

**IMPACTS OF CLIMATE CHANGE ON
NATURAL HAZARDS PROFILE
SYDNEY/CENTRAL COAST REGION**

December 2010



**Environment,
Climate Change
& Water**

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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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- 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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Department of Environment, Climate Change and Water NSW
59–61 Goulburn Street, Sydney
PO Box A290
Sydney South NSW 1232
Ph: (02) 9995 5000 (switchboard)
Ph: 131 555 (information & publications requests)
Fax: (02) 9995 5999
TTY: (02) 9211 4723
Email: info@environment.nsw.gov.au
Website: www.environment.nsw.gov.au

For further information contact:

Department of Environment, Climate Change and Water
59–61 Goulburn Street, Sydney
PO Box A290
Sydney South NSW 1232
Phone: 1300 361 967 or (02) 9995 5000

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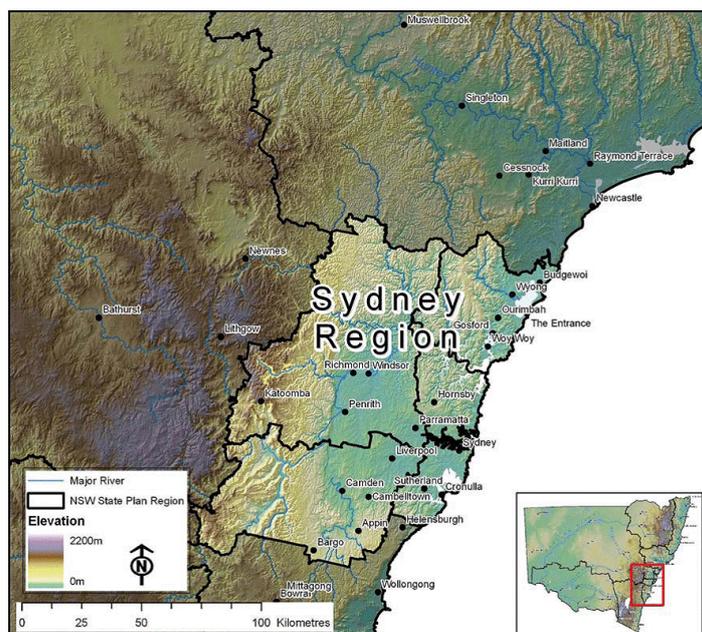
1 Introduction

The Sydney/Central 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 Sydney/Central Coast region is exposed:
 1. Fire
 2. Flash flooding
 3. Riverine flooding
 4. Hail
 5. Wind
 6. Lightning
 7. Heatwave
 8. Coastal erosion
- projections of how these natural hazards may change into the future due to climate change.

The Sydney/Central Coast region, shown in Figure 1, includes the Sydney, Western Sydney, South West Sydney and the Central Coast State Plan regions. It extends from the Royal National Park in the Sutherland Shire north to Barrenjoey Head in the Pittwater local government area (LGA) and on to the large Tuggerah Lakes system. The region covers 13,800 km², includes 43 LGAs and encompasses the Sydney East, Sydney North, Western Sydney and Georges River Emergency Management Districts (EMD), the majority of the Sydney South West EMD and part of the Hunter/Central Coast EMD.

Figure 1: Map of the Sydney/Central Coast region



2 Current climate and natural hazards of the Sydney/Central Coast region

2.1 Current climate

The climate of the Sydney/Central Coast region is warm temperate, with rainfall fairly evenly spread throughout the year for an annual average slightly less than 950 mm. Rainfall distribution ranges from more than 1200 mm/year near the coast to less than 800 mm/year in the west of the region. Rainfall events are greatest in summer and autumn, with a higher proportion of winter rainfall on the coast than over the inland. Runoff is highest in autumn and winter and lowest in spring.

2.2 Natural hazards

Some examples of recent significant natural hazards that have occurred in the Sydney/Central Coast region are detailed in Table 1.

