IMPACTS OF CLIMATE CHANGE ON NATURAL HAZARDS PROFILE

NORTH COAST REGION

December 2010

NSW GOVERNMENT | Environment, Climate Change & Water

This profile was developed by the NSW Department of Environment, Climate Change and Water (DECCW) in collaboration with:

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

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With respect to the content of this report, the following should also be noted:

- 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 North Coast 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:

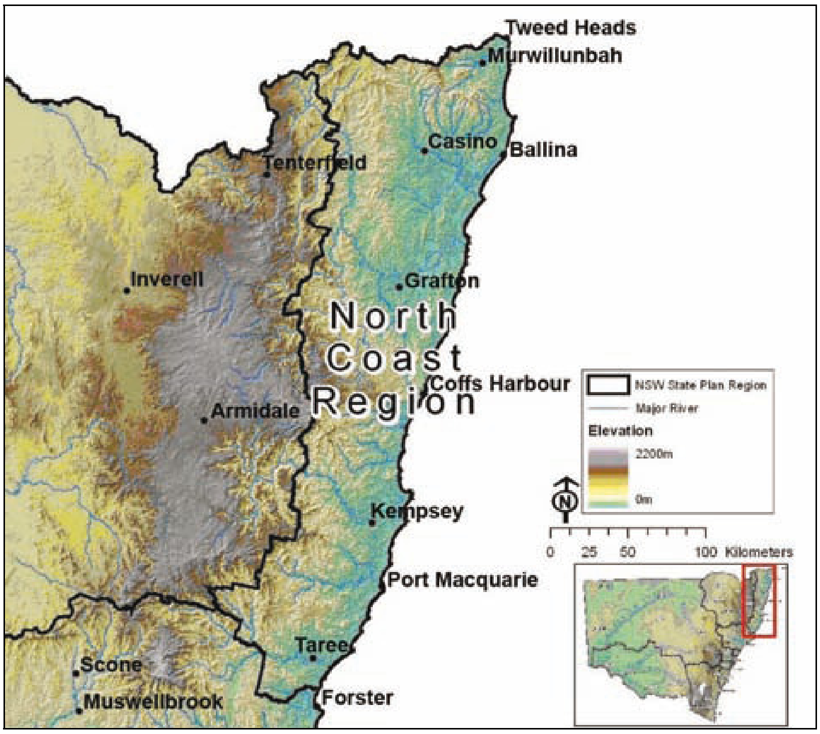
- the following natural hazards to which the North Coast region is exposed:

1. Fire	5. Wind
2. Flash flooding	6. Lightning
3. Riverine flooding	7. Heatwave
4. Hail	8. Coastal erosion

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

The North Coast region, as shown in Figure 1, extends from Tweed Heads south to Hallidays Point at the southern end of the Greater Taree City Council, covering 37,000 km^2, 585 km of coastline and incorporating 13 local government areas (LGAs). It encompasses the Northern Rivers Emergency Management District (EMD), and the Mid North Coast EMD (excluding the Gloucester and Great Lakes local government areas).

Figure 1: Map of the North Coast region



2 Current climate and natural hazards of the North Coast region

2.1 Current climate

The climate of the North Coast region varies from sub-tropical on the coast through sub-humid on the slopes, to temperate in the western uplands, characterised by warm summers and no dry season. It is the wettest region in New South Wales with an average annual rainfall of more than 1200 mm, which peaks at an average of over 2000 mm/year in the far north-east of the region. Rainfall is greatest in summer and early autumn, and is lowest in winter and spring. Seasonal patterns for runoff differ slightly from those for rainfall because evapo-transpiration rates are highest in spring and summer. The greatest runoff occurs in autumn, followed by summer, winter and spring.

2.2 Natural hazards

Some examples of recent significant natural events experienced in the North Coast region are detailed in Table 1.

Table 1: Recent significant natural events in the North Coast region

Event	Date	Estimated damage/cost*
Flash flood	25 November 1996	$140 million (cost)
Bushfires	29 December 1993 – 17 January 1994	$58 million (cost)
Lismore hailstorm	9 October 2007	$57 million (cost)
Floods	1–9 May 1996	$31 million (cost)
Floods	9 May 1963	417.5 mm rain at Alstonville over 7 days (4–10 May) Cost unknown

* 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 flash floods on 25 November 1996 and the Lismore hailstorm on 9 October 2007 to demonstrate the kind of impacts that recent significant natural hazards have had on the North Coast region.

