

**IMPACTS OF CLIMATE CHANGE ON
NATURAL HAZARDS PROFILE**

RIVERINA MURRAY 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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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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Contents

1	Introduction.....	4
2	Current climate and natural hazards of the Riverina Murray region.....	5
2.1	Current climate.....	5
2.2	Natural hazards.....	5
3	Projected changes to climate and natural hazards in the Riverina Murray region	7
3.1	Projected changes to climate	7
3.2	Projected changes to natural hazards.....	7
3.2.1	Fire (see Table 2).....	8
3.2.2	Wind (see Table 3).....	9
3.2.3	Hail (see Table 4).....	10
3.2.4	Lightning (see Table 5)	10
3.2.5	Flash flooding (see Table 6).....	11
3.2.6	Riverine flooding (see Table 7)	11
3.2.7	Heatwaves (see Table 8)	11
4	References	23

List of figures and tables

Figure 1:	Map of the Riverina Murray region.....	4
Table 1:	Recent significant natural events in the Riverina Murray region	5
Table 2:	Riverina Murray fire hazard indicators	13
Table 3:	Riverina Murray wind hazard indicators	15
Table 4:	Riverina Murray hail hazard indicators	16
Table 5:	Riverina Murray lightning hazard indicators	17
Table 6:	Riverina Murray flash flooding hazard indicators	18
Table 7:	Riverina Murray riverine flooding hazard indicators	20
Table 8:	Riverina Murray heatwave hazard indicators	22

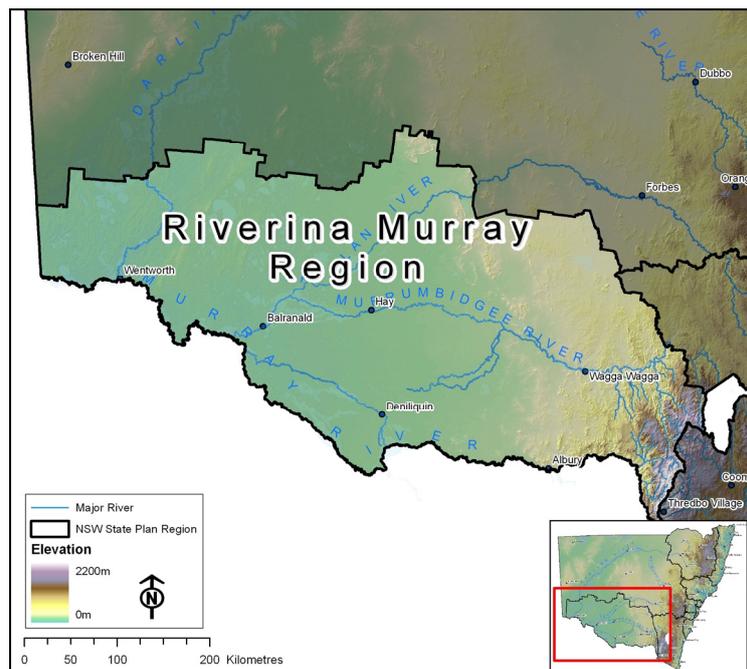
1 Introduction

The Riverina Murray 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 Riverina Murray 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 Riverina Murray region, as shown in Figure 1, lies in the drainage basin of the Murray and Murrumbidgee rivers and their tributaries and includes extensive floodplains and wetlands. The region covers 152,700 km² and includes 28 local government areas (LGAs). It encompasses the Riverina and Murray Emergency Management Districts (EMDs), the Gundagai and Tumut LGA portions of the Southern Highlands EMD, and the Wentworth LGA portion of the Far West EMD.

Figure 1: Map of the Riverina Murray region



2 Current climate and natural hazards of the Riverina Murray region

2.1 Current climate

The climate of the Riverina Murray region has a strong seasonal cycle, with cool to cold winters and warm to hot summers. It is considered likely to be one of the regions of New South Wales most severely impacted by climate change because of increasing temperatures, changes in the volume and distribution of rainfall, reduced snowfalls, and decreases in river flows. Rainfall throughout the region is winter–spring dominated, with average annual falls ranging from a low of about 240 mm in the north-west to a high of about 1050 mm on the western edge of the Snowy Mountains. The highest runoff originates from the Snowy Mountains and is winter–spring dominated, with the spring runoff high relative to rainfall because of melting snow. Runoff patterns in the more arid western parts of the region have a more uniform pattern.

