



Environment,
Climate Change
& Water



NSW Climate Impact Profile

The impacts of climate change on the biophysical environment of New South Wales

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Director General's foreword

Climate change is one of the most serious challenges we face. It has the potential to affect all aspects of our lives and the environment we live in. While many impacts may not be felt for decades, we need to start planning for climate change now to ensure we can cope with any future changes. The decisions we make today will have lasting consequences.

The Department of Environment, Climate Change and Water NSW (DECCW), with assistance from the University of New South Wales, has developed the *NSW Climate Impact Profile* to help government, business and the community plan for the future. The report describes some of the likely changes to our climate and the implications of these changes for our natural ecosystems, the lands we manage, and our towns and cities.

New South Wales has a very diverse climate, and future changes in temperature, rainfall and evaporation will affect each part of the state differently. The *NSW Climate Impact Profile* takes account of these regional differences by presenting information on the likely impacts of climate change in each of the State Plan regions. A better understanding of the local and regional impacts of climate change will help communities to develop responses that suit local conditions.

The NSW Government is committed to establishing a sound scientific basis for understanding climate change in NSW and developing adaptation responses. This document is only a first step in understanding some of the changes we may face in the future. As new science emerges, the NSW Government will continue to support research to ensure that NSW has access to the best-available information on future climate change.



Lisa Corbyn
Director General

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Abbreviations

AR4	IPCC Fourth Assessment Report
ASS	acid sulfate soils
AASS	actual acid sulfate soils
BOM	Australian Bureau of Meteorology
CAMBA	China–Australia Migratory Bird Agreement
CO ₂	carbon dioxide
CO ₂ -e	carbon dioxide equivalent
CMAR	CSIRO Marine and Atmospheric Research
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DECC	Department of Environment and Climate Change NSW
DECCW	Department of Environment, Climate Change and Water NSW
DEWHA	Department of the Environment, Water, Heritage and the Arts (Australian Government)
DWE	NSW Department of Water and Energy
ENSO	El Niño–Southern Oscillation
GCM	global climate model
IPCC	Intergovernmental Panel on Climate Change
JAMBA	Japan–Australia Migratory Bird Agreement
PASS	potential acid sulfate soils
ppm	parts per million
SAM	Southern Annular Mode
SLR	sea level rise
SST	sea surface temperature
TAR	IPCC Third Assessment Report
UNSW	University of New South Wales

Executive summary

The natural, social and economic systems of New South Wales will all be affected by climate change. Understanding the potential impacts of climate change on our biophysical environment is a vital first step in planning for future climate change.

The Department of Environment, Climate Change and Water NSW (DECCW), in partnership with the Climate Change Research Centre at the University of New South Wales (UNSW), has developed regional climate projections for NSW based on preliminary analyses of global modelling data. These projections were then used to assess the likely impacts of future climate change on five biophysical parameters – biodiversity, soils, stream flow and run-off, the coastal zone and flooding risk – in each of the NSW State Plan regions.

This report provides the NSW Government, business, industry and the community with a regional ‘snapshot’ of how NSW could be affected by climate change in 2050. The project is the first to attempt an integrated assessment of the biophysical changes predicted for this state as a result of climate change. It outlines some of the risks NSW may face, to help decision makers develop their planning and response strategies.

For each of the NSW State Plan regions and for NSW overall, the report outlines:

- the likely changes in climate (temperature, rainfall and evaporation) by 2050
- physical consequences of these climate changes (rise in sea level and changes in run-off, flooding behaviour and fire regimes), and
- the subsequent impacts of projected climate change and associated changes in physical processes on:
 - lands (soils and soil processes)
 - settlements (storm and flood damage), and
 - ecosystems (biological communities, individual species and ecological processes).

This report is limited to assessing impacts on the biophysical environment and coastal and flooding hazards. It is designed to establish a baseline of information for different sectors to use in determining the risks for their areas of responsibility. Further work is already being undertaken by NSW Government agencies on the implications of these biophysical changes for their areas of responsibility. As climate data and modelling improve, more detailed research will be needed to better understand how NSW may be affected by climate change and how we might respond to these changes.

The key findings of the assessment are outlined below.

Future changes in the climate of NSW

Temperature: NSW is expected to become hotter, with higher maximum and minimum temperatures very likely to be experienced across the state in all seasons. The greatest increases in maximum temperatures are projected to occur in the north and west of the state.

Rainfall: North-eastern NSW is likely to experience a slight increase in rainfall during summer while the south-western regions are likely to experience a significant decrease in winter rainfall. Many parts of the state will experience a shift from winter-dominated to summer-dominated rainfall.

Evaporation: Higher temperatures are likely to result in significantly increased evaporation across much of the state by 2050. The projected increases in evaporation are likely to counteract the expected increases in summer rainfall across NSW, leading to drier soil conditions in the west.

The projected changes to rainfall and evaporation in northern NSW appear to be within recorded levels of variability. However, the drying of the autumn, winter and spring seasons in the south, and particularly in the south-west, is expected to fall outside the natural variability observed in the historical climate record.

Physical responses to climate change

Sea level rise: Sea levels along the NSW coast are rising and this rate of rise is virtually certain to accelerate. This study has adopted a rise above the 1990 mean sea level of 0.4 m by 2050 and 0.9 m by 2100, consistent with the Government's sea level rise policy statement.

Run-off: Modelling projections indicate that there will be a shift in the seasonality of run-off patterns, with significantly more summer run-off (up to about 20% increase) and significantly less winter run-off (up to about 25% decrease). The projections also indicate some minor increases in autumn run-off and moderate to significant decreases in spring.

Annual run-off depends on the relative contribution of run-off in the different seasons. In northern NSW, which is dominated by summer rainfall and runoff, projections indicate a slight increase in mean annual run-off. In the southern regions of NSW, which currently experience winter-dominated rainfall and run-off, the projections indicate moderate to significant decreases in mean annual run-off.

Flooding: In lower portions of coastal floodplains, sea level rise is very likely to exacerbate catchment-driven flooding, resulting in increased flood frequency, height and extent. Potential increases in the intensity of flood-producing rainfall are also likely to affect flood behaviour.

Tidal inundation: Sea level rise will directly increase low, mid and high tide levels. This is very likely to result in larger areas of low-lying land around coastal waterways being exposed to more frequent tidal inundation.

Fire regimes: Higher temperatures and changes in rainfall patterns will more likely than not lead to increased fire frequency, but the return period of fires is considered likely to remain within the current domain of acceptable fire intervals for most vegetation classes. Very high to extreme fire danger days are projected to increase and the conditions conducive to large and intense fires (such as prolonged drought, low humidity, number of days with high temperature and high wind speeds) may increase.

Impacts of climate change

Impacts on land

Sheet, rill and gully erosion are likely to increase: The combination of the potential for more intense thunderstorms, especially in summer and spring, and an overall reduction in ground cover due to reduced net water balance (less rainfall relative to evaporation) is likely to lead to more sheet and rill erosion, as well as increased gully erosion where such erosion is caused by overland flow.

Mass movement of soil on slopes is likely to increase: All currently vulnerable slopes in coastal hinterlands are likely to experience an increased risk of mass movement due to higher summer and spring rainfalls.

Wind erosion is likely to increase: Reduced plant cover and drier soils in the south-western part of the state is likely to make the soils more vulnerable to wind erosion.

Soil salinity changes: Changes in rainfall, evaporation and plant growth throughout the eastern part of the state will very likely change the patterns of deep drainage and mobilisation of salts. Changes in the pattern of salinity occurrence are also likely, with potential consequences for soil salinity and water quality.

Coastal dunes are likely to be at risk: Many coastal dunes and beach-barrier systems are very likely to be under threat of erosion from a combination of sea level rise, changes in wave direction and changes in the intensity of storms associated with extreme low pressure systems. Wind-blown erosion could result from loss of protective vegetation.

Impacts on settlements

Sea level rise and extreme storms are virtually certain to adversely affect vulnerable developments along the coast: Some coastal areas are already subject to the effects of coastal erosion, which will be exacerbated by rising sea levels. It is predicted that sandy beaches are likely to recede by about 5–10 m for each 0.1 m (10 cm) of sea level rise, with a greater recession possible in some locations. Extreme storms are likely to become more frequent and peak ocean water levels during storms are virtually certain to increase, producing more intense and frequent coastal inundation, higher wave run-up levels, higher water levels in coastal lakes open to the ocean and estuaries, and more flooding on coastal rivers. The risks associated with sea level rise need to be assessed locally because they are dependent on shoreline geomorphology and the location and design of development.

Coastal structures are likely to be affected: Design parameters for coastal structures will need to be assessed as greater water depths result in larger waves against structures, as wind velocities increase, and as the height and direction of offshore waves change. Existing structures will need to be assessed to determine the level of risk associated with physical changes in conditions and to maintain adequate levels of protection.

Flooding of low-lying coastal developments is likely to increase: Low-lying developments along the NSW coast that are near current high-tide levels will be susceptible to frequent tidal and stormwater inundation, and stormwater drainage is extremely likely to be less effective during high tides. Urban areas near coastal rivers, lakes and estuaries will be particularly affected by the combined impact of marine and catchment flooding.

Impacts on ecosystems

A range of physical factors is likely to affect biodiversity: The physical changes likely to have the greatest impact on biodiversity include increases in temperature, changes in rainfall patterns and fire regimes and, on the coast, sea level rise and subsequent inundation and erosion.

The structure, composition and function of ecosystems are likely to change: All ecosystems in NSW, even the most hardy and resilient, are expected to change in structure and species composition. The structure of ecosystems is likely to change in response to changes in fire regimes and hydrology. Changes in species distribution and abundances will alter the composition of ecosystems. Changes in productivity are likely to occur, particularly where declines in rainfall and increased temperatures are most extreme. Ecological processes such as nutrient cycling are likely to be disrupted.

Distributions of individual species are likely to change: The distribution of individual species is likely to shift in latitude and altitude. Species abundance is likely to change. Those species with narrow climatic tolerances such as high altitude species are likely to decline, some even to extinction. Conversely, some hardy generalists and pests are likely to persist and spread.

1 Introduction

1.1 Our climate is changing

In November 2007, the Intergovernmental Panel on Climate Change (IPCC) released its Fourth Assessment Report (AR4) (IPCC 2007). Among the key conclusions of the report are the following findings:

- warming of the climate system is unequivocal, demonstrated by increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising global average sea level (IPCC 2007, p. 30)
- most of the observed increase in global average temperatures since the mid-twentieth century is very likely due to the observed increase in anthropogenic greenhouse gas concentrations (IPCC 2007, p. 39), and
- even if greenhouse gas concentrations were to be stabilised, anthropogenic warming and sea level rise would continue for centuries, due to the time scale associated with climate processes (IPCC 2007, p. 46).

Australia's annual mean temperatures have increased by about 0.9°C since 1910, with significant regional variations (CSIRO and BOM 2007). The climate later in the twenty-first century is virtually certain to be warmer than at present (IPCC 2007). CSIRO projections indicate that by 2030, average temperatures in Australia will rise by about 1°C, with average summer temperatures likely to be at least 3°C warmer by 2070 (CSIRO and BOM 2007; Pitman and Perkins 2008). The projections also indicate that extreme events such as heatwaves and droughts are likely to become more frequent and sea levels will continue to rise.

Box 1.1 The difference between predicting climate and predicting the weather

Climate is the average condition of the weather over a period of time. Weather is the set of all the phenomena occurring in the atmosphere at a given time, and is usually described in hourly to weekly time scales. In simple terms, the weather is what we experience if we go outside right now, while the climate is the average of all of these phenomena over a given period, usually over time scales from seasons to millennia. This fundamental difference between weather and climate is often translated into the saying 'climate is what we expect and weather is what we get'. As such, climate is often much easier to predict than the weather and climate is more predictable than weather into the future.

The following example may help to explain this concept. If you are asked on a Monday to predict whether the following Monday will be hotter or cooler, you may be able to make a prediction but with relatively low confidence. However, if you were asked 'Will the maximum temperature on the 1st of June in southern NSW be colder than on the 1st of December?', you would be moderately certain of the answer. As the first date is in winter and the second is in summer, the 1st of December is likely to be hotter than the 1st of June. However, because of the variability in daily weather patterns, you could not be absolutely certain. For example, the hottest maximum recorded at Sydney Observatory Hill for June is 26.9°C, which is considerably higher than the 15.2°C lowest maximum recorded for December.

If, on the other hand, you were asked 'Will the average monthly temperature for June next year be hotter or colder than that for the month of December?' you would be able to answer with certainty that the average monthly temperature in December will be hotter than the average monthly temperature in June because of our understanding of the seasonal climatic cycles and the weather (or meteorological) data we have amassed over time.

1.2 Climate change will affect our environment and communities

The natural, social and economic systems of NSW have all evolved under certain climatic conditions. NSW supports a range of industries such as agriculture, forestry and fishing, which have all developed based on the particular rainfall and temperature patterns of a region. Species and ecosystems have evolved to survive in a particular climate. The design of buildings and critical infrastructure such as roads, stormwater drains and dams are based on certain assumptions about temperature and extreme weather events. Our society and the natural resources on which we depend are all finely attuned to our climate.

Australia is vulnerable to the impacts of climate change. There is evidence of increasing stresses on water supply and agriculture, alterations to natural ecosystems, and of reduced extent of seasonal snow cover (Hennessy 2007). Extreme events such as heatwaves, severe storms and droughts are likely to become more frequent and sea levels will continue to rise (CSIRO and BOM 2007).

Climate change is likely to have significant impacts on NSW. It is the most populous state in Australia, containing 34% of the national population. The NSW population is highly concentrated in coastal areas, which increases our susceptibility to sea level rise. NSW also has a highly variable climate, with many areas prone to drought and flood. It has the largest and highest alpine areas in Australia, extensive rangelands, and some of Australia's largest and most productive agricultural areas, including the most productive part of the Murray–Darling Basin. The Murray–Darling Basin has already been impacted by prolonged severe drought, restricted water flows, salinity, soil erosion and soil acidification, and is particularly vulnerable to climate change.

Changes to the NSW climate will result in alteration to our natural environment and to the communities in which we live. Some changes may be beneficial, but many will be detrimental. For example, increases in winter temperatures may make winters more comfortable but increasing summer maximums may lead to increased heat stress, particularly for the elderly and vulnerable communities. If tropical cyclones were to migrate southwards, they would have dramatic effects on the agriculture, natural environment, housing and road design of those newly affected areas. Similarly, a reduction in snow cover would affect not only the ecology of the alpine zone, but also the seasonality and quantity of flow of water into the Murray River, associated freshwater biodiversity, and regional tourism from the skiing industry.

Changes to biophysical aspects of the environment may also have significant direct impacts on Aboriginal culture and heritage. In the Aboriginal world view, people and Country (including traditional lands and seas) are an integral whole and the entire landscape has spiritual significance. The wellbeing and resilience of Aboriginal communities is linked strongly to culture and heritage and hence can be influenced by the health of the environment. For example, particular communities have connections to and responsibilities for particular species; impacts on these species as a result of climate change will affect those communities. Aboriginal society within NSW has experienced both short-term and long-term variability in climate over a long period of time and has shown a clear capacity to adapt to those changes. The unique experience of Aboriginal communities in NSW should be recognised and is a valuable asset for the state.

As some climate change is now inevitable, NSW will need to develop strategies to adapt to the impacts of future climate change. Adaptation involves adjusting policies and operations to help prepare our ecosystems, infrastructure, communities and productive sectors to be able to cope with likely climate change impacts.

1.3 Regional information is needed to guide planning and decision making

Understanding the potential impacts of climate change is the first step in improving our capacity to deal with it.

The Department of Environment, Climate Change and Water NSW (DECCW) has compiled a 'first pass' integrated assessment of some of the likely impacts of climate change in NSW. For each of the NSW State Plan regions and for NSW overall, the assessment considers:

- the likely changes in climate (temperature, rainfall and evaporation) by 2050
- associated physical consequences of these climate changes (sea level rise and changes in run-off, flooding behaviour and fire regimes), and
- the subsequent impacts of projected climate change and associated changes in physical processes on:
 - lands (soils and soil processes)
 - settlements (storm and flood damage), and
 - ecosystems (biological communities, individual species and ecological processes).

The report presents estimates of the impact of climate change in NSW to the year 2050. Projected changes to sea level rise and flooding regimes (and associated impacts) are based on a time horizon of 2050–2100 due to the long time scale associated with these processes.

This report provides government, business and the community with a regional 'snapshot' of how NSW could be affected by climate change. It aims to give a picture of some of the risks the state may face, to help decision makers develop their planning and response strategies.

The report is limited to assessing impacts on the biophysical environment and coastal and flooding hazards. It is designed to establish a baseline of information for different sectors to use in determining the risks for their areas of responsibility. Further work is already being undertaken by NSW Government agencies on the implications of these biophysical changes for their areas of responsibility. For example, the NSW Department of Primary Industries is investigating the coping ranges of agricultural systems, and the State Emergency Management Committee is assessing the likely impacts of fire hazards on infrastructure.

Some matters, which are referred to in this report because they are important climate change considerations, require further assessment before more confident statements can be made about them. They include: fire behaviour and physical assets; hydrology and human settlements; Aboriginal and non-Aboriginal cultural heritage; invertebrate ecology; intertidal ecology; human disease and pathogens; natural resource-based industries such as agriculture, grazing, forestry and fisheries; groundwater resources and groundwater-dependent ecosystems; and marine environments.

This report offers a first step towards understanding the regional implications of climate change for NSW. As climate data and modelling improve, more research will be needed to better understand how NSW may be affected by future climate change and how we might respond to these changes.

1.4 How to use this report

The report is organised into the following major components:

Section 2: Overview of the assessment approach

This section contains details of how future climatic changes and sea level rise have been estimated and how the biophysical impacts of these changes have been assessed.

Section 3: Description of the likely state-wide climate changes in NSW

This section includes a summary of past climatic changes, a description of the current climate of Australia and NSW, and details of the climatic changes projected to occur by 2050.

Section 4: Summary of the biophysical impacts of climate change in NSW

This section summarises the most significant anticipated impacts of climate change on the biophysical environment across NSW.

Section 5: Description of the regional impact of climate change

This section includes more detailed information on the likely regional impacts of climate change, with separate regional impact statements for each (Hunter, Illawarra, North Coast, New England/North West, Riverina Murray, Western, South East, and Sydney/Central Coast).

Note: This report has been structured to allow each regional section in Section 5 to be read as a 'stand-alone' document.

2 Assessment approach

This section describes the approach used to assess the likely future changes in the climate of NSW and future sea level rise, and their implications for the biophysical systems of the state.

DECCW, in partnership with the Climate Change Research Centre at the University of NSW (UNSW), has developed refined regional climate projections for NSW based on the same models used for the IPCC's AR4 and as used by CSIRO and the Australian Bureau of Meteorology (CSIRO and BOM 2007). These projections were used in our assessment of the likely impacts of future climate change on five biophysical parameters – biodiversity, soils, stream flow and run-off, the coastal zone and flooding risk – in each of the NSW State Plan regions. When considered together, these five parameters provide an integrated projection of the biophysical changes expected in NSW by 2050 as a result of climate change.

2.1 Developing regional climate projections for NSW

The need for better information on future climate changes

There is much uncertainty in making global climate projections for any given location. Factors contributing to this include:

- remaining uncertainties about global biophysical and climatic processes
- variation in the ability of the range of global climate models to capture the complexities of the climate in different parts of the world, and
- difficulties in predicting the level of future emissions growth and global atmospheric concentrations of greenhouse gases.

To address uncertainty in relation to future emissions growth, the IPCC developed a range of potential greenhouse gas emissions scenarios for their Special Report on Emissions Scenarios (see Box 2.1, overleaf) (Nakicenovic *et al.* 2000). The scenarios were intended to portray a plausible set of future economic and social conditions (or story lines) that described alternative broad development patterns.

Each of the IPCC's emissions scenarios would result in a different concentration of greenhouse gases in the atmosphere, which would in turn have different effects on the climate system. For example, if we reach an atmospheric greenhouse gas concentration of 650 ppm carbon dioxide-equivalent (CO₂-e) in 2100, this is projected to lead to a global average rise in temperature of between 1.1 and 2.9°C. A concentration of 1350 ppm CO₂-e could lead to a rise of between 2.4°C and 6.4°C (CSIRO and BOM 2007). The climate change projections for Australia reflect this high variation; for instance, temperatures in south-eastern Australia are projected to rise by 1.1–6.4°C by 2100, with a reduction in average winter precipitation of 9–18 mm and an increase of 18–27 mm for summer (IPCC 2007).

Box 2.1 IPCC emissions scenarios

There are four base scenarios: A1, A2, B1 and B2. The A scenarios assume rapid economic growth and low uptake of carbon alternative fuels, while the B scenarios incorporate environmental protection and rapid uptake of alternative technologies. The A scenarios lead to higher greenhouse gas emissions and subsequent temperature change, while the B scenarios result in lower emissions and temperature change. The A1 and B1 scenarios assume more globalisation; the A2 and B2 scenarios assume more disparate regionalisation of economic development.

A1: Rapid convergent growth

The A1 scenarios all describe a future world of rapid economic growth and a global population that peaks in mid-century and declines thereafter, and the rapid introduction of new and more efficient technologies. Major underlying themes are convergence among regions, capacity building, and increased cultural and social interactions, with a substantial reduction in regional differences in per capita income.

The difference between the A1FI, A1B, and A1T scenarios is mainly in the source of energy used to drive this expanding economy:

- **A1FI: Fossil-fuel Intensive** – coal, oil and gas continue to dominate the energy supply for the foreseeable future
- **A1B: Balance** between fossil fuels and other energy sources
- **A1T: emphasis** on new **T**echnology using renewable energy rather than fossil fuel.

A2: Geographically uneven rapid growth

The A2 scenario describes a very heterogeneous world. The underlying theme is self-reliance and preservation of local identities. Fertility patterns across regions converge very slowly, resulting in a continuously increasing global population. Economic development is primarily regionally oriented and per capita economic growth and technological changes are more fragmented and slower than in other scenarios.

B1: Convergence with global environmental emphasis

The B1 scenario describes a convergent world with the same global population that peaks in mid-century and declines thereafter as in the A1 story line, but with rapid changes in economic structures toward a service and information economy, with reductions in material intensity, and the introduction of clean and resource-efficient technologies. The emphasis is on global solutions to economic, social and environmental sustainability, including improved equity, but without additional climate initiatives.

B2: Local sustainability

The B2 scenario describes a world in which the emphasis is on local solutions to economic, social and environmental sustainability. It is a world with a continuously increasing global population at a rate lower than A2, intermediate levels of economic development, and less rapid and more diverse technological change than in the B1 and A1 story lines. While the scenario is also oriented toward environmental protection and social equity, it focuses on local and regional levels.

Developing refined regional climate projections

It is difficult to determine the impacts and risks of impact on biophysical resources within a specific region from widely varying projections of global climate changes. Reducing the amount of variation provides greater certainty in relation to projections of future climate change.

In the absence of regional climate models, the degree of variation can be reduced by:

1. limiting the range of greenhouse gas emissions scenarios, or
2. evaluating which models perform best for our part of the world and using only the projections from that subset.

UNSW has used both of these techniques to develop refined regional climate projections for DECCW. Some of the variation has been removed by analysing the output of models for only one emissions scenario (the A2 scenario) and by using the four global climate models that work best for south-eastern Australia (see Box 2.2, overleaf).

The resulting data shows the expected changes to temperature, rainfall and evaporation between now and the year 2050. These projected climate changes are detailed in Section 3.

How does this data differ from other climate change projections?

The climate projections detailed in this report use the same modelling outputs as those used by the IPCC for its most recent assessment report (IPCC 2007). No new climate modelling has been undertaken for this project; however, the climate projections used in this project have been developed specifically to inform local and regional decision makers of expected climate change in NSW. They have therefore been analysed differently to other climate projections (such as the data released by the IPCC and CSIRO). The data in this report differs from previous data in a number of ways:

The climate projections are based on a single emissions scenario (the A2 scenario)

The IPCC has developed a range of emissions scenarios to project future climate change. However, it is difficult to make plans with such large variation in the projections; for instance, temperature in south-eastern Australia is projected to rise by 1.1–6.4°C by 2100 (IPCC 2007).

The rate of global emissions growth since 2000 has been greater than for the most fossil-fuel intensive of the IPCC's emissions scenarios (Raupach *et al.* 2007). The Garnaut Climate Change Review concluded that all of the IPCC's emissions scenarios may underestimate future growth in emissions in the early twenty-first century (Garnaut 2008). Analysis of global mean surface temperatures also shows that the rate of warming is in the upper range of the IPCC's climate projections (Rahmstorf *et al.* 2007).

The climate projections developed for this project use a single emissions scenario, the A2 scenario, which is towards the upper range of available scenarios and was based on current global emissions growth trends and the latest climate observations. Other high-range scenarios were used for projections of run-off and stream flow (A1B) and sea level rise (A1FI), as these projections had already been undertaken for other studies. This is explained in more detail in Sections 2.2 and 2.3.3.

Box 2.2 Evaluating the performance of global climate models (GCMs)

Climate models are based on well-established physical principles and, if we evaluate them on a global or large regional scale, they are able to reproduce the significant features of the observed climate very well (Randall *et al.* 2007). Therefore, there is now considerable confidence in the climate modelling profession that climate models provide credible quantitative estimates of future climate change, particularly at continental scales and above. In general, confidence in these estimates is higher for some variables (such as temperature) than it is for others (such as precipitation).

Nevertheless, not all climate models perform equally well for all features of the global climate system, nor do they perform equally well for all geographical regions. The differing ability of the global climate models to model both the temporal and spatial variability of the climate system is a major component of the range in projected values for future climate. One method we can use to reduce the amount of variation of climate projections is to evaluate all the models on how well they match with existing climate, and then make our projections based on the models that perform well in that evaluation. The projections used for this study are based on work conducted by the University of NSW (UNSW) to evaluate all of the available models in terms of how well they were able to predict the late twentieth century rainfall and temperature for south-eastern Australia (Perkins *et al.* 2007; Pitman and Perkins 2009).

Regional climate projections using climate models commonly use an 'all-model' ensemble based on data sets such as those detailed in the IPCC Fourth Assessment Report (AR4). Some regional assessments have omitted models based on specific criteria. The team at UNSW used an evaluation criterion based on the capacity of climate models to simulate the observed probability density function calculated using daily data, model-by-model and region-by-region, for each of the AR4 models over Australia. They found that a lot of the variation in projections was due to the influence of the poorly performing models. That is, the better performing models (those that were better able to predict the existing climate) tended to have more commonality or a lower range of variability in their predictions of future climate. Professor Pitman's team found that of the 16 models that had daily temperature and rainfall output, four performed better than the others for south-eastern Australia.

In comparison to projections that consider output of all global climate models, the refined projections show:

- greater increases in mean maximum and mean minimum temperatures
- lower increases in extreme annual temperatures (the maximum and minimum temperatures experienced on average once per year)
- similar projections of mean precipitation (despite the better models simulating a slightly larger increase in heavy rainfall events), and
- large decreases in the number of rain days (fewer drizzle days projected than the other models).

This study demonstrated that omitting weaker models based on a quantitative skill score derived using climate observations provides a method for reducing uncertainty in climate model projections. The weaker models appear to bias the amount of mean warming towards lower increases and to bias annual maximum temperatures towards excessive warming. The weaker models also bias precipitation so that the rainfall in the heaviest events is underestimated.

There is a smaller range in projections

Projections of future climate are based on the combined results of multiple global climate models, and this can result in a wide range of projected values. While using the full ensemble of models helps to ensure that all possible outcomes have been identified, a large range of values makes it difficult for decision makers to identify the likely changes and make planning decisions accordingly.

Not all global climate models perform equally well for all geographic regions. To help ensure the best possible estimate of climate change in NSW for the A2 emissions scenario, the regionalised projections for this report were derived by combining the outputs of the four models that are best able to simulate the past climate for our geographical region (see Box 2.2 for details).

The data is presented at a finer scale

Most global climate models simulate changes for the entire world at a fairly coarse scale. The projections developed by the IPCC have a resolution of about 300 km (that is, a value for the climate variable is calculated for each 300 km x 300 km grid square).

Following the release of the IPCC global reports, the CSIRO and Bureau of Meteorology published *Climate Change in Australia*, which was consistent with the global projections of the IPCC but provided greater detail on possible future changes to Australia's climate (CSIRO and BOM 2007). However, the spatial resolution of this data is also generally too low to be used to inform local and regional decision making. The data is presented on a grid measuring 100 km x 100 km – this means that a single grid square can include the area from Sydney to Newcastle. The complexity and variety of climates and ecosystems in NSW cannot be accurately examined at this scale.

The regionalised data for this project was derived by estimating the value of projections at a finer scale of 50 km x 50 km to identify local variations in climate change impacts and ensure the information is relevant to local and regional decision makers. However, great care must be exercised in using data below a regional scale since downscaling was not undertaken.

Limitations of current projections

The projections are subject to some important limitations.

Higher uncertainty around projections in coastal compared to inland areas

The coarse resolution of the models' input data (~300 km squared grid) means that both the NSW coastal zone and the mountainous areas and elevated plateaus of the Great Dividing Range are poorly represented in global climate models. The high altitude and complex terrain of the Great Dividing Range is reduced to a smoothed and significantly lower plateau within the models. This 'topographical smoothing' reduces the reliability of the models in projecting small-scale spatial variability and local-scale climatic effects caused by the terrain of eastern NSW, such as enhanced rainfall on the windward side of ranges, winter cold air drainage in valleys, or snowfall on the higher peaks. Coarse resolution also means the modelled coastline of NSW is highly distorted and appears as straight latitude-longitude lines around the large grid boxes. These are significant limitations when assessing the projections for the climate of the relatively narrow coastal and eastern ranges zones of NSW. The resolution also means some specific phenomena, such as east coast lows, may not be reproduced well.

Projections do not account for natural variability

Another limitation is that the models used to generate the climate projections were only assessed on their capacity to simulate the observed frequency, range and inter-annual variability of daily maximum and minimum temperatures and rainfall in the twentieth century. The models are yet to be assessed on their ability to reproduce observed multi-decadal climate variability in NSW. Variability on these longer time scales is an inherent component of the climate of eastern Australia, especially in NSW.

2.2 Developing sea level rise projections for NSW

The link between sea level rise and global warming

Increasing global temperature has a direct impact on sea level. As atmospheric temperature increases, water temperature also increases and water expands. Any long-term increase in global atmospheric temperature will therefore lead to a corresponding increase in sea levels. In addition, increases can also be expected from melting glaciers and ice caps (but not sea ice), although these may be slightly offset by changes to land-based water storage and snowfall over Antarctica.

IPCC's sea level rise projections for 2050 and 2100

Projections of future sea level rise have been published by the IPCC (2007). These projections suggest an increase of between 0.18 and 0.59 m by 2090–2099, relative to 1980–1999, based on the range of future emissions scenarios (Box 2.1).

When preparing AR4, the IPCC only projected sea level rise for the period 2090–2099 (IPCC 2007). To obtain a projection for 2050, the IPCC Third Assessment Report (TAR) has been used (IPCC 2001). The IPCC projections from this report suggest an increase of between 0.05 and 0.3 m by 2050, relative to 1990, based on the range of future emissions scenarios.

Table 2.1 Projected temperature change and sea level rise (due to thermal expansion only) for the six IPCC emissions scenarios

IPCC emissions scenario	Temperature rise IPCC AR4	Sea level rise 2100 IPCC AR4	Sea level rise 2050 IPCC TAR
B1	1.8°C	0.18–0.38 m	0.05–0.26 m
A1T	2.4°C	0.20–0.45 m	0.07–0.29 m
B2	2.4°C	0.20–0.43 m	0.06–0.28 m
A1B	2.8°C	0.21–0.48 m	0.06–0.28 m
A2	3.4°C	0.23–0.51 m	0.06–0.27 m
A1FI	4.0°C	0.26–0.59 m	0.06–0.3 m

(See Box 2.1 for an explanation of the IPCC emissions scenarios.)

In making the most recent projections, the IPCC did not include the full effects of dynamic ice-melt processes. These processes allow glaciers to flow faster and include increases in the amount of melt water finding its way to the base of glaciers and the break-up of grounded ice shelves that act as anchors. The 2007 IPCC report advises that if ice discharge from these processes were to increase in proportion to global average surface temperature change, it would add 0.1–0.2 m to the upper limit of sea level rise by 2100. The IPCC also acknowledged that ‘larger values could not be excluded’.

Observations of global sea level rise

An analysis of tide gauge records from around the world has found that during the twentieth century, global sea level rose by just under 0.2 m at a rate of 1.7 ± 0.3 mm per year, with the rate of sea level rise (SLR) accelerating over the century (Church and White 2006). This information is summarised in Figure 2.1, which includes tide gauge data between 1870 and 2001 and satellite altimeter data from 1993 to 2006. Recent data (1993–2007) shows the current global average annual sea level rise to be 3.4 mm per year (Beckley *et al.* 2007).