In New South Wales, flash flooding, riverine flooding, hail, wind and coastal erosion due to very rough seas, are often associated with low-pressure systems off the eastern coast of Australia. Known as East Coast Lows (ECLs), these systems occur on average 10 times each year. In addition, other weather systems including cyclones, ex-tropical cyclones, thunderstorms, and troughs may result in significant flash and riverine flooding.

The flash flooding at Coffs Harbour in November 1996 followed estimated rainfalls of between 168 and 300 mm in just over 2 hours (then regarded as a 1 in 50 year event). Official figures showed 168 mm over 24 hours for Coffs Harbour. A cold pool of air in the upper atmosphere formed south of the region, and a surface low developed as the system moved north-east with an easterly airstream dragging huge amounts of moisture off the ocean. An estimated $140 million worth of damage resulted from up to 1.5 m of water entering the Coffs Harbour central business district.

The hailstorm of 9 October 2007 was one of several experienced in that week, bringing widespread damage to Lismore and surrounding districts. Official figures showed rainfall reaching a rate of 20 mm in one 10 minute period, and hailstones were variously described as being between ping pong ball and grapefruit sizes. Lismore was declared a Natural Disaster Area, with the NSW State Emergency Service (SES) responding to 681 calls over a period of 6 days.

3 Projected changes to climate and natural hazards in the North Coast region

The following section details projected changes to climate and the frequency and intensity of natural hazards in the North Coast region out to 2050. Projections for significant fire, coastal erosion and weather-related hazards in the North Coast 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 North Coast region are projected to increase over all seasons by 1–3°C with the greatest warming in winter (2–3°C), and the smallest increases in summer (1–1.5°C). Nights are also projected to increase by 2–3°C in all seasons.

Summer rainfall is projected to show the greatest increase of 5–20%, with autumn likely to gain by 5–10%, while winter is projected to fall by 5–10%, and spring to be largely unchanged. Evaporation is likely to increase by 10–20% across all seasons except winter, where the gain is projected to be 5–20%. Overall, average annual runoff is unlikely to increase because projected increases in summer and autumn are likely to be offset by decreases in winter and more substantially in spring.

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.

Sea levels are projected to rise up to 40 cm above 1990 mean sea level by 2050. Sea level rise and storms are virtually certain to increase coastal inundation and erosion, causing sandy shorelines along the coast to recede, typically by 20–40 m over the same period. This will also increase the risk of coastal flooding.

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.

Factors affecting local shoreline positions such as sediment supply, near shore currents, and wave characteristics (height, period and direction) may change, and modelling at present is extremely coarse and relatively uncertain. Projections for global sea level rise are subject to ongoing refinement by the international scientific community.

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 North Coast 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 North Coast region is variable. The fire return period ranges from 5–30 years across most of the region, but wetter forests may experience little or no fire. Out to 2050, fire frequency is likely to increase but the fire return period is likely to remain largely within the current range. More detailed analysis of current fire regimes is required. More information on future climate is also needed along with more understanding of the frequency and intensity of El Niño, 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 high wind speed, plus low humidity, are anticipated to increase. 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 increase.

Length of fire season to increase

Peak fire dangers in the North Coast region are currently reached in spring/summer, and out to 2050 an extension forward into late winter is possible.

Very high to extreme fire danger days per year to increase

Historically, the region experiences fewer than 10 very high to extreme fire danger days annually near the coast and higher mountains, and 10–15 inland. These will possibly increase by 10–50%. Potential days for prescribed burning with fire danger levels moderate to high are currently more than 120 per year and these are projected to increase by up to 5%. 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 highly speculative, depending upon the degree to which vegetation fuel characteristics will change. Major research is also needed on the future effects of change in moisture and elevated carbon dioxide levels on plant growth, litter accession, decomposition, and changes to vegetation structure, including the spread of exotic species such as lantana. However, a projected decrease in available moisture out to 2050 could reduce litter and grass fuels in coastal regions and north, north-west mountain areas. Further expansion of lantana infestations may also decrease the flammability of forests, and changes to native grasses such as blady grass may also be important to future trends.