Table 1: Recent significant natural events in the Sydney/Central Coast region

Event	Date	Estimated damage/cost*
Severe storm	8 June 2007	\$1350 million (cost)
South-east hailstorm	14 April 1999	\$1700 million (cost)
Turrumurra hailstorm	21 January 1991	\$226 million (cost)
Bushfires in Sydney (also Canberra, Wollongong and Dubbo)	21 December 2001 – 15 January 2002	650,000 hectares burned, 121 houses destroyed and 340 more damaged \$68.79 million (cost)
Hawkesbury and Georges rivers floods	5 August 1986	10,000 affected, a flood peak of 11.3 m at Windsor Bridge \$53 million (cost)
Heatwave	1 December 1994	–
Heatwave	1 December 2000 – 25 January 2001	–

* 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 severe storm on 8 June 2007 and the hailstorm on 14 April 1999 to demonstrate the kinds of impacts that these events have had on the Sydney/Central 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, as was the case with the severe storm on 8 June 2007. Known as East Coast Lows (ECLs), these systems occur on average 10 times each year. The severe storm on 8 June 2007 resulted from an intense ECL – the first of five over the Tasman Sea for that month alone – and ultimately led to more than 20,000 calls to the NSW State Emergency Service (SES) over the following 17 days. The Australian Bureau of Meteorology (BoM) described this sequence of five ECLs as ‘rare but not unprecedented’.

The commencement of the storm brought three days of damage-causing gale force winds (average speed of 63 km/h and above) with top wind speeds measured at 106 km/h at Sydney Harbour’s Fort Denison and 135 km/h at Norah Head. A wave peak of 14.1 m was recorded at the Sydney offshore waverider buoy (the highest since recordings began at the buoy in 1992), with associated wave climates causing widespread beach erosion, and sinking the Cremorne ferry wharf. A top 24 hour rainfall of 174.4 mm was recorded at Berowra. The result was ultimately Sydney’s second wettest June on record, with a monthly total of 510.6 mm.

Significant damage and cost also resulted from a localised hailstorm on 14 April 1999, when a ‘supercell’ thunderstorm developed about 115 km south-west of Sydney and to the north of Nowra. It produced some of Sydney’s largest recorded hail (approximately 8 cm in diameter). This storm hit a total of 85 suburbs covering an area stretching from Bundeena north to Darling Point, and from Bondi Junction west to Sydenham. Damage was heaviest in the highly developed and heavily populated south-eastern Sydney area. It damaged 20,000 properties, 40,000 vehicles, 25 aircraft at Sydney Airport and resulted in 20,000 requests for SES assistance.

Over the last 20 years, the financial cost to New South Wales incurred from these events has increased, being three times higher from 1994–2005 than for the previous decade. Historically, hailstorms have resulted in the greatest financial cost, with the storm in Sydney on 14 April 1999 alone totalling nearly \$1.8 billion.

3 Projected changes to climate and natural hazards in the Sydney/Central Coast region

The following section details projected changes to climate and the frequency and intensity of natural hazards in the Sydney/Central Coast region out to 2050. Projections for significant fire, coastal erosion and weather-related hazards in the Sydney/Central 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 is needed to improve the accuracy of these projections in subsequent years.

3.1 Projected changes to climate

Daily maximum temperatures are projected to increase by an average of 1.5–3°C, with the greatest increase during winter and spring (2–3°C) and the smallest increase in summer (1–2°C). Nights are also projected to be warmer, particularly in spring (2–3°C).

Summer rainfall is projected to increase across the region by 20–50%, with a smaller increase (10–20%) in spring. Winter rainfall is projected to decrease by 10–20% with higher temperatures and increased evaporation, while no significant change in rainfall is projected for autumn. Evaporation is also projected to rise by 10–20% in spring and summer. Overall, some redistribution of runoff across the seasons is likely, with increases in summer and autumn and decreases in winter and 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 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 Sydney/Central Coast region and across New South Wales. Increases in temperature, evaporation and high-risk fire days are likely to influence fire frequency and intensity across the region. The fire season is likely to be extended as a result of higher temperatures.