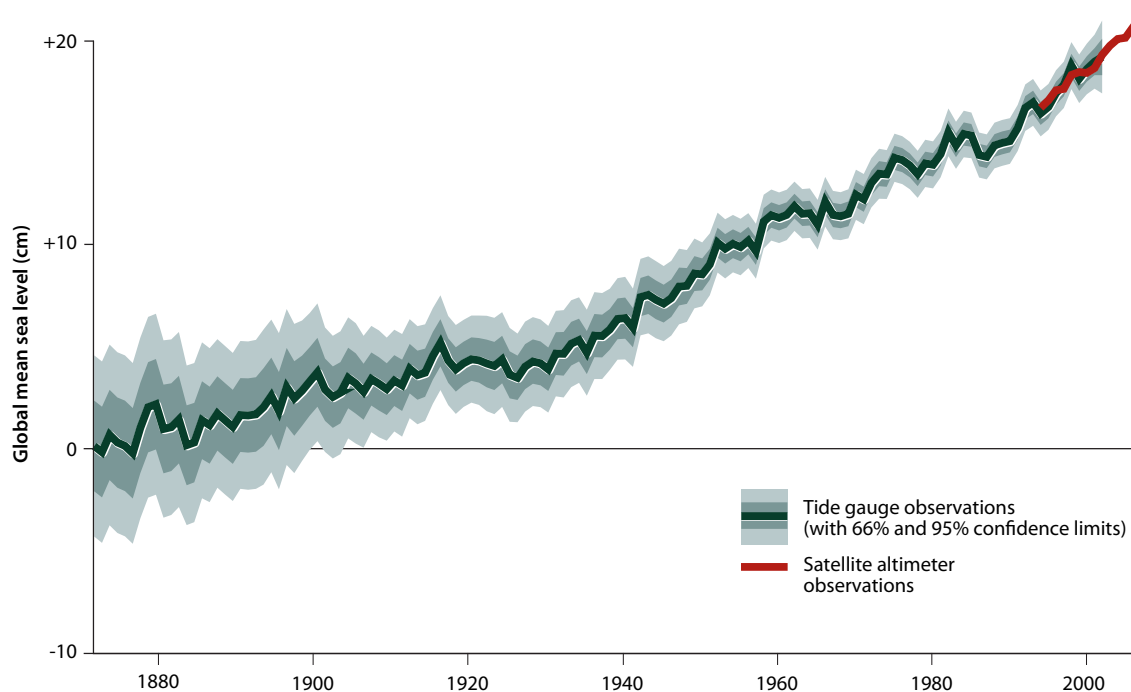


Figure 2.1 Annual averages of the global mean sea level (cm) (UNEP/GRID-Arendal 2007a)
Cartographer/Designer: Hugo Ahlenius, UNEP/GRID-Arendal

A comparison of this recent data with projections from the IPCC reports, as depicted in Figure 2.2 (overleaf), shows that the observed sea levels from tide gauges and satellites are tracking at or above the upper bound of the IPCC projections since projections started in 1990. This has raised concerns among the scientific community that the sea level projections made by the IPCC may have been underestimated (Rahmstorf *et al.* 2007). An upper value of sea level rise for the high emission (A1FI) scenario (0.59 m), and the additional 0.2 m for dynamic ice-melt processes, are the values used in this report.

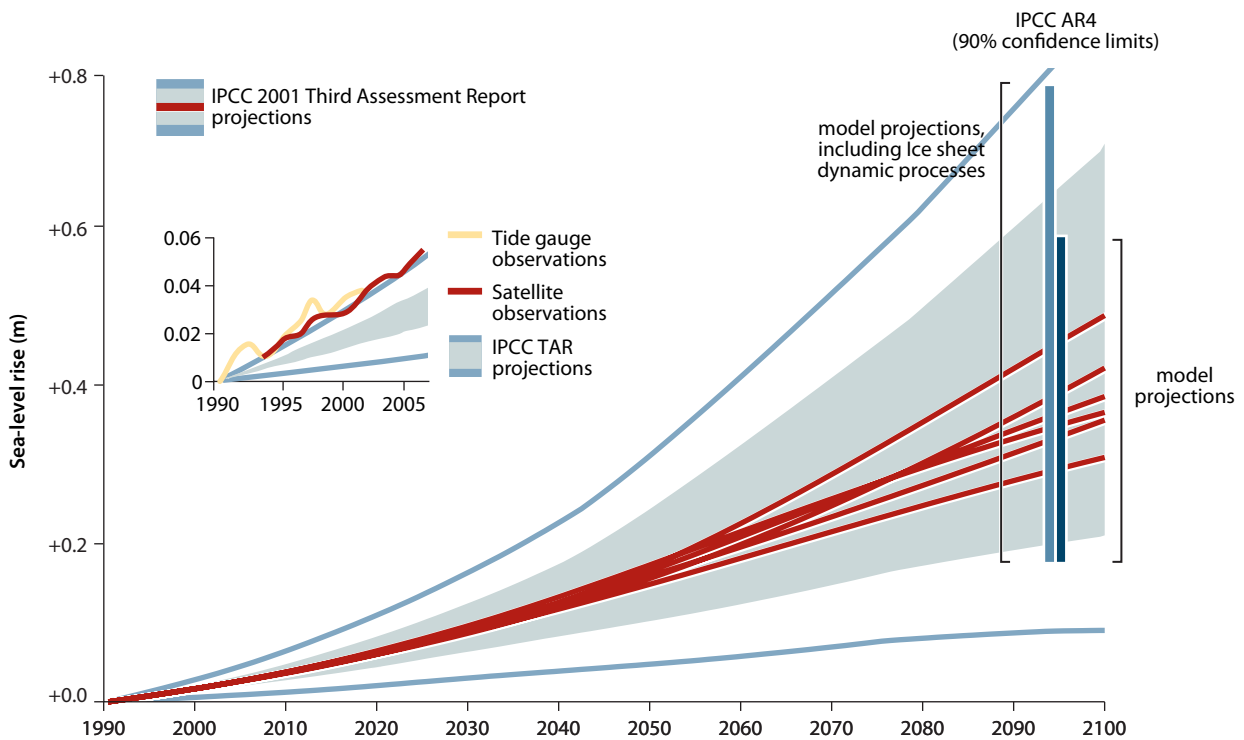


Figure 2.2 Projected sea level rise for the twenty-first century (UNEP/GRID-Arendal 2007b)
Cartographer/Designer: Hugo Ahlenius, UNEP/GRID-Arendal

Localised variations in sea level

Increases in sea level will not occur uniformly across the globe; some regions will experience higher levels of sea level rise and others lower. Such differences can be the result of variations in broadscale atmospheric and oceanographic circulation patterns. A recent study by CSIRO and DECC (McInnes *et al.* 2007) predicts a NSW regional variation above global levels of up to 0.08 m by 2030 and 0.12 m by 2070 because ocean waters off the NSW coast are projected to warm above the global average due to changes in the East Australian Current. This assessment extrapolates the 2070 value of 0.12–0.14 m for inclusion in the 2100 sea level rise value, while a linear interpolation (average of the values for 2030 and 2070) was used to establish a value of 0.1 m for inclusion in the 2050 sea level rise value.

Summary of contributions to sea level rise

Recent research indicates that the climate system, in particular sea level, may be responding more quickly to climate change than the current generation of models predict (Rahmstorf *et al.* 2007). In particular, there is evidence to suggest that the IPCC's 2007 report has underestimated the future rate of sea level rise. The current projections do not allow for the potential, but poorly quantified, additional contribution from a dynamic response of the Greenland and Antarctic ice sheets to global warming. The IPCC's 2007 report states 'larger values cannot be excluded, but understanding of these effects is too limited to assess their likelihood or provide a best estimate or an upper bound for sea-level rise.'

Considering the projections from the IPCC and CSIRO, and the uncertainty in the science, the values considered in this assessment include a projected sea level rise of 0.4 m by 2050 and 0.9 m by 2100, with both levels relative to 1990 sea levels. This is consistent with the approach taken by the NSW Government in its sea level rise policy statement. The components contributing to these values for sea level rise are summarised in Table 2.2.

Table 2.2 Summary of components contributing to future projections of sea level rise in NSW

Component	2050	2100
Sea level rise due to thermal expansion	0.3 m	0.59 m
Sea level rise due to accelerated ice melt	(included in above figure)	0.2 m
Regional sea level rise variation	0.1 m	0.14 m
Rounding	–	–0.03 m
Total	0.4 m	0.9 m

2.3 Assessing the biophysical impacts of climate change in NSW

The regional climate data and sea level rise projections (derived using the methods described in Sections 2.1 and 2.2) were used to undertake a preliminary scan of the biophysical exposure of NSW to climate change.

Changes in the climate are likely to affect our society and natural ecosystems in complex and far-reaching ways. As a first step, this report focuses on the impact of projected climate change on a set of five key biophysical parameters that are fundamental to a range of processes and activities:

- biodiversity
- soils and land degradation
- stream flow and run-off
- the coastal zone, and
- flooding risk.

For this report we analysed the impacts of the projected climate change by 2050 on each of these parameters in each of the NSW State Plan regions (Figure 2.3, overleaf). For the coastal zone, we also included an assessment of the impact of sea level rise for both 2050 and 2100. Some of the direct impacts of increasing greenhouse gas concentrations (such as changes in plant metabolism caused by increased carbon dioxide) have also been considered. Results of other studies were included where relevant (such as the impacts of climate change on Sydney’s air quality).

By scoping the extent of expected change across the different regions of NSW, this report provides a regional snapshot of the state’s vulnerability as the climate changes.

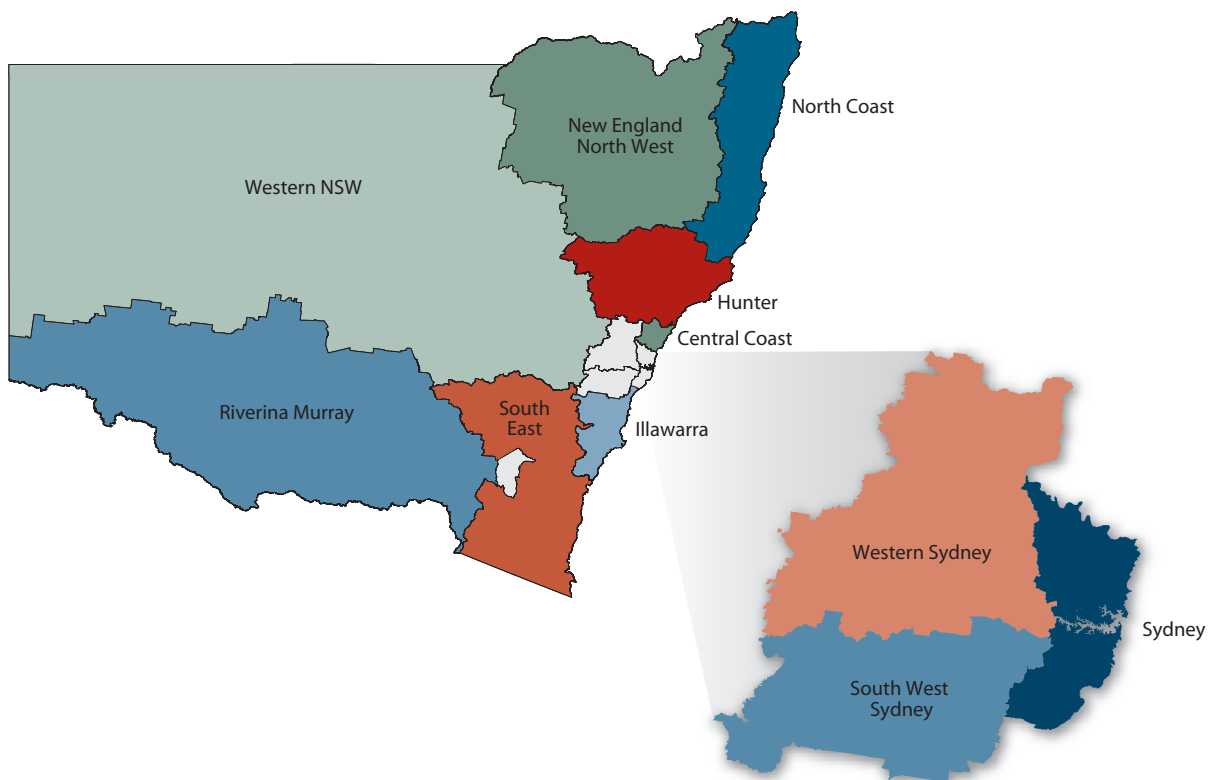


Figure 2.3 NSW State Plan regions (NSW Government 2006)

DECCW set up a series of technical working groups for each of the key biophysical parameters. The methods used by each of these technical working groups are presented below, and the major results of their analyses are summarised in Section 4 of this report. Detailed results for each region are contained in the regional summaries in Section 5.

Biodiversity

The biodiversity assessment was undertaken by panels of ecologists. Seven assessment panels were convened for the state, based on geographic areas (Sydney/Illawarra, South Coast, Hunter, North Coast/Northern Tablelands, Border Rivers, Southern Tablelands and Alps, north-western NSW and south-western NSW).

The assessment panels were provided with a summary of the regional climate projections and asked to consider the impacts on ecological communities (including all biological elements that constitute them) by 2050. The vegetation formations of NSW identified by Keith (2004) were used to guide the panel discussion on ecological communities in each area. These formations represent broad categories of climate, soils and habitat components of the NSW environment at a state-wide scale and coverage. Some individual species were discussed as case studies, but it is important to note that the panels undertook an ecosystem-scale assessment of impacts, not a systematic assessment of impacts on individual species.

The panel discussions and comments were collated into an annotated assessment (including specific regional examples) of the types and estimated degree of impacts to ecological communities, processes and functions as a result of the given climate scenario for each ecological community in each region.

Additional expert opinion was sought independently of the panel process to characterise some of the likely changes to freshwater and estuarine ecosystems. The project did not assess the likely changes to the marine environment.

Soils and land degradation

The assessment identified the likely degradation hazards to the state's land resources resulting from the predicted changes in rainfall, evaporation and temperature. The rainfall characteristics considered were seasonal rainfall amounts and the peak daily rainfall. The hazards included in the assessment were expected levels of biomass and ground cover, sheet and rill erosion, gully erosion, soil acidification, salinisation, mass movement, acid sulfate soil risk, soil carbon loss and soil structure decline. The assessment of the expected changes in degradation hazard was based on the method and guidelines in the DECCW land and soil capability assessment scheme (DNR 2005). The soil degradation hazards are described and explained in Charman and Murphy (2007).

The impact of the expected changes in soil degradation on other issues such as water quality and biodiversity were also briefly considered.

To test some of the predicted impacts on soil degradation, several case studies were undertaken using plant growth models and soil erosion models. The predicted climate data was used for these case studies. This small number of case studies was used to test the more general predictions in more detail. These predictions were reviewed by regionally based soil scientists and land management experts.

Stream flow and run-off

The hydrologic impacts of climate change were arrived at by analysing time series of run-off estimated from changes in climate, based on results of Vaze *et al.* (2008).

The baseline historical data set is a 112-year daily time series of rainfall derived from the 5 km x 5 km SILO database (BOM 2008d). This dataset was combined with an estimate of evaporation and used to calibrate rainfall run-off models of over 100 gauged subcatchments, which were then extended over the remainder of the state to produce a 112-year daily time series of run-off. The net result is 112 years of daily run-off at 5 km x 5 km resolution for all of NSW.

Vaze *et al.* (2008) derived these results for 15 global climate models that had daily data sets available. As this work preceded impact analysis work for the other themes in this report, the datasets were produced for the A1B scenario for 2030, instead of the A2 scenario for 2050. This state-wide dataset is the most informative and comprehensive available at the time of the study. Because the differences between these scenarios are less than the differences between the A1B scenario and historical climate, results from Vaze *et al.* (2008) were considered to be informative enough to estimate the direction and magnitude of hydrological changes.

The run-off results for the four global climate models selected for this study were then aggregated to a subregional basis, and compared to the historical run-off to estimate change in seasonal averages, seasonal high and low flow distributions, and drought severity.

The rainfall projections used to assess hydrological impacts were derived in a different way to the rainfall projections used for the rest of the report. The hydrological projections are sourced from an earlier report published by DWE (Chiew *et al.* 2008), which utilised the A1B scenario to 2030. The results from this earlier study were scaled to be comparable to the projections of the A2 scenario to 2050 as used in the remainder of this report (see Appendix A for further details). As a result, the rainfall projections presented in each regional section may not fully correspond to reported changes in seasonal run-off.

Coastal zone

The most significant biophysical impacts on the open coast are oceanic inundation and beach recession. The method used for defining assets at threat from sea level rise is based on establishing the envelope of land likely to be affected by coastal processes or hazards over the respective planning horizons (2050 and 2100). This has been undertaken using a combination of approaches:

- 1 Where existing hazard definition studies delineate coastal impact lines for 2050 and 2100, these have been considered and applied. The majority of existing studies have used more modest allowances for sea level rise than those considered for this assessment. Where existing studies have been used, the climate change estimate for sea level rise-induced recession has been increased proportionally to accord with the sea level rise scenario adopted for this assessment process.
- 2 Where there is no published hazard definition information, generic hazard allowances have been used to estimate the landward movement in the position of the coastline over 2050 and 2100 planning horizons. The allowances include 20 m for immediate storm bite, 0.3 m/year for underlying long-term recession and a component of sea level rise-induced recession using the Bruun Rule (20 and 45 m), multiplying the sea level rise by the offshore slope (assumed to be 1:50). When calculated, the total landward movement of the shoreline can be estimated at 50 and 90 m, respectively, for 2050 and 2100. However, movement of the shoreline outside this range cannot be ruled out due to local variability.
- 3 Both of the above approaches have been used where relevant to define the projected landward extent of the shoreline, using aerial photographic analysis and cadastral information to determine assets intersected by these hypothetical reference lines.
- 4 Where seawalls are currently protecting assets – such as at Manly, Bondi, Terrigal, Stockton, Maroubra and Warilla – it has been assumed that owners of seawalls will upgrade and maintain assets to an appropriate engineering standard over time, and therefore the assets behind the seawalls have not been included in the estimate of threatened assets for each region.

Flooding risk

The impacts of climate change on flooding relates to both sea level rise and changes in extreme rainfall. The IPCC provides a range of advice for sea level rise, but provides only indications of the potential impacts on flood-producing rainfall events.

Significant research into flood-producing rainfall events continues, but changes to extreme rainfall are expected to be significantly different from changes to average or seasonal rainfall, which are outlined more broadly in this report. The impacts of these changes are likely to vary with location and with the duration and drivers for the storm events that result in flooding. In addition, catchment conditions (i.e. how dry or wet the soils, and how full the major storages and groundwater aquifers) are likely to change and can affect flood behaviour. The impacts of changes to flood-producing rainfall events depend on the specifics of the location and would need to be examined locally.

Therefore, given the available timeframe, the following method has been used to define the flood impacts across regional areas:

- An indication of the overall numbers of properties affected by flooding in the different regions was based on figures provided by local councils to the NSW Department of Local Government for the purposes of the local government Grants Commission.

- The impacts of changes to sea level were assessed through case studies within the various regions to highlight the potential changes that could result from sea level rise in particular circumstances.
- The potential for areas to be affected by changes in flood-producing rainfall events was examined by looking at the sensitivity of areas to changes in these events. The depth of these assessments depended on the information available and the likely trends in the available climate modelling.

2.4 Assessment limitations

This report aims to provide regional communities and decision makers with an indication of the nature and likelihood of climate change impacts, based on a high emissions scenario. Based on this emissions scenario, the report presents the likely climate changes in a way that can be used to inform and guide planning and policy formulation and promote a consistent approach to climate change adaptation. The report does not, and can not, present definitive statements about future climate change. Significant changes to emissions growth in the future, for example, would lead to different impacts on the NSW climate and biophysical environment.

The complexity of our climate system may result in changes occurring more rapidly and abruptly than indicated in this report. Climate ‘tipping points’ can occur when gradual changes to the climate system produce feedbacks that affect the system in a non-linear manner, resulting in abrupt climate shifts. One example of this type of feedback is the loss of ice and snow cover from the margins of Greenland. Once the reflective ice and snow are removed, the ocean and land absorb radiation and heat at a faster rate, which leads to further melting of snow and ice. A sudden collapse of the Greenland ice sheet may, in turn, abruptly increase sea levels, which otherwise can be predicted to increase at a steady rate. The complexity and interrelationships of ocean, land, biosphere and atmospheric processes around the globe are likely to produce unexpected synergistic impacts, some of which are not well understood or are unable to be adequately captured in modelling projections (see Section 2.1). These uncertainties are a challenge for the policy development process; adaptation policies will need to be flexible and responsive to the changing science if they are to remain relevant.

It is also important to note that different levels of assessment were undertaken for each of the technical areas, based on existing technical capacity. For example, expert panels were used to assess impacts to biodiversity (a qualitative approach), while computer modelling was used to estimate changes in run-off and stream flow (a quantitative approach). The level of information presented in Sections 4 and 5 reflects the varying approaches for each of the technical areas.

Specific language has been used to indicate the level of certainty in the information presented in this report. All statements should be read in conjunction with the terminology described in Box 4.1 (p. 32).

3 Climate change in NSW

This section of the report describes the past, current and projected future climate of NSW based on the assessment method set out in Section 2.1.

3.1 Past climate change

Global temperature records show a strong warming trend, particularly over the past 30 years. Figure 3.1 below shows the global annual mean temperature anomalies between 1850 and 2007. The temperature anomaly is the difference between an annual average temperature and the climatological average, which by World Meteorological Organisation convention is the average of the 1961–1990 period. While there is a great deal of inter-annual variability, this figure shows that the overwhelming trend has been for rising annual average temperatures since the beginning of the twentieth century. Importantly, the data shows multi-decadal variability occurring concurrently with the overall long-term trend to warmer temperatures. Two periods of particularly rapid increases in average temperature are from 1910 to 1940, and a steeper rise from 1970 to the present.

Global average temperatures can fluctuate from year to year in response to a number of natural phenomena such as volcanic eruptions, changes in sun spot activity and the El Niño–Southern Oscillation (ENSO) cycle. El Niño years are usually warmer than La Niña years; the warmest year on record for the globe was 1998, which coincided with one of the strongest El Niño events yet recorded. A moderate-strength El Niño event occurred in 2005, which was the second warmest year on record. Although these values are part of natural climate variability, the continued trend and occurrence of above global average temperatures, even during La Niña years such as 2000 and 2007, indicate a long-term trend of rising temperatures.

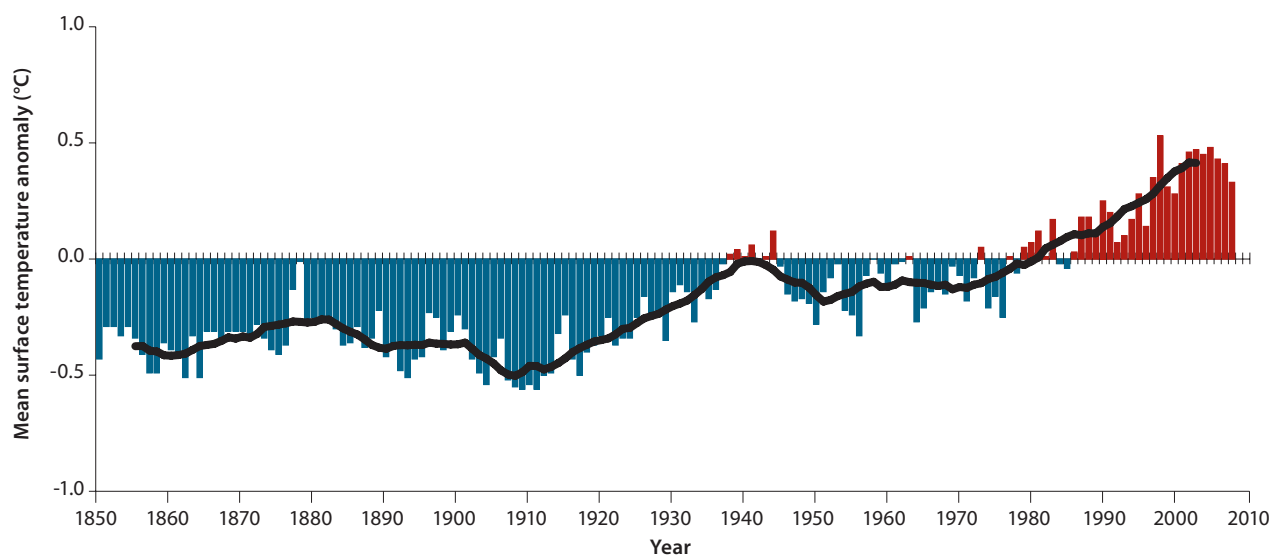


Figure 3.1 Global annual mean temperature anomalies, 1850–2007 (base 1961–1990). Rapid increases in global temperature are particularly evident between 1910 and 1940 and also from 1970 to the present. The highest global mean surface temperature on record occurred during the 1998 El Niño event. The black line represents the 11-year moving average of the measurements (BOM 2008a).

Figure 3.2 shows the annual mean temperature anomalies for the Australian region. These observations follow a similar trend to the global average rise, but between 1950 and 2007 the rise in Australian temperatures has been greater than the global average, especially over the past seven years.

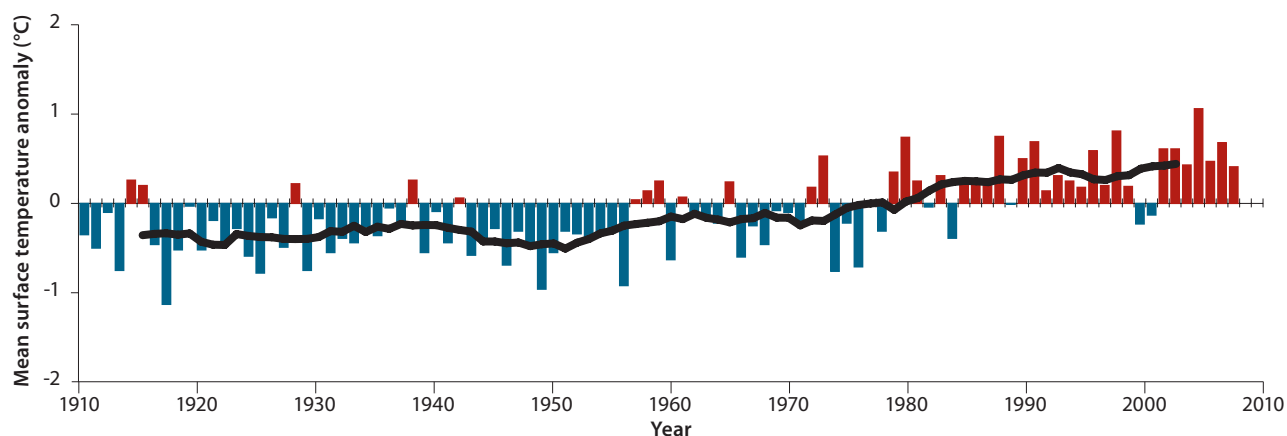


Figure 3.2 Annual mean temperature anomalies for Australia, 1910–2007 (base 1961–1990), displaying a clear warming trend from around 1950 (BOM 2008b). The black line represents the 11-year moving average of the measurements (Note that the scale of the temperature axis of the graph is different to the scale in Figure 3.1).

NSW has a very variable climate. As a result, when examining historical changes to the NSW climate, a cool or even exceptionally hot month or year is less important than a multi-decadal trend. Current climate trends indicate an accelerating increase in average annual temperature in NSW (see Figure 3.3 below). During the 1950s to 1980s, the annual average temperature rise was around 0.1°C per decade; since 1990 it has been about 0.5°C per decade. For NSW as a whole, 2007 was the warmest year on record for mean temperatures (average of maximum and minimum) and 2005 the third warmest. All years from 1997 to 2008 were warmer than average, an unprecedented sequence in the historical records. Since the turn of this century, all years have recorded an annual average mean temperature more than 0.5°C warmer than the climatological average, with 2007 a record 1.1°C above average (see Figure 3.3 below).

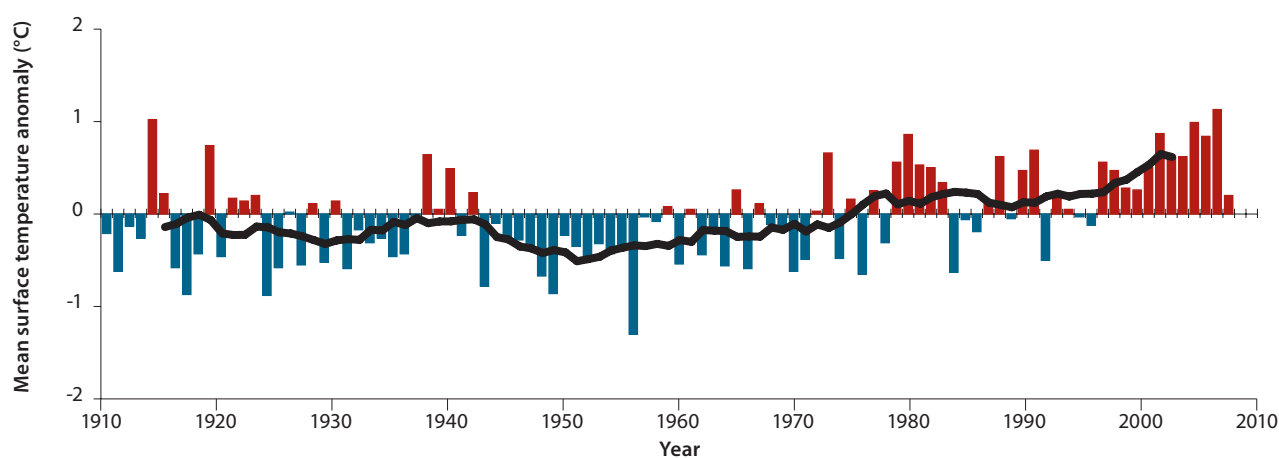


Figure 3.3 Annual mean temperature anomalies for NSW, 1910–2007 (base 1961–1990), displaying a clear warming trend from around 1950 and a particularly rapid increase in temperatures since 2000. The black line represents the 11-year moving average of the measurements (BOM 2008c).

Box 3.1 Climate change and variability from a long-term perspective

Global climate is determined by the balance of the radiation energy the planet receives from the sun and the heat energy it loses into space. There are three fundamental ways this balance can be altered, resulting in climate change:

- The amount of incoming solar radiation can change with variations in the earth's orbit or alterations in the amount of radiation emitted by the sun itself.
- Changes in the distribution of ice on the earth's surface, or changes in the atmosphere through cloud formation or dust concentration, can affect the amount of radiation that is reflected back into space. This is known as the 'albedo'.
- Finally, the balance can be altered by a change in the amount of long-wave energy that is absorbed by the atmosphere and radiated back to earth (most notably via changes in greenhouse gas concentrations). Local climate also depends on how heat is distributed by winds and ocean currents.

All these factors have played a role in past climate changes.

Past climate changes were due to a complicated array of phenomena arising from changes in the luminosity of the sun, variation in the earth's orbit around the sun (known as the Milankovitch cycles), and internal planetary processes such as continental drift, which on geological time scales cause immense changes in ocean circulation patterns and global heat transport. Other more localised planetary processes such as mountain formation and volcanic eruptions have also affected global air circulation patterns and incoming solar radiation respectively.

Temperature changes smaller than those which cause glacial and interglacial periods can also have major impacts on ecosystems and the societies that rely on those ecosystems. The relatively small temperature changes that accompanied the Medieval warm period (about 800–1300 AD) and the Little Ice Age in Europe (about 1400–1850 AD) affected the suitability of agricultural practices in many parts of the world. Localised climate change has been postulated as causing the demise of many early civilisations such as the Tiwanaku civilisation of the Andes mountains about 1100 years ago (Binford *et al.* 1997) and the collapse of early Bronze Age civilisations in India and Greece about 4200 years ago (Weiss and Bradley 2001).

Over the past 1000 years, the long-term average temperature in the southern hemisphere has been relatively stable, ranging between 0.1 and –0.5°C from today's temperature (Jones and Mann 2004). However, on a geological time scale our climate is constantly changing. During the Mid-Holocene warm period (approximately 6000–8000 years ago), the temperature was 0.5–1.5°C warmer than today, and sea level was up to 1–1.5 m higher than today (Sloss *et al.* 2007). At the other end of the scale, during the last glacial maximum (18,000–20,000 years ago), the global average temperature was 6°C cooler and sea level about 120 m lower than today (IPCC 2007). At first glance, a change in global average temperature of a few degrees does not seem to be so large, but even a small change in the global temperature can lead to monumental changes in the world's climate and ecosystems. Significantly, the temperature fluctuations that have wrought massive changes in global ecosystems in the past are within the same order of magnitude as the range of projections currently provided by the IPCC.

3.2 The current NSW climate

The Australian continent is a relatively arid landmass, with 80% having a median rainfall less than 600 mm per year and 50% less than 300 mm (BOM 2008d). Australia's aridity is primarily due to the continent spanning latitudes which are affected by the dry, sinking air of the subtropical ridge of high pressure. This zone of descending air is situated over central Australia in winter and the Great Australian Bight in summer, producing the clear skies and dry, warm weather which are characteristic of the central Australian deserts.

The subtropical high pressure belt shifts north and south with the seasons, causing the rainfall pattern over much of Australia to be strongly seasonal and helping to define the main climate regions shown in Figure 3.4. As winter approaches, the zone of high pressure shifts north, allowing westerly winds and rain-bearing systems from the Southern Ocean to affect southern Australia. Most of Australia's primary production occurs in the temperate regions of the south and east and relies on this winter rainfall. With the return of summer, the high pressure belt shifts south, allowing monsoonal rains and tropical thunderstorms to sweep across the north of the country.



Figure 3.4 Major seasonal rainfall zones of Australia (BOM 2008d)

Australia's climate, and the NSW climate in particular, is highly variable over both space and time. The north-east of the state is dominated by summer rainfall, with relatively dry winters (Figure 3.4). Conversely, agriculture in the south of the state is dependent on regular rainfall from cold fronts and cut-off lows traversing south-eastern Australia during the winter growing season. These southern districts receive little rain in summer. Figure 3.4 shows a large region of NSW where the distribution of summer and winter rainfall is fairly even (green area). The coast of NSW is influenced by the warm waters of the Tasman Sea, which moderate temperatures and provide moisture for abundant rainfall. Moist onshore winds deposit significant precipitation on the steeply rising terrain of the Great Dividing Range. The ranges enhance rainfall near the coast and contribute to a strong east to west drop in annual rainfall across much of the state. The dry north-west of the state receives most of its highly variable rainfall in very irregular, high intensity, rainfall events. Sporadic rainfall events can occur over the arid north-west at any time of the year but are more likely in summer. Annual average rainfall varies from less than 200 mm in the north-west of NSW, to more than 1800 mm along the north-east coast (BOM 2008d).