3.2.2 Wind (*see Table 3*)

High winds in the North Coast region are associated with a number of climatic systems including ECLs, severe thunderstorms, ex-tropical cyclones, and frontal systems.

Changes to frequency of ECLs uncertain

Historically, ECLs are a dominant source of high winds for the region with an average of 10 systems per year, and 3–5 of these produce gales with severe coastal impacts. They generally occur between autumn and spring, and are winter dominant. Limited research means that changes in the frequency and intensity of ECLs out to 2050 are unknown; however, the ECL project is designed to address this knowledge gap.

Changes to frequency of severe thunderstorms uncertain

Existing information on present day thunderstorm frequency is tied to those storms that generate hail, of which there are about eight that affect the North Coast region annually. Severe thunderstorms produce winds that can be in excess of 90 km/h. They occur from late spring through to autumn, particularly from October to January. 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 incidence of tropical and ex-tropical cyclones uncertain

The incidence of tropical and ex-tropical cyclones producing severe winds in the North Coast region is historically low, although northern parts of the region especially can be affected by cyclones in south-eastern 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 temperature (SST) and upper atmosphere circulation.

Changes to incidence of gales and frontal systems uncertain

The incidence of gales and frontal systems on the North Coast 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 North Coast region is affected by 13 hail-producing thunderstorms per year on average. These storms are more common slightly inland from the coast, with the period 2000–2007 recording only 12 events around coastal Port Macquarie, compared with 35 around the more inland and northern centre of Grafton. The hail season lasts from August to March, with the highest frequency between October and March, but particularly October, which averages four hail-producing storms per year. 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 North Coast region currently has an average of 30–40 days per year which experience thunder, reaching 40–50 days per year in southern areas. The frequency of lightning strikes is 1–2 per km^2 per year in southern regions, and 2–3 per km^2 per year in the north. They are summer dominant, but they can occur at any time of the 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 in some cases, due to rising sea levels caused by climate change. Overall, further research will be needed to provide more specific projections 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, along with fairly rare ex-tropical cyclones and severe thunderstorms, are among the current 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 is expected to increase with changing community profiles out to 2050 due to density of development and to any increase in exposure to flood-producing storm events. Exposure to this hazard is also expected to increase in settlements around the catchments in lower coastal areas and coastal lakes and lagoons of the North Coast region, where a combination of raised ocean levels and catchment flooding can be the controlling flood mechanism.

Again, further research will be needed to provide more specific advice on the potential scale of changes to the significant rainfall events that produce floods. The proposed ECL project will assist in addressing some of the research gaps as ECLs, along with fairly rare ex-tropical cyclones, severe thunderstorms and troughs, are among the current main causes of riverine flooding. The impact of sea level rise and changing flood-producing rainfall behaviour on riverine flooding will need to be assessed at specific locations due to its impacts on local flood behaviour and variations between communities in their exposure to flood risk.

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. In the North Coast region, summer heatwaves have historically been more common in the south of the region. Between 1979 and 2008, Port Macquarie recorded 13 spring, 20 summer and 9 March incidents compared to 14 spring and 15 summer heatwaves experienced much further north at Byron Bay. The definition of a heatwave for this assessment is at least three consecutive days with maximum temperatures above the 90^{th} percentile for the month.

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.

3.2.8 Coastal erosion and inundation (*see Table 9*)

Sea level rise to increase

According to the IPCC, global sea levels are rising and rose by an estimated 17 cm (±5 cm) through the 20th Century (IPCC 2007). Satellite measurements indicate that global sea levels have risen by around 3.2 mm (±0.4 mm) per year since 1992. A maximum rise of 0.4 m relative to 1990 sea levels by 2050 is projected with the next update in projections to be released by the IPCC in 2014.

Still water level to increase

Factors such as astronomical tides and variations in meteorological conditions including winds and barometric pressure, are included in still water level measurements. At present, on average, a still water level of 1.435 m Australian Height Datum (AHD) at Fort Denison is estimated to occur once every 100 years. By 2050, assuming a rise in mean sea level of 0.4 m (relative to 1990), this water level is expected to occur as frequently as once every 18 days. Assuming an equivalent rise in mean sea level, the 100 year recurrence still water level in 2050 is estimated to reach 1.815 m AHD. These projected changes to the still water level are based purely on changes due to sea level rise. Research suggests that a 1% increase in storm surge is possible, in addition to projected sea level rise, but the effects of climate change on these factors are not yet adequately known.