Fire frequency likely to increase

The average return period between fires for much of the Sydney/Central Coast region currently ranges from 10–30 years. 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 on the effect of climate change on the frequency and intensity of ENSO, ignition rates and fuel accumulation.

Weather conditions conducive to large, intense fires to increase

The conditions conducive to large and intense fires, such as prolonged drought, days of high temperature, 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 Sydney/Central Coast region are currently reached in spring through to early 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 both the forward extension (into late winter), and lengthening (into late summer) of the fire season. This is despite projected increases in summer rainfall.

Very high to extreme fire danger days per year to increase

Historically, the coastal areas of the Sydney/Central Coast region experience fewer than 10 very high to extreme fire danger days per year, while the inland areas experience 10–15 per year. With a broadening of the fire season, a 10–50% increase in the frequency of very high to extreme fire danger days is projected. Additionally, a 1–5% increase in potential days for prescribed burning (days when fire danger levels are to moderate to high) is also projected. 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 future fuel availability are regarded at present as highly speculative, and major research is required to determine the future effects of changes in moisture levels and elevated carbon dioxide levels on fire regimes. Future change in fuel availability is the least certain of all the fire hazard indicators. Projected decreases in available moisture will possibly reduce litter and grass fuels in coastal regions and north, north-west mountain regions, while projected increases in the moisture balance will possibly increase litter and grass fuels in the central and south-western mountain regions.

3.2.2 Wind (see Table 3)

High winds in the Sydney/Central 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, of which 3–5 produce severe coastal impacts with gale force winds. They generally occur from autumn through to spring, and are most frequent in winter. Limited research means that changes in the

frequency and intensity of ECLs out to 2050 are unknown; however, the proposed 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 about 10 affect the Sydney/Central Coast region annually. However, a larger number of thunderstorms produce severe winds of at least 50 km/h, of which about 5 per year result in significant damage. Severe thunderstorms occur from late spring through to autumn, and are summer dominant. 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 and further research is required.

Changes to incidence of tropical and ex-tropical cyclones uncertain

The incidence of tropical and ex-tropical cyclones producing severe winds in the Sydney/Central Coast region is historically low, and the 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 categories 3–5 systems. However, these studies do not provide with any certainty projections for the frequency and intensity of systems over NSW latitudes. Such projections are likely to be highly dependent 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 is currently low to moderate, with some projected changes out to 2050 indicating a likely decline in the frequency of westerly gales as the winter westerly belt moves south. However, further daily wind speed modelling is required to improve the level of confidence associated with extreme wind speed projections.

3.2.3 Hail (see Table 4)

Changes to frequency of hail days uncertain

The Sydney/Central Coast region is on average affected by 10 hail-producing thunderstorms per year. The hail season lasts from August to March, with peak frequency in the period October to February. One study has reported a decline of about 30% for hailstorms in Sydney between 1989 and 2002 compared with numbers from 1953–1988 (Schuster *et al.* 2005). Some research has suggested an increase of around six hail days per year by 2070 (CSIRO 2007a), but research overall is limited and severe thunderstorms are not adequately captured by the resolution of climate models, which will need further work to improve future projections for extreme winds and other effects of severe thunderstorms.

3.2.4 Lightning (see Table 5)

Changes to lightning frequency uncertain

The Sydney/Central Coast region currently has an average of 20–25 days per year which experience thunder, with a frequency of lightning strikes of 2–3 per km² per year. Lightning strikes are more frequent in the western suburbs and about the ranges, and while they are summer dominant, they can occur at any time of year. Projections out to 2050 are mostly unknown, but some studies have suggested a 5–6% change in global lightning frequency for every 1°C of global temperature change (Price and Rind 1992), and there are indications of a possible increase in the incidence of 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 because of 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 Sydney/Central 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 the variation of the exposure of the community 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 the very young. Heatwaves

have accounted for more deaths in Australia than any other natural hazard. The definition for this assessment is at least three consecutive days with maximum temperatures above the 90th percentile for the month. In the Sydney Central/Coast region, the frequency of heatwaves has historically been higher in the west of the region where maximum temperatures are also higher than nearer the coast. In the period 1979–2008, Sydney city (Observatory Hill) experienced 14 spring and 14 summer heatwave events, while the north-western inland centre of Richmond had 29 spring and 29 summer heatwave events.