While average annual temperatures across the state are generally mild, very high temperatures are regularly recorded in the arid north-west of NSW and sub-freezing temperatures are frequently observed in the southern alpine regions (BOM 2008d). Afternoon sea breezes usually moderate the summer temperatures along the coast of NSW. In contrast, the arid north-west of the state regularly experiences maximum temperatures above 35°C during the summer months. Occasionally the heat from these desert regions is drawn south and east ahead of summer cold fronts, and this produces very hot conditions in the southern and coastal districts of NSW. The very high temperatures, strong winds and low humidity ahead of these fronts increase the risk of bushfire. In winter, cold snaps may lead to inland frosts and snowfall on the alps and tablelands. Temperatures near the coast are generally mild all year round.

As well as this strong spatial variability, many areas of NSW are prone to strong temporal climate variability. The state experiences extremes of climate from seasonal to inter-annual to multi-decadal time scales mainly due to the combined influences on the eastern Australian climate of the El Niño–Southern Oscillation, the Southern Annular Mode and the Indian Ocean Dipole (see Box 3.2).

Box 3.2 Major climate influences for Australia and NSW (BOM 2008e)

The El Niño–Southern Oscillation (ENSO)

The term El Niño refers to the extensive warming of the central and eastern tropical Pacific Ocean which leads to a major shift in weather patterns across the Pacific. This occurs every three to eight years and is associated with drier conditions in eastern Australia. El Niño–Southern Oscillation (ENSO) is the term used to describe the oscillation between the El Niño and La Niña (or opposite) phases.

In the eastern Pacific, the northward flowing Humboldt current brings cooler water from the Southern Ocean to the tropics. Furthermore, along the equator, strong east to south-easterly trade winds cause the ocean currents in the eastern Pacific to draw water from the deeper ocean towards the surface, helping to keep the surface cool. Driven by the trade winds the cold water then flows westward along the equator and is heated by the tropical sun. This means that under 'normal' conditions the western tropical Pacific is 8–10°C warmer than the eastern tropical Pacific. The warmth of the western Pacific drives convection and is associated with cloudiness and rainfall.

During El Niño years however, the trade winds weaken and the central and eastern tropical Pacific warms. This change in ocean temperature sees a shift in cloudiness and rainfall from the western to the central tropical Pacific Ocean, away from the Australian landmass. This westward shift of the area of active convection usually results in below average rainfall across eastern Australia. Conversely, during La Niña phases, the trade winds are enhanced, transporting additional moisture to the western Pacific region. Eastern Australia usually receives above average rainfall during these events.

The Southern Annular Mode

The Southern Annular Mode (SAM), also known as the Antarctic Oscillation, is a mode of variability which can affect rainfall in southern Australia. The SAM refers to the north–south movement of the strong westerly winds that dominate the middle to higher latitudes of the Southern Hemisphere. The belt of strong westerly winds in the Southern Hemisphere is also associated with the storm systems and cold fronts that move from west to east.

During a ‘positive’ SAM event, the belt of strong westerly winds contracts towards the south pole. This results in weaker than normal westerly winds and higher pressure over southern Australia. Conversely, a ‘negative’ SAM event reflects an equator-ward expansion of the belt of strong westerly winds. This shift in the westerly winds results in more storm systems and lower pressure over southern Australia.

It is interesting to note that there appears to be an increasing trend in the SAM. During the summer and autumn months (December through to May), the SAM shows an increasing tendency to remain in a positive phase, with westerly winds contracted towards the south pole.

The contribution that the SAM makes to the climate variability in Australia and the apparent positive trend in the SAM are relatively recent discoveries and as such are still active areas of research.

The Indian Ocean Dipole

Sea surface temperatures (SSTs) in the Indian Ocean have a profound impact on the rainfall patterns over much of Australia. In general, warmer than average Indian Ocean SSTs near Australia may enhance Australian rainfall, while cooler than average SSTs can result in reduced rainfall. This concept is strongly linked to the formation of north-west cloudbands, which are a significant source of winter and spring rainfall for the western slopes of the Great Divide.

The most commonly referred to Indian Ocean influence on Australian climate is called the Indian Ocean Dipole. The Indian Ocean Dipole is a major contributor to the variability of rainfall over Australia. When the dipole is in a positive phase, sea surface temperatures (SSTs) around Indonesia are cooler than average while those in the western Indian Ocean are warmer than average. There is an increase in the easterly winds across the Indian Ocean in association with this SST pattern, while convection in areas near Australia reduces. This results in suppressed rainfall over the Australian region. Conversely, during a negative phase, there are warmer than average SSTs near Indonesia and cooler than average SSTs in the western Indian Ocean, resulting in more westerly winds across the Indian Ocean, greater convection near Australia, and enhanced rainfall in the Australian region.

The contribution that Indian Ocean SSTs make to Australia’s climate is an active area of research. The details of how they influence Australian climate are still not well understood.

From widespread flooding to prolonged drought, the climate of New South Wales is heavily influenced by the El Niño–Southern Oscillation, the Indian Ocean Dipole and the Southern Annular Mode. The perpetual interaction of these oceanic and atmospheric influences around Australia has resulted in the inherent strong temporal variability of the NSW climate. The response of these phenomena to enhanced greenhouse gas concentrations is an area of active research. There remain many uncertainties about how these major climate drivers surrounding Australia will interact and influence the continent’s climate in a warmer world.

When investigating the impact of future climate change on ecosystems, it is important to consider the amount of known variability that we assume our ecosystems have adapted to, and compare that to the range and probable values that we get from climate projections. Even though the long-term average temperature has been relatively consistent for the past thousand or more years, Australian ecosystems have had to deal with more unstable rainfall patterns. The inter-annual and longer term decadal variability in Australia is extremely high, and ecosystems have an inbuilt adaptive capacity or resilience to change. Most ecosystems in Australia have to deal with a rainfall variability that is more extreme than elsewhere on the planet (see example in Box 3.3).

Even though our ecosystems may be resilient to a high degree of variability, modern society and our infrastructure may be less so. This is particularly the case for infrastructure where long-term averages used in the design process do not cover a long enough time span to incorporate the full amount of possible variation.

Box 3.3 Climate variability in the southern Blue Mountains

The rainfall data for a 106-year period from 1900–2006 in the southern Blue Mountains is shown in Figure 3.5 below. From this graph, we can see that the lowest rainfall was just over 400 mm and the highest was almost 1700 mm. If the lower of these two figures was representative of the average rainfall for this region, then we would expect the semi-arid grassy woodlands found around Griffith to be the major type of vegetation. At the other end of the scale, 1700 mm is as wet as the rainforest areas in Kiama to the east. The ecology of this environment has to deal with conditions that range from very dry to very wet. Even if we look at decade-long averages, the variability is still extremely high, with ranges from a low of about 700 mm to a high of over 1000 mm. Today the area is a mix of moist eucalypt forests in the sheltered gullies and dry eucalypt forest, woodlands and heaths on the slopes.

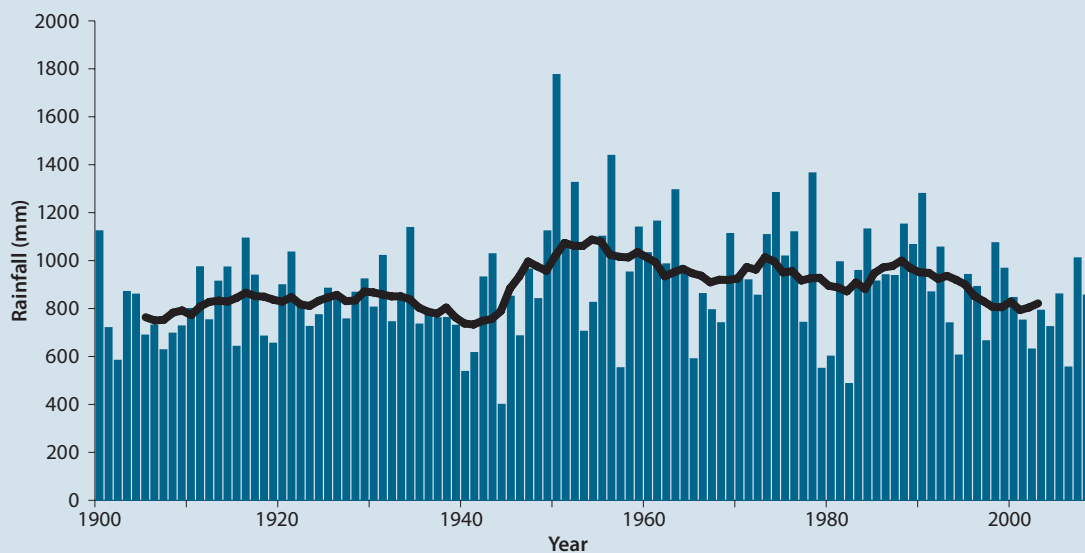


Figure 3.5 Annual rainfall for the southern Blue Mountains over a 106-year period from 1900 to 2006 (adapted from BOM 2008d)

3.3 Future climate change in NSW

The IPCC's Fourth Assessment Report incorporates projections from a suite of global climate models, which provide projections up to the year 2100 for a wide range of climate variables including sea surface temperature, precipitation, air pressure, air temperature, specific humidity and wind speed and direction. In this study we have focused on the projections to 2050 for a limited set of climate variables: rainfall, evaporation and maximum and minimum temperatures. These are the four climate variables considered to most directly affect biophysical systems across the state and therefore are the priority for this initial assessment of the impacts of projected climate change. The types of climate projections developed for this project are described in Table 3.1.

Table 3.1 Types of climate data modelled for this project

Modelled variable		Description
Temperature	Change in mean daily maximum temperatures by season (°C)	A measure of the projected change in the average warmest temperature on any day for summer, autumn, winter and spring.
	Change in mean daily minimum temperatures by season (°C)	A measure of the projected change in the average coolest temperature on any day for summer, autumn, winter and spring.
	Change in annual maximum temperatures by season (°C)	A measure of the projected average warmest temperature on any day for summer, autumn, winter and spring. We can expect the warmest temperature of the day to be this hot.
	Change in annual minimum temperatures by season (°C)	A measure of the projected average coolest temperature on any day for summer, autumn, winter and spring. We can expect the coolest temperature of the day to be this cold.
Rainfall	Change in mean daily rainfall by season (%)	A measure of the projected percentage change, either increase or decrease, in mean daily rainfall across summer, autumn, winter and spring.
	Change in peak daily rainfall by season (%)	A measure of the projected percentage change in rainfall on the wettest day expected in each season. Storms may be more intense in any given year, but this is the most intense event expected to occur at least once each season.
Evaporation	Change in evaporation rates	A measure of the projected percentage change, either increase or decrease, in seasonal evaporation across summer, autumn, winter and spring.

Changes in maximum and minimum temperatures

NSW is expected to become hotter, with higher maximum and minimum temperatures very likely to be experienced across the state in all seasons. The greatest increases in maximum temperatures are projected to occur in the north and west of the state (Figure 3.6). Winter and spring maximum temperatures are expected to rise by around 2–3°C across much of northern NSW by 2050.

Significant increases in minimum temperatures are expected across much of the state, particularly in the north and east (Figure 3.7). The radiative effects of enhanced greenhouse gas concentrations, combined with increased relative humidity and cloudiness, are likely to reduce radiative cooling and cause warmer nights in the north-east of the state in all seasons. Conversely, south-west NSW is expected to experience clearer and drier skies by 2050. Decreased humidity and cloudiness in the south-west will enhance radiative cooling of the land surface overnight. The additional cooling caused by clearer night skies will likely counteract the warming effects of additional greenhouse gases in the atmosphere. These countering influences are responsible for the minor increases in seasonal minimum temperatures projected for the south-west when compared to the remainder of the state.

Changes in average and seasonal rainfall

The projected changes to average and seasonal rainfall between now and 2050 are summarised in Figures 3.8 and 3.9. A slight increase in summer rainfall is projected for north-east NSW; however, this is likely to be accompanied by a significant decrease in winter rainfall in the south-western regions. Many parts of the state will experience a shift from winter-dominated to summer-dominated rainfall, which may have implications for the duration and severity of drought in these areas.

The global climate models are predicting a trend toward the positive phase of the Southern Annular Mode through the coming century. This trend is one of the most robust signatures of future climate change found anywhere in the world (Miller *et al.* 2006). In the models, the belt of westerly winds (sometimes referred to as the 'Roaring Forties') contract further south away from the Australian continent and into the Southern Ocean. This will result in weaker westerly winds over southern Australia. Cold fronts embedded in this westerly wind belt are a major source of reliable rainfall for NSW, especially in the south during the cooler months of the year. The reduced strength and frequency and southerly displacement of these westerly winds and their associated cold fronts is likely to be the primary cause of significant decreases in rainfall in autumn, winter and spring in the south of the state by 2050. Conversely, there will be a significant increase in summer rainfall across the state as the influence of tropical moisture and instability spreads south from the tropics over the coming century.

The changes to rainfall in northern NSW appear to be within recorded levels of variability. However, the drying of the autumn, winter and spring seasons in the south, and particularly in the south-west, is expected to be outside the variability observed in the historical record (see example in Figure 3.10). There is also likely to be a significant reduction in winter snowfalls on the alps and southern tablelands, with warmer conditions producing rainfall instead of snow over the higher elevations of the state.

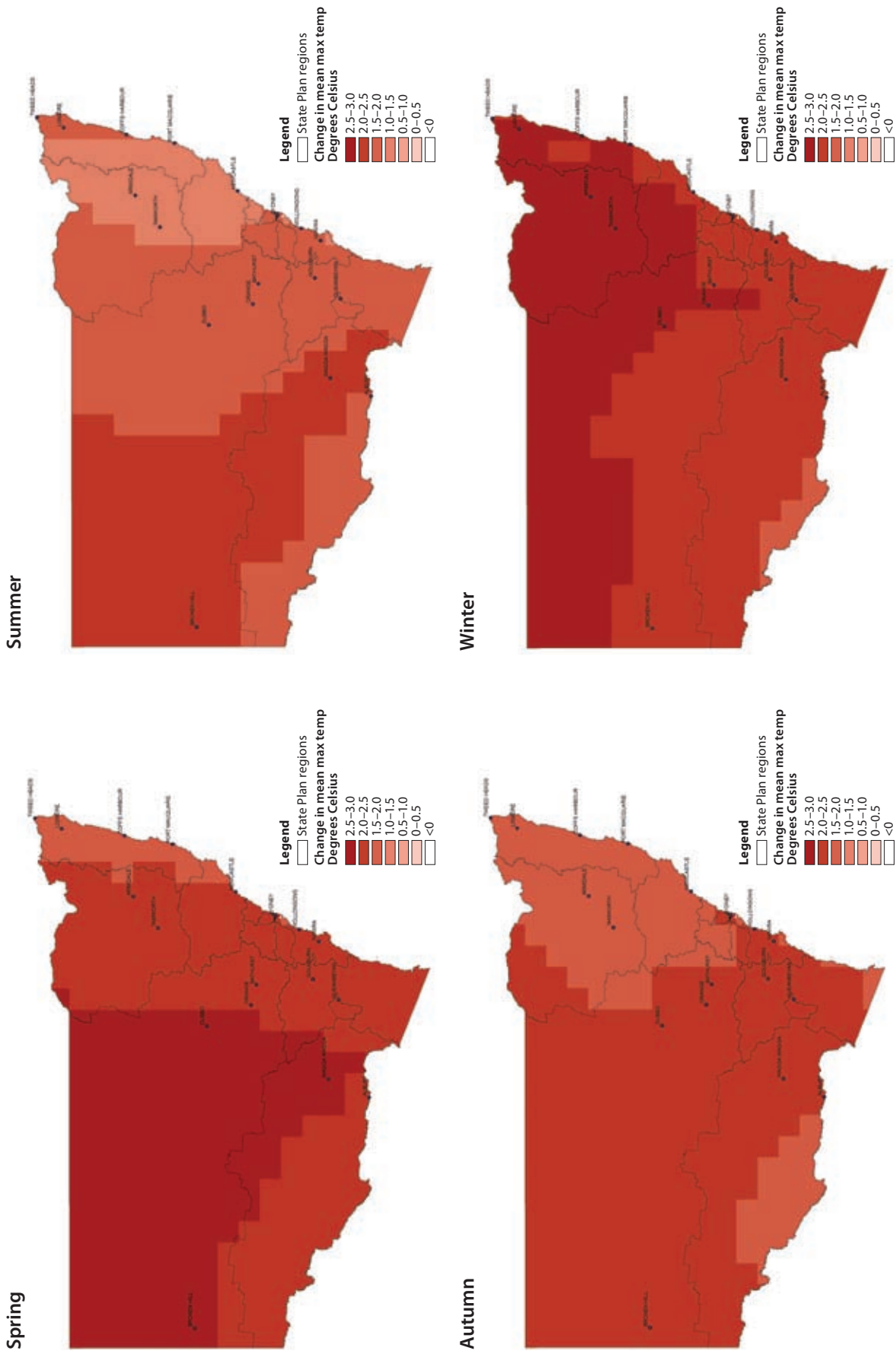


Figure 3.6 Projected increases in seasonal average maximum temperatures by 2050

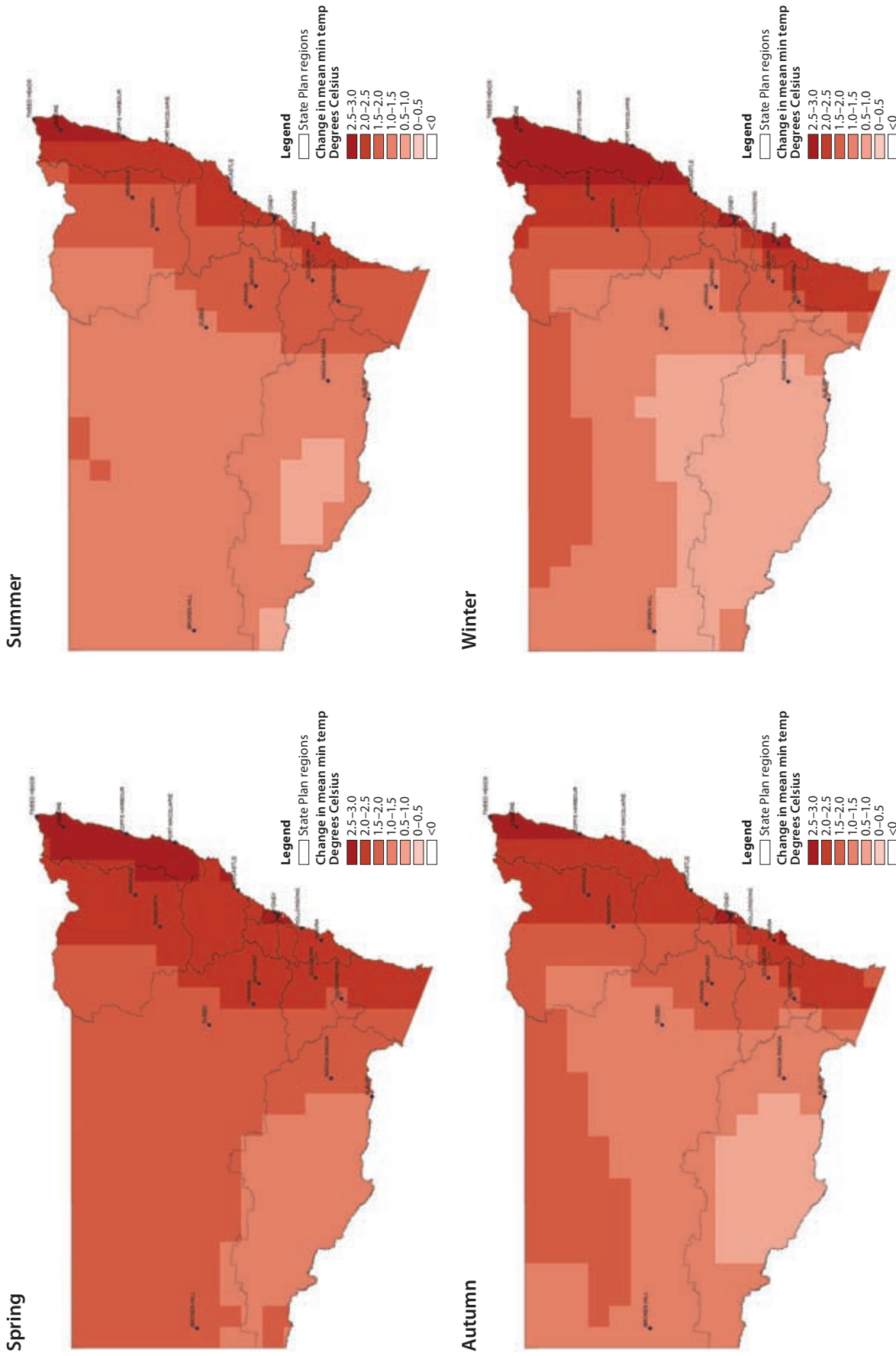


Figure 3.7 Projected increases in seasonal average minimum temperatures by 2050

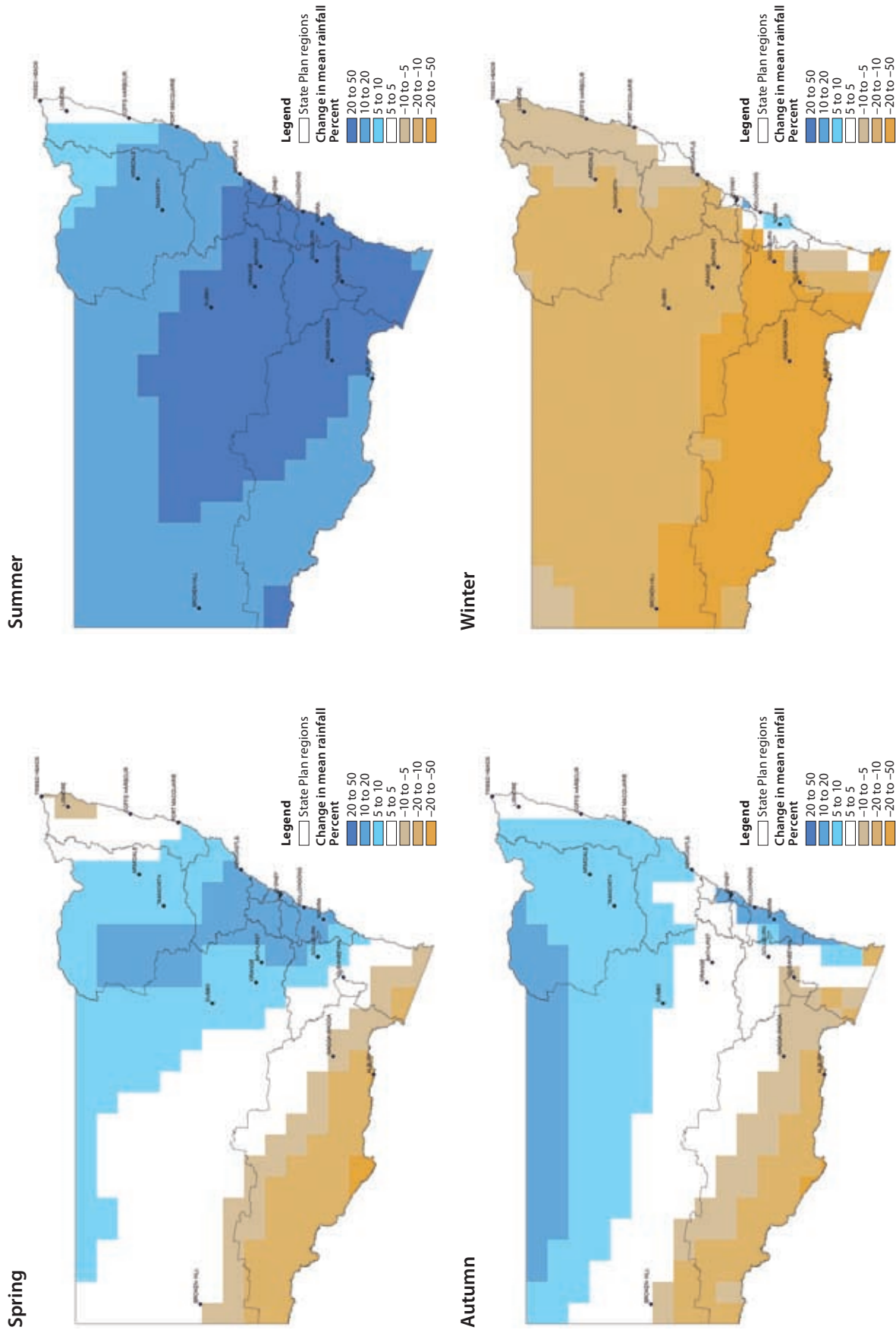


Figure 3.8 Projected changes in rainfall by 2050, in spring, summer, autumn and winter

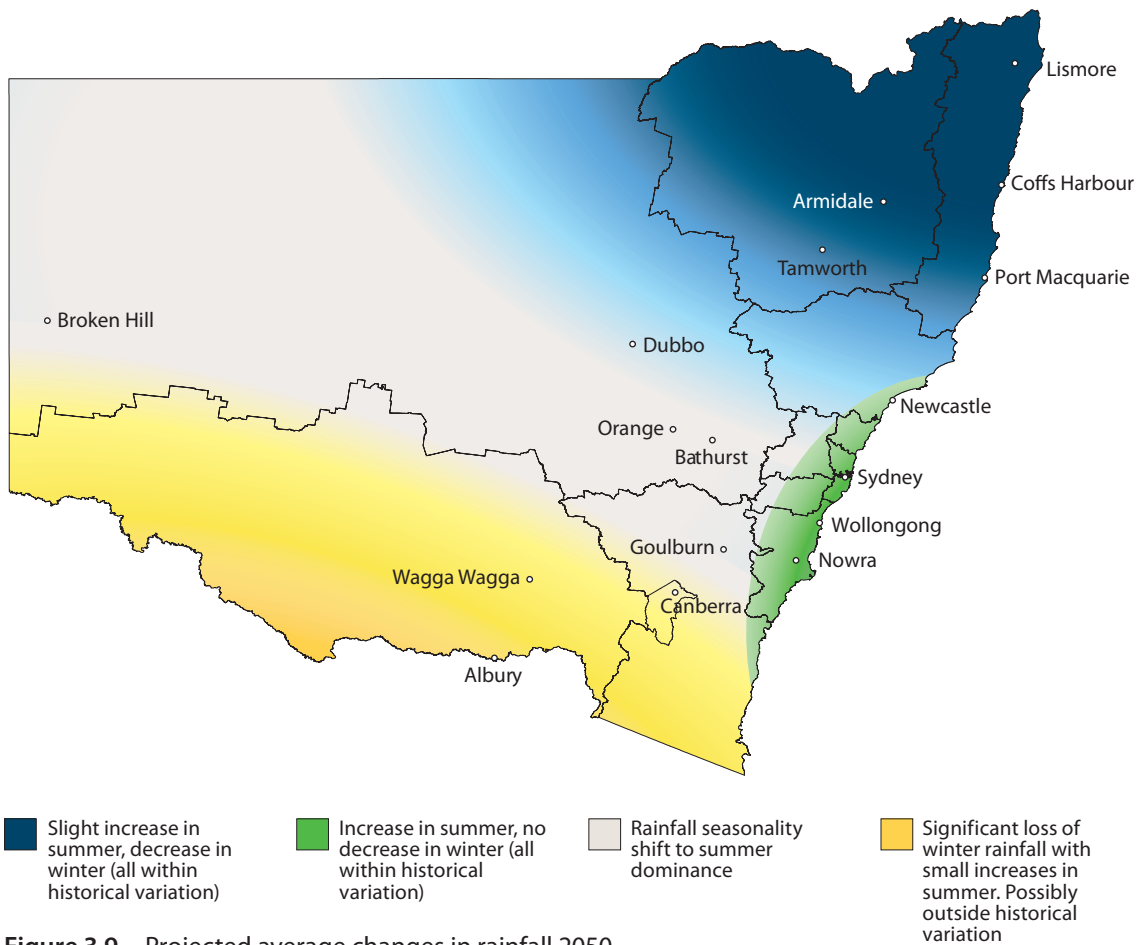


Figure 3.9 Projected average changes in rainfall 2050

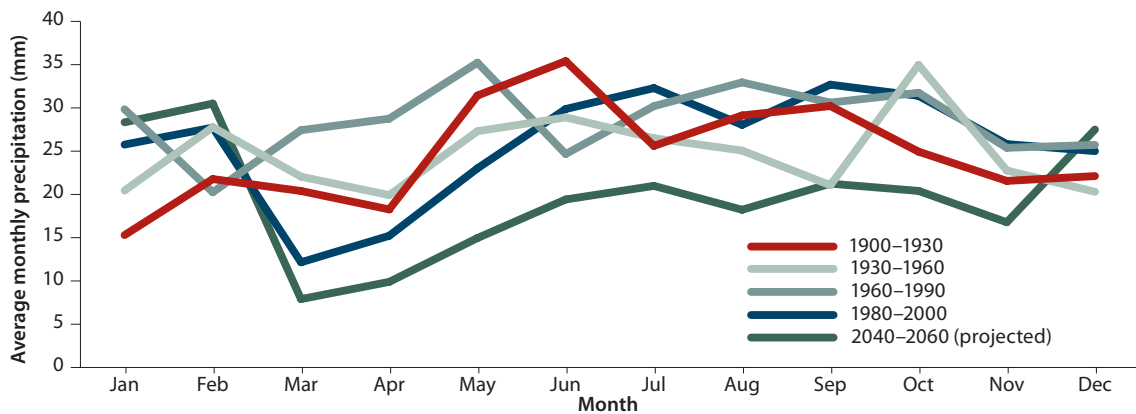


Figure 3.10 Historical rainfall variability compared with 2050 projections for the south-western Riverina

The impacts of climate change on flood-producing rainfall events are likely to be different from the impacts on seasonal or average rainfalls, with the intensity of significant flood events likely to increase even where seasonal or average rainfalls are expected to decrease.

Changes in evaporation

As higher temperatures are projected to affect the state, evaporation is also expected to significantly increase by 2050 across much of NSW. Summer evaporation is likely to increase across the entire state, especially in central areas. The projected increases in evaporation are likely to counteract the expected increases in summer rainfall across the state, with dry soil conditions expected to be even more prevalent in the west of the state by 2050. Similarly, despite projected increases in rainfall across the north and east of the state in autumn and particularly spring, these regions can also expect an increase in evaporation which may result in drier soil conditions.

4 Impacts of climate change in NSW

This section summarises some of the likely physical responses to climate change across NSW and the likely impacts on land (soils and soil processes), settlements (storm and flood damage) and natural ecosystems (biological communities, individual species and ecological processes).

Some changes can be predicted with more certainty than others, because knowledge of how climatic and biophysical systems work is variable. To avoid ambiguity, the estimated probability of each change has been described in Sections 4 and 5 using the standard terms used by the IPCC to define the likelihood of an outcome or result (see Box 4.1).

These projections are based on the findings of each of the technical groups and assume:

- the changes to temperature and rainfall described in Section 3.3, and
- a sea level rise of 0.4 m above the 1990 mean sea level by 2050 and a 0.9 m rise by 2100.

This assessment has also assumed an increase in the frequency and intensity of flash flooding across many areas of the state by 2050. This assumption is based on the projections in the Climate Change in NSW Catchments Series completed by the CSIRO for the NSW Government in 2007 (CSIRO 2007). There remains a great deal of uncertainty in future projections of thunderstorm frequency and intensity, and of changes in thunderstorm-related phenomena such as flash flooding and hail. This is an active area of research which is likely to rapidly evolve as models capable of higher spatial and temporal resolution are developed.

Box 4.1 Terminology for probability of occurrence and magnitude of impacts

Where uncertainty in specific outcomes is assessed using expert judgment and statistical analysis of a body of evidence (e.g. observations or model results), the following likelihood ranges have been used to express the assessed probability of occurrence. This is consistent with the terminology used by the IPCC (IPCC 2007).

Virtually certain	>99% probability	About as likely as not	33%–66%
Extremely likely	>95%	Unlikely	<33%
Very likely	>90%	Very unlikely	<10%
Likely	>66%	Extremely unlikely	<5%
More likely than not	>50%	Exceptionally unlikely	<1%

Specific terminology has also been used to describe the magnitude of predicted changes:

	Rainfall	Temperature	Evaporation
Slight	5–10%	0.5–1°C	5–10%
Moderate	10–20%	1–2°C	10–20%
Substantial	More than 20%	More than 2°C	More than 20%

Slightly different terminology has been used to describe the projected hydrological impacts (run-off). An additional category ('minor') has been included to clearly describe the distinction between the magnitudes of projected changes. Each of the four global climate models (GCMs) resulted in a different estimate of run-off changes. The reporting of these results is based on the following characteristics:

- the magnitude of the average of the changes from the four GCMs
- the full range of changes (from lowest to highest % change), and
- the degree of agreement between the four GCMs on the direction of change.

For the magnitude of changes, the following terms are used to describe the average increase or decrease (as a percentage):

	Run-off depths	Magnitude of high flows	Frequency of low flows
Slight	0–3%	0–5%	0–10%
Minor	3–6%	n/a	n/a
Moderate	6–9%	5–10%	10–20%
Substantial	>9%	>10%	>20%

For the degree of agreement between the four GCMs (i.e. the degree of consensus), the following terminology has been used:

	Number of GCMs agreeing on the direction of change
Very likely	4
Likely	3
About as likely as not	2

4.1 Expected physical responses

Run-off is likely to increase slightly in the north and decrease significantly in the south

Analyses of modelled run-off projections indicate a shift in the seasonality of run-off patterns is virtually certain, with significantly more summer run-off (up to about 20% increase) and significantly less winter run-off (up to about 25% decrease). The projections also indicate some minor increases in autumn run-off and moderate to significant decreases in spring run-off.

Annual run-off depends on the relative contribution of run-off in the different seasons. In northern NSW, which is dominated by summer rainfall and run-off, projections indicate a slight increase in mean annual run-off. In the southern regions of the state, which currently experience winter-dominated rainfall and run-off, the projections indicate moderate to significant decreases in mean annual run-off.