Wave height and period to increase, wave direction to change

The North Coast region experiences an average wave climate of 1–2 m from the south-east. Based on 31.2 years of wave data collection from the Byron Bay offshore waverider buoy, significant wave heights exceeding 5.7 m for a period of up to 12 hours are likely to be experienced once every 100 years, with a 1 hour significant wave height of 7.5 m having an equivalent 100 year average recurrence interval (ARI). Based on 31.6 years of wave data collection from the Coffs Harbour offshore waverider buoy, the 100 year ARI significant wave height is 6.5 m for a period of up to 12 hours and the 100 year ARI significant wave height for a 1 hour period is 8.2 m.

An 8% increase in the maximum storm wave height and period is projected out to 2050 for waves arriving from the southerly, easterly and south-easterly directions. In northern New South Wales, the frequency of swell waves is projected to increase, while in the south that frequency is projected to decrease. Major research such as the ECL project is required to improve projections.

Change to shoreline recession rates due to underlying processes uncertain

A combination of underlying factors including wave characteristics (particularly wave direction), beach orientation, presence of control features (such as bedrock, headlands and entrance breakwater structures), and sediment transport processes currently contribute to shoreline recession in the North Coast region by 0–1.0 m per year. Future rates of shoreline recession may vary as a result of climate change, but the nature and extent of that change out to 2050 is not currently known. In addition, embedded within current measured rates of shoreline recession is a component attributable to historical sea level rise. Further research is needed to de-couple the sea level rise component from measured recession.

Shoreline recession due to sea level rise to increase

Historical sea level rise is estimated to contribute to sandy shoreline recession by 0.15–0.3 m per year based on a rate of global average sea level rise of approximately 3 mm per year. A projected rise in sea level of up to 40 cm out to 2050 is likely to result in a recession of sandy parts of the coastline of up to 20–40 m. These changes in shoreline position are based on a general rule of thumb (the 'Bruun rule'), and detailed study at individual locations is required for more accurate projections.

Sea level rise may increase the potential coastal impacts from tsunamis

Ocean tsunamis are not driven by meteorological processes; however, their impacts are directly influenced by the proximity of people and property to coastal water level. The entire coast of New South Wales is known to be exposed to tsunamis. The effect of a tsunami reaching the coast can range from so slight as to be unnoticed, to an event large enough to overtop coastal dunes and waterfronts to inundate low-lying coastal land. The actual risk of tsunami inundation is currently under investigation for the SES. As of August 2009 the extent of inundation and indicative probability of tsunami events was not established with any confidence for any locations. However, it can be reasonably inferred that any low-lying coastal location which has a vulnerability to coastal inundation due to estuarine flooding or storm surge, or any area identified as a coastal erosion hot spot, will have a vulnerability to tsunami inundation.

Table 2: North Coast fire hazard indicators

Indicator	Current conditions	Projected change (to 2050)	Status of research
Frequency range	Variable – the fire cycle is 5–30 years across the bulk of the region. Wetter forests, including rainforest, may experience little or no fire.	Increased frequency of fire likely but the fire cycle will remain largely within this range.	Some detailed analyses of current fire regimes are available for this region. 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	Spring – summer.	An extension into late winter is possible.	See above.
Potential days for prescribed burning **(i.e. average annual days of moderate – high fire danger)**	>120 days.	Projected increase (1–5%).	See above.
Average number of days (per annum) of very high – extreme fire danger	<10 near coast and higher mountains. 10–15 inland.	A 10–50% increase is possible.	See above.
Weather conditions conducive to large, intense fires	Prolonged drought. Days of high temperature and wind speed, plus low humidity.	The incidence of these conditions may increase (see above).	Some detailed analyses of weather conditions associated with large fires are available for this region. Future trends – see above.

