gap.

Meteorological source	Indicator	Current conditions	Status of research
	Intensity	Unknown.	
	Seasonality	Can occur at any time of year but most prevalent in the October to March period with summer dominance.	

Table 8: New England/North West heatwave hazard indicators

Indicator	Current conditions	Status of research
Frequency	Over the period 1979–2008: Tamworth – 36 in spring, 32 in summer. Moree – 32 in spring, 34 in summer. Armidale – 33 in spring, 35 in summer. Tamworth and Moree both exhibit an increase in frequency with time, 44% of events occurring since 2000, including a 13 day event at both stations on 18 September 2000.	Frequency of heatwaves is expected to increase however this is dependent on mid-latitude circulation patterns and these have not yet been confidently projected to 2050. Research limited by lack of a consistent and relevant definition for heatwaves. BoM, DECCW and DoH are working on developing a heatwave definition relevant to human health and morbidity. The definition used for this assessment has been 3 consecutive days with maximum temperatures above the 90^{th} percentile for the month. This definition is yet to be tested against human morbidity studies in NSW as these are yet to be published by DoH.
Intensity	At least 3 consecutive days above the 90^{th} percentile for maximum temperatures during 1979–2008.	By 2050 maximum temperatures will increasingly exceed the 1979–2008 90^{th} percentile. Mean maximum temperature increases of between 1–3°C are likely. Heatwaves are usually associated with extreme heat days with exceedingly high temperatures (far greater than 1–3°C rise in mean maximum temperatures expected). It is clear that when a heatwave does occur the maximum temperatures involved are likely to be much higher than they currently are. The severity of heatwaves is almost certain to increase whilst the frequency is still to be evaluated properly. Research into extreme temperature projections for eastern Australia is very limited.
Distribution	Fairly consistent spatially. Moree and Tamworth show high coincidence of dates.	
Seasonality	Spring and summer.	Research needed to better understand early season high temperatures and their frequency. Single significantly above average hot days in early spring and summer can have a considerable effect on morbidity and mortality.

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