Flooding behaviour is virtually certain to change

In lower portions of coastal floodplains, the combination of rises in sea level and catchment-driven flooding is virtually certain to increase flood frequency, height and extent. More broadly, increases in the intensity of flood-producing rainfall are likely to affect flood behaviour. However, catchment conditions at the time of rainfall events (soil moisture conditions and levels of major water storages) will influence the degree of the changes.

Sea level rise is virtually certain to increase low, mid and high tide levels. This will result in larger areas of low-lying land around coastal waterways being exposed to more frequent tidal inundation.

Fire regimes are likely to change, but changes to fuel availability are uncertain

Higher temperatures and changes to rainfall patterns will more likely than not lead to increased fire frequency towards the year 2050, but the return period of fires is considered likely to remain within the current domain of acceptable fire intervals for most vegetation classes.

Very high to extreme fire danger days are projected to increase by 10–50% and the conditions conducive to large and intense fires (such as prolonged drought, low humidity, number of days with high temperature and high wind speeds) will more likely than not increase.

Future change in fuel availability is the least certain of all the factors that drive fire. Projected decreases in available moisture will possibly reduce fuel availability; however, projections of fuel availability are presently regarded as highly speculative.

4.2 Impacts on land

Sheet, rill and gully erosion are generally likely to increase

Sheet, rill and gully erosion across the whole state are very likely to be modified by changes in the erosive power of rainfall and the protective cover of ground vegetation. The combination of more intense storms, especially in summer and spring, and an overall reduction in net water balance (less rainfall relative to evaporation) is likely to lead to more sheet and rill erosion, as well as increased gully erosion where such erosion is caused by overland flow. However, reduced water balances in most seasons are likely to decrease gully erosion that is due to seepage flows, as in some sodic (sodium-dominated) subsoils, unless this effect is offset by declines in stabilising vegetation.

Mass movement of soil on slopes is likely to increase

An increased risk of mass movement is likely on all currently vulnerable slopes in coastal hinterlands due to higher summer and spring rainfalls.

Sediment shedding is likely in coastal hinterlands

Higher rainfall in summer is likely to cause more sediment shedding from soils in coastal hinterlands, resulting in channel changes and sediment inundation on coastal floodplains.

Coastal dunes are likely to be at risk

Most coastal dunes and some beach-barrier systems are very likely to be under threat from erosion from a combination of sea level rise, changes in wave direction and increased storm intensity. A number of sites along the NSW coast already exhibit this coastal erosion threat. Wind-blown erosion could result from potential loss of protective vegetation.

More wind erosion is likely in the south

Reductions in rainfall, especially in the south and south-west of the state, are likely to result in more wind erosion. Soils will be more susceptible to wind by being drier and having less ground vegetation cover.

Changes in soil salinity are generally difficult to predict

Likely changes in rainfall and evaporation in all regions will impact on the balance between run-off and overland flows, and shallow drainage and deep drainage. These changes are likely to affect the mobilisation and concentration of salts, with responses differing between catchments. Whether salinity will increase or decrease in particular areas will depend on local factors for each catchment.

Saline incursions are likely to impact on soils on coastal plains

More saline incursions into low-lying, coastal-plain subsoils are likely, reducing agricultural potential. Initially, increased salinity is likely to cause declines in soil structure. Eventually, permanent waterlogging is likely, especially after flooding.

Soil acidification is likely to remain a problem

Changes in rainfall and evaporation are likely to reduce leaching and therefore decrease soil acidification in many areas, especially in the south of the state where reduced winter rainfall is likely to decrease the amount of deep drainage. However, acidification is likely to remain a problem because leaching is only one of its causes.

Acid sulfate soils on the coast are likely to increase initially but then decline

Major changes are likely in the character and development of acid sulfate soils on coastal plains. Initially, changes in rainfall seasonality are likely to increase the production and mobilisation of acid. However, reductions in acid development will occur over the next 50–100 years as watertables rise with sea levels.

The organic content of some soils is likely to decline

Decreases in the amount of organic matter in soil are very likely in the southern half of the state because of reduced plant growth in drier conditions. Increased soil temperatures may also lead to further loss of soil organic matter in some soils as a result of accelerated respiration.

4.3 Impacts on settlements

Sea level rise and extreme storms are virtually certain to adversely affect vulnerable developments along the coast

Sandy beaches are likely to recede by about 5–10 m for each 0.1 m (10 cm) of sea level rise, with recession outside this range possible in some locations. Extreme storms are likely to become more frequent and peak ocean water levels during storms are virtually certain to increase, producing more intense and frequent coastal inundation, higher wave run-up levels, higher water levels in lakes and estuaries and more flooding on coastal rivers. Tidal dynamics and tidal ranges in estuaries are also virtually certain to change, with consequent impacts on conditions in entrance channels and the location of shoaling and erosion. It is virtually certain that this suite of changes will progressively damage existing low-lying coastal development.

Coastal structures are likely to be affected

Design parameters for coastal structures are virtually certain to change as greater water depths result in larger waves against structures, wind velocities change, and the height and direction of offshore waves change. Existing structures will need to be assessed against the changing physical conditions to determine risk profiles and the need for upgrading, to ensure they do not reduce protection significantly or fail.

Flooding of low-lying coastal developments is likely to increase

Developments along the NSW coast that are near current high-tide levels will be susceptible to frequent tidal and stormwater inundation, and stormwater drainage is extremely likely to be less effective during high tides. Urban areas near coastal rivers, lakes and estuaries will be particularly affected by the combined impact of marine and catchment flooding, but the scale of impacts will depend on the vulnerability of each location.

Degree of change in flood risk elsewhere is likely to be variable

Development is currently affected by flooding in many parts of NSW, often as a legacy of historical patterns of settlement. Flooding impacts are likely to alter with climate change, but the degree of change is likely to vary greatly between locations. Climate change is likely to increase the frequency and intensity of flood-producing rainfall events, but changes in soil moisture and the levels of water storages, resulting from altered average and seasonal rainfall patterns, are also likely to affect flood behaviour. The impacts of changes in flood-producing rainfall are likely to be greatest in coastal areas, on the western slopes and in urbanised catchments, where short storms have most impact on flooding and floodplains are often confined. Impacts of the changes are likely to be lower in the broader floodplains of western NSW, where storms that last longer have more influence on flooding.

Changes in rainfall, run-off and evaporation are likely to affect NSW water supplies

A detailed study looking specifically at the potential impacts of climate change on Sydney's water supply and demand is currently underway. This study, being conducted as part of the Sydney Metropolitan Water Plan, will take into account local conditions in drinking water catchments, as well as projected customer demand, under climate change scenarios. Investigations are also underway to assess the impacts of potential climate change on the secure yield of town water supplies in country NSW.

4.4 Impacts on ecosystems

The structure, composition and function of ecosystems are likely to change

All ecosystems in NSW, even the most hardy and resilient, are expected to alter in response to climate change. The structure of ecosystems will be influenced by changes in fire regimes and hydrological flows. Changes in species' distributions and abundances will alter the composition of ecosystems. The most sensitive species are likely to be those with the following traits: immobile or sedentary habits, inability to disperse over long distances, limited geographic ranges, complex thermoregulatory components of life histories (e.g. reptiles, mound-nesting birds, and mammals with periodic torpor or hibernation), narrow thermal tolerances (e.g. low lethal temperatures or strict temperature requirements for seed production), high metabolic rates, complex dependent relationships with other species, and existing decline caused by other threatening processes. Generalist species with wide geographic ranges and broad environmental tolerances will be likely to cope better.

Changes in productivity are likely to occur, particularly where declines in rainfall and increases in temperatures are most extreme. Ecological processes such as nutrient cycling are also likely to be disrupted.

Distributions of individual species are likely to change

The distribution of individual species is likely to shift in latitude and altitude in response to increased temperatures. Drier conditions over much of the west of NSW, as well as a shift in seasonal patterns of rainfall in the south-west are likely to cause range contraction in a number of species. Those species with narrow climatic tolerances such as high altitude species are likely to decline, with some of these likely to become extinct. Conversely, some hardy generalists and pests are likely to persist and spread.

Changes in fire frequency and intensity are likely to have widespread impacts

Larger and more intense fires are likely to extend in the future into infrequently burnt wet forests and refuges such as canyons that are protected by their topography, changing forest structure and composition. Species that are highly sensitive to fire are likely to disappear, while those that depend on old or dead hollow-bearing trees and woody debris are likely to have less habitat. Small patches of fire-sensitive ecosystems in a matrix of extensive drier vegetation are most at risk. More extensive fire combined with drought stress is likely to decrease the flowering of plants such as banksias and eucalypts in dry forests and heaths, impacting on nectar-feeding animals.

Changes in invertebrate populations are difficult to predict but likely to be substantial

Invertebrates have many functions in ecosystems – for example as pollinators, predators, herbivores, detritus feeders, disease vectors, biological controllers of pests and food for other organisms. Invertebrate ecology and population dynamics are likely to change greatly, with consequences that are likely to be substantial but are generally hard to predict from current knowledge. Changes are already apparent in some of the better known and more significant invertebrates, such as the plague locust *Chortoicetes terminifera*. Breeding adults of this species were observed as early as July in 2008, and it is expected to benefit from warmer and wetter summers and warmer night-time temperatures.

Sea level rise is virtually certain to eliminate some coastal ecosystems

Rising sea levels, saline intrusion and coastal recession are virtually certain to destroy some ecosystems. The rainforests, wetlands, heaths and dry forests of the coastal sands are particularly at risk. Rock platforms, sand spits and mudflats, which are highly vulnerable to sea level rise, are rich in invertebrates and form the main foraging and nesting habitats for shorebirds, many of which are already threatened. Waders that breed just above the high-tide mark are very likely to be affected by even temporary loss of habitat. Seagrass beds, mangroves and salt marshes, which contribute greatly to estuarine food webs, are extremely likely to decline with consequent reduction in fish populations. Some ecosystems such as mangrove forests are as likely as not to re-form in new locations, but re-establishment is very likely to be slow and incomplete.

Sea level rise is likely to threaten some estuarine communities

Sea level rise and shoreline retreat are likely to induce a large-scale modification or loss of intertidal and subtidal communities. Conditions such as turbidity, pH, temperature and salinity are likely to change. The Hunter region has large areas of seagrasses, mangroves and salt marshes, with the most significant sites at Wallis Lake, Lake Macquarie, Port Stephens, Karuah and the Hunter River. Seagrasses are likely to be displaced from some of their current extent and their ability to re-colonise is difficult to predict. Some stands of mangroves and salt marshes are also likely to be displaced from their current locations, but new mangrove habitat is likely to form in other places. Salt marsh is slow to colonise and its establishment in new habitats is likely to be limited by the rapidity of sea level rise and increased rates of sediment deposition. Species composition of these communities is also likely to change in response to altered environmental conditions. It is virtually certain that re-establishment of estuarine habitats will be impeded in some places by infrastructure and development, such as that near the entrance to the Hunter River. The composition and distribution of invertebrate communities on mudflats are also likely to change.

High-altitude ecosystems are likely to contract

Many types of ecosystems are likely to contract to higher altitudes, and southward and eastward to the coolest parts of their ranges, as temperatures increase beyond the tolerances of the constituent species. The ecosystems most likely to be affected include temperate rainforest, cool-climate wet sclerophyll forest and grassy woodlands. Some ecosystems such as montane and tablelands bogs and fens are likely to disappear altogether. Impacts are likely to occur in all high-altitude areas, but will be most pronounced in uplands that are isolated from the Great Dividing Range, such as Mount Kaputar and the Warrumbungle and Liverpool ranges, where there is little or no opportunity for relocation in response to climatic changes.

Snow-dependent species and ecosystems are likely to be lost

Reductions in the extent and persistence of snow cover are likely to have substantial impact on snow-dependent species and ecosystems, many of which are endemic to the NSW alpine zone. Many alpine and sub-alpine species are likely to become extinct because they will be unable to migrate to suitable habitat elsewhere.

Rainfall decline and reversed seasonality are likely to cause major changes in the Murray Valley

The Riverina and Murray Valley are very likely to suffer major ecological changes as a result of reduced annual rainfall, a shift in rainfall seasonality from winter to summer dominance, declining overall river flows and a loss of spring snow-melt. Species adapted to 'Mediterranean' conditions (wet winters and hot, dry summers) are likely to be displaced or lost. Floodplain and wetland species that have already declined dramatically over the past decade are likely to decrease further. Many ecosystems are likely to collapse.

Species and ecosystems that are stressed by other factors are less likely to resist climate change

Many Australian ecosystems and species have evolved in highly variable climates, and consequently are likely to have some capacity to resist expected climate changes. However, many ecological communities and species in NSW have declined severely because of land clearing, water extraction, habitat fragmentation, grazing and introduced pests. Species and ecosystems that are stressed by non-climatic factors are less likely to be resilient to climate change impacts.

5 Regional impacts of climate change

This section describes some of the likely impacts of projected climate change in each of the NSW State Plan regions. The aim is to provide an overview of the ways in which the biophysical environment can be affected by changes in climate and the implications of these changes for lands, settlements and natural ecosystems.

For each region, the section outlines:

- 1 expected regional climatic changes, including projected changes in temperature, rainfall and evaporation
- 2 expected physical responses, including projected changes in sea level, run-off, droughts, floods and fires, and
- 3 regionally significant impacts – some of the likely impacts of the climatic changes and physical responses, including:
 - (a) impacts on lands
 - (b) impacts on settlements, and
 - (c) impacts on ecosystems.

The estimated probability of each change has been described using the standard terms detailed in Box 4.1.

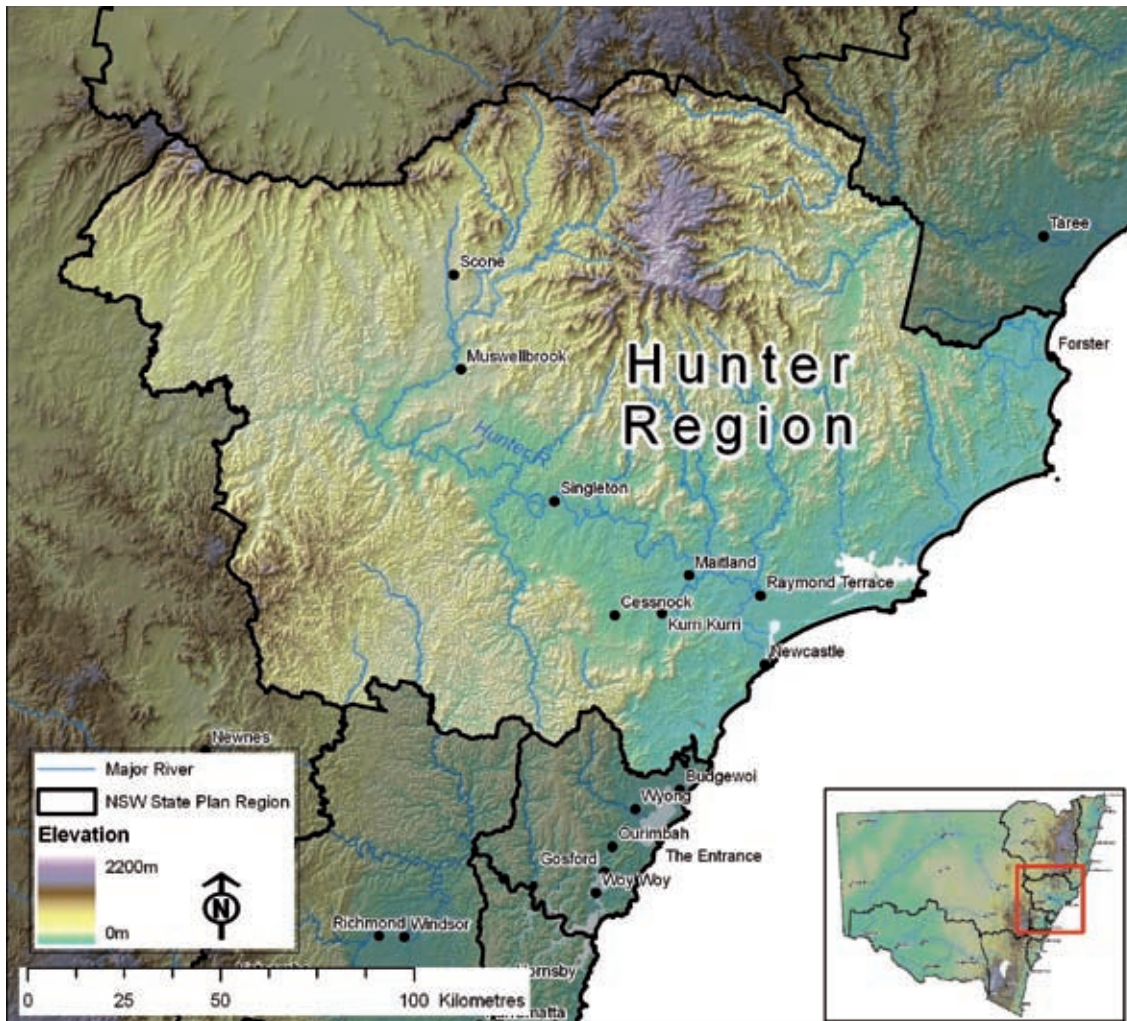
5.1 The Hunter region

Note: The changes described in this section should be reviewed in conjunction with the terminology in Box 4.1.

- By 2050, the climate is virtually certain to be hotter, with a likely decrease in rainfall in winter and an increase in rainfall in spring, summer and autumn. However, changes in weather patterns that cannot be resolved by the climate models mean that rainfall in coastal regions is difficult to simulate.
- Run-off and stream flow are likely to increase in summer and autumn and decrease in spring and winter.
- Sea level is virtually certain to keep rising.
- Soil erosion is likely to increase on steeper slopes in the upper catchments. River-channel change is very likely to remobilise sediments. Sea level rise is likely to increase soil salinity and reduce soil organic content in low-lying coastal areas. Development of acid sulfate soils is likely to increase in the short term but decline over time. Coastal erosion is virtually certain to increase.
- Sea level rise, coupled with increased flooding, is very likely to pose an increased risk to property and infrastructure. Developments near coastal lakes and estuary entrances and on coastal floodplains are vulnerable.
- Sea level rise is virtually certain to alter estuarine and coastal lowland ecosystems. Higher temperatures are likely to cause temperate and sub-alpine ecosystems to change or contract. Changes in hydrology and fire regimes are likely to alter the species composition and structure of many ecosystems.

Characteristics of the region

Local Government Areas: Cessnock; Dungog; Gloucester; Great Lakes; Lake Macquarie; Maitland; Muswellbrook; Newcastle; Port Stephens; Singleton; Upper Hunter.



Location and topography

The Hunter region covers an area of 29,600 square kilometres, stretching from Hallidays Point south to Catherine Hill Bay. It incorporates the catchment of the Hunter River and 150 km of coastline, including 10 significant estuaries and coastal lakes. The southern section of the region incorporates the sandstones of the Sydney Basin, the north-west is bounded by the Liverpool Ranges, and the north abuts the New England Tablelands.

Climate

The region has a warm temperate climate with a rainfall that varies from east to west, averaging about 870 mm per year. Rainfall is nearly evenly distributed throughout the year with a slight summer-autumn dominance. The highest totals (above 1100 mm) occur on Barrington Tops and along the coast, and the lowest (below 600 mm) in the west. Run-off is highest on the northern ranges and lowest on the coastal plains and foothills. It is uniformly distributed across summer, autumn and winter in the northern ranges, with a distinct spring minimum. The plains and foothills have more autumn-winter run-off, with slightly less in summer, and significantly less in spring.

Settlements and industry

The region includes the Lower Hunter (Newcastle, Port Stephens, Lake Macquarie, Maitland and Cessnock), Barrington Tops (Gloucester and Dungog), the Upper Hunter (Singleton, Muswellbrook and Scone) and the Great Lakes Shire. The population of the region is increasing rapidly and is concentrated along the coast and the Hunter River floodplains. The Hunter is a major coal mining region and supports coal-based heavy industry such as aluminium smelting and electricity generation.

Natural ecosystems

This region is a convergence zone for ecosystems that are characteristic of the north coast, western slopes and Sydney Basin. Large areas of the coast, escarpment and sandstone plateaux are protected in the Barrington Tops, Yengo, Wollemi, Myall Lakes and other national parks. Extensive areas on the lowlands have been cleared and much of the remaining vegetation in these areas is fragmented. The region contains several estuaries and large lake systems including Wallis Lake, Port Stephens and Lake Macquarie. The Hunter Estuary Wetlands (Kooragang Nature Reserve and Shortland Wetland) and Myall Lakes are of international significance (Ramsar sites) and Barrington Tops National Park forms part of the Gondwana Rainforests of Australia World Heritage Area.

Expected regional climatic changes

Temperatures are virtually certain to rise

Average daily maximum temperatures are virtually certain to increase in all seasons. The greatest increases are projected to occur in spring and winter (2.0–3.0°C) and the smallest in summer (1.0–1.5°C). Average daily minimum temperatures are very likely to increase by 1.5–3.0°C, with the greatest warming occurring in the east.

Rainfall is likely to decrease in winter and increase in summer

The region is likely to experience a slight to moderate decrease in rainfall in winter, particularly in the west. Rainfall is projected to increase in other seasons, particularly in summer. In spring, a slight to moderate increase in rainfall is likely throughout the region, while in autumn a slight increase in rainfall is likely in the north. However, changes in weather patterns that cannot be resolved by the climate models mean that rainfall in coastal regions is difficult to simulate.

Increased evaporation is likely in all seasons

Evaporation during spring is likely to increase substantially throughout the region. Slight to moderate increases are also likely in summer and autumn. In winter, evaporation is likely to increase moderately in the north-east, but decrease slightly in the south-west of the region.

The impact of the El Niño–Southern Oscillation is likely to become more extreme

Our current understanding of how climate change may influence major drivers of climate variability such as the ENSO phenomenon is limited (PMSEIC 2007). However, current scientific literature indicates that the pattern of climate variability associated with ENSO will continue under enhanced greenhouse conditions. This assessment assumes that the ENSO phenomenon will continue to drive climatic variability across NSW. It is noted, however, that ENSO is a weaker influence on annual average rainfall in coastal areas than in inland areas.

This assessment assumes that ENSO years will continue to be drier than average but also become hotter, leading to more extreme impacts. La Niña years are likely to continue to be wetter than average but will also become warmer. In El Niño events, water stress is likely to be more intense because of higher temperatures.

Summary: Projected temperature and rainfall changes in the Hunter region to 2050				
Season	Minimum temperatures	Maximum temperatures	Precipitation	Evaporation
Spring	2.0–3.0°C warmer	2.0–3.0°C warmer	5–20% increase	20–50% increase
Summer	2.0–3.0°C warmer in the east 1.5–2.0°C warmer in the west	1.0–1.5°C warmer	10–50% increase	10–20% increase
Autumn	2.0–3.0°C warmer in the east 1.5–2.0°C warmer in the west	1.5–2.0°C warmer	5–10% increase	5–20% increase
Winter	2.0–3.0°C warmer in the east 1.5–2.0°C warmer in the west	2.0–3.0°C warmer	5–20% decrease	10–20% increase in the north-east 0–10% decrease in the south-west

Examples of projected climate change in the Hunter region by 2050

1. Cessnock

The current average daily maximum temperature in summer is 29.4°C. This is very likely to increase to between 30.4°C and 30.9°C.

The current average rainfall over summer is 248 mm. This is likely to increase to between 273 mm and 371 mm.

The current average rainfall over winter is 129 mm. This is likely to decrease to between 103 mm and 122 mm.

2. Newcastle

The current average daily maximum temperature in summer is 24.9°C. This is very likely to increase to between 25.9 and 26.4°C.

The current average rainfall over summer is 269 mm. This is likely to increase to between 296 mm and 404 mm.

The current average rainfall over winter is 270 mm. This is likely to decrease to between 243 mm and 270 mm.

3. Jerrys Plains

The current average daily maximum temperature in summer is 30.8°C. This is very likely to increase to between 31.8°C and 32.3°C.

The current average rainfall over summer is 226 mm. This is likely to increase to between 248 mm and 339 mm.

The current average rainfall over winter is 121 mm. This is likely to decrease to between 97 mm and 115 mm.

Expected physical responses

Sea level is virtually certain to rise

This study assumed a sea level rise of 0.4 m above the 1990 mean sea level by 2050 and a 0.9 m rise by 2100, consistent with the A2 emissions scenario adopted (see Section 2.2 for details).

Increased evaporation is likely to lead to drier conditions in autumn and winter

Increased evaporation and projected changes in rainfall are likely to result in drier conditions in the north of the region during autumn and winter.

A minor increase in annual run-off is projected as a result of substantial increases in summer run-off

A minor increase in total annual run-off is about as likely as not. Substantial increases in run-off depths and the magnitude of high flows are very likely in summer as a result of projected changes in rainfall, and current levels of low flows are likely to be slightly less frequent. A minor increase in run-off depths is about as likely as not in autumn, but a minor decrease is likely in winter and spring. The average modelled changes in run-off are shown in Figure 5.1 with the range of projected changes in Table 5.1.

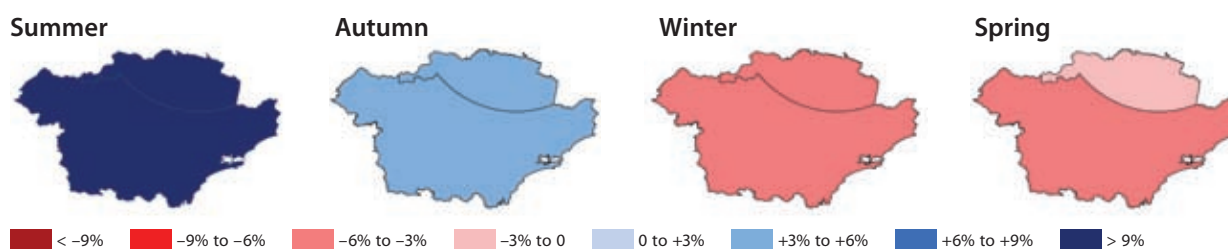


Figure 5.1 Estimated four-model mean percentage change in seasonal run-off for the Hunter region for projected 2030 climatic conditions¹

Short-term hydrological droughts are projected to become more severe, while medium and long-term droughts are projected to become less severe

Estimates of the change in total run-off during short drought periods range from 12% drier to 30% wetter compared to historical conditions. The corresponding estimates for medium drought periods range from 10% drier to 20% wetter, and for long periods range from 5% drier to 15% wetter. The average of the four modelled results indicates that short-duration droughts are about as likely as not to become more severe, and medium and long-term droughts are about as likely as not to be less severe.

Flooding behaviour is likely to change

The combination of rising sea levels and catchment-driven flooding is likely to increase flood frequency, height and extent in lower portions of coastal floodplains. Increases in the intensity of flood-producing rainfall events are likely to change flood behaviour everywhere, but catchment conditions at the time of each rainfall event (soil moisture conditions and levels in major water storages) will affect the degree of change.

Fire regimes are likely to change, but changes to fuel availability are uncertain

Higher temperatures and changes to rainfall patterns will more likely than not lead to increased fire frequency towards the year 2050, but the return period of fires is considered likely to remain within the current domain of acceptable fire intervals of 5–30 years across the majority of the region. Wetter forests, including rainforests that currently experience little or no fire, could be affected by an increase in fire activity under future conditions of increased fire danger. Fire dangers in the region currently peak in spring and summer and no major change is expected.

Historically, the coastal areas of the region experience an average of 10 very high to extreme fire risk days a year, while inland areas have between 10 and 15 a year. Very high to extreme fire danger days are projected to increase by 10–50% and the conditions conducive to large and intense fires (such as prolonged drought, low humidity, number of days with high temperature and high wind speeds) will more likely than not increase.

Future change in fuel availability is the least certain of all the factors that drive fire. Projected decreases in available moisture will possibly reduce fuel availability; however, projections of fuel availability are presently regarded as highly speculative.

¹ Run-off projections are for 2030, rather than 2050, as they are based on an existing study (Vaze *et al.* 2008). The 2030 projections are considered indicative of the direction and magnitude of hydrological changes by 2050 (see Section 2.3 and Appendix A for further details).

Table 5.1 Modelled changes in run-off in the Hunter region

Period	Run-off depths		Range of projected change	Magnitude of high flows		Frequency of occurrence of current levels of low flows	
	Magnitude ¹ and direction of projected changes	Degree of agreement ²		Magnitude ¹ and direction of projected changes	Degree of agreement ²	Magnitude ¹ and direction of projected changes	Degree of agreement ²
Spring	Minor decrease	Likely	-9% to +6%	Slight decrease	Very likely	Slight increase	About as likely as not
Summer	Substantial increase	Very likely	+6% to +18%	Substantial increase	Very likely	Slight decrease	Likely
Autumn	Minor increase	About as likely as not	-6% to +17%	Moderate increase	Likely	Slight decrease	About as likely as not
Winter	Minor decrease	Likely	-15% to +9%	Slight decrease	Likely	Slight increase	About as likely as not
Annual	Slight increase	About as likely as not	-3% to +14%	N/A	N/A	N/A	N/A

Changes in run-off depths and stream flows were estimated using results from each of the four GCMs selected for this assessment. Run-off projections are for 2030, rather than 2050, as they are based on an existing study (Vaze *et al.* 2008). The 2030 projections are considered indicative of the direction and magnitude of hydrological changes by 2050 (see Section 2.3.3 and Appendix A for further details).

The range of the estimates and their degree of agreement are presented in this table.

Notes:

1 The magnitude of the average of the changes from the four GCMs (see Box 4.1 for definitions)

2 The degree of agreement between the four GCMs in terms of the direction of change (see Box 4.1 for definitions)

N/A Not applicable (not modelled)

Regionally significant impacts

The climate changes and physical responses described above are expected to result in the following impacts on land, settlements and natural ecosystems.

Impacts on land

The major impact on the coastline is likely to be from sea level rise and resulting inundation and shoreline recession, including erosion of coastal dunes. Erosion is also likely to increase on the steeper slopes of the hinterland, with shedding of substantial quantities of sediment. The organic content of soils is likely to increase, but many soil problems such as acidification, salinity and mass movement are likely to become worse.

Rising sea level is virtually certain to increase coastal recession

Sea level rises combined with storms are virtually certain to increase coastal inundation and erosion events, causing permanent recession of the erodable coastline, typically of 20–40 m by 2050 and 45–90 m by 2100, but possibly outside this range depending on local factors. Impacts will be locally intensified or reduced by changes in factors such as rainfall patterns, storm intensities and frequencies, river flows, and wind and wave action. Shoreline retreat is very likely to be higher in estuaries and on beaches with lower gradients, particularly where the ocean breaks through or washes over coastal dunes. Seawalls behind beaches, while protecting the area landward, can cause the loss of sandy recreational areas unless beach replenishment programs are put in place. Erosion is virtually certain to affect sandy beaches along the whole Hunter coast.

Coastal dune erosion and soil decline are likely to increase

Coastal dunes are stabilised against wind erosion by specialised vegetation in what is a hostile environment for most plants, with low nutrient levels, low structural stability and high leaching. Wind erosion and nutrient leaching on dunes are likely to increase. The barrier dunes and back-barrier flats behind many of the region's beaches, e.g. Stockton Beach, are likely to come under increasing pressure from the interaction of sea level rise and soil decline.

Saltwater from sea level rise is very likely to affect subsoils on coastal plains

Increases in saline incursions into certain coastal plain subsoils are extremely likely as a result of sea level rise. Saline water is likely to intrude locally into currently fresh groundwater, triggering the need for review of current management of fresh groundwater supplies.

The agricultural capability of soils of the region's coastal plains is likely to come under increasing threat from major changes in soil hydrology due to sea level rise. Saline incursions, changes in the character of acid sulfate soils, soil structural decline, losses of organic matter and nutrients, and increased waterlogging all pose threats to the region's agricultural viability. Some abandonment of previously viable lands will be required, regardless of attempts to mitigate the changes through infrastructure developments.

Increased sheet, rill and gully erosion due to higher rainfall is likely to induce sediment inundation in coastal floodplains

Projected higher rainfall in most seasons is likely to substantially increase sheet, rill and some types of gully erosion on the steeper hinterland areas, resulting in more sediment shedding and sediment inundation in the coastal floodplains of affected catchments. Areas that are highly vulnerable to erosion include the volcanic soils of the Merriwa Plateau, the cleared steeper slopes of the Barrington Tops massif, and disturbed soils surrounding the region's coal mines. Rehabilitated mine spoil dumps are likely to come under pressure from a change in the character of erosion processes. Declines in soil moisture, particularly in winter, are likely to reduce deep drainage and therefore some gully erosion caused by seepage flows, but this effect is likely to be offset by reductions in stabilising vegetation.

Sediment inundation of the coastal and hinterland floodplains is likely to reduce the agricultural viability of some floodplains in a similar way to the impacts of the 1955 flood on the lower Hunter River, when previously productive floodplain soils were covered by thick deposits of sand.

Mass movement of soils in localised areas is likely to continue

An increased risk of mass movement is likely in all currently vulnerable slopes in coastal hinterlands because of higher rainfall in most seasons. Reduced run-off in winter, leading to less water in soil profiles, has the potential to mitigate mass movement, but localised events are still likely. Freeze–thaw effects at higher elevations (e.g. Barrington Tops) are likely to decline because of warmer winter minimum temperatures, leading to greater slope stability in these areas.

River banks and channels are likely to become less stable

Stream bank erosion and channel stability are likely to be affected by changes in run-off to streams, changes in bank-stabilising vegetation and higher watertables in lower floodplain areas. The channels and banks of the lower Hunter River are likely to be destabilised by rising sea levels.

Acidification is likely to increase in the drier western parts of the region

Most coastal soils in the region have acid subsoils, but most pastures and native vegetation are adapted to these conditions. In lower rainfall areas to the west of the coastal catchments (e.g. the upper Hunter), soils are likely to come under increased threat from acidification as increased spring, summer and autumn rainfalls intensify leaching.