Indicator	Current conditions	Projected change (to 2050)	Status of research
Influence of runoff on water availability (average seasonal trends)	Highest in autumn, lowest in spring.	A decrease projected prior to and during the fire season (spring). Major increase projected in summer.	See above.
Fuel	Predominantly litter fuels in dry sclerophyll woodland/forest. Grassy fuels are important in woodlands and forests throughout the region and in agricultural land. Lantana infestations are common in forests.	Projected decrease in available moisture could reduce litter and grass fuels in coastal regions and north, north-west mountain regions. Further expansion of lantana may also decrease the flammability of forests. Exotic grasses have the potential to alter fire regimes. Changes to native grasses such as blady grass may also be important.	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. Further research on the spread of exotic species such as lantana required.

Table 3: North Coast wind hazard indicators

Meteorological source	Indicator	Current conditions	Status of research
East Coast Low	**Frequency**	Average of 10 per year.	Existing research is very limited and is yet to give a consistent projection for changes to east coast lows under enhanced greenhouse gas conditions beyond 2050 (McInnes *et al*. 1992; Hennessy *et al*. 2004; Abbs and McInnes, 2004). A proposed ECL research project is the first priority for the ESCCI and is designed to address this research gap.
	Intensity	On average 3–5 per year produce severe coastal impacts with gale force winds.	
	Seasonality	Autumn through spring. Winter dominant.	
Severe thunderstorm	**Frequency**	Average of 8 storms with severe winds affect the North Coast each year.	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	Late spring through to autumn, particularly from October to January.	
Ex-tropical cyclone	**Frequency**	Low – only a few recorded crossings into NSW of decaying cyclones from the Pacific or the Gulf of Carpentaria. This region can be affected by cyclones in south-east QLD, particularly in northern areas.	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.

Meteorological source	Indicator	Current conditions	Status of research
	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 changes and upper atmosphere circulation changes.
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: North Coast hail hazard indicators

Indicator	Current conditions	Status of research
Frequency	The North Coast region experiences on average 13 thunderstorms with hail per year, including on average 3 per year with hail at least 5 cm in diameter. These are more common slightly inland, with only 12 events within 25 km of Port Macquarie but 35 within 25 km of Grafton during the period 1990–2007. Schuster *et al*. (2005) reported a decline of 30% in the number of hailstorms affecting Sydney from 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 most severe hailstorm in this area from 1990–2007 had 14 cm hail at Kempsey on 21 December 1991.	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 August to March, with highest frequency between October and March, particularly October, which experiences on average 4 hail-producing storms per year.	

Table 5: North Coast lightning hazard indicators

Indicator	Current conditions	Status of research
Frequency	Average of 30–40 thunder days per year in the North Coast area, reaching 40–50 per year in southern regions (Kuleshov *et al*. 2002).	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 1–2 per km^2 per year (ground flash) in southern regions, 2–3 per km^2 per year in northern.	
Distribution	Thunder days are more prevalent in a small area in the south-west of the region, but otherwise fairly evenly distributed. Annual frequency of lightning strikes is highest in northern parts of the region, indicating storms may be more severe in these areas.	
Seasonality	Summer dominant but can occur at any time of the year.	

Table 6: North Coast 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 ECLs. Expected to increase with the changing community profiles and any change in scale of 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. Increasing due to changes in density of development and any increase in exposure to flood-producing storm events discussed below. The exposure 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. In catchments in lower coastal areas a combination of raised ocean levels and catchment flooding can be the controlling flood mechanism.	Assessment of climate change impacts of sea level rise and 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	On average 3–5 per year produce severe coastal impacts with flooding.	
	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.
	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.

Meteorological source	Indicator	Current conditions	Status of research
Severe thunderstorm	**Frequency**	Severe thunderstorms produce flash flooding on average 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	Severe thunderstorms produce flash flooding on average 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: North Coast 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. Expected to increase with the changing community profiles and any change in scale of events.	Can be derived from a wide range of weather events including thunderstorms and ECLs, tropical cyclones and troughs. Research needs to be undertaken to provide more specific advice on potential scale of changes to these flood-producing rainfall events.
	Exposure	Significant, widespread but varies with location. Increasing due to changes in density of development and any increase in exposure to flood-producing storm events discussed below The exposure 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. In catchments in lower coastal areas a combination of raised ocean levels and catchment flooding can be the controlling flood mechanism.	Assessment of climate change impacts of sea level rise and 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	On average 3–5 per year produce severe coastal impacts with flooding.	
	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.
	Intensity	Unknown.	

