IMPACTS OF CLIMATE CHANGE ON NATURAL HAZARDS PROFILE

SOUTH EAST 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 South East 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:

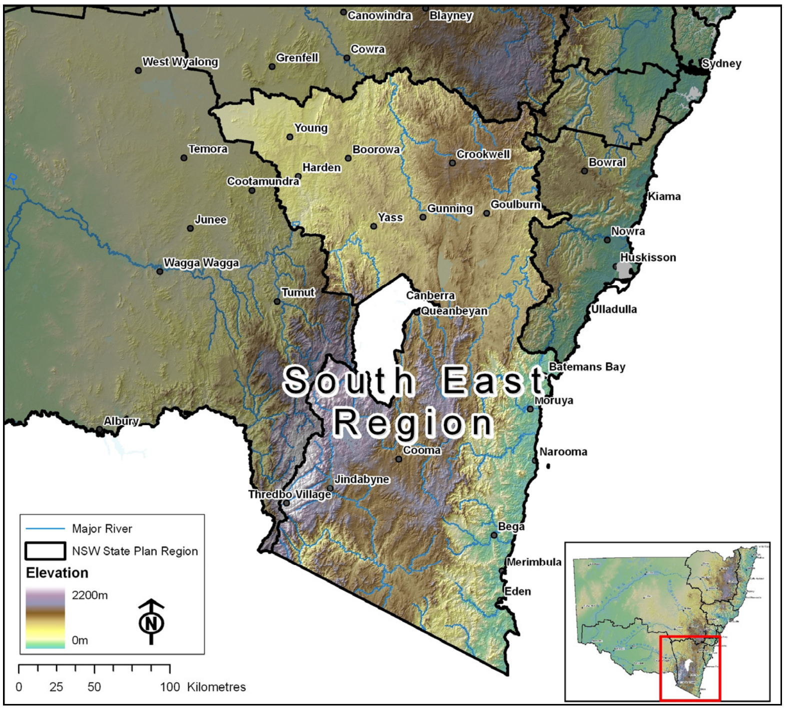
- the following natural hazards to which the South East region is exposed:

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 South East region, shown in Figure 1, extends from the south-western slopes across the Snowy Mountains and tablelands of the Great Dividing Range to the coast, and from Durras Lake 200 km south to Cape Howe on the Victorian border. It covers approximately 60,900 km^2 and includes 13 local government areas (LGAs). The region encompasses all of the Monaro Emergency Management District (EMD) and the Southern Highlands EMD (excluding the Gundagai and Tumut LGAs).

Figure 1: Map of the South East region



2 Current climate and natural hazards of the South East region

2.1 Current climate

The climate of the South East region is predominantly cool-temperate, with the tablelands having greater daily extremes, colder winters and hotter summers than coastal areas. Average annual rainfall over the region is about 730 mm. Rainfall is highest in the Snowy Mountains (above 2000 mm per year); relatively high on the south coast and hinterland (nearly 900 mm); and lower on the western slopes (above 600 mm per year). Rainfall seasonality is variable across the region. Distribution is fairly uniform in the northern parts; slightly dominant in summer/autumn on the south coast; and winter dominant in the Monaro, Snowy Mountains, and southern slopes and plains. Runoff is significantly higher in winter.

2.2 Natural hazards

Natural hazards that periodically affect the South East region include fires, flash flooding, riverine flooding, coastal erosion, hail, wind, lightning and heatwaves. Some examples of recent significant natural events experienced in the South East region are detailed in Table 1.

Table 1: Recent significant natural events in the South East region

Event	Date	Estimated damage/cost*
Severe storms	1–2 February 2005	$216.7 million (cost)
Bushfires	29 December 1993 – 17 January 1994	$58 million (cost state-wide)
Severe storm (also in Sydney and wider SE Australia)	24 August 2003	$25 million (cost)
Floods	16–17 June 1991	$15 million (cost)
Severe storm – gales, snow	17–18 July 2004	$3 million (cost)

* 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.

The South East region is often buffeted by strong winds and heavy rain from intense low-pressure systems, which bring snowfalls (sometimes out of season) to the Snowy Mountains. A low with a central pressure of 976 hPa crossed Tasmania on 24 August 2003, with a vigorous cold front extending to near the Tropic of Capricorn. It produced widespread gales (10 minute average wind speeds of greater than 63 km/h). Braidwood recorded an unusually strong inland gust of 111 km/h; Montague Island 109 km/h; and Bombala 104 km/h. Thredbo had 118 km/h winds as blizzards brought 50 cm of snow to the Snowy Mountains. The Eurobodalla Shire experienced a blackout, 50 schools from Eden north to Wollongong were closed and building roof damage was a major part of the total cost of $25 million across the South East region and further afield.

3 Projected changes to climate and natural hazards in the South East region

The following section details projected changes to climate and the frequency and intensity of natural hazards in the South East region out to 2050. Projections for significant fire, coastal erosion and weather-related hazards in the South East 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 needed to improve the accuracy of these projections.