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 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, an average still water level of 1.435 m Australian Height Datum (AHD) is estimated to occur once every 100 years at Fort Denison. 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, by 2050 a still water level of 1.815 m AHD is estimated to occur once every 100 years. 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, although the effects of climate change on these factors are not yet adequately known.

Wave height and period to increase, wave direction to change

The Sydney/Central Coast region experiences an average wave height of 1–2 m from the south-east. Based on 15.8 years of wave data collected from the Sydney offshore waverider buoy, significant wave heights (those exceeding 8.3 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 9.4 m having an equivalent 100 year recurrence interval. 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. 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 Sydney/Central Coast region by 0–0.3 m/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/year based on a rate of global average sea level rise of approximately 3 mm/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: Sydney/Central Coast fire hazard indicators

Indicator	Current conditions	Projected change (to 2050)	Status of research
Frequency range	Variable – the fire cycle is 10–30 years across the bulk of the area. The fire cycle is longer in the north-west of the region.	Increased frequency of fire likely but the fire cycle will remain largely within this range.	Detailed analyses of current and (simulated) future fire regimes are available for 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	Spring to early summer.	No change over the bulk of the region but an intensification of fire danger within the season is projected. A lengthening of the fire season into late winter and late summer is possible in the Metropolitan area.	See above.
Potential days for prescribed burning (i.e. average annual days of moderate – high fire danger)	>100 near coast. >60 inland.	Projected increase (1–5%). Days falling within the prescribed burning window (Forest Fire Danger Index of 5–25) are projected to increase.	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).	Detailed analyses of weather conditions associated with large fires are available for this region. Projection models (remote sensing based) of fire severity are available. 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–winter, lowest in spring.	For Central Coast, a projected increase in autumn–winter prior to fire season and decline during fire season. For Sydney, an increase in summer–autumn is projected along with a decline in winter and spring, prior to the fire season.	
Fuel	Predominantly litter fuels in dry sclerophyll woodland/forest. Grassy fuels in Cumberland plain and cleared 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 the central and south-western mountain regions. Exotic species such as lantana, along with 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 native and exotic species such as grasses and lantana required.

Table 3: Sydney Central Coast wind hazard indicators

Meteorological source	Indicator	Current conditions	Status of research
East Coast Low	Frequency	Average of 10 per year	<p>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 <i>et al.</i> 1992, Hennessy <i>et al.</i> 2004, Abbs and McInnes 2004).</p> <p>A proposed ECL research project is the first priority for the ESCCI and is designed to address this research gap.</p>
	Intensity	3–5 per year produce severe coastal impacts with gale force winds.	
	Seasonality	Autumn through spring. Winter dominant.	
Severe thunderstorm	Frequency	Average of 5 storms per year have winds causing significant damage, with a larger number having strong winds with speeds in excess of 50 km/h.	<p>Research is currently limited to only a couple of studies for NSW: Schuster <i>et al.</i> 2005; Leslie <i>et al.</i> 2007.</p> <p>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.</p>
	Intensity	Severe thunderstorms can produce wind gusts of 90 km/h or greater.	
	Seasonality	Late spring through to autumn. Summer dominant.	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.