2.2 Natural hazards

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

Table 1: Recent significant natural events in the Riverina Murray region

Event	Date	Estimated damage/cost*
Bushfires	17–20 January 1987	\$3 million (cost)
Hailstorms	10 October 1999	-
Severe storm	26 December 1998	-

*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 past flooding and bushfire events to demonstrate the kinds of impacts that recent significant natural hazards have had on the Riverina Murray region.

The local impact of flooding in the Riverina Murray region varies with terrain and is influenced by human-made structures such as roads, embankments, bridges and culverts. On the headwaters of the rivers and creeks within the region, flood levels depend on peak stream flows and the warning time is generally short. In the western areas of the region that are dominated by wide floodplains, warnings can be given earlier but floods stay near peak levels for long periods of time. Flooding can be a major problem for many weeks in some places. Many townships in the region are close to rivers and streams and have suffered serious flooding, particularly in 1956 and 1974. The experience of floods has led to the construction of levees, and local

government now manages 150 km of levees protecting Wagga Wagga, Deniliquin, Albury, Hay, Balranald, Wentworth and other centres in the region.

During January 1987, bushfires were widespread through the south-west of New South Wales. One fire alone covered an area extending from Deniliquin through Cootamundra to Gundagai.

3 Projected changes to climate and natural hazards in the Riverina Murray region

The following section details projected changes to climate and the frequency and intensity of natural hazards in the Riverina Murray region out to 2050. Projections for significant fire, and weather-related hazards in the Riverina Murray 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 rise across all seasons by an average of 1.5–3°C, with the greatest increase in winter and spring (2–3°C). Nights are also projected to be warmer by an average 0.5–2°C, with the greatest increase in spring (1–2°C).

Rainfall is projected to shift from winter to summer dominance with overall total falls declining, especially in the winter growing season. This decline is projected to be 20–50%, with the greatest reduction in southern parts of the region. Spring and autumn are projected to be similar to winter with rainfall decreasing by up to 50%, and the largest decreases occurring in the south and west. Evaporation is projected to increase in these seasons, exacerbating the dry conditions. Projected increases in the severity of short, medium and longer term droughts are likely to lead to a decrease of up to 15% in total runoff.

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.

Projections indicate that despite water stress overall becoming more intense, there is a risk that flood-producing rainfall events are likely to become more frequent and more intense with increased summer rainfall in La Niña years in the Riverina Murray region which includes extensive floodplains and wetlands.

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 Riverina Murray 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, and the fire season is likely to be extended.

Changes to fire frequency uncertain

The average return period between fires for the Riverina Murray region is highly variable. It ranges from 20–50 years within mallee shrublands and forest/woodland remnants about the eastern slopes and tableland fringe, but may be longer in the region's western woodlands depending on land use and vegetation. 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. Current prolonged wet periods, including successive years with wet winter–spring seasons, may decline out to 2050; 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 and intensity likely to increase

Peak fire dangers in the Riverina Murray region are currently reached in summer, with changes out to 2050 projected to include a tendency for the season to commence earlier (spring) and to continue later. Fire danger is also likely 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, much of the Riverina Murray region experiences more than 30 very high to extreme fire danger days annually, and more again in the west. These will possibly increase by 10–50%. Potential days for prescribed burning (days when fire danger levels are moderate to high) are currently more than 150 per year in the Western Division, scaling down to more than 110 per year about the South Western Slopes. Such days are projected to decline by up to 10%. 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 fuel availability are regarded as highly speculative at this time, 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 could reduce the predominantly herbaceous/grassy fuels currently found in woodlands. Also, there is a possible tendency for increased shrub and mulga cover in woodlands due to higher carbon dioxide levels, and this would decrease herbaceous fuel and flammability. Projected rises in available moisture could increase litter and grass fuels in some parts of the Riverina Murray 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 Riverina Murray 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 four annually over the Riverina Murray region, and they frequently generate winds that can be in excess of 90 km/h. Severe thunderstorms occur mostly from October through to February, predominantly in the north-east and about the slopes of the region. 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 have a very low frequency over inland areas such as the Riverina Murray region. Future changes for 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 temperature (SST) and upper atmosphere circulation.