3.1 Projected changes to climate

Daily maximum temperatures are projected to increase by an average of 1–3°C, with the greatest increases projected for autumn, winter and spring (2–3°C), and the smallest increases in summer (1.5–2°C). Nights are also likely to be warmer, with mean minimum temperatures projected to increase by 1–3°C, with increases in the east of the region greater than those expected in the west.

Most of the region is projected to receive 20–50% more rainfall in summer, but winter rainfall is projected to decrease by 10–50%, with the decline likely to be greatest in the north and the west of the region. Reduced winter and spring rainfall and increased minimum temperatures are likely to result in a significant reduction in snow cover for alpine parts of the region, where a greater proportion of precipitation is likely to fall as rain rather than snow. Evaporation is likely to increase moderately in the northern part of the region during spring and throughout the region during summer, but there is no clear pattern in projections for autumn and winter. Overall there will more likely than not be a decrease in average annual runoff, with lower rainfall bringing a substantial decrease in spring, but higher rainfall in summer increasing runoff in that season.

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 East Coast Lows (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 extreme 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 South East 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

The average return periods between fires vary across much of the South East region, ranging from 10–50 years for most woodlands and forests. Wetter forests at high altitude or escarpments, along with sub-alpine and alpine vegetation, may have longer fire return periods, and grasslands of the Monaro have irregular fires. Out to 2050, fire frequency is likely to increase but the fire return period is likely to remain largely within the current range. However, these projections are regarded as conservative and may require revision after further research into 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, high wind speed and 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 South East region are currently reached in the summer, and no major change is expected over most of the region. However, intensification of fire danger levels within the existing season is projected. Projected changes in temperature and evaporation are likely to create drier conditions in winter and spring, leading to a possible forward extension of the fire season into spring.

Very high to extreme fire danger days per year to increase

Historically, the near coastal and higher mountain areas of the South East region experience on average fewer than 10 very high to extreme fire risk days per year; inland areas have 10–15, while sub-alpine areas have less than 1 day per year. Despite the possible extension of the fire season and a projected increase of 10–50% in the frequency of very high to extreme fire risk days, an increase of 1–5% is also projected in potential days for prescribed burning (days when fire danger levels are moderate to high). 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, forecast unfavourable weather and other safety considerations.

Fuel availability changes possible

Future change in fuel availability is the least certain of all the fire hazard indicators; however, projected decreases in available moisture in coastal and north, north-west mountain regions will possibly reduce litter and grass fuels, and projected increases in the moisture balance in higher parts of the ranges and tablelands will possibly increase litter and grass fuels. Note that projections of fuel availability and type are regarded as highly speculative, and that major research is required to determine the future effects of changed moisture levels and elevated carbon dioxide levels on fire regimes.

3.2.2 Wind (*see Table 3*)

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

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 have severe coastal impacts with gale force winds. They generally occur between autumn and spring, and are most frequent in winter. Limited research means that changes in the frequency and intensity of ECLs due to climate change are unknown; however, the proposed ECL research project is designed to address this knowledge gap.

Changes to frequency of severe thunderstorms uncertain

Thunderstorms with severe winds affect the South East region approximately four times each year, usually in the period late spring through to autumn, and particularly from November to January. They can produce wind gusts of 90 km/h or greater. 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 ex-tropical cyclones uncertain

The incidence of ex-tropical cyclones producing severe winds in the South East region is very low, and projected 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 systems in categories 3–5, 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 in the South East region is currently moderate, 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 South East region is affected by four hail-producing thunderstorms per year on average. These storms are more common in the north and slightly inland parts of the region. The hail season lasts from November to March, with the highest frequency in January. 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 South East region currently has an average of 20–25 thunder days per year, with a frequency of lightning strikes of 2–3 per km² per year. Thunder days are less frequent in the mountains and western parts of the region. They are summer dominant, but they 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. This can be an issue in urban areas where protection is provided to mitigate the impacts of riverine flooding.

Current incidence is variable depending on location with this risk expected to increase with changing community profiles in urban areas, and in some coastal areas, 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 in lower coastal areas and around coastal lakes and lagoons of the South East region. This is due to projected changes in sea level caused by climate change 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. The definition of heatwaves used in this assessment is at least three consecutive days with maximum temperatures above the 90^{th} percentile for the month.

The frequency of heatwaves has historically been higher in northern and inland parts of the South East region. In the period 1979–2008, the region experienced 17 spring and 20 summer heatwave events in near coastal Bega; while inland at Goulburn, the figures were 26 for spring and 30 in summer. Inland centres have also exhibited a significant increase in recent times, with 45% of heatwave 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.