Problems of acid sulfate soils are likely to increase in the short term but decrease in the longer term

Acid sulfate soils (ASS) are a recognised problem on the Hunter coastal plain. They are restricted to low-lying coastal floodplains, estuaries and back-barrier flats, especially where imposed drainage has occurred. In the longer term, as sea level rises and more ASS are inundated, problems are likely to ease. In the shorter term, seasonal changes in soil hydrology are likely to exacerbate ASS problems in localised areas.

Sodic soils are likely to be under increased risk of erosion

Sodic soils are highly erodible. The impacts of higher rainfall volumes in the region will depend on local groundwater interactions, but increases in rainfall intensity are likely to impact most adversely on sodic soils. Higher rain-splash impacts in spring and summer are likely to reduce structure on unprotected soil surfaces.

Dryland salinity problems are more likely than not to increase

Dryland salinity is a major degradation issue in the central Hunter Valley, particularly associated with basal Sydney Basin rocks. Watertable fluctuations can exacerbate dryland salinity problems. Changes to hydrological conditions are likely to influence the mobilisations of salts in areas where salinity currently occurs. The likely increase in rainfall will cause greater salt mobilisation, and the greater seasonality of rainfall will cause the salts to be concentrated.

Organic matter in soils is likely to increase in most areas, but decline in coastal swamps

Organic matter in soils is important in maintaining structure and nutrient availability for plants. Several factors influence the accumulation of organic matter in soil, including the rate of accumulation of leaf litter and debris, the activity of soil micro-organisms, soil moisture and erosion. In general, higher CO₂ concentrations, temperatures and rainfall are likely to increase biomass production in almost all coastal areas. This increase is likely to lead to rises in organic matter accumulation and soil carbon levels, provided extra inputs are not offset by higher decomposition rates or lost through burning. Likely exceptions are those coastal swamps that lose organic matter as a consequence of sea level rise and saltwater incursion.

Impacts on soils are likely to be complicated by changes in land use

The probable effects of ancillary changes in land management induced by climate change are uncertain. It is not possible to adequately model these management changes but it is critical to recognise their potential to modify impacts.

Sea level rise and flooding are likely to affect Aboriginal cultural heritage values

The Hunter region includes a variety of sites, places and objects that are culturally significant to Aboriginal people, including stone artefacts, ceremonial sites, middens, grinding grooves and fish traps. Sea level rise and storm surge are likely to result in the loss of or damage to middens and other coastal sites. Flooding is likely to result in damage to inland sites.

Impacts on settlements

Settlements adjacent to estuaries and beaches are likely to be most vulnerable. Low-lying areas adjacent to these features are likely to flood more frequently with a resulting reduction in the protection provided by some existing management measures such as levees.

Rising sea level is virtually certain to increase the threat of erosion to many settlements near estuaries and beaches

Settlements on low-lying floodplains and those near estuaries are vulnerable to seawater intrusion and beach recession. Developed sand spits that lie between the ocean and estuaries are extremely likely to be at increased risk of breaching from the combined effect of sea level rise and more intense rainfall. Built assets extremely likely to be affected include dwellings, outbuildings, stormwater infrastructure, roads and sewerage infrastructure.

Community assets, residential property and associated infrastructure are virtually certain to be at risk from inundation or recession

Although only a few places in the region have development at risk from sea level rise, some dwellings, commercial premises, caravan parks, surf clubs, beachfront roads and associated infrastructure are likely to be threatened by sea level rise in 2050. Areas include Stockton, Jimmys, Blueys and Boomerang beaches. Other areas with assets at risk include Middle Camp,

Caves, Blacksmiths, Nine Mile, Redhead, Fingal and Boat Harbour beaches. Beachfront dwellings are likely to be at risk across the region with a 0.9 m sea level rise. Estuaries with settlements vulnerable to sea level rise include the Manning River, Lake Macquarie, Port Stephens, Lower Myall, Wallis Lake and the Hunter River.

Most property boundaries referenced to the high water mark will change

An important consequence of sea level rise is that beachfront or waterfront property boundaries referenced to the mean high water mark are virtually certain to move inland over time.

Existing coastal protection structures are extremely likely to be affected

Engineered structures currently protect a broad mix of high-density residential, commercial and public assets and infrastructure at beaches. These structures will need to be assessed against the changing physical conditions to determine risk profiles and the need for upgrading.

Existing port and boating facilities are virtually certain to be affected

As sea level rises, redesign and dredging of the Hunter River entrance works and the port facilities are virtually certain to be necessary to maintain the operations of this port. Fishing ports and trained river entrances in the Hunter region are also virtually certain to require modification, together with many boat ramps, jetties and wharves within estuaries and lakes.

Urban streams are likely to flood more frequently

Local government flood studies in Newcastle and Lake Macquarie have identified many urban areas that are currently exposed to flooding with an average frequency of once every 100 years. The intensity of flood-producing rainfall events is likely to increase, particularly in shorter duration storms. This impact is of particular concern for urban streams where brief storms cause significant damage. Urban streams often have flash flooding where flood warnings are not feasible, and only severe-weather warnings are possible. Increases in flood-producing rainfall intensities due to climate change are likely to increase the rate of rise of floodwaters and increase the danger to people from flash floods.

Sea level rise is virtually certain to exacerbate flooding on the coast

Settlements in the region often lie at entrances to rivers and on coastal lakes, and consequently are vulnerable to both flooding from the catchment and inundation from sea level rise (as indicated in Box 5.1). Climate change impacts on flooding, and consequent implications for settlements, are likely to vary greatly between locations because flood behaviour is modified by local terrain and man-made structures such as roads, embankments, bridges and culverts. In some low-lying areas of the coast, flooding may also be influenced by beach-entrance berms, which are in turn affected by sea level and likely to respond differently in individual cases. Four of the region's trained river or lake entrances and one coastal lake currently rely on entrance management policies to deal with inundation.

Some levees are likely to become less effective at protecting townships from floods

The region has over 200 km of levees and control embankments. Changes in flood-producing rainfall events are likely to reduce the protection provided by some existing mitigation works, resulting in increases in the frequency of damage and the need for evacuation.

Water supplies are likely to be affected by hydrological changes

The effects of changes in catchment run-off on water consumers are uncertain because run-off projections span a wide range. If the drier end of the range eventuates, opportunities for pumping water from streams will decrease and towns with smaller water storages will suffer inflow reductions of 5–10% during drier periods.

The risk of saline incursion into groundwater is likely to increase as a result of rising water levels in the ocean and estuaries. Water supply from the lower Hunter River and the Tomago sand beds is likely to be affected. Lower reaches of rivers and creeks and groundwater supplies that are currently used for farm irrigation are likely to become increasingly saline as sea level rises, and this salinity is likely to limit opportunities for irrigation.

Box 5.1 Examples of areas vulnerable to flooding in the Hunter region

The areas likely to be most susceptible to flooding are those around the coastal lakes (for example, Lake Macquarie and Wallis Lake), the Port Stephens foreshore and the lower portion of the urban floodplains (for example, Throsby and Cottage creeks in Newcastle). Urban streams around Newcastle and Lake Macquarie already suffer severe damage in brief storms. For example, the June 2007 flood resulted in nine fatalities and is reported to have caused more than \$2 billion in damage in Newcastle and the Central Coast. In low-lying areas such as Throsby and Cottage creeks, even a small change in flow can increase flood depths and consequent damage. On Lake Macquarie – a lake heavily influenced by ocean level – a high range sea level rise would cause the number of properties affected by flooding to increase almost six-fold by 2100, with damages increasing 31-fold. For Wallis Lake, the number of properties affected is likely to treble and damages increase 7-fold by 2100. The impact of sea level rise will be lower on the Port Stephens foreshore because of the relatively steep land gradients around much of the foreshore, particularly nearer the entrance. Key infrastructure likely to be affected includes Newcastle port facilities and low-lying roads at Lake Macquarie, Port Stephens and Wallis Lake. On many coastal lakes, low-lying sewerage infrastructure is at risk, with potential for consequent water pollution.

Impacts on ecosystems

Low-lying coastal ecosystems, including those on foreshores, are at risk from sea level rise and changes in catchment hydrology. Increased temperatures, changes to hydrology and altered fire regimes are likely to impact on ecosystems across the region, particularly highly cleared and fragmented forests and woodlands and ecosystems at higher altitudes.

Sea level rise is likely to threaten some estuarine communities

Sea level rise and shoreline retreat are likely to induce a large-scale modification or loss of intertidal and subtidal communities. Conditions such as turbidity, pH, temperature and salinity are likely to change. The Hunter region has large areas of seagrasses, mangroves and salt marshes, with the most significant sites at Wallis Lake, Lake Macquarie, Port Stephens, Karuah and the Hunter River. Seagrasses are likely to be displaced from some of their current extent and their ability to re-colonise is difficult to predict. Some stands of mangroves and salt marshes are also likely to be displaced from their current locations, but new mangrove habitat is likely to form in other places. Salt marsh is slow to colonise and its establishment in new habitats is likely to be limited by the rapidity of sea level rise and increased rates of sediment deposition. Species composition of these communities is also likely to change in response to altered environmental conditions. It is virtually certain that re-establishment of

estuarine habitats will be impeded in some places by infrastructure and development, such as that near the entrance to the Hunter River. The composition and distribution of invertebrate communities on mudflats are also likely to change.

Some fish species are likely to decline

Estuaries provide important nurseries for fish stocks. The likely loss of saltwater wetlands due to increasing sea level has the potential to adversely affect the estuarine food web and could result in a decline in population numbers of some fish species. Protected fish species already at risk of decline, such as the estuary cod and Queensland groper, are likely to be particularly vulnerable. If ASS run-off increases this is likely to cause more frequent and severe fish kills. The geographic range of some species is also likely to change with increasing temperatures and changes in estuarine salinity.

Climate change is likely to reduce shorebird habitat and reduce shorebird numbers

The extensive salt marshes, sand flats and mudflats in the Hunter region provide important roosting and foraging habitats for a suite of shorebirds, including some species that migrate seasonally to other parts of the world. Estuaries that have international significance for shorebirds include Lake Macquarie (1,000–3,000 waders), the Hunter River (7,000–10,000 waders) and Port Stephens, which form part of the East Asian–Australasian Flyway. Refuges for shorebirds are being reduced globally by human activities along migratory routes. As sea levels rise, the loss of foraging and nesting habitats is likely to place increased pressure on already endangered shorebirds.

The rise in sea level is likely to alter ecosystems on shores and coastal lowlands

Inundation and erosion of the fore-dunes are likely to impact on coastal freshwater lagoons, maritime grasslands (strandline spinifex) and forested wetlands on the shoreline and along estuaries. Lowland ecosystems in the coastal zone are likely to be affected by rising watertables. In permeable substrates such as sand plains, salt water intruding into watertables is likely to raise water levels. The saltwater table is likely to rise and push fresh water upwards, increasing the amount of fresh water at or near the surface. In lower parts of the landscape, salt water is likely to approach or reach the surface. These physical changes in watertables are virtually certain to alter the vegetation in affected areas. Ecosystems are likely to undergo changes as species adapted to the new conditions establish and others die off. For example, in areas that become more saline, freshwater species are likely to be replaced by species adapted to brackish conditions. Communities that re-establish in affected areas are extremely likely to contain a lower diversity of species than the communities they replace, particularly in the more isolated areas. Ecosystems affected by these changes in watertables are likely to include littoral rainforest, lowland subtropical rainforest, coastal heath swamps, wallum sand heaths, coastal swamp forests, coastal floodplain wetlands and coastal-dune dry sclerophyll forest. Significant freshwater-dependent ecosystems in the region that are likely to be affected include freshwater and forested wetlands and wet heath in Myall Lakes National Park.

Higher temperatures, altered hydrology and altered fire regimes are likely to cause major changes

Higher temperatures, altered fire regimes and altered hydrology (with wetter summers and drier winters) are likely to bring about changes to many ecosystems including changes to structure, species composition and species abundances. Ecosystems most at risk include high altitude and fire sensitive species, wetlands and those ecosystems which, due to fragmentation or isolation, have a reduced resilience to disturbance.

Specialised or localised communities are likely to be substantially reduced

Higher temperatures are likely to cause contraction of some higher altitude ecosystems, as many species within these ecosystems are unlikely to tolerate the changed conditions. For example, at Barrington Tops, cool temperate rainforest is likely to contract from the lower altitudes of its range and be replaced by subtropical rainforest. Cool temperate forest is likely to expand from the higher parts of its range with a corresponding contraction of the sub-alpine woodlands that occur at the highest points. The species composition and relative species abundances in these ecosystems are likely to change in response to changing conditions. Altered hydrology, with wetter summers and drier winters, is likely to bring about changes in species composition and abundances in many wetlands. Isolated communities such as high altitude swamps may be particularly vulnerable to species loss.

Increased temperatures are likely to reduce the range of a suite of freshwater invertebrates, some of which are endemic to the region and occur only at higher altitudes. Some species are likely to be lost altogether. Cold-water fish species such as trout are likely to contract in distribution.

Altered fire regimes are likely to cause changes in wetter ecosystems

If fire extent increases under future conditions of increased fire danger, fire sensitive ecosystems such as freshwater and forested wetlands, wet coastal heaths and dry rainforest could undergo structural and compositional changes. Changes in the fire regime are likely to compound the impacts of other climatic changes; for instance, disturbance by fire together with an increase in summer rainfall is likely to benefit weeds such as lantana.

Fire and drought are likely to reduce seed and nectar production and affect granivores and nectarivores, including pollinators

Nectar-feeding vertebrates such as honeyeaters, gliders, possums and flying foxes are important pollinators of many plants, and in turn rely on the flowering of eucalypts in the dry forests and woodlands, particularly those of the coastal plains in this region. Extensive fire and drought reduce the flowering of eucalypts, and hence impact on nectarivores. Such environmental conditions are likely in the predicted warmer El Niño periods, threatening nectarivore populations and pollination. In many eucalypt and casuarina species, fire and drought conditions also reduce seed production, decreasing food resources for specialist granivores such as gang-gang (*Callocephalon fimbriatum*) and glossy black (*Calyptorhynchus lathamii*) cockatoos.

Climate change is likely to increase stress on fragmented and degraded ecosystems and on threatened species

Dry forest and woodland ecosystems of this region that have been extensively cleared and fragmented are likely to suffer impacts as a result of increases in temperature, changes in the fire regime and warmer El Niño periods. These ecosystems are already under substantial pressure and may have lowered resistance to climate change. Impacts are likely to include changes in species composition, loss of species diversity and changes in understorey structure. Ecosystems at risk include some dry sclerophyll forests and woodlands of the Hunter Valley floor and foothills, riparian forest and dry rainforest, many of which are currently listed in NSW as endangered ecological communities.

More subtle but widespread changes are likely for more resistant ecosystems

The more widespread biological communities within wet and dry sclerophyll forests outside the coastal lowlands are likely to be more resistant to the impacts of climate change than many others in the region. Their widespread occurrence and connectivity confer greater potential for component species to persist in climatic refuges, for genetic exchange and for species re-colonisation between patches – processes that are likely to improve the resilience of ecosystems to climate change. These forests also contain dominant elements that are adapted to more frequent fire. Nevertheless, changes are still likely to occur in these ecosystems. Species abundances and community composition and understorey structure are likely to change. Many changes are likely to occur over long time frames and may not be readily apparent by 2050.

Box 5.2 Grassy woodlands

Grassy woodlands in the Hunter region provide a significant nectar resource for fauna. The barrier formed by the Great Dividing Range is low in the western Hunter, allowing species typical of the western slopes to occur closer to the coast. The influence of coastal rainfall allows these grassy woodlands to remain productive at times when areas further west are in drought, providing a refuge for nomadic and migratory species. Changes in temperature and rainfall are likely to change the volume and duration of nectar production, with flow-on effects for migratory and nomadic nectar feeders such as honeyeaters, lorikeets and flying foxes.

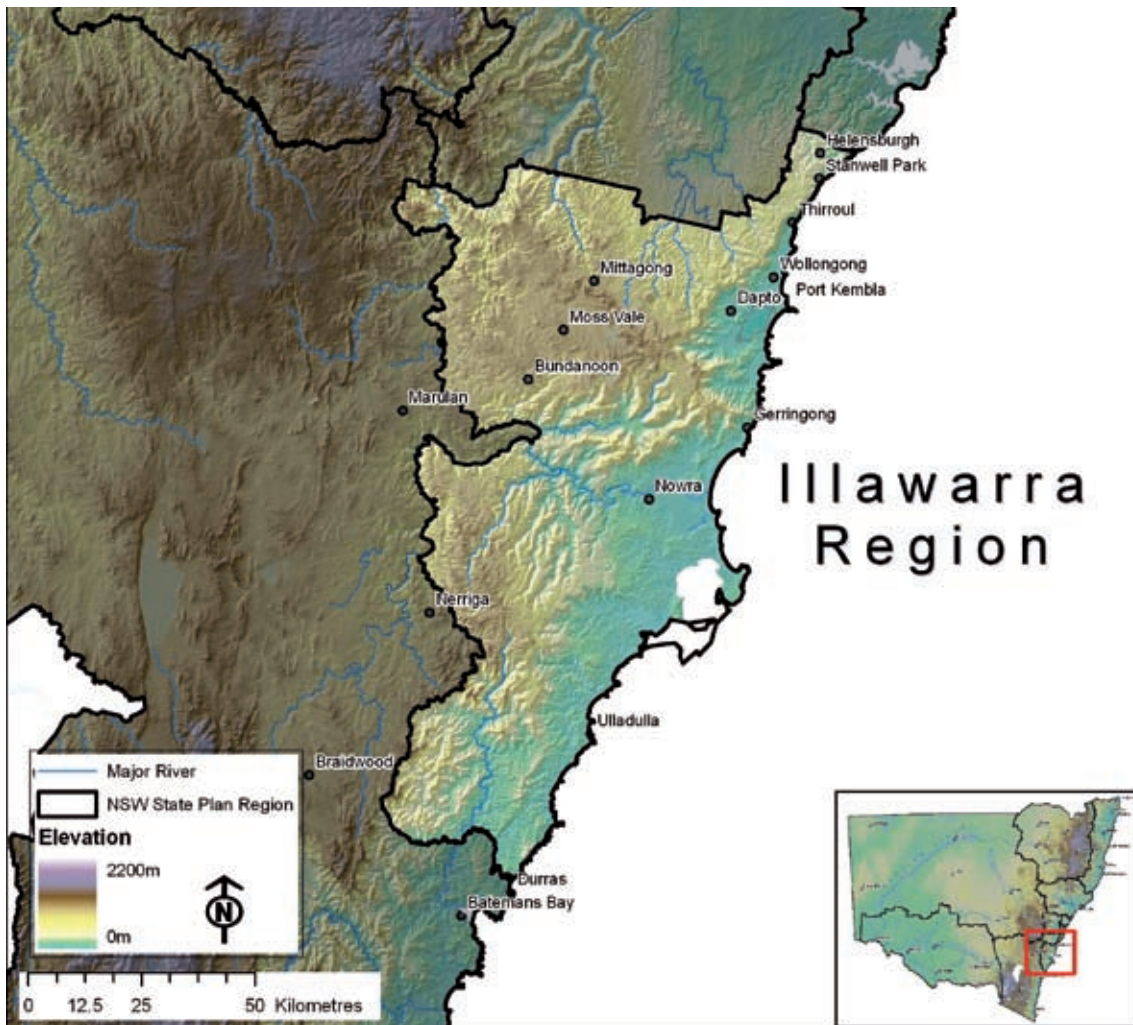
5.2 The Illawarra region

Note: The changes described in this section should be reviewed in conjunction with the terminology in Box 4.1.

- By 2050, the climate is virtually certain to be hotter, with a likely increase in rainfall, especially in summer. Winter rainfall is unlikely to change. However, changes in weather patterns that cannot be resolved by the climate models mean that rainfall in coastal regions is difficult to simulate.
- Run-off and stream flow are likely to increase in summer and autumn and decrease in spring and winter.
- Sea level is virtually certain to keep rising.
- Sea level rise is likely to affect agricultural soils in low-lying areas. Coastal dune erosion is likely to increase significantly. Soil erosion is likely to increase on steeper slopes in the upper catchments, potentially causing sedimentation on the floodplains.
- Sea level rise, coupled with increased flooding, is virtually certain to pose a risk to property and infrastructure. Developments near estuary entrances and beaches and on coastal floodplains are most vulnerable.
- Sea level rise is very likely to alter estuarine and coastal lowland ecosystems. Seasonal drying is likely to degrade freshwater wetlands and higher temperatures are likely to cause cool-adapted ecosystems to change or contract. Altered fire regimes have the potential to cause major ecological change.

Characteristics of the region

Local Government Areas: *Kiama; Shellharbour; Shoalhaven; Wingecarribee; Wollongong.*



Location and topography

The Illawarra region covers over 7,000 square kilometres with about 200 km of coastline, stretching from Garie Beach in the Royal National Park in the north to Durras Lake in the south. The region includes the Illawarra Escarpment and coastal plain, the Shoalhaven floodplain, sandstone plateaux extending from Milton to the Woronora Plateau and the fertile Southern Highlands.

Climate

The region has a mostly cool temperate climate, with an average annual rainfall slightly under 1100 mm. Rainfall is nearly uniformly distributed throughout the year with slight summer-autumn dominance. Average run-off of 310 mm is the second highest in the state. The highest rainfall occurs to the east of the steep escarpment, south of Wollongong, with an average annual rainfall of over 1600 mm. Lower evaporation in autumn and winter results in substantially more run-off in these seasons than during summer.

Settlements and industry

The city of Wollongong and regional centres at Shellharbour and Nowra are important bases for commercial and residential development in the region. International shipping and trade are facilitated through the major seaport of Port Kembla. Tourism and primary industries such as dairying, forestry and fisheries provide an economic base for towns like Kiama, Gerringong, Mittagong and Milton/Ulladulla.

Natural ecosystems

The natural ecosystems of the region tend to be concentrated along the escarpment and sandstone plateaux. Major reserves in the region include Morton and Jervis Bay national parks. The sandstone plateaux are largely covered in dry sclerophyll forest, though rainforest and tall eucalypt forest occur along the Illawarra escarpment and in sheltered gorges. Smaller patches of heath and upland swamps are interspersed among the dry forests. Saline wetlands are found in all of the major estuaries, particularly the Crookhaven River. Freshwater wetlands occur around the margins of coastal lakes, on coastal sand plains and on the floodplains of the major rivers such as the Shoalhaven. The estuaries of the region comprise rivers such as the Shoalhaven River, coastal lakes varying in size from the large Lake Illawarra to the small Meroo Lake, and numerous creeks, many rising on the steep escarpment.

Expected regional climatic changes

Temperatures are virtually certain to rise

Both minimum and maximum daily temperatures are very likely to increase by 1.5–3.0°C throughout the region. The increase is projected to be greatest in spring, autumn and winter.

Summer rainfall is likely to increase substantially

The region is likely to experience a substantial increase in summer rainfall and a slight to moderate increase in spring and autumn rainfall. There is no significant trend in rainfall projections for winter. However, changes in weather patterns that cannot be resolved by the climate models mean that rainfall in coastal regions is difficult to simulate.

Increased evaporation is likely in all seasons

Evaporation is likely to increase by up to 50% in spring and summer as a result of increased temperatures. Slight to moderate increases in evaporation are likely in autumn and winter.

The impact of the El Niño–Southern Oscillation is likely to become more extreme

Our current understanding of how climate change may influence major drivers of climate variability such as the ENSO phenomenon is limited (PMSEIC 2007). However, current scientific literature indicates that the pattern of climate variability associated with ENSO will continue under enhanced greenhouse conditions. This assessment assumes that the ENSO phenomenon will continue to drive climatic variability across NSW. It is noted, however, that ENSO is a weaker influence on annual average rainfall in coastal areas than in inland areas.

This assessment assumes that ENSO years will continue to be drier than average but also become hotter, leading to more extreme impacts. La Niña years are likely to continue to be wetter than average but will also become warmer. In El Niño events, water stress is likely to be more intense because of higher temperatures.

Summary: Projected temperature and rainfall changes in the Illawarra region to 2050

Season	Minimum temperatures	Maximum temperatures	Precipitation	Evaporation
Spring	2.0–3.0°C warmer	2.0–3.0°C warmer	Up to 20% increase	10–50% increase
Summer	2.0–3.0°C warmer	1.5–2.0°C warmer	Up to 50% increase	20–50% increase
Autumn	2.0–3.0°C warmer	2.0–3.0°C warmer	Up to 20% increase	10–20% increase
Winter	2.0–3.0°C warmer	2.0–3.0°C warmer	No significant change	5–20% increase

Examples of projected climate change in the Illawarra region by 2050

1. Wollongong

The current average daily maximum temperature in summer is 25.3°C. This is very likely to increase to between 26.8°C and 27.3°C.

The current average rainfall over summer is 363 mm. This is likely to increase to up to 545 mm.

The current average rainfall over winter is 272 mm. This is likely to remain unchanged.

2. Nowra

The current average daily maximum temperature in summer is 25.5°C. This is likely to increase to between 27.0°C and 28.5°C.

The current average rainfall over summer is 285 mm. This is likely to increase to up to 427 mm.

The current average rainfall over winter is 224.6 mm. This is likely to remain unchanged.

3. Bowral

The current average daily maximum temperature in summer is 24.5°C. This is likely to increase to between 26.0°C and 26.5°C.

The current average rainfall over summer is 244 mm. This is likely to increase to up to 366 mm.

The current average rainfall over winter is 200 mm. This is likely to remain unchanged.

Expected physical responses

Sea level is virtually certain to rise

This study assumed a sea level rise of 0.4 m above the 1990 mean sea level by 2050 and a 0.9 m rise by 2100, consistent with the A2 emissions scenario adopted (refer to Section 2 for details).

Increased evaporation is likely to lead to drier conditions in spring and winter

Projected increases in temperature and evaporation, combined with projected changes to rainfall, are likely to result in drier soil conditions in winter and spring.

Run-off is likely to decrease moderately in spring but increase substantially in summer

Average annual run-off will about as likely as not increase slightly and some redistribution in run-off across the seasons is likely. A moderate decrease in run-off is likely in spring, whereas a substantial increase is likely in summer. The average of modelled changes in run-off are shown in Figure 5.2 and detailed (including the range of projected changes) in Table 5.2.

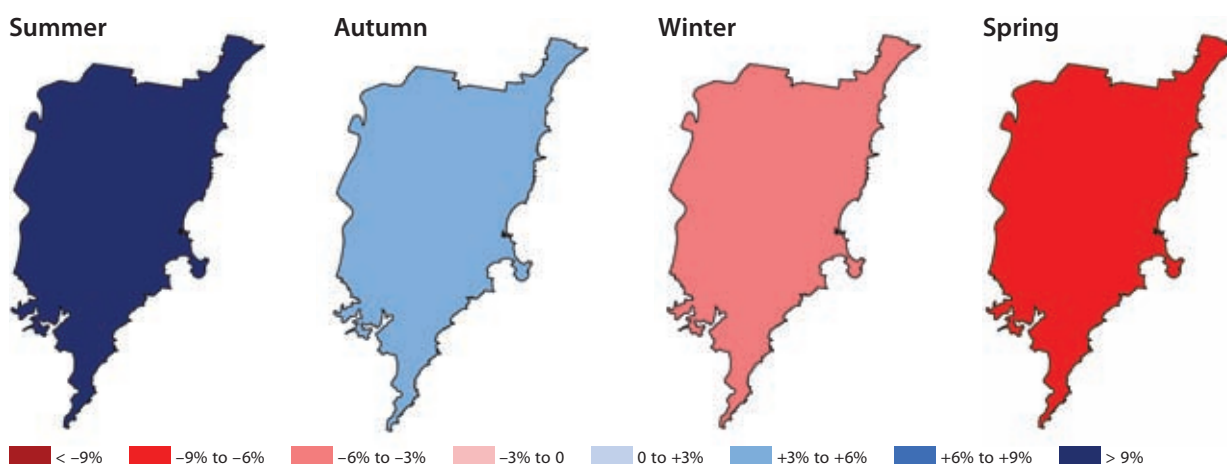


Figure 5.2 Estimated four-model mean percentage change in seasonal run-off for the Illawarra region for projected 2030 climatic conditions²

Short-term hydrological droughts are projected to become more severe, while medium and long-term droughts are projected to become less severe

Estimates of the change in total run-off during short-term drought periods range from 15% drier to 15% wetter compared to historical conditions. The corresponding estimates for medium to long-term drought periods range from 10% drier to 15% wetter, and for long drought periods range from 10% drier to 10% wetter. The average of the four modelled results indicates that short-duration droughts are about as likely as not to become more severe, and medium and long-term droughts are about as likely as not to be slightly less severe.

² Run-off projections are for 2030, rather than 2050, as they are based on an existing study (Vaze *et al.* 2008). The 2030 projections are considered indicative of the direction and magnitude of hydrological changes by 2050 (see Section 2.3 and Appendix A for further details).

Flooding behaviour is likely to change

The combination of rising sea levels and catchment-driven flooding is likely to increase flood frequency, height and extent in the lower portions of coastal floodplains. Increases in the intensity of flood-producing rainfall events are likely to change flood behaviour everywhere, but catchment conditions at the time of each rainfall event (soil moisture conditions and levels in major water storages) will affect the degree of change.

Fire regimes are likely to change, but changes to fuel availability are uncertain

Higher temperatures and changes to rainfall patterns will more likely than not lead to increased fire frequency towards the year 2050, but the return period of fires is considered likely to remain within the current domain of acceptable fire intervals of 10–30 years across the majority of the region. Wetter forests, including rainforests that currently experience little or no fire, will more likely than not be affected by an increase in fire activity under future conditions of increased fire danger. Fire dangers in the region currently peak in spring and summer and no major change is expected.

Historically, the near coastal and higher mountain areas of the region experience an average of fewer than 10 very high to extreme fire risk days a year, while inland areas have between 10 and 15 a year. Very high to extreme fire danger days are projected to increase by 10–50% and the conditions conducive to large and intense fires (such as prolonged drought, low humidity, number of days with high temperature and high wind speeds) will more likely than not increase.

Future change in fuel availability is the least certain of all the factors that drive fire. Projected decreases in available moisture will possibly reduce fuel availability; however, projections of fuel availability are presently regarded as highly speculative.

Table 5.2 Modelled changes in run-off in the Illawarra region

Period	Run-off depths		
	Magnitude ¹ and direction of projected changes	Degree of agreement ²	Range of projected change
Spring	Moderate decrease	Likely	–16% to +1%
Summer	Substantial increase	Likely	–1% to +28%
Autumn	Minor increase	About as likely as not	–6% to +17%
Winter	Minor decrease	Likely	–11% to +3%
Annual	Slight increase	About as likely as not	–8% to +8%

Changes in run-off depths and stream flows were estimated using results from each of the four GCMs selected for this assessment. Run-off projections are for 2030, rather than 2050, as they are based on an existing study (Vaze *et al.* 2008). The 2030 projections are considered indicative of the direction and magnitude of hydrological changes by 2050 (see Section 2.3.3 and Appendix A for further details).

The range of the estimates and their degree of agreement are presented in this table.

Notes:

- 1 The magnitude of the average of the changes from the four GCMs (see Box 4.1 for definitions)
- 2 The degree of agreement is based on the number of GCMs (out of four) which agree with the direction of projected average change (see Box 4.1 for definitions)

Regionally significant impacts

The climate changes and physical responses described are expected to result in the following impacts on land, settlements and natural ecosystems.

Impacts on land

Sea level rise will inundate and erode parts of the coastline. Changes in rainfall are likely to increase sediment shedding from the hinterland and cause bank erosion and other changes in stream channels. Problems of acid sulfate soils are likely to lessen in the longer term.

Rising sea level is virtually certain to increase coastal recession

Sea level rise and storms are virtually certain to increase coastal inundation and erosion causing additional recession of the erodable coastline, typically of 20–40 m by 2050 and 45–90 m by 2100, but could fall outside this range depending on local factors. Impacts will be locally intensified or reduced by changes in other factors such as rainfall patterns, storm intensities and frequencies, river flows, and wind and wave action. Shoreline retreat is very likely to be greater in estuaries and on beaches with lower gradients, particularly where the ocean breaks through or washes over coastal dunes. Seawalls behind beaches, while protecting the area landward, can cause the loss of sandy recreational areas unless beach replenishment programs are put in place. Erosion is virtually certain to affect sandy beaches along the whole Illawarra coast.

Increased sediment shedding due to higher rainfall is likely to change river channels and cause sediment inundation in coastal floodplains

Changes in the character of all forms of soil erosion are likely to increase the vulnerability of the region to major erosion and river channel changes during wetter periods. The very steep slopes in the hinterland of the region are already highly vulnerable to erosion, and increased sediment shedding from these slopes is expected. This shedding is likely to cause channel changes and sediment inundation in coastal floodplains. Major rises in summer rainfall could increase the existing vulnerability of areas in Wollongong's hinterland to significant mass movement.

Stream bank erosion is likely to increase; vulnerable rivers include the Shoalhaven and Kangaroo rivers

Increased rainfall in summer and more intense storms are likely to lead to increased run-off to streams in the summer months, producing stream bank erosion, particularly where greater flow is coupled with higher watertables in lower floodplain areas and declines in bank-stabilising vegetation. The most vulnerable streams in the region are likely to be the larger, unregulated tributaries of the Shoalhaven River, as well as the Kangaroo River upstream of Lake Yarrunga. Highly productive lands such as the Kangaroo Valley are likely to come under extra pressure from erosion and stream bank instability, exacerbated by lower levels of stabilising vegetation in this predominantly agricultural landscape. These changes are likely to increase sediment delivery to Lake Yarrunga.

Acid sulfate soil problems are likely to continue in the short term but reduce over the longer term

The acid sulfate soils (ASS) of the lower Shoalhaven floodplain are likely to continue to shed acid, but this effect will probably ameliorate over time. It is likely that initial rises in sea level will cause saline waters to inundate some areas with ASS, leading to a structural decline of the soil. Over time, successive flood events down the Shoalhaven River, coupled with a continuing rise in sea level, should lead to progressive inundation of parts of the floodplain, resulting in an improvement in ASS in the area.

