IMPACTS OF CLIMATE CHANGE ON NATURAL HAZARDS PROFILE

WESTERN REGION

December 2010

NSW GOVERNMENT
Environment, Climate Change & Water

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

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

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1 Introduction

The Western 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:

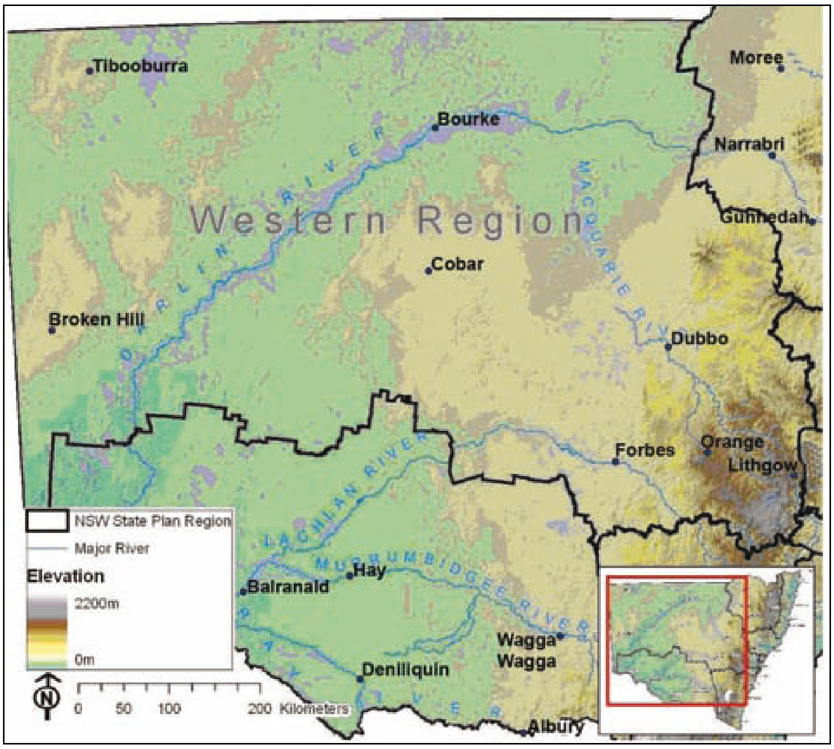
- the following natural hazards to which the Western region is exposed:

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

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

The Western region, shown in Figure 1, extends from the Queensland and South Australian borders to the central tablelands and western slopes of the Great Dividing Range. It falls within the Murray–Darling Basin and is dominated by the extensive, broad floodplains of the Darling River and its tributaries. It covers 402,800 km^2 or about 50% of the state, and includes 26 local government areas (LGAs).

Figure 1: Map of the Western region



The region covers all of the Western Slopes Emergency Management District (EMD), the Far West EMD (excluding Wentworth LGA); the Central West EMD (excluding Lithgow LGA); and the Weddin LGA portion of the Southern Highlands EMD.

2 Current climate and natural hazards of the Western region

2.1 Current climate

The spread and location of the Western region takes it through a range of climatic zones, with overall average annual rainfall of about 360 mm. Rainfall distribution ranges from 180–200 mm per year in the arid far west, around 400 mm per year on the semi-arid plains of central New South Wales, around 600 mm per year on the slopes, and up to 1000 mm per year on the highlands of the extreme south-east. Rainfall is summer dominant, especially in the central and western parts of the region. Runoff is winter dominant in the wetter eastern parts, but summer dominant in the drier western parts.

2.2 Natural hazards

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

Table 1: Recent significant natural events in the Western region

Event	Date	Estimated damage/cost*
Nyngan floods	April 1990	$50 million (cost; Nyngan alone)
Bushfires	September 1984 – February 1985	$45 million (cost)
Orange hailstorm	1 January 1986	$41 million (cost)
Dubbo–Central West floods	7–9 November 2005	$19.3 million (cost)
Severe storm	5 January 1998	$12 million (cost)

* Emergency Management Australia estimates – 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 flooding of April 1990 and bushfires of 1984–1985 to demonstrate the kinds of impacts that recent significant natural hazards have had on the Western region.