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

Table 8: North Coast heatwave hazard indicators

Indicator	Current conditions	Status of research
Frequency	Over the period 1979–2008: Byron Bay – 14 in spring, 15 in summer. Grafton – 13 in spring, 20 in summer, 10 in March. Port Macquarie – 13 in spring, 20 in summer, 9 in March.	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 NSW Department of Health (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 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	Spring events are evenly distributed. Summer events are more common in southern regions.	The changing nature of rainfall to summer dominated may be a factor in reducing heatwaves in northern regions; this bears further investigation.
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.

Table 9: North Coast coastal erosion and inundation hazard indicators

Indicator	Current conditions	Projected change (to 2050)	Status of research
Sea level rise	Total 20th century global sea level rise (SLR) estimated to be 17 ± 5 cm (IPCC 2007). Global average eustatic sea level rise from 1961–2003 is estimated at 1.8 ± 0.5 mm per year (IPCC 2007). Global SLR measured from satellite altimeters post-1992 at around 3.2 ± 0.4 mm per year (University of Colorado 2009).	An upper limit of SLR of 0.4 m relative to 1990 levels.	Projections of SLR are continually refined by the international community and released by the IPCC. Updated projection of SLR will next be released in 2014.
Still water level **(Sydney Harbour still water level data and analyses have been used as a surrogate for the North Coast due to the quality of the data and length of record)**	1.435 m AHD 100 year Average Return Interval (ARI) design still water levels based on Fort Denison data from 1914 to present (Watson and Lord 2008). Still water level includes components due to astronomical tides and variations due to meteorological conditions (including winds, barometric pressure, etc.).	1.815 m AHD 100 year ARI Design Sydney Harbour still water level based on upper range SLR (Watson and Lord 2008). Today's 100 year ARI design still water level of 1.435 m AHD is projected to have an ARI of 0.05 by 2050, equivalent to occurring once every 18 days, based on upper range SLR (Watson and Lord 2008). A 1% increase in storm surge is projected but within errors of present day storm surge estimates (CSIRO 2007b). Not appropriate for planning but acceptable for sensitivity analysis.	Changes to the still water level ARI are purely based on changes due to SLR (including regional changes due to water temperature). Changes to storm intensity and local changes in barometric pressure may also affect still water levels. The effect of climate change on these factors is not adequately known at this point in time.

Indicator	Current conditions	Projected change (to 2050)	Status of research
Wave characteristics (height, period and direction)	1-Hour 100 Year ARI significant wave height is 7.5 m. 12-Hour 100 Year ARI significant wave height is 5.7 m (based on 31.2 years of records from Byron Bay directional offshore waverider buoy, MHL 2009). 1-Hour 100 Year ARI significant wave height is 8.2 m. 12-Hour 100 Year ARI significant wave height is 6.5 m (based on 31.6 years of records from Coffs Harbour offshore waverider buoy, MHL 2009). Dominant storm wave direction is from the south-east to south.	An 8% increase in the maximum storm wave height and period from the southerly, easterly and south-easterly directions. Not appropriate for planning but acceptable for sensitivity analysis. In northern NSW the frequency of occurrence of swell waves is projected to increase, while in the south this frequency is projected to decrease. This data is based on Global Climate Models (GCMs) which do not model meso-scale climate systems that generate waves along the NSW east coast.	The mechanisms that generate extreme wave heights are not resolved by GCMs. Proposed research on ECLs and their change in frequency under future climate is planned and should provide better projections of changes.
Shoreline recession (underlying process driven)	0–1.0 m per year. These present day rates of shoreline recession currently contain changes due to historical sea level rise. Further research to de-couple the SLR component is required.	Unknown. The effect of climate change on the processes that drive underlying shoreline recession are poorly understood and require further research.	Changes in local shoreline position are highly variable and determined by a range of factors including local sediment supply, nearshore currents, wave characteristics (height, period and direction). There may be changes to these factors, which may affect recession rates into the future, however current modelling on these is extremely coarse and relatively uncertain on these aspects.
Shoreline recession due to sea level rise	0.15–0.3 m per year (based on use of the Bruun rule and assuming current global average SLR at 3 mm per year and active profile slope of 1:50 – 1:100).	20–40 m (relative to present day and based on Bruun rule assuming SLR over the period to be 0.4 m with active profile slope ranging from 1:50 – 1:100).	

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