Organic matter in soils is likely to increase in most areas, but decline in some coastal swamps

Organic matter in soils is important in maintaining soil structure and nutrient availability for plants. Several factors influence the accumulation of organic matter in soil, including the rate of leaf litter and debris accumulation, the activity of soil micro-organisms, soil moisture and erosion. In general, higher CO₂ concentrations, temperatures and rainfall are likely to increase biomass production in almost all coastal areas. This increase should lead to rises in organic matter accumulation and soil carbon levels, provided extra inputs are not offset by higher decomposition rates or lost through burning. Likely exceptions are those coastal swamps that lose organic matter as a consequence of sea level rise and saltwater incursion.

Sea level rise, flooding and increased rainfall are likely to affect Aboriginal cultural heritage values

The Illawarra region includes a variety of sites, places and objects that are culturally significant to Aboriginal people, including rock art, middens, and grinding grooves. Sea level rise, flooding and increased rainfall are likely to result in the loss of or damage to middens and other coastal sites.

Impacts on settlements

Settlements near estuaries and beaches are vulnerable to sea level rise and resulting inundation and erosion. Increases in heavy downpours are also likely to affect flooding risks, particularly on urban streams. The risk of some levees being overwhelmed is likely to increase.

Sea level rise is virtually certain to threaten many settlements near estuaries and beaches

Many developed sections of coastline in the region are virtually certain to be threatened by either ocean inundation or coastline recession. By 2050, many dwellings, unit developments, commercial premises, registered clubs, caravan parks, surf clubs and a sewage treatment facility are likely to be at risk between Mollymook and Thirroul. Estuaries where parts of settlements are vulnerable to sea level rise include Towradgi Creek and Fairy Creek (Wollongong suburbs), Lake Illawarra (Windang and Warilla), Elliot Lake (Warilla and Shellharbour), the Shoalhaven River (Shoalhaven Heads and Orient Point), St Georges Basin (Sussex Inlet), Swan Lake (Swanhaven and Cudmirrah), Lake Conjola, Burrill Lake and Tabourie Lake. Built assets within these settlements that are extremely likely to be vulnerable include buildings, roads and stormwater and sewerage infrastructure.

Most property boundaries referenced to the high water mark will change

An important consequence of sea level rise is that beachfront or waterfront property boundaries referenced to the mean high water mark are virtually certain to move inland over time.

Existing coastal protection structures are extremely likely to be affected

Engineered structures currently protect some residential development. These structures will need to be assessed against the changing physical conditions to determine risk profiles and the need for upgrading.

Major roads and other infrastructure are very likely to be affected

Major roads such as the Princes Highway are currently affected by flooding from time to time at low-lying locations such as Ulladulla (via Millards Creek), Burrill Lake and Tabourie Lake. Roads to towns such as Cudmirrah, Berrara and Bawley Point are also vulnerable in several places. Flood risks are very likely to increase with increasing water levels.

Sewerage infrastructure including pumping stations is likely to be threatened at a number of locations. Sewerage infrastructure known to be currently at risk is located at Corrimal East, Towradgi, Gerringong and Gerroa.

Many boat ramps, jetties and wharves are likely to be affected by sea level rise, in turn affecting industries such as commercial fishing and tourism. The NSW Government maintains five fishing ports and one trained river entrance in the Illawarra region, all of which are likely to be impacted by sea level rise.

Flooding from urban streams is likely to increase

Local government has reported that parts of the Wollongong urban area are currently exposed to potential flooding in a storm that occurs on average once every 100 years. Climate change is likely to increase rainfall intensities, particularly during short storms. Of particular concern are the urban streams around Wollongong, where such storms cause significant damage (e.g. the 1998 flood). Increased flow in urban streams flowing from the steep escarpment is likely to result in more frequent flash flooding which is likely to pose an increased safety risk to the community.

Sea level rise is virtually certain to increase flooding risks near the coast

The areas where flooding is likely to be exacerbated by sea level rise are generally those around the coastal lakes (e.g. Lake Illawarra and St Georges Basin) and in the lower portions of the urban floodplains (e.g. Towradgi Creek in the area below the Princes Highway). Climate change impacts on flooding, and consequent implications for settlements, are likely to vary greatly between locations because flood behaviour is modified by local terrain and man-made structures such as roads, embankments, bridges and culverts. Around Lake Illawarra – a lake heavily influenced by ocean level – projected rises to 2100 are likely to increase the number of properties affected by flooding almost three-fold, with damages rising eight-fold. The same rise is likely to lead to a 60% increase in the number of properties affected by flooding around St Georges Basin and near Towradgi Creek. These areas are likely to suffer lower impact because less development is exposed to the changes. On the coast, particularly below the tidal limit, the ways in which river and estuary entrances change with sea level rise are likely to affect flooding characteristics. Three trained entrances and a further 10 lakes and lagoons in the region have entrance management strategies that reduce flood impacts.

The combined effects of sea level rise, increased flood flows and higher watertables are likely to cause saline waters to inundate some agricultural coastal plains. Agriculture on some low-lying areas such as parts of the lower Shoalhaven River floodplain is likely to become unsustainable.

Some levees are likely to become less effective at protecting townships from floods

Levees provide some protection from flooding for areas behind them such as the Riverview Road near Nowra. The Shoalhaven Council states that it manages over 20 km of levees. Changes in flood-producing rainfall are likely to reduce the protection provided by the existing works, resulting in increases in the frequency of damage and the need for evacuation.

Water supplies are likely to be affected by hydrological changes

If future run-off is at the drier end of the range of estimates, pumping from streams will be possible less often and inflows to water storages are likely to decrease by 5–10% during drier periods. This will have most impact on towns with small storages.

A more detailed study looking specifically at the potential impacts of climate change on Sydney's water supply and demand is currently underway. This study, being conducted as part of the Sydney Metropolitan Water Plan, covers all of Sydney's hydrological catchment, which encompasses the Illawarra region. The study will take into account local conditions in drinking water catchments, as well as projected customer demand, under climate change scenarios.

Impacts on ecosystems

Ecosystems on foreshores are likely to be affected by coastal recession and rising waters, and other low-lying coastal ecosystems are at risk from saltwater intrusion into watertables and up-river systems. Increased temperatures and altered fire regimes are also likely to impact on ecosystems across the region. Highly cleared and fragmented ecosystems such as those on the Illawarra coastal plain are likely to be at greater risk than more intact ecosystems.

Sea level rise is likely to threaten coastal ecosystems

Rising watertables and saltwater intrusion are likely to affect lowland ecosystems in the coastal zone. Saline intrusion is likely to eliminate salt-intolerant vegetation in areas near the present tidal limit such as some of the freshwater and forested wetlands on the Shoalhaven floodplain and the Minnamurra River. In permeable substrates such as sand plains, salt water intruding into watertables is likely to push fresh water upwards, increasing freshwater volumes at or near the surface. Salt water is likely to approach or reach the surface in lower parts of the landscape, converting freshwater ecosystems into types adapted to more saline conditions. Ecosystems that establish in affected areas are extremely likely to contain a reduced structural complexity and diversity of species, particularly in more fragmented landscapes. Affected ecosystems are likely to include coastal swamp forests, coastal floodplain wetlands, wallum sand heaths, littoral rainforest, coastal heath swamps and coastal-dune dry sclerophyll forest. Lowland forests and heathlands contain flowering trees and shrubs that are important to nectarivores and insectivores such as honeyeaters, flying foxes, micro-bats and arboreal mammals such as pygmy possums. Migratory honeyeaters that rely on winter nectar supplies from a narrow strip of coastal forest between Batemans Bay and Jervis Bay are likely to be adversely affected.

Sea level rise is likely to threaten some estuarine communities

Sea level rise and shoreline retreat are likely to induce a large-scale modification or loss of intertidal and subtidal ecosystems as water depth, turbidity, sedimentation, pH, temperature and salinity change. The region has large areas of seagrasses, mangroves and salt marshes at such sites as the Crookhaven and Minnamurra rivers, Jervis Bay, St Georges Basin and Lake Illawarra, and smaller estuaries such as Tabourie Lake and Towradgi Creek also have significant seagrass beds. Seagrasses are likely to be displaced from some of their current extent and their ability to re-colonise is difficult to predict. Mangroves and salt marshes are also likely to be displaced but new mangrove habitat should form in other places, including areas currently occupied by salt marsh. Salt marsh is slow to colonise however, and its establishment in new habitats is likely to be limited by the rapidity of sea level rise and increased rates of sediment movement. Changes in the species composition of estuarine invertebrate communities are likely to adversely affect estuarine food webs and result in declines in some fish populations. It is virtually certain that re-establishment of estuarine ecosystems will be impeded by infrastructure and development in some places, such as the Wollongong region.

Climate change is likely to reduce migratory shorebird habitat and populations

Rock platforms, sand spits, mudflats and salt marshes provide important foraging and nesting areas for a suite of shorebirds, including some species that migrate seasonally along the East Asian–Australasian Flyway. Estuaries in the region such as the Shoalhaven River, Sussex Inlet, Jervis Bay, the Ulladulla coastline and Lake Wollumboola are of international significance for shorebirds. Many migratory shorebirds have already declined because of habitat modification along migratory routes and climate change is likely to exacerbate this trend.

Altered fire regimes are likely to cause widespread changes in many ecosystems

An increase in more intense or extensive fires is likely to cause contraction of the most fire-sensitive ecosystems. Rainforest and wet sclerophyll forests are unlikely to be extensively affected where protected by features such as the mesic escarpment, but are likely to contract around their edges elsewhere. Even in fire-adapted ecosystems, more severe fires can cause subtle but widespread changes in species composition and vegetation structure. Altered fire regimes can influence litter depth and structure, litter breakdown by invertebrates and decomposition by microbes, plant regeneration and recruitment and fauna populations, with relatively immobile species being particularly at risk. Numbers of hollow-bearing trees, important for many mammals and birds, are likely to be reduced. Changes in fire regimes are likely to interact with the effects of other climatic factors. For example, opening of the canopy by fire, together with warmer temperatures and wetter summers, are likely to advantage weeds such as lantana.

Highly fragmented ecosystems are likely to come under added pressure from climate change

The forests and grassy woodlands of the Illawarra Plain are highly fragmented and some are listed as endangered ecological communities. Edge effects, arson, weeds and lack of recruitment are the main factors threatening these ecosystems. Climate change is likely to exacerbate these existing impacts, with increased temperatures creating harsher microclimates at ecosystem edges.

5.3 The North Coast region

Note: The changes described in this section should be reviewed in conjunction with the terminology in Box 4.1.

- By 2050, the climate is virtually certain to be hotter, with rainfall increasing in summer and decreasing in winter. However, changes in weather patterns that cannot be resolved by the climate models mean that rainfall in coastal regions is difficult to simulate.
- Run-off and stream flow are likely to increase in summer and autumn and decrease in spring and winter.
- Sea level is virtually certain to keep rising.
- Soil erosion is likely to increase on steeper slopes in the upper catchments, potentially causing sedimentation on the floodplains. Gully erosion is likely to ease.
- Sea level rise is virtually certain to pose a major risk to property and infrastructure. Developments closest to the shore and on sand spits are most at risk. Increases in brief, heavy rainfalls are expected to increase the likelihood of flooding along urban streams. Towns on coastal plains and near estuaries are likely to suffer additional risk of flooding.
- Sea level rise is virtually certain to have a substantial impact on estuarine and foreshore ecosystems. Sea level rise, increased temperatures and changes in hydrology and fire regimes are likely to have a substantial impact on terrestrial and freshwater ecosystems. Vulnerable ecosystems include saline wetlands, low-lying coastal ecosystems and fragmented forests and woodlands in the hinterland.

Characteristics of the region

Local Government Areas: *Ballina; Bellingen; Byron; Clarence Valley; Coffs Harbour; Greater Taree; Hastings; Kempsey; Kyogle; Lismore; Nambucca; Richmond Valley; Tweed.*

Location and topography

The North Coast region covers an area of 37,000 square kilometres and extends from the coast to the escarpment of the Great Dividing Range, incorporating 585 km of coastline from Tweed Heads on the Queensland border south to Hallidays Point. The natural environment varies from coastal sand dunes, major estuaries and floodplains, through low foothills and ranges, to the very steep hinterland of the Great Dividing Range.

Climate

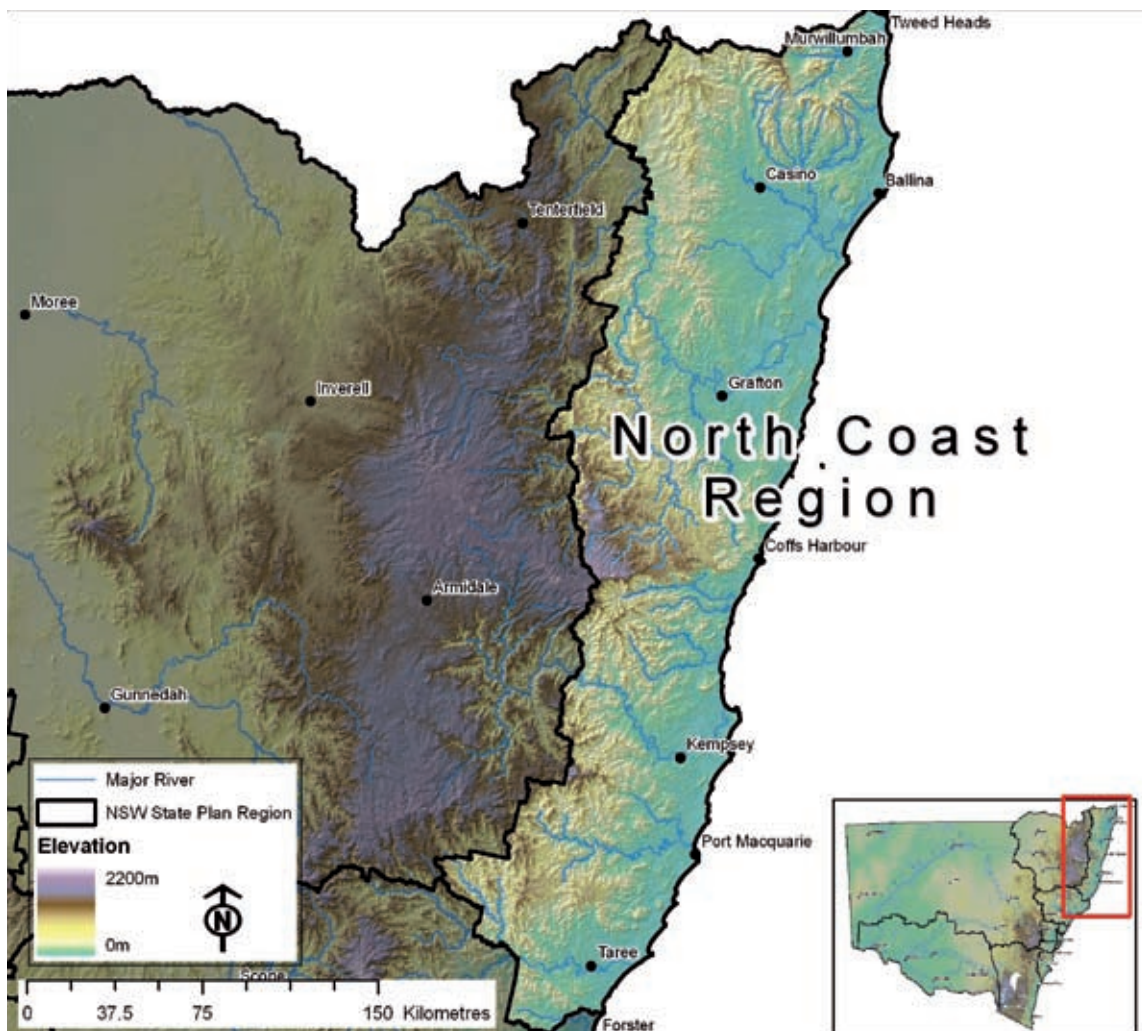
The climate varies from subtropical on the coast, through subhumid on the slopes to temperate in the western uplands. The region is the wettest in NSW, with an average annual rainfall of over 1200 mm that peaks in summer and early autumn and is lowest in winter and spring. The far north-east of the region has an average annual rainfall above 2000 mm. The seasonal pattern of run-off differs slightly from that of rainfall because evaporation rates are highest in spring and summer. The greatest run-off occurs in autumn, followed by summer, winter and spring.

Settlements and industry

The region includes the centres of Tweeds Heads, Ballina, Lismore, Grafton, Coffs Harbour, Port Macquarie and Taree. The coastal area supports a mixture of intensifying residential and tourist development, with one of the fastest growing populations in NSW. Primary industries such as agriculture, forestry and fisheries provide an important economic base.

Natural ecosystems

The North Coast is one of the most biologically diverse regions in NSW. Natural ecosystems are relatively well conserved, with close to one-fifth of the region protected within national parks, mainly on the coast and escarpment. However, clearing has been extensive on many parts of the coast and the river floodplains. The region contains World Heritage areas: the Lord Howe Island Group, and parts of the Gondwana Rainforests of Australia. It also includes the Clarence River, which is the largest coastal river in NSW.



Expected regional climatic changes

Temperatures are virtually certain to rise

Average daily maximum temperatures are virtually certain to increase in all seasons. The smallest increases are projected to occur in summer (1.0–1.5°C) and the greatest in winter (2.0–3.0°C). Average daily minimum temperatures are projected to increase by 2.0–3.0°C in all seasons.

Rainfall is likely to increase in summer and autumn

Spring rainfall is not expected to change. Summer and autumn rainfalls are expected to increase slightly, while winter rainfall is expected to decrease slightly. However, changes in weather patterns that cannot be resolved by the climate models mean that rainfall in coastal regions is difficult to simulate.

Increased evaporation is likely in all seasons

Evaporation is likely to increase moderately throughout the region during spring, summer and autumn. A slight to moderate increase in evaporation is likely in winter.

The impact of the El Niño–Southern Oscillation is likely to become more extreme

Our current understanding of how climate change may influence major drivers of climate variability such as the ENSO phenomenon is limited (PMSEIC 2007). However, current scientific literature indicates that the pattern of climate variability associated with ENSO will continue under enhanced greenhouse conditions. This assessment assumes that the ENSO phenomenon will continue to drive climatic variability across NSW. It is noted, however, that ENSO is a weaker influence on annual average rainfall in coastal areas than in inland areas.

This assessment assumes that ENSO years will continue to be drier than average but also become hotter, leading to more extreme impacts. La Niña years are likely to continue to be wetter than average but will also become warmer. In El Niño events, water stress is likely to be more intense because of higher temperatures.

Summary of temperature and rainfall changes in the North Coast region to 2050				
Season	Minimum temperatures	Maximum temperatures	Precipitation	Evaporation
Spring	2.0–3.0°C warmer	1.5–2.0°C warmer	No change	10–20% increase
Summer	2.0–3.0°C warmer	1.0–1.5°C warmer	5–20% increase	10–20% increase
Autumn	2.0–3.0°C warmer	1.5–2.0°C warmer	5–10% increase	10–20% increase
Winter	2.0–3.0°C warmer	2.0–3.0°C warmer	5–10% decrease	5–20% increase

Examples of projected climate change in the North Coast region by 2050

1. Murwillumbah

The current average daily maximum temperature in summer is 29.0°C. This is very likely to increase to between 30.0°C and 31.0°C.

The current average rainfall over summer is 556 mm. This is likely to increase to 611 mm.

The current average rainfall over winter is 218 mm. This is likely to decrease to between 196 mm and 207 mm.

2. Taree

The current average daily maximum temperature in summer is 28.9°C. This is very likely to increase to between 29.9°C and 30.9°C.

The current average rainfall over summer is 348 mm. This is likely to increase to between 365 mm and 417 mm.

The current average rainfall over winter is 203 mm. This is likely to decrease to between 183 mm and 193 mm.

Expected physical responses

Sea level is virtually certain to rise

This study assumed a sea level rise of 0.4 m above the 1990 mean sea level by 2050 and a 0.9 m rise by 2100 consistent with the A2 emissions scenario (refer to Section 2 for details).

Increased evaporation is likely to lead to drier conditions for most of the year

Despite projected increases in rainfall in summer and autumn, soil conditions are likely to be drier for most of the year, particularly in spring and winter, as a result of increased temperatures and evaporation.

Average annual run-off will about as likely as not increase slightly as a result of substantial increases in summer run-off

Substantial increases in run-off depths and the magnitude of high flows are very likely in summer. A moderate decrease in run-off depths is likely in spring. The average of modelled changes in run-off are shown in Figure 5.3, and listed with the range of projected changes in Table 5.3.

Short-term hydrological droughts are likely to become more severe

Estimates of total run-off during short-term drought periods range from 30% drier to 10% wetter compared to historical conditions. The corresponding estimates for medium to long-term periods range from 15% drier to 15% wetter. The average of the four modelled results indicates that short-duration droughts are likely to become more severe, and medium and long-term droughts will about as likely as not remain similar to current conditions.

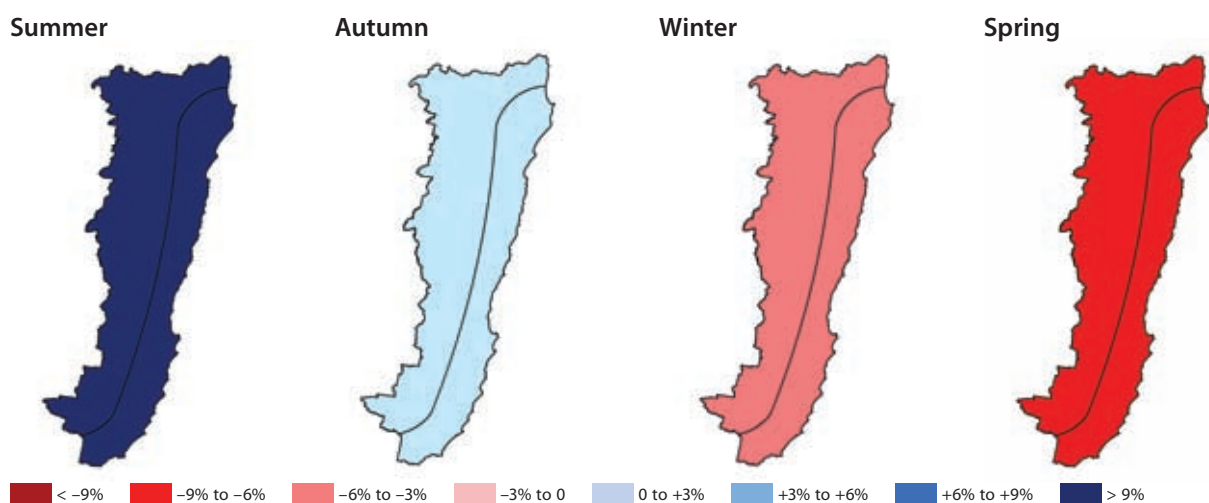


Figure 5.3 Estimated four-model mean percentage change in seasonal run-off for the North Coast region for projected 2030 climatic conditions³

Flooding behaviour is likely to change

The combination of rising sea levels and catchment-driven flooding is likely to increase flood frequency, height and extent in the lower portions of coastal floodplains. Increases in the intensity of flood-producing rainfall events are likely to change flood behaviour everywhere, but catchment conditions at the time of each rainfall event (soil moisture conditions and levels in major water storages) will affect the degree of change.

Fire regimes are likely to change, but changes to fuel availability are uncertain

Higher temperatures and changes to rainfall patterns will more likely than not lead to increased fire frequency towards the year 2050, but the return period of fires is considered likely to remain within the current domain of acceptable fire intervals of 5–30 years across the majority of the region. Wetter forests, including rainforests that currently experience little or no fire, could be affected by an increase in fire activity under future conditions of increased fire danger. Fire dangers in the region currently peak in spring and summer and an extension into late winter is possible.

Historically, the coast and higher mountains of the region experience an average of less than 10 very high to extreme fire risk days a year, while inland areas have between 10 and 15 a year. Very high to extreme fire danger days are projected to increase by 10–50% and the conditions conducive to large and intense fires (such as prolonged drought, low humidity, number of days with high temperature and high wind speeds) will more likely than not increase.

Future change in fuel availability is the least certain of all the fire hazard indicators. Projected decreases in available moisture will possibly reduce fuel availability; however, projections of fuel availability are presently regarded as highly speculative.

³ Run-off projections are for 2030, rather than 2050, as they are based on an existing study (Vaze *et al.* 2008). The 2030 projections are considered indicative of the direction and magnitude of hydrological changes by 2050 (see Section 2.3 and Appendix A for further details).

Table 5.3 Modelled changes in run-off in the North Coast region

Period	Run-off depths			Magnitude of high flows			Frequency of occurrence of current levels of low flows	
	Magnitude ¹ and direction of projected changes	Degree of agreement ²	Range of projected change	Magnitude ¹ and direction of projected changes	Degree of agreement ²	Magnitude ¹ and direction of projected changes	Degree of agreement ²	
Spring	Moderate decrease	Likely	-13% to +4%	Substantial decrease	Likely	Moderate decrease	Likely	
Summer	Substantial increase	Very likely	+5% to +18%	Substantial increase	Likely	No change	Likely	
Autumn	Slight increase	About as likely as not	-11% to +18%	Slight increase	Likely	Slight decrease	About as likely as not	
Winter	Minor decrease	Likely	-17% to +8%	Slight decrease	Likely	Moderate decrease	Likely	
Annual	Slight increase	About as likely as not	-8% to +14%	N/A	N/A	N/A	N/A	

Changes in run-off depths and stream flows were estimated using results from each of the four GCMs selected for this assessment. Run-off projections are for 2030, rather than 2050, as they are based on an existing study (Vaze *et al.* 2008). The 2030 projections are considered indicative of the direction and magnitude of hydrological changes by 2050 (see Section 2.3.3 and Appendix A for further details).

The range of the estimates and their degree of agreement are presented in this table.

Notes:

1. The degree of agreement is based on the number of GCMs (out of four) which agree with the direction of projected average change (see Box 4.1 for definitions)
 2. The degree of agreement between the four GCMs in terms of the direction of change (see Box 4.1 for definitions)
- N/A Not applicable (not modelled)

Regionally significant impacts

The climate changes and physical responses described above are expected to result in the following impacts on land, settlements and natural ecosystems.

Impacts on land

Sea level rise and resulting inundation and shoreline recession are likely to have major impacts on the coastline. Significant increases in saline incursions into coastal plain subsoils are likely to make agriculture on some low-lying lands unsustainable. Erosion is likely to increase on the steeper slopes in the upper catchments, potentially causing sedimentation on the floodplains and adversely affecting agriculture. The reduced net water balance in winter and spring is likely to reduce the risk of gully expansion, but mass movement is likely to increase in all currently vulnerable slopes in coastal hinterlands because of slightly higher summer and spring rainfalls. Potential higher biomass accumulations should help organic matter build-up and hence nutrient-storage potential. However, this change is likely to be offset by higher leaching, acidification and salinity changes in local areas.

Rising sea level is virtually certain to increase coastal recession

Sea level rise and storms are likely to increase coastal inundation and erosion, causing recession of the erodible coastline, typically of 20–40 m by 2050 and 45–90 m by 2100 but could be outside this range depending on local factors. Impacts will be locally intensified or reduced by changes in other factors such as rainfall patterns, storm intensities and frequencies, river flows, and wind and wave action. Shoreline retreat is very likely to be higher in estuaries and on beaches with lower gradients, particularly where the ocean breaks through or washes over coastal dunes. Seawalls behind beaches, while protecting the area landward, can cause the loss of sandy recreational areas unless beach replenishment programs are put in place. Increased erosion is virtually certain to affect sandy beaches along the whole North Coast.

Wind erosion is likely to continue on coastal dunes

Wind erosion in the region is generally a problem only in coastal dunes. Many dune systems in the region will continue to be vulnerable to wind erosion, particularly if beach-barrier systems are breached by sea level rise. Erosion of dunes is likely to be governed by a complex interplay of higher storm intensity in summer and autumn, promotion of dune vegetation by heavier summer rainfall, and inhibition of vegetation by increased nutrient leaching and water erosion.

Saline incursion into subsoils is likely on the coastal plains

It is unclear how changes in climate will affect dryland salinity in the region, although expected reductions in net water balance and increased seasonality of rainfall have the potential to concentrate salts. Significant increases in saline incursions into coastal-plain subsoils are likely as a result of sea level rise, leading to the loss of agricultural productivity in many low-lying areas.

Higher rainfall is likely to increase sheet and rill erosion, leading to increased sedimentation of coastal floodplains

Higher summer rainfall and rainfall intensity in the region are likely to increase sheet and rill erosion on the steeper slopes of the hinterland. Sediment inundation of coastal and hinterland floodplains is likely where major erosion occurs. Significant channel alteration on coastal rivers is more likely than not.

Gully erosion is likely to decrease, and mass movement of soil to increase in localised areas

Expected declines in run-off in spring and winter are likely to reduce seepage flows and hence activity of some forms of gully erosion, although this change will be offset where stabilising vegetation declines. Higher summer and autumn rainfalls are likely to increase the risk of mass movement in all currently vulnerable slopes in the hinterlands, but negative water balances may offset this effect through reduced water content in soil profiles.

Problems of acid sulfate soils are likely to continue in the short term but reduce over the longer term

The widespread acid sulfate soils (ASS) of the region's coastal floodplains are likely to continue to shed acid as a result of increased seasonality of rainfall, but this effect will probably ameliorate over time. It is likely that initial rises in sea level will cause saline waters to inundate some areas with ASS, leading to a structural decline of the soil. Over time, successive flood events down the coastal rivers, coupled with a continuing rise in sea level, should lead to progressive inundation of parts of the floodplains, generally reducing ASS risk.

Organic matter in soils is likely to increase in most areas, but decline in some coastal swamps

Organic matter is important in maintaining soil structure and nutrient availability for plants. Several factors influence the amount of organic matter in soil, including the rate of accumulation of leaf litter and debris, the activity of soil micro-organisms, soil moisture and erosion. In general, higher CO₂ concentrations, temperatures and rainfall are likely to increase biomass production in almost all coastal areas. This increase should lead to organic matter accumulation if extra inputs are not offset by higher decomposition rates or lost through burning. Likely exceptions are those coastal swamps that lose organic matter as a consequence of sea level rise and saltwater incursion.

Sea level rise and changes to soils are likely to have implications for agriculture

The agricultural capability of the soils of the region's coastal plains is likely to come under increasing threat from major changes in sea level rise and other factors. Saline incursions, changes in the character of ASS, soil structural decline, losses of organic matter and nutrients, and increased waterlogging all have the potential to impact on the viability of agriculture. Sedimentation of floodplains could also reduce agricultural viability in the manner exemplified by the 1955 flood on the lower Hunter River, when previously productive floodplain soils were covered by thick deposits of sand. Lower reaches of rivers and creeks and some groundwaters that are currently used for farm water supplies are likely to become increasingly saline, restricting irrigation practices. Extensive coastal floodplains used for production of sugar cane are at risk, and some previously viable agricultural land is likely to be abandoned, regardless of attempts to mitigate change with infrastructure developments.

Sea level rise and flooding are likely to affect Aboriginal cultural heritage values

The North Coast region includes a variety of sites, places and objects that are culturally significant to Aboriginal people, including ceremonial sites, burial sites, fish traps, and stone and ochre quarries. Sea level rise, flooding and increased rainfall are likely to result in the loss of or damage to middens and other coastal sites.

Impacts on settlements

Sea level rise and resulting erosion are likely to have substantial impacts on coastal settlements, beaches, coastal rivers and estuaries in the region. Residential and commercial property and public infrastructure will be affected. Salt water penetrating further upstream is likely to limit farm irrigation and the use of groundwater. Changes in rainfall are likely to increase flood risks on lower floodplains and flooding from urban streams and drainage systems. Some protection measures such as levees are likely to be overwhelmed more often.

Community assets, residential property and associated infrastructure are virtually certain to be threatened by coastal inundation and recession

The region contains residential and commercial beachfront developments that are vulnerable to either ocean inundation or shoreline recession. Houses, apartment buildings, tourist developments, hotels, motels, commercial premises, registered clubs, caravan parks, surf clubs, beachfront roads and other infrastructure are considered at risk by 2050. Estuaries with settlements vulnerable to sea level rise include the Tweed, Richmond, Clarence, Wooli Wooli, Bellinger, Hastings and Camden Haven.

Infrastructure that is likely to be affected as water levels rise includes fishing ports at Tweed, Ballina, Evans Head, Iluka, Yamba, South-West Rocks, Goodwin Island and Coffs Harbour, as well as the commercial shipping wharf on Goodwin Island. Many boat ramps, jetties and wharves are likely to be affected within estuaries and lakes.

Most property boundaries referenced to the high water mark will change

An important consequence of sea level rise is that beachfront or waterfront property boundaries referenced to the mean high water mark are virtually certain to move inland over time.

Urban streams are likely to flood more frequently

Local government has reported that more than 33,000 urban buildings in the region are subject to flooding with an average frequency of once every 100 years. Climate change is likely to increase rainfall intensities, particularly during shorter storms. This impact is of particular concern for urban streams where these storms cause significant damage, as in the 1996 flood in Coffs Harbour. Increased flow in urban streams is likely to result in more frequent flash flooding which is likely to pose an increased safety risk to the community. In Yamba and Iluka, increases in flood-producing rainfall would lead only to a small change in the number of properties affected by a one-in-100-year flood and the amount of damage caused. In contrast, flood risk in Mullumbimby and Casino is more sensitive to changes in the intensity of flood-producing rainfall events.