Many townships in the region are close to rivers and streams and have suffered serious flooding, particularly in 1955, 1976 and 1990. The experience of floods has led to the construction of levees, and local government manages over 90 km of levees protecting Bathurst, Bourke, Brewarrina, Nyngan, Coonamble, Warren, Walgett and other towns in the region.

Severe flooding in April 1990 extended over an estimated one million square kilometres from south-west Queensland through a broad area of inland New South Wales to northern Victoria, but was worst at Nyngan where record rainfall (exact total unknown because of flooding) took the Bogan River to a new peak level.

In the period between September 1984 and February 1985, a total of 6000 separate bushfires burned across 3.5 million hectares of mainly farming and grazing land in New South Wales, with the loss of an estimated 40,000 livestock. Lightning strikes on Christmas Day 1984 alone were responsible for starting 100 fires, but the largest came at Cobar in January 1985. High temperatures coincided with a period of significantly below average rainfall ahead of the outbreak, with only 1.4 mm recorded at Cobar in December 1984, and 8.6 mm at the same centre through the following month.

3 Projected changes to climate and natural hazards in the Western region

The following section details projected changes to climate and the frequency and intensity of natural hazards in the Western region out to 2050. Projections for significant fire, and weather-related hazards in the Western 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 during autumn, winter and spring (2–3°C). Maximum temperatures in summer are projected to increase by 2–3°C in the west, and by 1.5–2°C in the east. Minimum temperatures are projected to increase by 0.5–2°C across the region.

Summer rainfall is projected to increase by 20–50% in the tablelands and central west, and to increase moderately by 10–20% in the rest of the region. Winter rainfall is projected to decrease by 10–20% across most of the region, while some areas in the south are projected to decrease by 20–50%.

Evaporation is projected to rise by more than 50% during spring in the far north-west of the region, and substantial increases are likely for the rest of the region during spring, and throughout the region in summer. In autumn, evaporation is likely to increase most in the west (20–50%) with smaller increases in the east (10–20%). In winter, a slight increase is likely in the north-east of the region, but the south-west is likely to experience a moderate decrease. An increase in evaporation across most of this large region is projected overall to create drier conditions throughout the year.

Overall, a slight increase in runoff is considered more likely than not, and it is likely to be redistributed across the seasons with increases in summer and autumn and decreases in spring and winter.

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

3.2 Projected changes to natural hazards

The current resolution of global climate models means that relatively large damaging weather events such as 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.

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 Western region and across New South Wales. Increases in temperature, evaporation and high fire-risk days are likely to increase further, but more research is needed to assess the impact on fire frequency and intensity across the region. The fire season is likely to be extended as a result of higher temperatures.

Changes to fire frequency uncertain

The average return period between fires for the Western region is highly variable. It ranges from 20–50 years depending on vegetation and conditions. Out to 2050, the fire return period may increase over most of the region due to the possibility of reduced availability of herbaceous fuels. Changes in farming practices are likely to further reduce fire on cropping lands. However, further detailed analyses of fire regimes will be required for most of the region after further research on the effect of climate change on the frequency and intensity of ENSO, ignition rates and fuel accumulation.

Weather conditions conducive to large, intense fires to increase

The conditions conducive to large and intense fires, such as prolonged drought, days of high temperature and wind speed, and low humidity, are anticipated to increase. 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 Western region are currently reached in summer. Projections out to 2050 include a tendency for the season to commence earlier (spring) and for the fire danger to be more intense during the season as the incidence of prolonged wet periods through winter–spring declines.

Very high to extreme fire danger days per year to increase

Historically, the Western region experiences more than 30 very high to extreme fire danger days per year, and more again in the far west. These will possibly increase by 10–50%. Potential days for prescribed burning with fire danger levels moderate to high are currently more than 160 days per year in the Western region, scaling down to more than 120 days per year about the Western Slopes. Such days are projected to decline by up to 10%. Current prolonged wet periods including successive years with wet winter–spring seasons may decline out to 2050, while the incidence of days of high temperature, high wind speed and low humidity may increase. Again, a much better understanding of future changes to the frequency and intensity of El Niño, and more research on ignition sources is needed. 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 on future fuel availability are regarded at this point 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 out to 2050 could reduce the predominantly herbaceous/grass fuels currently found in the region. Also, there is a possible tendency for increased shrub and mulga cover in western woodlands due to higher carbon dioxide levels, and this would decrease herbaceous fuel and flammability. Projected decreases in available moisture could reduce litter and grass fuels in parts of the region, and possible changes to rainfall patterns could increase the presence of crop stubble.