Table 4: Sydney/Central Coast hail hazard indicators

Indicator	Current conditions	Status of research
Frequency	<p>On average, 10 hailstorms affect the Sydney area per year, with ~2 per year with hail at least 5 cm in diameter.</p> <p>The greater Sydney region has slightly decreased frequency, with 34 events during the period 1990–2007 in Katoomba and 24 in Camden and Norah head, compared to 89 in Sydney city during the same period; this may be an artefact of better reporting in the city, however.</p> <p>Schuster <i>et al.</i> (2005) reported a decline of 30% in the number of hailstorms affecting Sydney in the period 1989–2002 compared with 1953–1988.</p>	<p>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).</p> <p>Research is currently limited to only a couple of studies for NSW: Schuster <i>et al.</i> 2005; Leslie <i>et al.</i> 2007; Niall and Walsh 2005.</p> <p>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.</p>
Intensity	<p>Severe thunderstorms can produce hail over 2 cm in diameter. The largest hail recorded in the 1990–2007 period was 11 cm in Cherrybrook, on 9 December 2007.</p>	<p>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.</p>
Seasonality	<p>The hail season lasts from August to March, with peak frequency in October to February.</p>	

Table 5: Sydney/Central Coast lightning hazard indicators

Indicator	Current conditions	Status of research
Frequency	Average of 20–25 thunder days per year on average in the Sydney area (BoM website).	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 2–3 per km ² per year (ground flash).	
Distribution	More prevalent in the western suburbs and ranges.	
Seasonality	Summer dominant but can occur at any time of the year.	

Table 6: Sydney/Central Coast flash flooding hazard indicators

Meteorological source	Indicator	Current conditions	Status of research
<p>All types of relatively short duration storms</p>	<p>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</p>	<p>Varies significantly with exposure of specific locations or communities to flooding.</p> <p>Can be derived from a range of weather events including thunderstorms and ECLs.</p> <p>Expected to increase with the changing community profiles and any change in scale of events.</p>	<p>Research needs to be undertaken to provide more specific advice on potential scale of changes to these flood-producing rainfall events.</p>
	<p>Exposure</p>	<p>Significant, widespread exposure varying with location.</p> <p>Increasing due to changes in density of development and any increase in exposure to flood-producing storm events discussed below.</p> <p>The exposure levels of individual locations to flooding are quite specific and need to be addressed by flood investigations in specific catchments and locations.</p> <p>Studies have been undertaken to examine existing risks in many areas but others remain unstudied.</p> <p>In catchments in lower coastal areas a combination of raised ocean levels and catchment flooding can be the controlling flood mechanism.</p>	<p>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.</p>
<p>East Coast Low</p>	<p>Frequency</p>	<p>Average of 10 per year.</p>	<p>Very limited literature: McInnes <i>et al.</i> 1992; Hennessy <i>et al.</i> 2004; Abbs and McInnes 2004.</p> <p>These studies are yet to give a consistent projection for changes to ECLs beyond 2050.</p> <p>The proposed ECL research project is the first priority for the ESCCI and is designed to address this research gap.</p>

Meteorological source	Indicator	Current conditions	Status of research
	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 (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. <i>Abbs et al. 2006; Leslie et al. 2007; Walsh et al. 2004.</i> 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.
Severe thunderstorm	Frequency	On average, severe thunderstorms produce flash flooding several times per storm season though the location of impact within the region would vary.	Limited to only a couple of studies for NSW: <i>Schuster et al. 2005; Leslie et al. 2007.</i> CSIRO (2007a) states that severe thunderstorms are not adequately captured by the resolution of the climate models. Future projections for extreme winds associated with severe thunderstorms are therefore currently unavailable.
	Intensity	On average, severe thunderstorms produce flash flooding several times per storm season.	There is no published work on observed trends in intensity. Models are currently unable to resolve these relatively small scale phenomena and are therefore unable to provide future projections.
	Seasonality	Late spring through to autumn. Summer dominant.	