Sea level rise is virtually certain to exacerbate flooding on the coast

Many settlements in the region lie along beaches and at the entrances of rivers, lakes and lagoons. In some cases they are vulnerable to inundation caused by sea level rise, flooding from catchments and the interaction of the two, whereby rising sea levels alter river and estuary entrances, which in turn affect flood behaviour. Local terrain and man-made structures including roads, embankments, bridges, culverts and entrance training works also affect local flooding patterns. There are six coastal creeks (Belongil, Tallow, Coffs, Deep, Saltwater and Killick) and two coastal lakes (Woolgoolga and Lake Cathie) in the region that rely on berm-management and artificial opening strategies to reduce flood impacts. Future sea level rise will reduce the effectiveness of these strategies.

The degree of impact from coastal flooding will vary locally according to proximity to the shoreline and other factors. Areas in which flooding is likely to be most affected by sea level rise are generally those in the lower end of the major coastal floodplains (e.g. Lower Richmond, Lower Clarence, Lower Macleay and Lower Hastings), those on coastal creeks (e.g. Coffs Harbour, particularly below Grafton Street, and Sawtell), those draining into intermittently closed and open lakes and lagoons (e.g. Byron Bay adjacent to Belongil Creek) and those on the coast such as Ballina, Yamba and Port Macquarie. Sea level rise is unlikely to impact significantly on flood levels in areas such as Casino, Murwillumbah, Lismore and Bellingen and other areas farther upriver.

Some levees are likely to become less effective at protecting property from floods

About 200 km of levees in the region provide protection from floods to Murwillumbah, Lismore, Grafton, Maclean, Kempsey and other areas. Levees reduce the frequency of flooding but do not remove the potential of the area protected by the levee to flood. Sea level rise and changes in flood-producing rainfall events have the potential to reduce the protection given by levees, leading to more frequent overtopping and increases in damages and the need for evacuation.

Water supplies and sewerage infrastructure are at risk

If future run-off is at the drier end of the range of estimates, inflows to water storages may decrease by 10–20% during drier periods. This will have most impact on towns with small storages. Some water supplies on the coast are immediately upstream of tidal limits that are likely to move upstream as ocean levels increase (e.g. the Macleay River, where water supplies needed to be trucked during the recent drought). Low-lying sewerage systems near many coastal lakes are likely to be affected by sea level rise, with consequent water-quality risks.

Box 5.3 Examples of areas vulnerable to coastal erosion and oceanic inundation in the North Coast region

Although sea level rise will affect the entire coastline, development at various locations is already vulnerable to coastal erosion processes. Development at Byron Bay, Lennox Head, Woolli, Coffs Harbour and Old Bar is particularly vulnerable. Narrow, developed sand spits that lie between the ocean and an estuary are exposed from both sides and at risk of sudden and catastrophic breaching during storms. Assets known to be at risk now and likely to be further at risk by 2050 include the following:

- dwellings, commercial premises, a portion of the old North Coast railway line and associated infrastructure at Belongil Spit
- residential beachfront dwellings, commercial premises and associated infrastructure at Lennox Head, and
- beachfront dwellings and associated infrastructure at New Brighton, Woolli, Lake Cathie and Diamond Beach.

Parts of settlements at Fingal, Kingscliff, Cabarita, Mooball, South Golden Beach, Byron Bay Main Beach, Clarkes Beach, Evans Head, Woody Head, Yamba, Brooms Head, Woolgoolga, Campbells Beach, Town Beach, Rainbow Beach, Grants Beach, Old Bar and Wallabi Point are all likely to experience increased erosion and inundation by 2050.

Impacts on ecosystems

Rises in sea level, salinity and temperature are likely to have a substantial impact on estuarine ecosystems. Sea level rise, increased temperatures and changes in water and fire regimes are likely to substantially affect terrestrial and freshwater ecosystems. Vulnerable ecosystems include saline wetlands, low-lying coastal ecosystems and fragmented forests and woodlands in the hinterland and high altitude forest. More widespread and fire-adapted forests are likely to be relatively resistant to climate change and undergo more subtle changes.

Sea level rise is likely to alter estuarine communities

Sea level rise and shoreline retreat are likely to induce a large-scale modification or loss of intertidal and subtidal communities as water depth, turbidity, sedimentation, pH, temperature and salinity change. The region has large areas of seagrasses, mangroves and salt marshes, most notably in the estuaries of the Clarence, Macleay and Richmond rivers and in lakes Innes and Cathie. Seagrasses, mangroves and salt marshes are likely to be displaced from some current locations. The ability of seagrasses to re-colonise is difficult to predict. New mangrove habitat is likely to form in other places, including areas currently occupied by salt marsh. Some northern mangrove species are likely to colonise farther south. Salt marsh is slow to colonise and its establishment in new habitats is likely to be limited by the rapidity of sea level rise and increased rates of sediment movement. Changes in the species composition of estuarine invertebrate communities are likely.

Some fish species are likely to decline

Estuaries provide important nurseries for fish stocks. The likely loss of saltwater wetlands due to increasing sea level has the potential to adversely affect the estuarine food web and is likely to result in a decline in population numbers of some fish species. Protected fish species already at risk, such as the estuary cod (*Epinephelus coioides*) and Queensland groper

(*Epinephelus lanceolatus*), are likely to be particularly vulnerable. If ASS run-off increases this is likely to cause more frequent and severe fish kills. The geographic ranges of some species are also likely to change with increasing temperatures and changes in estuarine salinity.

Habitat loss and alteration are likely to impact on shorebirds

Estuaries in the region with international significance for shorebirds include the Tweed River (supporting 750 waders), the Clarence River (3,000 waders), the Richmond River (1,700 waders), and Sawtell, Harrington and Farquhar Inlet (important for the little tern, *Sterna albifrons*). Many migratory shorebirds are already listed as near threatened or critically endangered under the risk criteria of the International Union for the Conservation of Nature, and their habitat is in decline globally. Reductions in coastal wetlands, sand flats and mudflats are likely to further reduce the foraging and roosting habitat of shorebirds.

Sea level rise is likely to alter ecosystems on shores and coastal lowlands

Inundation and erosion of fore-dunes are likely to impact on maritime grasslands (strandline spinifex), forested wetlands on the shoreline, and coastal freshwater wetlands in areas such as The Broadwater in the Clarence catchment. Lowland ecosystems in the coastal zone are likely to be affected by rising watertables. In permeable substrates such as sand plains, salt water intruding into watertables is likely to raise water levels. The saltwater table is likely to rise and push fresh water towards the surface, increasing freshwater volumes at or near the surface. In lower parts of the landscape, salt water is likely to approach or reach the surface. These physical changes in watertables are virtually certain to alter the vegetation in affected areas. Ecosystems are likely to undergo changes as species adapted to the new conditions establish and others die off. For example, in areas that become more saline, freshwater species are likely to be replaced by those adapted to brackish conditions. Communities that re-establish in affected areas are extremely likely to contain a lower diversity of species than the communities they replace, particularly in the more isolated areas. Ecosystems affected by these changes are likely to include lowland subtropical rainforest, littoral rainforest, coastal heath swamps, wallum sand heaths, coastal swamp forests, coastal floodplain wetlands and coastal-dune dry sclerophyll forest. Significant wetlands in the region that are likely to be threatened by climate change include Everlasting Swamp and freshwater wetlands in Bundjalung National Park.

Higher temperatures, altered hydrology and altered fire regimes are likely to cause major changes

Higher temperatures, altered fire regimes and altered hydrology (with wetter summers and drier winters) are likely to bring about changes to many ecosystems including changes to structure, species composition and species abundances. Ecosystems most at risk include high-altitude and fire-sensitive species, wetlands and those ecosystems which have a reduced resilience to disturbance due to fragmentation or isolation.

High-altitude ecosystems are likely to change or contract

Increases in temperature are likely to affect the altitude of cloud cover. Moisture from clouds contributes significantly to the water budgets of high-altitude rainforests such as the cool temperate rainforest of the Border Ranges (Mount Ballow and Mount Nothofagus) and Mount Hyland Nature Reserve, and the cloud forests of Lord Howe Island. A reduction in cloud cover and misting combined with changes in seasonal rainfall and increases in temperature are likely to cause these ecosystems to contract. Some species specialising in these higher

altitude ecosystems may be unable to tolerate higher temperatures and may be lost. Cloud forest is particularly at risk as it covers no more than 300 hectares and contains many endemic species.

Altered fire regimes are likely to cause changes in wetter ecosystems

If fire extent increases under future conditions of increased fire danger, fire-sensitive ecosystems such as freshwater and forested wetlands, wet coastal heaths and dry rainforest could undergo structural and compositional changes. Changes in the fire regime are likely to compound the impacts of other climatic changes; for instance, disturbance by fire together with an increase in summer rainfall is likely to benefit weeds such as lantana.

Fragmented and degraded ecosystems are likely to have poor adaptation potential

Ecosystems that are already in decline because of other threatening processes, and those that are highly fragmented, are least likely to adapt to climate change. Such vulnerable ecosystems include lowland subtropical rainforest, littoral rainforest, dry sclerophyll forests on coastal dunes, and some grassy woodlands on the hinterland. Climate change is likely to cause major reductions in the extent of some of these ecosystems, with remaining patches at risk of substantial alteration by weeds, fire and changes in moisture levels.

More subtle but widespread changes are likely for more resistant ecosystems

The more widespread biological communities within wet and dry sclerophyll forests outside the coastal lowlands are likely to be more resistant to the impacts of climate change than many others in the region. Their widespread occurrence and connectivity confer greater potential for component species to persist in climatic refuges, for genetic exchange and for species re-colonisation between patches – processes that are likely to increase the resilience of ecosystems to climate change impacts. These forests also contain dominant elements that are adapted to more frequent fire. Nevertheless, changes are still likely to occur in these ecosystems. Understoreys are likely to become more open and simplified if the fire regime is altered. Species abundances and composition are likely to change. Many of these changes are likely to occur over longer time frames and may not be readily apparent by 2050.

Box 5.4 Impacts on low-lying subtropical rainforests on the North Coast

Past clearing has substantially reduced the extent of lowland subtropical rainforest. Remnant vegetation is listed as an endangered ecological community in the North Coast bioregion. Small, isolated pockets remain on the true lowlands, the foothills of the main ranges, and riverine alluvial islands such as Susan Island on the Clarence River, Bellingen Island on the Bellinger River and Stotts Island on the Tweed River. Sea level rise, flooding and erosion are likely to remove the lowest lying examples, further reducing the total area of this community. In places that are not inundated, warmer temperatures are likely to worsen weed infestations, which are already severe in many locations. Weeds can replace native species as a major food source for seed dispersers such as fruit-eating birds, thereby facilitating weed invasion. Low-lying subtropical rainforest is likely to undergo further structural change, functional disruption, and reduced species diversity.

5.4 The New England/North West region

Note: The changes described in this section should be reviewed in conjunction with the terminology in Box 4.1.

- By 2050, the climate is virtually certain to be hotter. Rainfall is likely to increase in all seasons except winter.
- Run-off and stream flow are likely to increase in summer and autumn and decrease in spring and winter.
- Sheet, rill and gully erosion are likely to worsen on the western slopes and plains but gully erosion on the tablelands is likely to ease on the most vulnerable soils. Soil acidification problems are likely to ameliorate on the tablelands and slopes.
- Floods are likely to increase in frequency and intensity, particularly along smaller streams. Levees are likely to be less effective at protecting towns.
- Widespread changes to natural ecosystems are likely. Highly vulnerable ecosystems include higher altitude ecosystems, inland wetlands and highly fragmented ecosystems. Plant cover is likely to decline on the drier central western slopes and plains but to increase on the warmer tablelands. Changes in the fire regime are likely to have widespread impacts.

Characteristics of the region

Local Government Areas: *Armidale; Dumaresq; Glen Innes Severn; Gunnedah; Guyra; Gwydir; Inverell; Liverpool Plains; Moree Plains; Narrabri; Tamworth Regional; Tenterfield; Uralla; Walcha.*

Location and topography

The New England/North West region covers an area of 98,600 square kilometres. It extends from Glen Innes and Armidale on the New England Tablelands in the north-east, through Inverell and Tamworth in the centre, to Moree and Narrabri on the north-western plains. The regional landscape varies from elevated inland tablelands and slopes to broad floodplains on west-flowing rivers, including the Namoi, Gwydir and Macintyre rivers.

Climate

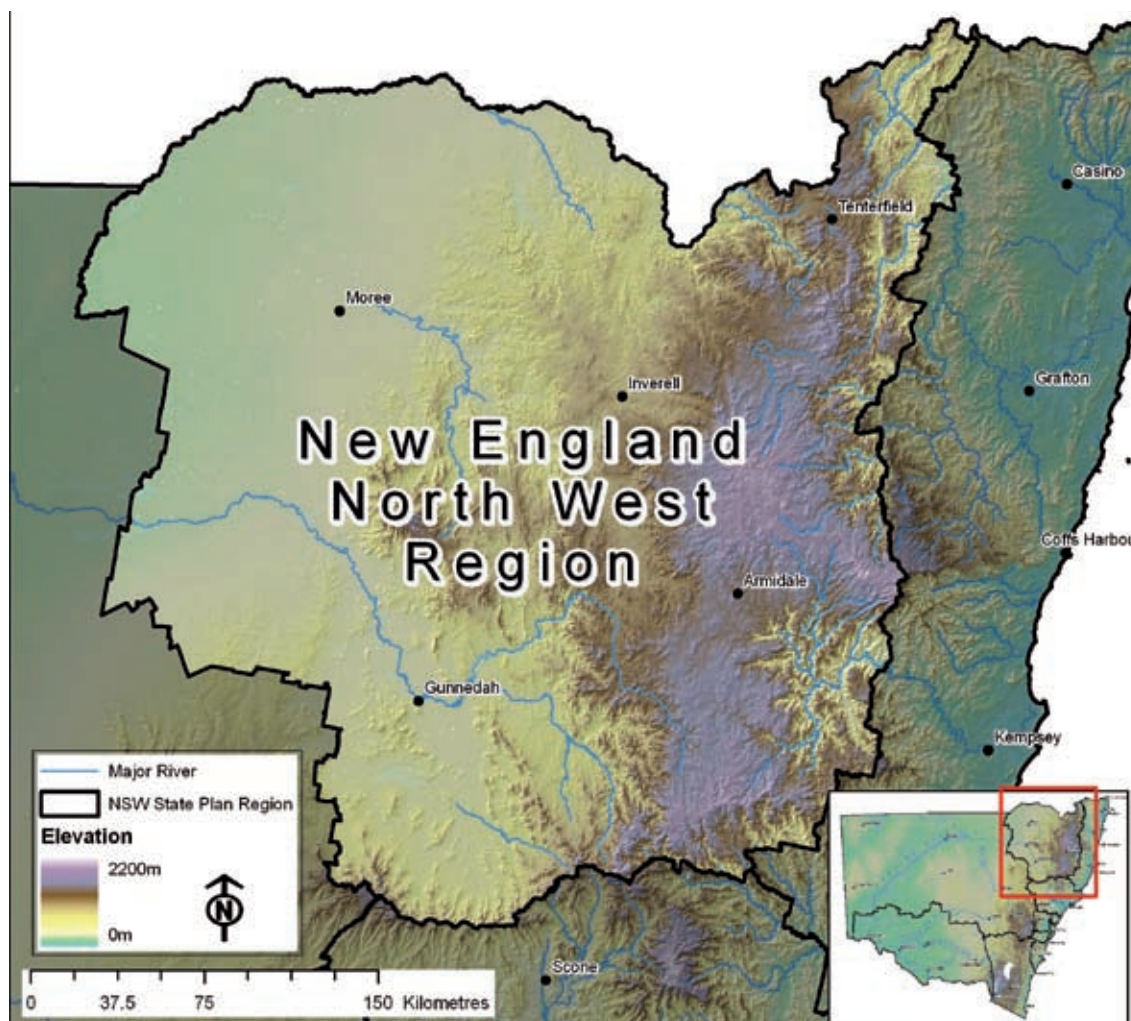
The tablelands have a temperate climate with warm summers and cool winters. The far north-west of the region is hot and semi-arid, while much of the centre of the region is subhumid. The overall average rainfall is a moderate 700 mm per year, ranging from over 1200 mm on the tablelands to a minimum of less than 600 mm in the west. Rainfall is summer dominated and comparatively uniformly distributed across the other seasons. Run-off is almost four times as high on the tablelands as in the west, with a seasonal pattern similar to that of rainfall.

Settlements and industry

Land use varies widely, with grazing and horticulture dominating on the tablelands, and cropping and rotational grazing found on the slopes and plains. Irrigation is important on the riverine plains.

Natural ecosystems

Extensive national parks occur along the escarpment and other large parks include Mount Kaputar and Torrington on the tablelands and the Pilliga Community Conservation Areas on the western plains. However, most other national parks in the region are small and scattered, and many ecosystem types are not represented in reserves. The region's wetlands support a diversity of flora and fauna that mostly depend on fluctuating water regimes of wetting and drying. The region contains some major floodplain wetlands including the internationally significant Gwydir Wetlands (Gingham and Lower Gwydir [Big Leather] Watercourses) and Little Llangothlin Lagoon.



Expected regional climatic changes

Temperatures are virtually certain to rise

The climate is virtually certain to be hotter in all seasons, with the greatest warming in spring and winter. Average daily maximum and minimum temperatures are very likely to increase by between 1 and 3°C in different parts of the region. Minimum temperatures are projected to increase more on the tablelands than on the plains, while maximum temperatures are projected to increase more in the west. The frequency of frosts is likely to decrease because of projected increases in minimum temperatures in winter.

Rainfall is likely to increase in all seasons except winter

Rainfall is likely to increase in spring, summer and autumn, but decrease moderately in winter.

Increased evaporation is likely in all seasons

Evaporation is likely to increase throughout the year, particularly in spring when a 10–20% increase is likely in the east, grading to a 20–50% increase in the west. Moderate increases are likely in summer and autumn, whereas in winter a 5–10% increase is likely in the east and a 10–20% increase is likely in the west.

The impact of the El Niño–Southern Oscillation is likely to become more extreme

Our current understanding of how climate change may influence major drivers of climate variability such as the ENSO phenomenon is limited (PMSEIC 2007). However, current scientific literature indicates that the pattern of climate variability associated with ENSO will continue under enhanced greenhouse conditions. This assessment assumes that the ENSO phenomenon will continue to drive climatic variability across NSW.

This assessment assumes that ENSO years will continue to be drier than average but also become hotter, leading to more extreme impacts. La Niña years are likely to continue to be wetter than average but will also become warmer. In El Niño events, water stress is likely to be more intense because of higher temperatures.

Summary of temperature and rainfall changes in the New England/North West region to 2050				
Season	Minimum temperatures	Maximum temperatures	Precipitation	Evaporation
Spring	2.0–3.0°C warmer in the east	2.0–3.0°C warmer	5–10% increase in the east	10–20% increase in the east
	1.5–2.0°C warmer in the west		10–20% increase in the west	20–50% increase in the west
Summer	1.5–3.0°C warmer in the east	1.0–1.5°C warmer in the east	10–20% increase	10–20% increase
	1.0–1.5°C warmer in the west	1.5–2.0°C warmer in the west		
Autumn	2.0–3.0°C warmer in the east	1.5–2.0°C warmer in the south-east	5–10% increase	10–20% increase
	1.0–1.5°C warmer in the west	2.0–3.0°C warmer in the north-west		
Winter	2.0–3.0°C warmer in the east	2.0–3.0°C warmer	10–20% decrease	5–10% increase in the east
	1.0–1.5°C warmer in the west			10–20% increase in the west

Examples of projected climate change in the New England/North West region by 2050

1. Tenterfield

The current average daily maximum temperature for summer is 26.6°C.
This is very likely to increase to between 27.3°C and 27.8°C.

The current average rainfall over summer is 83 mm.
This is likely to increase to between 91 mm and 99 mm.

The current average rainfall over winter is 48 mm.
This is likely to decrease to between 38 mm and 46 mm.

2. Narrabri

The current average daily maximum temperature in summer is 33.6°C.
This is very likely to increase to between 35.1°C and 35.6°C.

The current average rainfall over summer is 227 mm.
This is likely to increase to between 250 mm and 273 mm.

The current average rainfall over winter is 134 mm.
This is likely to decrease to between 107 mm and 121 mm.

3. Murrurundi

The current average daily maximum temperature in summer is 29.0°C.
This is very likely to increase to between 30.0°C and 30.5°C.

The current average rainfall over summer is 277 mm.
This is likely to increase to between 304 mm and 415 mm.

The current average rainfall over winter is 212 mm.
This is likely to decrease to between 170 mm and 201 mm.

4. Guyra

The current average daily maximum temperature in summer is 22.9°C.
This is very likely to increase to between 23.9°C and 24.9°C.

The current average rainfall over summer is 340 mm.
This is likely to increase to between 357 mm and 408 mm.

The current average rainfall over winter is 165 mm.
This is likely to decrease to between 132 mm and 148 mm.

Expected physical responses

Increased evaporation is likely to lead to drier soil conditions in spring and winter

Drier soil conditions are likely in spring and winter as a result of projected changes in rainfall, temperatures and evaporation.

Average annual run-off is likely to increase as a result of a substantial increase in summer run-off

Substantial increases in run-off depths and the magnitude of high flows are very likely in summer. A moderate decrease in run-off depths is likely in spring and winter. A minor increase in annual run-off is likely, mainly because of the summer rise. The average of modelled changes in run-off are shown in Figure 5.4, and listed with the range of projected changes in Table 5.4.

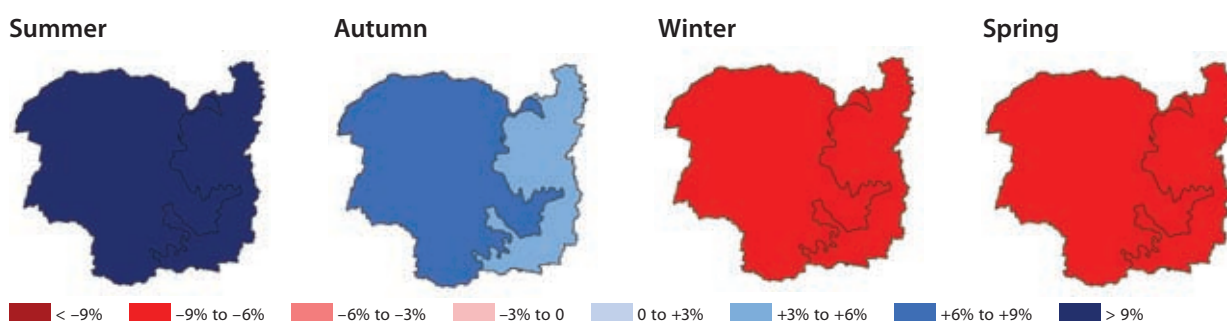


Figure 5.4 Estimated four-model mean percentage change in seasonal run-off for the New England/ North West region for projected 2030 climatic conditions⁴

Short-term hydrological droughts are projected to become more severe, while medium and long-term droughts are projected to become less severe

Estimates of the change in total run-off during short-term drought periods range from 25% drier to 25% wetter compared to historical conditions. The corresponding estimates for medium-term drought periods range from 20% drier to 15% wetter, and for long-term drought periods range from 10% drier to 20% wetter. The average of the four modelled results indicates that short-duration droughts are likely to become more severe, and medium and long-term droughts are about as likely as not to be slightly less severe.

Flooding behaviour is likely to change

Increases in the intensity of flood-producing rainfall events are likely to change flood behaviour, but catchment conditions at the time of each rainfall event (soil moisture conditions and levels in major water storages) will affect the degree of change.

⁴ Run-off projections are for 2030, rather than 2050, as they are based on an existing study (Vaze *et al.* 2008). The 2030 projections are considered indicative of the direction and magnitude of hydrological changes by 2050 (see Section 2.3 and Appendix A for further details).

Fire regimes are likely to change, but changes to fuel availability are uncertain

Existing fire frequency in this region is highly variable with fire cycles of 20–50 years common in dry forest/woodlands (e.g. Pilliga), 5–20 years common in wet forests (eastern margins) and fire often absent from remnant and modified vegetation on the plains, slopes and tablelands. Higher temperatures and changes to rainfall patterns will more likely than not lead to increased fire frequency towards the year 2050, but the return period of fires is considered likely to remain within the current domain of acceptable fire intervals. Fire dangers in the west of the region peak in summer (e.g. Pilliga/Kaputar) while in the east of the region they peak in spring to summer. An extension of the fire season into spring in the west and late summer in the east is possible.

Historically, the tableland areas of the region experience an average of less than 10 very high to extreme fire risk days a year, while inland areas experience over 30 a year. Very high to extreme fire danger days are projected to increase by 10–50% and the conditions conducive to large and intense fires (such as prolonged drought, low humidity, number of days with high temperature and high wind speeds) will more likely than not increase in inland areas and decrease on the tablelands.

Future change in fuel availability is the least certain of all the factors that drive fire. Projected decreases in available moisture will possibly reduce fuel availability; however, projections of fuel availability are presently regarded as highly speculative.

Table 5.4 Modelled changes in run-off in the New England/North West region

Period	Run-off depths			Magnitude of high flows			Frequency of occurrence of current levels of low flows	
	Magnitude ¹ and direction of projected changes	Degree of agreement ²	Range of projected change	Magnitude ¹ and direction of projected changes	Degree of agreement ²	Magnitude ¹ and direction of projected changes	Degree of agreement ²	
Spring	Moderate decrease	Likely	-16% to +6%	Moderate decrease	Likely	Slight increase	About as likely as not	
Summer	Substantial increase	Very likely	+6% to +23%	Substantial increase	Very likely	Slight decrease	Likely	
Autumn	Moderate increase	About as likely as not	-12% to +27%	Slight increase	About as likely as not	Slight increase	About as likely as not	
Winter	Moderate decrease	Likely	-21% to +11%	Moderate decrease	Likely	Moderate increase	Likely	
Annual	Minor increase	About as likely as not	-7% to +18%	N/A	N/A	N/A	N/A	

Changes in run-off depths and stream flows were estimated using results from each of the four GCMs selected for this assessment. Run-off projections are for 2030, rather than 2050, as they are based on an existing study (Vaze *et al.* 2008). The 2030 projections are considered indicative of the direction and magnitude of hydrological changes by 2050 (see Section 2.3.3 and Appendix A for further details).

The range of the estimates and their degree of agreement are presented in this table.

Notes:

- 1 The degree of agreement is based on the number of GCMs (out of four) which agree with the direction of projected average change (see Box 4.1 for definitions)
- 2 The degree of agreement between the four GCMs in terms of the direction of change (see Box 4.1 for definitions)

N/A Not applicable (not modelled)

Regionally significant impacts

The climate changes and physical responses described above are expected to result in the following impacts on land, settlements and natural ecosystems.

Impacts on land

Reduced vegetation cover, caused by poorer growing conditions, is very likely to leave some soils vulnerable to increased erosion. This risk is likely to be exacerbated by increased rainfall in summer and autumn, but is likely to be reduced on the plains in spring. Gully erosion on the slopes and plains is likely to increase in summer with increased run-off, and ease on the tablelands with reduced seepage flows. Wind erosion is likely to increase in the drier areas and the management of sodic surface soils is likely to be more difficult on the plains. Vulnerable areas include some surface soils on the plains and gullies on the slopes and plains. Changes in salinity hazards are difficult to predict but acidification hazards are likely to be slightly reduced.

Changes in rainfall and evaporation are likely to alter conditions for plant growth

Lower rainfall in winter and increased evaporation in all seasons are likely to result in less soil moisture in spring, autumn and winter, and consequently less plant growth during these seasons. Changes in plant growth and cover have implications for several soil processes and soil degradation hazards.

Sheet and rill erosion are likely to increase

Reduced ground cover can increase the risk of sheet and rill erosion, which is likely to worsen under increased summer and autumn rainfall. However, the increased likelihood of perennial pasture growth in summer is likely to alleviate this problem in some areas. In the plains the reduction in peak daily rainfall is likely to reduce rainfall erosivity in spring, but more information is needed. Increased summer run-off is likely to intensify gully erosion on the slopes and plains.

Some forms of gully erosion are likely to ease

Some forms of gully erosion are expected to be less active with reduced through-flow, seepage flow and deep drainage in winter, especially in vulnerable sodic soils such as granite soils in the tablelands.

Wind erosion is likely to increase on the plains

Reduced rainfall in winter and spring is likely to have an adverse effect on ground cover in the drier areas of the plains, increasing the wind erosion hazard for these areas.

Erosion is likely to become worse on sodic soils on the plains

The impact of a drying climate on sodic surface soils on the western clay plains is likely to be serious. These soils are highly vulnerable to erosion and structure decline and dependent on surface cover to maintain and develop soil structure.

The potential effects of climate change on soil salinity are unclear but more likely than not will cause an increase in salinity hazard

The combination of wetter summers and drier winters will more likely than not increase the risk of dryland salinity. Higher summer flows have the potential to mobilise salts, whereas drier conditions in winter are likely to concentrate these salts. The actual effect will depend on the characteristics of individual catchments.

Soil acidification is likely to be reduced

The soil acidification hazard is likely to be slightly reduced in the region, although the response will depend on land-management practices. The potential for leaching in winter is likely to decline, and increased summer rain is likely to promote the growth of perennial plants.

Changes to rainfall and higher temperatures are likely to affect Aboriginal cultural heritage values

The New England/North West region includes a variety of sites, places and objects that are culturally significant to Aboriginal people, including ceremonial sites, stone quarries and scarred trees. Changes to rainfall and higher temperatures are likely to result in damage to these sites.

Impacts on settlements

Increases in short and intense rainfall events are likely to increase flooding from smaller urban streams and urban drainage systems.

Flood-producing rainfall events are likely to increase in intensity

Many settlements in the region are close to rivers and streams and have suffered serious past flooding, particularly in 1955 and 1976. The experience of floods has led to the construction of levees, and local government manages over 40 km of levees protecting Walcha, Tamworth, Wee Waa, Mungindi and other centres in the region. The urban areas behind these levees are provided with some protection from flooding.

Local government has reported that urban development in the Narrabri and Moree Plains shires is subject to inundation in floods that occur on average once every 100 years. The local impact of flooding varies with terrain and is influenced by man-made structures such as roads, embankments, bridges and culverts. On the headwaters of the streams 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 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.

The frequency and intensity of flood-producing rainfall events in the region are likely to rise. However, the degree of increase in flood levels will depend on the catchment conditions (including soil moisture and water levels in reservoirs such as Split Rock, Chaffey, Keepit and Copeton) before each flood event. Drier soils and lower reservoir levels will lessen the flood impact of this flood-producing rainfall. Catchment conditions are likely to change as a result 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.

The greatest change in the risk of flooding is likely to be on smaller urban streams

Increases in flood-producing rainfall intensities, particularly during short storms, are likely to cause additional flooding from local streams and for drainage systems through levees. Towns such as Inverell and Armidale are sensitive to such changes.

Rural floodplain management plans are likely to need review

Floods also impact on small rural communities, individual rural properties and agricultural production. Rural floodplain management plans that coordinate development to minimise flood risk, while allowing for flood access to flood-dependent ecosystems, have been adopted or are under development on a number of floodplains in the Gwydir and Namoi catchments. These plans are likely to require review in future to respond to changes in floodplain hydrology, ecology and land use induced by climate change.

Water supplies are likely to be affected by hydrological changes

If future run-off is at the drier end of the range of estimates, inflows to water storages are likely to decrease by 10–20% during drier periods. This will have most impact on towns with small storages. Towns and irrigators with higher security water from major storages are likely to be buffered against reductions in inflows, whereas divertible volumes are likely to decline slightly for general security users.

Impacts on ecosystems

Higher temperatures and drier soil conditions for much of the year are likely to impact on natural ecosystems. Higher altitude forests west of the tablelands, such as Mount Kaputar and the Liverpool Ranges, are likely to contract significantly — eastward and to higher altitudes. Climate change is likely to place additional pressures on biological communities that are already stressed by fragmentation and less resistant to disturbances. Specialised communities that are naturally very limited in distribution are likely to be at risk of degradation or loss. Fauna are likely to be affected by long hot spells, habitat loss and reduction in key habitat resources such as hollow-bearing trees and nectar. Increased fire frequencies are likely to lead to widespread changes across many ecosystems.

Major impacts on ecosystems will flow from increased temperature and drier conditions

This region contains a number of biological communities and species at their altitudinal, latitudinal or longitudinal limits. Temperature increases are likely to cause range contraction for many of them. Drier conditions are likely to impact on the significant wetlands in the region, many of which are already highly stressed. The western slopes support ecosystems that have been highly cleared and fragmented, and climate change is likely to cause their continued degradation and decline. Other major impacts are likely as a result of altered fire regimes and changes in the timing and occurrence of flowering events, both potential consequences of increased temperatures and increased variability in rainfall among seasons.

Highly fragmented grasslands and grassy woodlands on the western slopes are particularly vulnerable to degradation

Ecosystems that are relatively widespread are better able to withstand disturbances. A wider distribution increases the chances of patches surviving extreme events, and where species loss occurs locally, re-colonisation from neighbouring patches or refuges can proceed rapidly. Conversely, highly fragmented ecosystems are more vulnerable to disturbances, and many in this region are already under stress from weed invasion, pasture improvement, cropping and other edge effects. These communities are likely to be less resistant to the impacts of climate change. For example, grasslands and grassy woodlands on fertile soils on the western slopes have been cleared to less than 30% of their original coverage; most remnants are small and isolated, and almost all are degraded by weed invasion and other changes. Heavy grazing in many remnants has caused changes to species abundances and composition and prevented the regeneration of trees. Climate change is likely to add yet another pressure on these already highly stressed ecosystems, with many species that cannot cope with the increase in temperature disappearing from lower altitudes. A loss of biodiversity is likely, resulting in simplified ecosystems.

Increased temperatures are likely to cause higher-altitude communities to contract

Higher altitude forests and heath in the west and south of this region are likely to be particularly sensitive to increases in temperature. These forests include tableland clay and New England grassy woodlands, Northern Tablelands wet sclerophyll forest and Northern Tablelands dry sclerophyll forest. Mount Kaputar is a western outlier for tableland woodland and heath communities, some of which are remnants from the last glacial period and would have once extended across the Nandewar Range. Higher altitude communities also occur along the Liverpool Range, forming a vegetated link and a significant fauna corridor from the Northern Tablelands to Coolah Tops. These communities have persisted because of the cooler temperatures at higher altitudes, and higher temperatures are likely to be beyond the tolerance limits of many component flora and fauna species. A radical change in species composition in these areas is likely, causing the range limits of communities to contract to the east, to the south and upslope.