3.2.2 Wind (*see Table 3*)

High winds in the Western region are associated with a number of climatic systems including severe thunderstorms and frontal systems, but only rarely is the region affected by ex-tropical cyclones and ECLs.

Changes to frequency of severe thunderstorms uncertain

Storms producing severe winds currently number about 11 annually over the Western region, and they frequently generate winds that can be in excess of 90 km/h. Severe thunderstorms occur mostly from October through to February, and particularly during summer months. Projections of wind speeds associated with severe thunderstorms out to 2050 are currently unavailable, as these weather events are not adequately covered by climate models.

Changes to incidence of tropical and ex-tropical cyclones uncertain

Tropical and ex-tropical cyclones which can produce severe winds rarely reach inland areas such as the Western region. Future changes to these systems are largely unknown. Studies have concluded that no significant change is likely in overall tropical cyclone numbers out to 2050, but there could be an increase in the proportion of categories 3–5 systems depending on changes in sea surface temperatures (SST) and upper atmosphere circulation.

Changes to incidence of gales and frontal systems uncertain

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

3.2.3 Hail (*see Table 4*)

Changes to frequency of hail days uncertain

The Western region experiences 8.5 hail-producing thunderstorms per year on average. These storms occur mostly around the tablelands to the east. The hail season lasts from September to March, with the highest incidence in the summer months. 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 Western region currently has an average of 15–25 days per year which experience thunder, with a small area of higher frequency around Cobar. The overall frequency of lightning strikes is 0–2 per km^2 per year. They are more prevalent in the east, with very low incidence along the western border. They are summer dominant, but they can occur at any time of the year. Projections under climate change are mostly unknown, but some studies have suggested a 5–6% change in global lightning frequency for every 1°C of global temperature change and a possible increase in high based (dry) thunderstorms.

3.2.5 Flash flooding (*see Table 6*)

Incidence of flash flooding may increase

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

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

Further research will be needed to provide more specific information on the potential scale of changes to these flood-producing rainfall events.

Severe thunderstorms and cut-off lows are the current main cause of flash flooding; however, systems such as troughs may also result in flash flooding under some antecedent conditions.

3.2.6 Riverine flooding (*see Table 7*)

Incidence of riverine flooding likely to increase

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

Further research will be needed to provide more specific advice on the potential scale of changes to the significant rainfall events that produce floods and how seasonal changes will impact on likely antecedent catchment conditions. The main causes of riverine flooding in western areas are trough systems and more rarely north-west cloud bands, with cut-off lows having significant impact in southern parts of the region, but none of these are currently studied in New South Wales.

3.2.7 Heatwaves (*see Table 8*)

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

In the Western region, the frequency of heatwaves by definition has historically been higher in the east of the region, but with lower temperatures. In the period 1979–2008, the region experienced 35 spring and 39 summer heatwave events at Bathurst; while in Broken Hill, the figures were 23 in spring and 29 during summer.

Frequency and intensity of heatwaves to increase

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

Table 2: Western fire hazard indicators

Indicator	Current conditions	Projected change (to 2050)	Status of research
Frequency range	Highly variable – the fire cycle is highest (e.g. 20–50 years) within mallee shrublands and forest/woodland remnants in eastern slopes/tableland fringe. The fire cycle may be considerably longer in Western region woodlands subject to grazing, in fragmented grassy woodlands on the western slopes and in chenopod dominated vegetation. Irregular fire in land used for cropping (stubble burning and unplanned ignitions).	The most likely trend is for decreased fire over the bulk of the region due to lower availability of herbaceous fuels. Changes in farming practices (less stubble burning) will further reduce fire on cropping lands.	Detailed analyses of current fire regimes are required for the bulk of this region. Future, quantitative projections (not available at present) are also required. 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.	A tendency for the season to commence earlier (spring) is projected along with an intensification of fire danger within the season.	See above.
Potential days for prescribed burning **(i.e. average annual days of moderate – high fire danger)**	>160 (Western region). >120 (Western Slopes).	Projected decline (1–10%).	See above.
Average number of days (per annum) of very high – extreme fire danger	Typically >30 with higher values in the west.	A 10–50% increase is possible.	See above.