Table 7: Sydney/Central 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	<p>Varies significantly with exposure of specific locations or communities to flooding.</p> <p>Expected to increase with the changing community profiles and any change in scale of events.</p>	<p>Can be derived from a wide range of weather events including thunderstorms and ECLs, tropical cyclones and troughs.</p> <p>Research needs to be undertaken to provide more specific advice on potential scale of changes to these flood-producing rainfall events.</p>
	Exposure	<p>Significant, widespread but varies with location.</p> <p>Increasing due to changes in density of development and any increase in exposure to flood-producing storm events discussed below.</p> <p>The exposure levels of individual locations to flooding are quite specific and need to be addressed by flood investigations in specific catchments and locations.</p> <p>Studies have been undertaken to examine existing risks in many areas but other areas remain unstudied.</p> <p>In catchments in lower coastal areas a combination of raised ocean levels and catchment flooding can be the controlling flood mechanism.</p>	<p>Assessment of climate change impacts of sea level rise and flood-producing rainfall events is necessary for specific locations.</p> <p>Research needs to be undertaken to provide more specific advice on potential scale of changes to these flood-producing rainfall events.</p>
East Coast Low	Frequency	Average of 10 per year.	<p>Very limited literature: McInnes <i>et al.</i> 1992; Hennessy <i>et al.</i> 2004; Abbs and McInnes 2004.</p> <p>These studies are yet to give a consistent projection for changes to ECLs beyond 2050.</p> <p>The proposed ECL research project is the first priority for the ESCCI and is designed to address this research gap.</p>
	Intensity	On average 3–5 per year produce severe coastal impacts with flooding.	

Meteorological source	Indicator	Current conditions	Status of research
	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. <i>Abbs et al. 2006; Leslie et al. 2007; Walsh et al. 2004.</i>
	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.	
	Seasonality	Can occur at any time of year but most prevalent in the October to March period with summer dominance.	

Table 8: Sydney/Central Coast heatwave hazard indicators

Indicator	Current conditions	Status of research
Frequency	<p>Over the period 1979–2008:</p> <p>Richmond – 29 in spring, 29 in summer. Parramatta – 21 in spring, 19 in summer. Sydney Obs. Hill – 14 in spring, 14 in summer.</p> <p>Greater Sydney:</p> <p>Norah Head – 11 in spring, 14 in summer. Camden – 14 in spring, 11 in summer. Katoomba – 22 in spring, 25 in summer.</p>	<p>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.</p> <p>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.</p> <p>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.</p>
Intensity	<p>3 consecutive days above the 90th percentile for maximum temperatures during 1979–2008.</p>	<p>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).</p> <p>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.</p>
Distribution	<p>More prevalent in the western suburbs and Blue Mountains.</p>	<p>The importance of the sea breeze in curtailing heatwaves is evident in the reduction in heatwave frequency in the east of the Sydney basin. Heatwave frequency increases with distance from the coast. Richmond experiences almost twice the frequency of heatwaves as the Sydney Central Business District.</p>
Seasonality	<p>Spring and summer.</p>	<p>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.</p>

Table 9: Sydney/Central Coast coastal erosion and inundation hazard indicators

Indicator	Current conditions	Projected change (to 2050)	Status of research
Sea level rise	1.2 mm/year from 1920–2000, which is equivalent to 9.6 cm rise in sea level.	An upper limit of sea level rise (SLR) of 0.4 m from 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	1.435 m AHD 100 year Average Return Interval (ARI) for still water levels at Fort Denison (Watson and Lord 2008). Still water level includes variations to water level by tides, storm surge, water temperature and barometric pressure.	1.815 m AHD 100 year ARI for still water levels at Fort Denison. Today's 100 year ARI of 1.435 m AHD is projected to have an ARI of 0.05, equivalent to 18 days. A 1% increase in storm surge is projected but within errors of present day storm surge estimates (CSIRO 2007b). Not appropriate for planning but adequate for sensitivity analysis.	Projected 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.
Wave characteristics (height, period and direction)	8.3 m 100 year ARI for 12-hour significant wave height based on 15.8 years of data recording. 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.

Indicator	Current conditions	Projected change (to 2050)	Status of research
Shoreline recession (underlying process driven)	0–0.3 m per year. These present day rates of shoreline recession 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 position 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, near shore 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 1990 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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