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) during the 20^{th} Century, (IPCC 2007). Satellite measurements indicate global sea levels have risen by around 3.2 mm (±0.4 mm) per year since 1992. A maximum rise of 40 cm relative to 1990 sea levels by 2050 is projected for New South Wales, 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, a still water level of 1.435 m Australian Height Datum (AHD) at Fort Denison is estimated to have an average recurrence interval (ARI) of 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 ARI 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, 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 South East region experiences an average wave climate of 1–2 m from the south-east. Based on 29.9 years of wave data collection from the Eden offshore waverider buoy, significant wave heights exceeding 7.2 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 8.9 m having an equivalent 100 year recurrence interval. Based on 21.6 years of wave data collection from the Batemans Bay offshore waverider buoy, the 100 year ARI significant wave height is 6.7 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 south, east and south-east. 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 South East region by 0–0.3 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 NSW State Emergency Service (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: South East region fire hazard indicators

Indicator	Current conditions	Projected change (to 2050)	Status of research
Frequency range	Highly variable – the fire cycle is 10–50 years across woodlands and forests. Wetter forests (high altitude/escarpment), sub-alpine and alpine vegetation may experience longer fire cycles. Monaro grasslands have irregular fire.	Increased frequency of fire likely but the fire cycle will remain largely within this range.	Some detailed analyses of current and (simulated) future fire regimes are available for parts of this region. Projections are conservative – 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.	An extension into spring is possible.	See above.
Potential days for prescribed burning **(i.e. average annual days of moderate – high fire danger)**	>110 near coast and hinterlands. >100 days on tablelands. >10 sub-alpine.	Projected increase (1–5%).	See above.

Indicator	Current conditions	Projected change (to 2050)	Status of research
Average number of days (per annum) of very high – extreme fire danger	<10 near coast and higher mountains. 10–15 inland. <1 sub alpine.	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).	Detailed analyses of weather conditions associated with large fires are available for some parts of this region. Projection models (remote sensing based) of fire severity are available. Future trends – see above.
Influence of runoff on water availability (average seasonal trends)	Highest in winter, lowest in summer with the exception of the coast where minimum runoff occurs in spring.	Projected major increase in summer and decrease (major in inland regions) in winter, prior to the fire season.	See above.
Fuel	Predominantly litter fuels in dry sclerophyll woodland/forest. Grassy fuels are important in the Monaro, some woodlands and forests, and in agricultural land.	Projected decreases in available moisture could reduce litter and grass fuels in coastal regions and north, north-west mountain regions. Projected increases in moisture balance could increase litter and grass fuels in higher parts of the ranges and tablelands. Exotic species such as lantana (coastal forests), along with grasses, have the potential to alter fire regimes.	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 native exotic species such as grasses and lantana required.

Table 3: South East 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 ECLs 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 4 storms with severe winds affect the South East 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 November 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.	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		Moderate.	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: South East hail hazard indicators

Indicator	Current conditions	Status of research
Frequency	The South East region experiences 4 thunderstorms with hail per year, with very few exceeding 5 cm. These are more common to the north and inland, with only 2 events within 25 km of Bega but 21 within 25 km of Canberra during the period 1990–2007. 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 5.5 cm.	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 November to March, with highest frequency in January.	

Table 5: South East lightning hazard indicators

Indicator	Current conditions	Status of research
Frequency	Average of 20–25 thunder days per year in the South East region (Kuleshov *et al*. 2002).	Currently no research for the Australian region on 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 2–3 per km^2 per year (ground flash).	
Distribution	Thunder days are less frequent in the mountains in western regions.	
Seasonality	Summer dominant but can occur at any time of the year.	

Table 6: South East 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 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. 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 sea surface temperatures for development.
Ex-tropical cyclone	**Frequency**	Low to none at these latitudes.	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 once or twice per storm season, predominantly on the coast and in urban areas such as Canberra.	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 once or twice 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: South East 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 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. 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, predominantly affecting coastal areas.	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: South East heatwave hazard indicators

Indicator	Current conditions	Status of research
Frequency	Over the period 1979–2008, Goulburn – 26 in spring, 30 in summer. Canberra – 35 in spring, 36 in summer. Bega – 17 in spring, 20 in summer. Canberra and Goulburn both exhibit a significant increase since 2000, with 45% of events occurring in these 9 years.	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 90th 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 90th percentile for maximum temperatures during 1979–2008.	By 2050 maximum temperatures will increasingly exceed the 1979–2008 90th 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	More common in northern and inland regions.	The changing nature of rainfall to become 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: South East 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 estimated to be 17 ± 5 cm (IPCC 2007). Global average eustatic SLR 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 South-East 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 8.9 m. 12-Hour 100 Year ARI significant wave height is 7.2 m. (based on 29.9 years of records from Eden 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 6.7 m. (based on 21.6 years of records from Batemans Bay 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 southern NSW the frequency of occurrence of swell waves 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)	0–0.3 m per year. These present day rates of shoreline recession currently contain changes due to historical SLR. 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 the 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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