Changes to incidence of gales and frontal systems uncertain

The incidence of gales and frontal systems in the Riverina Murray region is currently low to 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 Riverina Murray region experiences on average 2.5 hail-producing thunderstorms per year. Reporting indicates that these storms occur mostly about the north-east. The hail season lasts from October to February. 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 Riverina Murray region currently has an average of 10–20 days per year which experience thunder, with the incidence higher in the east. The overall frequency of lightning strikes is 1–2 per km² per year. They are more prevalent in the east, and 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 areas in 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.

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, with 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. Particularly important areas of research include cut-off lows and north-west cloud bands.

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 Riverina Murray region, heatwaves have been fairly consistent spatially, although slightly more frequent and lasting longer in the east. In the period 1979–2008, the region experienced 29 spring and 34 summer heatwave

events at Wagga Wagga; while further west at Hay, the figures were 26 spring and 33 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: Riverina Murray fire hazard indicators

Indicator	Current conditions	Projected change (to 2050)	Status of research
Frequency range	<p>Highly variable – the fire cycle is highest (e.g. 20–50 years) within mallee shrublands and forest/woodland remnants in eastern slopes/tableland fringe.</p> <p>The fire cycle may be considerably longer in western woodlands subject to grazing, in fragmented grassy woodlands on the western slopes and in chenopod dominated vegetation.</p> <p>Irregular fire in land used for cropping (stubble burning and unplanned ignitions).</p>	<p>The most likely trend is for decreased fire over the bulk of the region due to lower availability of herbaceous fuels.</p> <p>Changes in farming practices (less stubble burning) will further reduce fire in cropping lands.</p>	<p>Detailed analyses of current fire regimes are required for the bulk of this region. Future, quantitative projections (not available at present) are also required.</p> <p>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.</p> <p>Research on ignitions (lightning and human) is required.</p>
Season of peak fire danger	Summer.	A tendency for the season to commence earlier (spring) and continue later 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)	<p>>150 (Western Division).</p> <p>>110 (South Western Slopes).</p>	Projected decline (1–10%).	See above.
Average number of days (per annum) of Very High to 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	<p>Prolonged wet periods including successive years with wet winter–spring seasons.</p> <p>Days of high temperature and wind speed, plus low humidity.</p>	<p>The incidence of these conditions may decline (see above).</p> <p>The incidence of these conditions may increase (see above).</p>	<p>Some detailed analyses of weather conditions associated with large fires are available for parts of this region (e.g. mallee).</p> <p>Future trends – see above.</p>
Influence of runoff on water availability (average seasonal trends)	<p>Highest in winter and lowest in summer–autumn.</p>	<p>A major increase in summer and major decrease in winter–spring (prior to the fire season), is projected.</p>	
Fuel	<p>Predominantly herbaceous/grassy fuels in woodlands.</p> <p>Litter and spinifex are important in mallee.</p> <p>Crops and crop stubble.</p>	<p>Projected decrease in available moisture could reduce the mass and availability of herbaceous grass fuels throughout the region.</p> <p>Possible tendency for increased plant woody cover (e.g. shrubs, mulga) in woodlands due to elevated CO₂ effects on plant growth. This would tend to decrease herbaceous fuel and therefore flammability.</p> <p>Projected increases in available moisture could increase litter and grass fuels in forest/woodland remnants in eastern slopes/tableland fringe.</p> <p>Possible change to summer cropping due to rainfall seasonality changes. More crop stubble present.</p>	<p>Major research effort required to resolve future effects of changes in moisture and elevated CO₂ 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.</p>