Indicator	Current conditions	Projected change (to 2050)	Status of research
Weather conditions conducive to large, intense fires	Prolonged wet periods including successive years with wet winter–spring seasons. Days of high temperature and wind speed, plus low humidity.	The incidence of these conditions may decline (see above). The incidence of these conditions may increase (see above).	Some detailed analyses of weather conditions associated with large fires are available for parts of this region (e.g. mallee). Insights from elsewhere (e.g. Central Australia Mulga and Spinifex country) are applicable to the arid north-west. Future trends – see above.
Influence of runoff on water availability (average seasonal trends)	Highly varied seasonal patterns across the region with winter peaks in east and summer peaks in the west and north-west.	Projections are for major increases in summer (the fire season) and major decreases in winter, prior to the fire season.	See above.
Fuel	Predominantly herbaceous/grassy fuels in woodlands. Litter and spinifex are important in mallee. Spinifex important in the arid north-west. Crops and crop stubble.	Projected decrease in available moisture could reduce the mass and availability of herbaceous grass fuels throughout the region. Possible tendency for increased plant woody cover (e.g. shrubs, mulga) in western woodlands due to elevated CO_2 effects on plant growth. This would tend to decrease herbaceous fuel and therefore flammability. Projected decreases in available moisture could reduce litter and grass fuels in forest/woodland remnants in eastern slopes/tableland fringe. Possible change to summer cropping due to rainfall seasonality changes. More crop stubble present.	Major research effort required to resolve future effects of changes in moisture and elevated CO_2 on plant growth, litter accession, decomposition, plus overall changes to vegetation structure (cover and woody/herbaceous plant balance). Projections are currently highly speculative and the degree to which vegetation fuel characteristics will change and affect fire regimes is unknown.

Table 3: Western wind hazard indicators

Meteorological source	Indicator	Current conditions	Status of research
East Coast Low	**Frequency**	Rarely affect inland areas.	
Severe thunderstorm	**Frequency**	Storms with severe winds affect the Western region on average 11 times per year, predominantly in the tablelands and slopes to the east, with very few in the north-west corner.	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	October through February, particularly summer.	
Ex-tropical cyclone	**Frequency**	These rarely reach inland areas.	No significant change in East Coast cyclone numbers projected to 2050 (Abbs *et al.* 2006; Leslie *et al.* 2007; Walsh *et al.* 2004). Likely to be highly dependant on the level of emissions and the magnitude of SST changes and upper atmosphere circulation changes.
	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.

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

Table 4: Western hail hazard indicators

Indicator	Current conditions	Status of research
Frequency	The Western region experiences on average 8.5 thunderstorms with hail per year, predominantly in the tablelands to the east, which experience ~5 per year, with ~1 per year with diameters of at least 5 cm. 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 hailstone recorded from 1990–2007 in this region was 10 cm on 21 March 2004 at Forbes.	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 September to March, with highest incidence in summer months.	

Table 5: Western lightning hazard indicators

Indicator	Current conditions	Status of research
Frequency	Average of 15–25 thunder days per year in the Western region, with a small area of higher frequency in the Cobar area (Kuleshov *et al.* 2002).	Currently no research for the Australian region of expected changes to lightning under enhanced greenhouse conditions. Some studies such as Price and Rind (1992) have suggested a 5–6% change in global lightning frequency for every 1°C global temperature change. US studies have also indicated that there may be an increase in high based (dry) thunderstorm activity. The regional scale effects on lightning for NSW are unclear.
Intensity/scale	Average of 0–2 per km^2 per year (ground flash).	
Distribution	More prevalent in the east, with very low incidence along the western border.	
Seasonality	Summer dominant but can occur at any time of the year.	

Table 6: Western 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, predominantly thunderstorms. Expected to increase with the increase in scale of development or flood-producing rainfall events.	Research needs to be undertaken to provide more specific advice on potential scale of changes to these flood-producing rainfall events.
	Exposure	Significant, widespread exposure varying with location. May increase with any changes to density or scale of development and any increase in exposure to flood-producing storm events discussed below. The exposure levels of individual locations to flooding are quite specific and need to be addressed by flood investigations in specific catchments and locations. Studies have been undertaken to examine existing risks in many areas but other areas remain unstudied.	Assessment of climate change impacts of flood-producing rainfall events is necessary for specific locations. Research needs to be undertaken to provide more specific advice on potential scale of changes to these flood-producing rainfall events.
East Coast Low	**Frequency**	None in inland regions.	

Meteorological source	Indicator	Current conditions	Status of research
Ex-tropical cyclone	**Frequency**	None in inland regions.	
Severe thunderstorm	**Frequency**	Severe thunderstorms produce flash flooding on average several times per storm season though the location of impact within the region would vary.	Limited to only a couple of studies for NSW: Schuster *et al.* 2005; Leslie *et al.* 2007. CSIRO (2007a) states that severe thunderstorms are not adequately captured by the resolution of the climate models. Future projections for extreme winds associated with severe thunderstorms are therefore currently unavailable.
	Intensity	Severe thunderstorms produce flash flooding on average several times per storm season.	There is no published work on observed trends in intensity. Models are currently unable to resolve these relatively small scale phenomena and are therefore unable to provide future projections.
	Seasonality	Late spring through to autumn. Summer dominant.	
Cut-off low	**Frequency**	Unknown, predominantly affect southern areas. Responsible for over 50% of winter rain in Mildura (on the VIC border).	Most research currently available focuses on the southern Murray in Victoria, such as Pook *et al*. (2006). No current trends in 500 hPa cut-off lows around Australia (Fuenzalida 2005). No research available on future trends.
	Intensity	Responsible for 80% of days with rainfall greater than 25 mm in North West Victoria, including Mildura.	
	Seasonality	Can occur year-round, but dominant during autumn and winter.	

Table 7: Western riverine flooding hazard indicators

Meteorological source	Indicator	Current conditions	Status of research
All types of relatively short duration storms	**Vulnerability of people and property to above floor flooding from rivers**	Varies significantly with exposure of specific locations or communities to flooding. Can be derived from a wide range of weather events including thunderstorms and troughs, cut-off lows and north-west cloud bands. Expected to increase with the increase in scale of development or flood-producing rainfall events.	Research needs to be undertaken to provide more specific advice on potential scale of changes to these flood-producing rainfall events and potential changes to likely antecedent conditions within catchments.
	Exposure	Significant, widespread but varies with location. Expected to increase with the increase in scale of development or flood-producing rainfall events. The exposure levels of individual locations to flooding are quite specific and need to be addressed by flood investigations in specific catchments and locations. Studies have been undertaken to examine existing risks in many areas but other areas remain unstudied.	Assessment of climate change impacts of flood-producing rainfall events is necessary for specific locations. Research needs to be undertaken to provide more specific advice on the potential scale of changes to flood-producing rainfall events and potential changes to likely antecedent conditions within catchments.
East Coast Low	**Frequency**	None in inland regions.	
Ex-tropical cyclone	**Frequency**	None in inland regions.	

Meteorological source	Indicator	Current conditions	Status of research
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.	
North-west cloud band	**Frequency**	Unknown. Responsible for a large proportion of rain events over western parts of NSW.	No research available on current climatology or future trends in these systems. This is a significant research gap. These are related to warm temperatures in the Indian Ocean.
	Intensity	Unknown.	
	Seasonality	Most prevalent in the March to October period, particularly between April and September.	
Cut-off low	**Frequency**	Unknown, predominantly affect southern areas. Responsible for over 50% of winter rain in Mildura (on the VIC border).	Most research currently available focuses on the southern Murray in Victoria, such as Pook *et al*. (2006). No knowledge available on expected trends.
	Intensity	Responsible for 80% of days with rainfall greater than 25 mm in southern areas of the Murray–Darling Basin during winter.	
	Seasonality	Can occur year-round, but dominant during autumn and winter.	

Table 8: Western heatwave hazard indicators

Indicator	Current conditions	Status of research
Frequency	Over the period 1979–2008: Bathurst – 35 in spring, 39 in summer. Dubbo – 34 in spring, 33 in summer. Broken Hill – 23 in spring, 29 in summer. Bourke – 28 in spring, 31 in summer.	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. Highest temperatures tend to be in the years since 2000; this needs further investigation.	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 the 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	Slightly more frequent in the east, but with lower temperatures. Some consistency spatially, with several major events showing up in all, especially a 10–12 day event around 8 February 2004.	

Indicator	Current conditions	Status of research
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.

4 References

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