Table 3: Riverina Murray 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 Riverina region on average 4 times per year, predominantly in the north-east and slopes.	Research is currently limited to only a couple of studies for NSW: Schuster <i>et al.</i> 2005; Leslie <i>et al.</i> 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.	
Ex-tropical cyclone	Frequency	Low to none at this latitude.	
Gales and frontal systems		Low to 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: Riverina Murray hail hazard indicators

Indicator	Current conditions	Status of research
Frequency	<p>The Riverina region experiences on average 2.5 thunderstorms with hail per year.</p> <p>These are more common in the north-east at Wagga Wagga, with 7 in the period 1990–2007, though this may reflect better reporting.</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. Kuleshov <i>et al.</i> (2002) found no such decline.</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. Only five events in the period 1990–2007 had diameters of at least 5 cm, with the largest 6.3 cm at Mannus on 16 February 2002.</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 October to February.</p>	

Table 5: Riverina Murray lightning hazard indicators

Indicator	Current conditions	Status of research
Frequency	Average of 10–20 thunder days per year in the Riverina area (Kuleshov <i>et al.</i> 2002). Higher in the east.	Currently no research for the Australian region of expected changes to lightning under enhanced greenhouse conditions. Some studies such as Price and Rind (1992) have suggested a 5–6% change in global lightning frequency for every 1°C global temperature change. US studies have also indicated that there may be an increase in high based (dry) thunderstorm activity. The regional scale effects on lightning for NSW are unclear.
Intensity/scale	Average of 1–2 km ² per year (ground flash).	
Distribution	More prevalent in the east.	
Seasonality	Summer dominant but can occur at any time of the year.	

Table 6: Riverina Murray 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 cut-off lows.</p> <p>Expected to increase with the increase in scale of development or flood-producing rainfall 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>May increase with any changes in density or scale 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>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.</p>
<p>East Coast Low</p>	<p>Frequency</p>	<p>Rarely affect inland areas.</p>	

Meteorological source	Indicator	Current conditions	Status of research
Ex-tropical cyclone	Frequency	Low to none.	
Severe thunderstorm	Frequency	Severe thunderstorms produce flash flooding on average once per storm season though the location of impact within the region would vary.	Limited to only a couple of studies for NSW: Schuster <i>et al.</i> 2005; Leslie <i>et al.</i> 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 per storm season, generally minor.	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.	Most research currently available focuses on the southern Murray in Victoria, such as Pook <i>et al.</i> (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 southern areas of the Murray–Darling Basin (MDB) during winter.	
	Seasonality	Can occur year-round, but dominant during autumn and winter.	

Table 7: Riverina Murray 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>Can be derived from a wide range of weather events including thunderstorms, troughs, cut-off lows, and north-west cloud bands.</p> <p>Expected to increase with the increase in scale of development or flood-producing rainfall events.</p>	<p>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.</p>
	Exposure	<p>Significant, widespread but varies with location.</p> <p>Expected to increase with the increase in scale of development or flood-producing rainfall events.</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>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.</p>
East Coast Low	Frequency	Rarely affect inland areas.	
Ex-tropical cyclone	Frequency	Low to none at these latitudes.	

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.	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.	Most research currently available focuses on the southern Murray in Victoria, such as Pook <i>et al.</i> (2006). No knowledge available on expected trends.
	Intensity	Responsible for 80% of days with rainfall greater than 25 mm in southern areas of the MDB during winter.	
	Seasonality	Can occur year-round, but dominant during autumn and winter.	

Table 8: Riverina Murray heatwave hazard indicators

Indicator	Current conditions	Status of research
Frequency	<p>Over the period 1979–2008:</p> <p>Wagga Wagga – 29 in spring, 34 in summer.</p> <p>Hay – 26 in spring, 33 in summer.</p> <p>Deniliquin – 23 in spring, 31 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>At least 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 between 1–3°C are likely. Heatwaves are usually associated with extreme heat days with exceedingly high temperatures (far greater than 1–3°C rise in mean maximum temperatures expected).</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>Fairly consistent spatially, slightly more frequent in east, which tend to be longer.</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>

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