Higher temperatures are likely to impact on some specialist tablelands communities

Some of the more specialised Northern Tablelands communities are also at risk of substantial alteration, decline and loss. Montane bogs and fens are widespread but locally restricted to drainage depressions with specific soil chemistry. Changes in inundation are likely to alter soil chemistry in these locations, and this process is likely to be exacerbated by increasing temperature.

Inland wetlands are likely to undergo a substantial reduction in extent

Wetlands are likely to be at risk from increased temperature, increased fire frequency and even minor changes in water regimes. Inland wetlands (inland floodplain swamps and inland floodplain shrublands) are particularly vulnerable, because these communities have been heavily cleared and remnants are highly fragmented, with an estimated 10% of the original extent left in this region. Many are already under threat from weeds and altered water regimes and these problems are very likely to continue. Inland wetlands are therefore likely to undergo significant changes to species composition and structure, and a substantial reduction in area.

Wetland-dependent colonial birds are likely to be reduced in numbers

Inland wetlands provide important foraging and breeding areas for many bird species including several trans-equatorial species. Wetlands such as the Gwydir support large numbers of breeding birds during flood events. The degree to which climate change will alter the frequency, duration or intensity of major floods cannot yet be determined; however if flood events occur less frequently, this will reduce the breeding opportunity for individual birds during their lifespan. If flood durations become shorter, breeding events are likely to fail more frequently; flooding events must last a certain period for birds to complete nesting and rearing and when water levels drop too early, birds will abandon their nests. Extended hot periods are likely to cause heat stress and death of nesting birds, affecting large numbers of birds in localised areas. Such impacts on mortality and recruitment are very likely to reduce population sizes over time.

Hot spells are likely to affect populations of susceptible species such as koalas and flying foxes

Hotter and drier conditions are likely to have substantial impacts on many animal species, particularly in the west of the region, including microchiropteran bats, flying foxes and koalas. Cave-dwelling bats are highly sensitive to roosting temperatures, and extremely hot days can wipe out a whole colony. Flying fox camps have also been known to suffer deaths on very hot days and are similarly at risk across their range. Koala colonies in the more open forests and woodlands of areas such as Pilliga are vulnerable to heat stress and death over long hot spells.

Changes in the fire regime are likely to impact on key resources for some animals

An increase in fire frequency is likely to alter some ecosystems, affecting species composition and structure. Communities sensitive to fire include lignum-dominated wetlands and *Callitris*-dominated woodland. If intense, crown-scorching fires increase in frequency in inland areas this is likely to increase mortality rates in mature trees, resulting in younger stands and a reduction in hollow-bearing trees. More frequent fire also enhances recruitment of some weed species. In many eucalypt and casuarina species, fire and drought conditions also reduce seed production, decreasing food resources for specialist granivores such as glossy black cockatoos (*Calyptorhynchus lathami*).

5.5 The Riverina Murray region

Note: The changes described in this section should be reviewed in conjunction with the terminology in Box 4.1.

- By 2050, the climate is virtually certain to be hotter, with a likely shift in the rainfall pattern from winter to summer dominance. Total annual rainfall is likely to decline, particularly in the winter growing season.
- A reduction in rainfall and spring snow-melt in the east of the region is likely to cause substantial declines in stream flow.
- Substantial reductions in plant growth and cover are likely. Sheet, rill, gully and wind erosion are likely to worsen on the western slopes and plains, but gully erosion is likely to ease on the tablelands. Soil acidification problems are likely to lessen on the tablelands and slopes.
- The severity of flooding from urban streams is likely to increase.
- Widespread changes in natural ecosystems are likely. Those likely to be worst affected are wetlands, riverine communities and smaller woodland communities, which are already under substantial threat.

Characteristics of the region

Local Government Areas: *Albury; Balranald; Berrigan; Bland; Carrathool; Conargo; Coolamon; Cootamundra; Corowa; Deniliquin; Greater Hume; Griffith; Gundagai; Hay; Jerilderie; Junee; Leeton; Lockhart; Murray; Murrumbidgee; Narrandera; Temora; Tumbarumba; Tumut; Urana; Wagga Wagga; Wakool; Wentworth.*

Location and topography

The Riverina Murray region covers an area of 152,700 square kilometres. It lies in the drainage basin of the Murray, Murrumbidgee and Lachlan rivers and their tributaries and includes extensive floodplains and wetlands.

Climate

Rainfall throughout this region is winter–spring dominated. Average annual rainfall is lowest in the north-west (240 mm) and highest in the south-east (nearly 1050 mm on the western edge of the Snowy Mountains). The highest run-off in the region originates from the Snowy Mountains and is winter–spring dominated, with high spring run-off relative to rainfall because of snow-melt. The more arid western parts of the region have a more uniform run-off pattern. Temperatures in this region have a strong seasonal cycle with cool-to-cold winters and warm-to-hot summers.

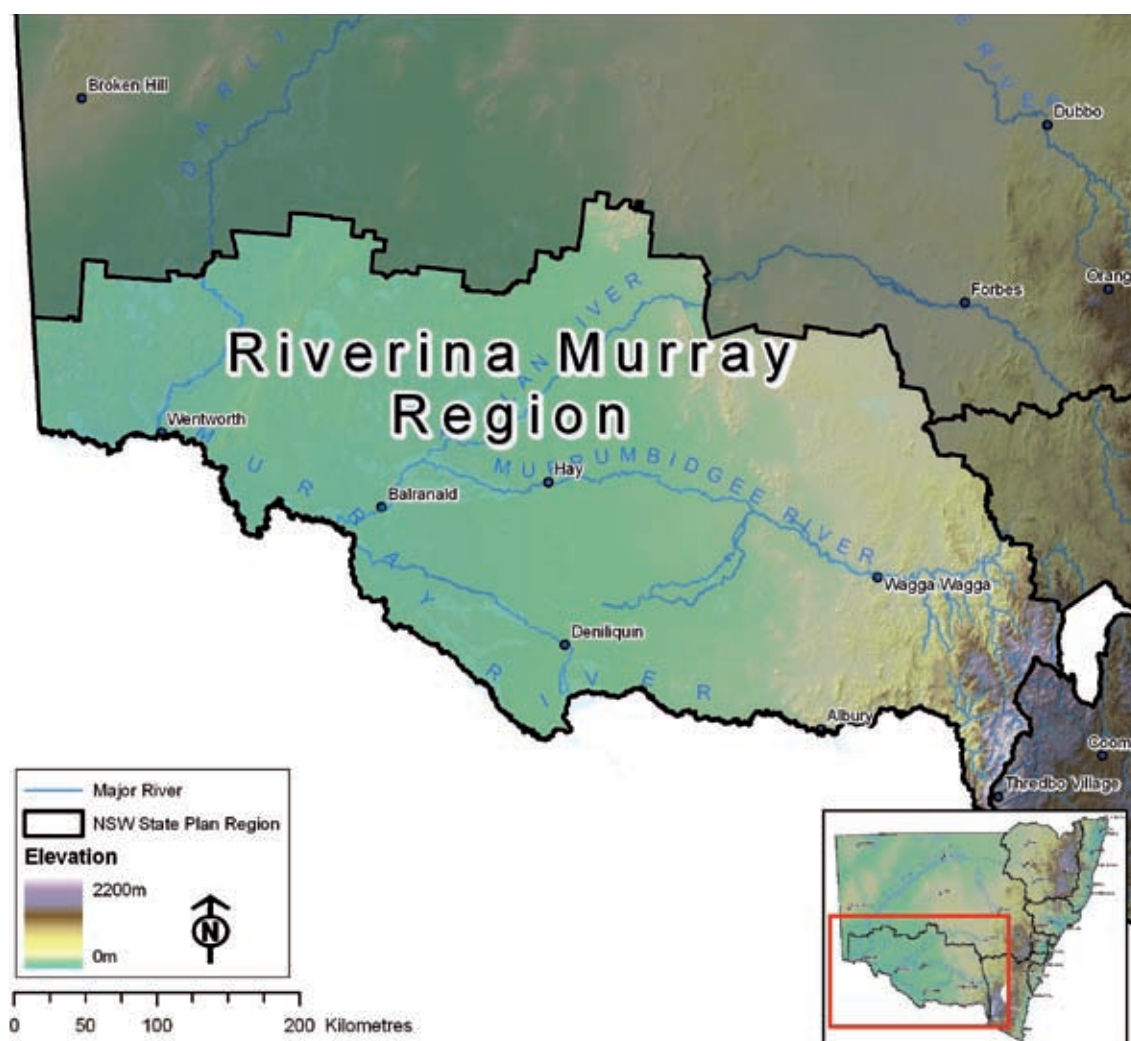
Settlements and industry

Major regional cities in the region include Albury–Wodonga, Wagga Wagga, Griffith, Mildura–Buronga, and Echuca–Moama. Many towns straddle the Murray River state border (Wodonga, Mildura and Echuca are in Victoria). Much of the regional economy is based on primary

industries, notably the large irrigation areas of the Murray and Murrumbidgee rivers, forestry in the river red gum forests and pine plantations, grazing and cereal cropping. Albury and Wagga Wagga also support mixed industries and are the main regional service centres.

Natural ecosystems

The region retains significant natural ecosystems, many of which rely on flooding, including internationally significant Ramsar sites (NSW Central Murray state forests and Fivebough and Tuckerbil swamps) and the World Heritage listed Willandra Lakes region. The region's biota is predominantly adapted to arid and semi-arid environments, with some eastern and cool-climate influences on the slopes and along major watercourses. Many of the region's plant and animal species are threatened by predation by introduced pests, competition with introduced herbivores, habitat modification for agriculture and altered river flow regimes.



Expected regional climatic changes

Temperatures are virtually certain to rise

Average daily maximum temperatures are very likely to be 1.5–3.0°C higher in all seasons. Daily minimum temperatures are also projected to increase, but to a lesser extent than maximum temperatures.

Rainfall is likely to increase moderately in summer but decline substantially in spring, autumn and winter

Rainfall projections show a similar pattern for both spring and autumn – a decrease of up to 50% – with the severity of the deficit rising sharply with latitude. A 20–50% decrease in winter rainfall is likely, the deficit being greater in the south, whereas most of the region is likely to receive a 10–20% increase in summer rainfall. The eastern Riverina and south-west slopes are likely to have the greatest increase, although these areas currently receive relatively low rainfall.

Increased evaporation is likely in all seasons except winter

Evaporation during summer is likely to increase substantially throughout the region. Spring evaporation is likely to remain unchanged in the south of the region but increase by 10–50% in the north, and a slight to moderate increase is also likely in autumn. In winter, however, evaporation is likely to decrease moderately to substantially, particularly in the north of the region.

The impact of the El Niño–Southern Oscillation is likely to become more extreme

Our current understanding of how climate change may influence major drivers of climate variability such as the ENSO phenomenon is limited (PMSEIC 2007). However, current scientific literature indicates that the pattern of climate variability associated with ENSO will continue under enhanced greenhouse conditions. This assessment assumes that the ENSO phenomenon will continue to drive climatic variability across NSW.

This assessment assumes that ENSO years will continue to be drier than average but also become hotter, leading to more extreme impacts. La Niña years are likely to continue to be wetter than average but will also become warmer. In El Niño events, water stress is likely to be more intense because of higher temperatures.

Summary of temperature and rainfall changes in the Riverina Murray region to 2050				
Season	Minimum temperatures	Maximum temperatures	Precipitation	Evaporation
Spring	1.0–2.0°C warmer (warmer in the eastern Riverina and south-west slopes)	2.0–3.0°C warmer	Up to 50% decrease, more severe in the south and west	No change in the south <i>grading to</i> 10–50% increase in the north
Summer	0.5–1.5°C warmer	1.5–3.0°C warmer	10–50% increase, higher in the eastern Riverina and south-west slopes	20–50% increase
Autumn	0.5–1.5°C warmer	1.5–3.0°C warmer	Up to 50% decrease, more severe in the south and west	5–20% increase
Winter	0.5–1.0°C warmer	2.0–3.0°C warmer	20–50% decrease	20–50% decrease in the south <i>grading to</i> 10–20% decrease in the north

Examples of projected climate change in the Riverina Murray region by 2050

1. Deniliquin

The current average daily maximum temperature for summer is 31.0°C.
This is very likely to increase to between 32.5°C and 34.0°C.

The current average rainfall over summer is 82 mm.
This is likely to increase to between 90 mm and 123 mm.

The current average rainfall over winter is 113 mm.
This is likely to decrease to between 56 mm and 90 mm.

2. Temora

The current average daily maximum temperature in summer is 30.8°C.
This is very likely to increase to between 32.3 and 33.8°C.

The current average rainfall over summer is 120 mm.
This is likely to increase to between 144 mm and 180 mm.

The current average rainfall over winter is 158 mm.
This is likely to decrease to between 79 mm and 126 mm.

3. Mildura

The current average daily maximum temperature in summer is 31.5°C.
This is very likely to increase to between 33.0°C and 33.5°C.

The current average rainfall over summer is 68 mm.
This is likely to increase to between 75 mm and 82 mm.

The current average rainfall over winter is 82 mm.
This is likely to decrease to between 66 mm and 41 mm.

3. Corowa

The current average daily maximum temperature in summer is 30.9°C.
This is very likely to increase to between 32.4°C and 33.9°C.

The current average rainfall over summer is 109 mm.
This is likely to increase to between 120 mm and 164 mm.

The current average rainfall over winter is 183 mm.
This is likely to decrease to between 91 mm and 147 mm.

Expected physical responses

Increased evaporation is likely to lead to drier soil conditions in all seasons

Increases in temperature and evaporation, combined with projected changes in rainfall, are likely to exacerbate the dry soil conditions in the region. Drier conditions are likely in all seasons.

A minor decrease in annual average run-off is projected

Modelling predicts moderate to substantial decreases in average run-off depth in spring and winter, but summer run-off is likely to increase moderately while a minor increase is projected for autumn. A minor decrease in annual run-off is about as likely as not, because increases in summer and autumn are not sufficient to offset decreases in spring and winter. The average of modelled changes in run-off are shown in Figure 5.5, and listed with the range of projected changes in Table 5.5.

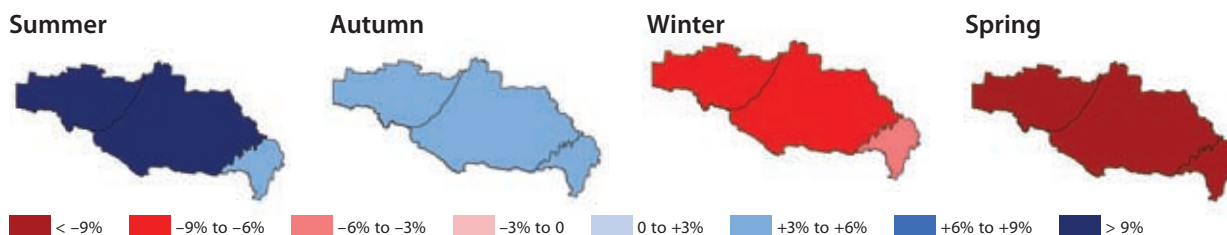


Figure 5.5 Estimated four-model mean percentage change in seasonal run-off for the Riverina Murray region for projected 2030 climatic conditions⁵

Hydrological droughts are likely to become more severe

Short, medium and longer duration droughts are all likely to become more severe due to a projected decrease in run-off during these periods. The model results nearly all indicate an increase in severity, with estimates ranging up to a 15% decrease in total run-off.

Flooding behaviour is likely to change

Increases in the intensity of flood-producing rainfall events are likely to change flood behaviour, but catchment conditions at the time of each rainfall event (soil moisture conditions and levels in major water storages) will affect the degree of change.

Fire regimes are likely to change, but changes to fuel availability are uncertain

Existing fire frequency in this region is highly variable, with fire cycles of 20–50 years common in mallee shrublands and forest/woodland remnants in the eastern slopes/tableland fringe and longer in the Western Division woodlands. Reduced fuel availability due to increasing dryness will more likely than not decrease fire frequency towards the year of 2050. Fire dangers peak in summer, with the season more likely than not to commence earlier (spring), and conclude later, along with an intensification of fire danger within the season.

Historically, the region experiences over 30 very high to extreme fire danger days a year, with higher number further west. Very high to extreme fire danger days are projected to increase by 10–50% and the conditions conducive to large and intense fires (such as prolonged drought, low humidity, number of days with high temperature and high wind speeds) will more likely than not increase.

Future change in fuel availability is the least certain of all the factors that drive fire. Projected decreases in available moisture will possibly reduce fuel availability; however, projections of fuel availability are presently regarded as highly speculative.

⁵ Run-off projections are for 2030, rather than 2050, as they are based on an existing study (Vaze *et al.* 2008). The 2030 projections are considered indicative of the direction and magnitude of hydrological changes by 2050 (see Section 2.3 and Appendix A for further details).

Table 5.5 Modelled changes in run-off in the Riverina Murray region

Period	Run-off depths			Magnitude of high flows			Frequency of occurrence of current levels of low flows		
	Magnitude ¹ and direction of projected changes	Degree of agreement ²	Range of projected change	Magnitude ¹ and direction of projected changes	Degree of agreement ²		Magnitude ¹ and direction of projected changes	Degree of agreement ²	
Spring	Substantial decrease	Very likely	-20% to -3%	Moderate decrease	Very likely		Substantial increase	Very likely	
Summer	Moderate increase	Likely	-7% to +23%	Moderate increase	About as likely as not		Minor decrease	Likely	
Autumn	Minor increase	About as likely as not	-8% to +19%	Minor increase	About as likely as not		Minor decrease	Likely	
Winter	Moderate decrease	About as likely as not	-14% to +1%	Minor decrease	About as likely as not		Moderate increase	About as likely as not	
Annual	Minor decrease	About as likely as not	-14% to +3%	N/A	N/A		N/A	N/A	

Changes in run-off depths and stream flows were estimated using results from each of the four GCMs selected for this assessment. Run-off projections are for 2030, rather than 2050, as they are based on an existing study (Vaze *et al.* 2008). The 2030 projections are considered indicative of the direction and magnitude of hydrological changes by 2050 (see Section 2.3.3 and Appendix A for further details).

The range of the estimates and their degree of agreement are presented in this table.

Notes:

- 1 The magnitude of the changes from the four GCMs (see Box 4.1 for definitions)
 - 2 The degree of agreement is based on the number of GCMs (out of four) which agree with the direction of projected average change (see Box 4.1 for definitions)
- N/A Not applicable (not modelled)

Regionally significant impacts

The climate changes and physical responses described above are expected to result in the following impacts on land, settlements and natural ecosystems.

Impacts on land

Reduced vegetation cover, caused by a reversal of seasonal rainfall patterns and overall drier conditions, is likely to leave many soils vulnerable to increased erosion. This risk is likely to be exacerbated by increased summer rain with more intense storms. Vulnerable areas include the alluvial plains of the Riverina and susceptible gullies on the south-west slopes and plains. Acidification hazards are likely to be reduced for the slopes. Salinity hazards are likely to change but the risk cannot yet be quantified.

Poorer conditions for plant growth are very likely to increase erosion hazards

Overall drying and a trend from winter-dominated to summer-dominated rainfall are very likely to result in reduced plant cover, exposing soils to additional erosion and degradation. The erosion risk is likely to be exacerbated by increased summer rainfall across the region and an increase in storm activity, particularly on the plains during spring.

Sheet and rill erosion are very likely to increase

Sheet and rill erosion, which have been major causes of land degradation in the region for a long time, are likely to increase in many areas as plant cover declines and summer rainfall increases.

Gully erosion is likely to become worse on the slopes and plains

Gully erosion, a particular problem on the cropping lands of the slopes, is likely to increase on both the slopes and plains because of increased summer rainfall and associated increases in run-off. Gully erosion in the tablelands is likely to be reduced, with a reduction in seepage flows that cause gully erosion of unstable subsoils.

Wind erosion is likely to increase

The wind erosion hazard, currently significant for the drier areas of the plains, is likely to increase because of reduced vegetation cover and lower soil moisture levels.

Sodic surface soils are particularly at risk

Sodic surface soils occur on the alluvial plains of the Riverina. Reduced plant cover is likely to make these soils more difficult to manage and result in degraded structure, increasing the risk of erosion. This risk is likely to be exacerbated by increases in summer rainfall and storm intensity.

Acidification hazards are likely to ease

Acidification is currently a significant issue for the tablelands and slopes. With the reduction in the potential for leaching in winter and increased summer rain that is likely to promote the growth of perennial plants, the soil acidification hazard is likely to be slightly reduced in the region. However, the overall response will depend on land management practices because the amount of leaching is only one factor in the acidification of soils.

Potential changes in salinity are difficult to predict

Increasing salinity has been a major problem for land and water in this region. The combination of wetter summers and drier winters is likely to increase the salinity hazard through mobilisation of salts and evaporation from discharge sites. However, the development of salinity is a complex process and will vary with local catchment conditions. Therefore, it is currently not possible to predict salinity changes in response to climate change with confidence without more detailed investigations at the local level.

Increased temperatures and changes to rainfall and run-off are likely to affect Aboriginal cultural heritage values

The Riverina Murray region includes a variety of sites, places and objects that are culturally significant to Aboriginal people, including burial sites, earth mounds, hearths and scarred trees. Higher temperatures, decreased rainfall, decreased run-off and increased erosion are likely to result in the loss of culturally significant trees. Flooding and erosion are likely to result in damage to burial sites.

Impacts on settlements

Despite the likelihood of drier conditions for much of the year, flood-producing rainfall events are likely to increase in frequency and intensity. Whether these changes lead to an increase in flooding of property will depend on catchment moisture levels and water levels in major storages at the time of the event. Changes in short, intense rainfall events are likely to increase flooding from smaller urban streams and drainage systems.

Changes in the risk of riverine flooding of property cannot yet be determined

Many settlements 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.

Local government has reported that urban development in the Wagga Wagga area is subject to inundation in a flood of the size that occurs on average once every 100 years. The local impact of flooding varies with terrain and is influenced by man-made structures such as roads, embankments, bridges and culverts. On the headwaters of the streams 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.

The frequency and intensity of flood-producing rainfall events in the region are likely to rise, with potential impacts on the extent and frequency of flooding of property. However, flood levels also depend on the catchment conditions before each rainfall event, including soil moisture and water levels in reservoirs such as Hume and Burrinjuck and the numerous storages associated with the Snowy Mountains Scheme. Drier soils and lower reservoir levels will lessen the flood impact of this flood-producing rainfall. Catchment conditions are likely to change as a result of altered seasonal rainfall patterns, with drier conditions likely in spring and winter and wetter conditions in autumn and summer. Given the complex role of changes in catchment conditions, the degree to which climate change will alter the frequency of major floods in the region cannot yet be determined.

The risk of flooding along urban streams is likely to increase

Increases in rainfall intensities, particularly during short storms, are likely to cause additional flooding from local streams in towns such as Griffith, and may also exceed the capacity of stormwater systems through levees. Floodwaters from these events are likely to rise more rapidly, potentially increasing the danger of these local floods to the community.

Rural floodplain management plans are likely to need review

Floods also impact on small rural communities, individual rural properties and agricultural production. Rural floodplain management plans that coordinate development to minimise flood risk, while allowing for flood access to flood-dependent ecosystems, have been adopted or are under development on a number of floodplains in the Central Murray area and the lower Murrumbidgee floodplain. These plans will require review in future to respond to changes in floodplain hydrology, ecology and land use induced by climate change.

Changes in run-off are likely to have implications for water usage

If future run-off is at the drier end of the range of estimates, inflows to water storages are likely to decrease by up to 15% during drier periods. This will have most impact on towns with small storages. Pumping from unregulated streams is likely to be possible less often, but towns and irrigators with higher security water from major storages are likely to be buffered against reductions in inflows. Divertible volumes are likely to decline slightly for general security users.

Impacts on ecosystems

Higher temperatures, changes in the volume and seasonal distribution of rainfall, reduced snowfall and decreases in river flows are virtually certain to have major impacts on natural ecosystems in the region. All ecosystems are likely to be affected, with wetlands and ecosystems that are already under pressure suffering the most. Ecosystem productivity and nutrient cycling are likely to decline and some ecosystem types are virtually certain to be lost.

Higher temperatures and drier conditions are likely to cause major changes in ecosystems

Many ecosystems in the region are likely to change substantially as a result of increasing temperatures, substantial loss of snowfall and winter rainfall, reduction of flows in the Lachlan, Murrumbidgee and Murray river systems, and reversal of the rainfall seasonality to which many species in the region are adapted. Many species that cannot cope with reduced water availability and changed seasonality of rainfall are likely to decline in numbers, contract in distribution or become extinct.

Riverine, floodplain and wetland ecosystems are highly vulnerable

The region's many riverine, wetland and floodplain ecosystems that depend on periodic over-bank floods, particularly in spring, are highly vulnerable. River red gum/black box floodplain ecosystems and freshwater wetlands are almost certain to face severe declines in condition and extent. Inadequate water volumes and quality have caused mass tree deaths in these ecosystems in recent years, particularly on banks, floodplains and tributaries along the mid-to-lower reaches of the Murray, Murrumbidgee and Darling rivers and much of the Lachlan River. The widespread death of mature trees and other plants has caused long-term loss of major structural components in these ecosystems that will continue to be problematic

in future. Affected areas are widespread and include all of the Living Murray icon sites and the largest river red gum forests in the NSW Central Murray state forests and Yanga National Park on the lower Murrumbidgee River. The declines in these ecosystems are almost certain to continue with increasing extent and severity, and are very likely to ultimately result in ecosystem collapse unless major intervention occurs. Existing drought-related water quality problems such as toxic cyanobacterial blooms, salinity, acid sulfate soils, anoxic water, heavy-metal leaching and noxious gas release are all likely to increase, causing mass mortalities of invertebrates, fish, frogs, turtles, birds and other wildlife that depend on river systems and wetlands for water and habitat.

The decline of wetland ecosystems in the Riverina is likely to affect ecosystem services

Functioning ecosystems provide a range of services useful to humans such as water filtration, pollination and pest control. The substantial decline of riverine and wetland ecosystems in the Riverina is likely to lead to a loss of ecosystem services provided by these systems. For example, fish, dragonflies, diving beetles, turtles, microbats and birds are natural predators of mosquitoes and their larvae. Declines in populations of these natural predators are likely to lead to increases in mosquito numbers and the incidence of associated mosquito-borne diseases such as Barmah Forest virus, Murray Valley encephalitis and Ross River virus. Other changes are likely to compound this problem; stagnant river channels and temporary waters created by higher summer rainfall are likely to provide more mosquito habitat, and warmer temperatures are likely to foster rapid mosquito and virus development.

Wetland-dependent colonial birds are likely to be reduced in numbers

The extensive wetlands in the Riverina Murray such as Fivebough and Tuckerbil swamps, the Great Cumbung Swamp and the Booligal wetlands provide foraging and breeding areas for several trans-equatorial colonial bird species as well as many Australian species such as brolgas. Drier catchment conditions, substantially reduced winter and spring run-off, and river regulation may result in increased periods between winter/spring floods and shorter duration flooding. These conditions are likely to reduce the breeding success of these birds, the available habitat for breeding and possibly also the population numbers if the period between flood events exceeds the life expectancy of many individuals. Extended hot periods are likely to cause heat stress and death of nesting birds, substantially affecting local populations.

Productivity and nutrient cycling are likely to be affected

The primary productivity of almost all ecosystems in the region is likely to decline with increasing aridity, in some cases to a point where they are no longer recognisable. Lower plant growth rates will almost certainly result in reduced foliage biomass; winter growing grasses in particular are likely to decline. Decreased leaf palatability as a result of changes in species composition and elevated CO₂ levels is likely to cause a decline in plant-eating and detritivorous invertebrates such as termites, earthworms, mites, slaters and burying beetles. These insects make up most invertebrate biomass, play a key role in organic matter turnover and are a major food resource for vertebrates. Entire food webs are therefore likely to be affected, as are processes such as nutrient cycling. Lower soil moisture and reduced vegetation cover and organic matter are likely lead to increased soil erosion and a further loss of nutrients, which will in turn reduce foliage and invertebrate biomass in a loop of declining productivity in most ecosystems.

Climate change is likely to increase stress on fragmented and degraded ecosystems and on threatened species

Ecosystems and species particularly vulnerable to climate change include those that have already undergone major declines because of land clearing, fragmentation, timber removal, grazing, weeds and other non-climatic pressures. Such ecosystems include the grassy box gum woodlands of the eastern Riverina, the riverine sand hills that are found on prior stream beds and source-bordering dunes throughout the region, and boree (*Acacia pendula*) woodlands on the Hay Plains. Climatic changes are likely to exacerbate many of the existing stresses on these communities. Species that have retracted to small, isolated populations are at high risk of extinction; for example, the southern bell frog (*Litoria raniformis*) was once common on the floodplains and tributaries of the Murray and Murrumbidgee rivers. It now exists only in isolated populations in the Coleambally Irrigation Area, the Lowbidgee floodplain and around Lake Victoria. Disease (chytrid fungus) is believed to be the primary cause of the frog's decline, and while it is unknown how the disease will respond to future climate, changes in water availability and quality at the location of these isolated populations could easily cause local extinctions and substantial losses for the species.

Climate change is likely to alter the size and frequency of plague locust outbreaks

Increased summer rainfall and warmer minimum temperatures are likely to favour the earlier breeding and hatching of the Australian plague locust, particularly in favourable years (e.g. La Niña years), with larger outbreaks impacting on vegetation cover. However, wetter summer conditions are also likely to favour parasites and diseases that control plague locusts, and reduced grass cover is likely to limit food availability. The broadscale use of pesticides to control locust outbreaks has potential to impact on invertebrate and vertebrate fauna through primary or secondary poisoning.

More mobile habitat generalists, including some pests and weeds, are likely to persist while species that are sedentary or specialists or have complex life cycles are at greatest risk of decline

Hardy, disturbance-tolerant, unpalatable shrubs, such as Dillon bush (*Nitraria billardierei*) and copper burrs (*Sclerolaena* spp.), are likely to persist in areas where other plant species decline. An increase in weeds is likely, particularly summer-growing opportunists. However, some Mediterranean-climate winter weeds such as barley grass (*Hordeum leporinum*) and capeweed (*Arctotheca calendula*) are likely to become less problematic because of the rainfall seasonality shift. Animals with special thermal requirements, high metabolic rates and low mobility – such as southern hairy-nosed wombats (*Lasiorhinus* spp.), malleefowl (*Leipoa ocellata*) and western pygmy possums (*Cercartetus concinnus*) – are likely to be most at risk. Highly mobile generalists (e.g. Australian magpies (*Cracticus tibicen*)) and those with lower metabolic requirements (e.g. skinks) are likely to cope better with the changes.

Fire and drought are likely to reduce seed and nectar production and affect granivores and nectarivores, including pollinators

Nectar-feeding vertebrates such as honeyeaters, gliders, possums and flying foxes are important pollinators of many plants, and in turn rely on the flowering of eucalypts in the dry forests and woodlands, particularly those on the western slopes in this region. Extensive fire and drought reduce the flowering of eucalypts, and hence impact on nectarivores. Such environmental conditions are likely in the predicted warmer El Niño periods, threatening nectarivore populations and pollination. In many eucalypt and casuarina species, fire and drought conditions also reduce seed production, decreasing food resources for specialist granivores such as gang gang (*Callocephalon fimbriatum*) and glossy black (*Calyptorhynchus lathami*) cockatoos.

Change is likely even in biological communities that are adapted to aridity

Species abundances and composition are very likely to change in all ecosystems, even those dominated by hardy species. For example, in the arid-adapted chenopod shrublands that are typically found on low sandy rises throughout the central and western Riverina, black bluebush (*Maireana pyramidata*) is likely to have a competitive advantage over pearl bluebush (*Maireana sedifolia*) because the former recruits more easily and is more resistant to heat and grazing. Perennial winter-growing grasses and forbs that intersperse with shrubs, such as the daisies *Chrysocephalum* spp., are also likely to decline because of reduced winter rainfall. These declines are likely to result in a loss of species diversity, food resources for animals and soil productivity.

5.6 The Western region

Note: The changes described in this section should be reviewed in conjunction with the terminology in Box 4.1.

- By 2050, the climate is virtually certain to be hotter and is also likely to be drier, with storms increasing in frequency and intensity.
- Run-off and stream flow are likely to increase in summer and autumn but decrease in winter and spring.
- Plant cover is likely to decline on the drier central western slopes and plains but is likely to be enhanced on the warmer tablelands. Sheet, rill and gully erosion are likely to worsen on the western slopes and plains but gully erosion is likely to ease on the most vulnerable soils on the tablelands. Soil acidification is expected to lessen on the tablelands and slopes.
- The likelihood of flooding from urban streams is expected to increase.
- Widespread changes in natural ecosystems are likely. The biological communities most vulnerable to species loss are those of rivers and wetlands, and smaller woodland communities already under substantial threat.

Characteristics of the region

Local Government Areas: Bathurst; Blayney; Bogan; Bourke; Brewarrina; Broken Hill; Cabonne; Central Darling; Cobar; Coonamble; Cowra; Dubbo; Forbes; Gilgandra; Lachlan; Lithgow; Mid Western Region; Narromine; Oberon; Orange; Parkes; Walgett; Warren; Warrumbungle; Weddin; Wellington.

Location and topography

The Western region covers 50% of the state (402,800 square kilometres) extending from the Queensland and South Australian borders to the central tablelands and western slopes of the Great Dividing Range. It contains a wide range of climatic zones, soils, ecosystems and land uses. The great majority of the region falls within the Murray–Darling Basin. The region is dominated by the extensive, broad floodplains of the Darling River and its tributaries.

Climate

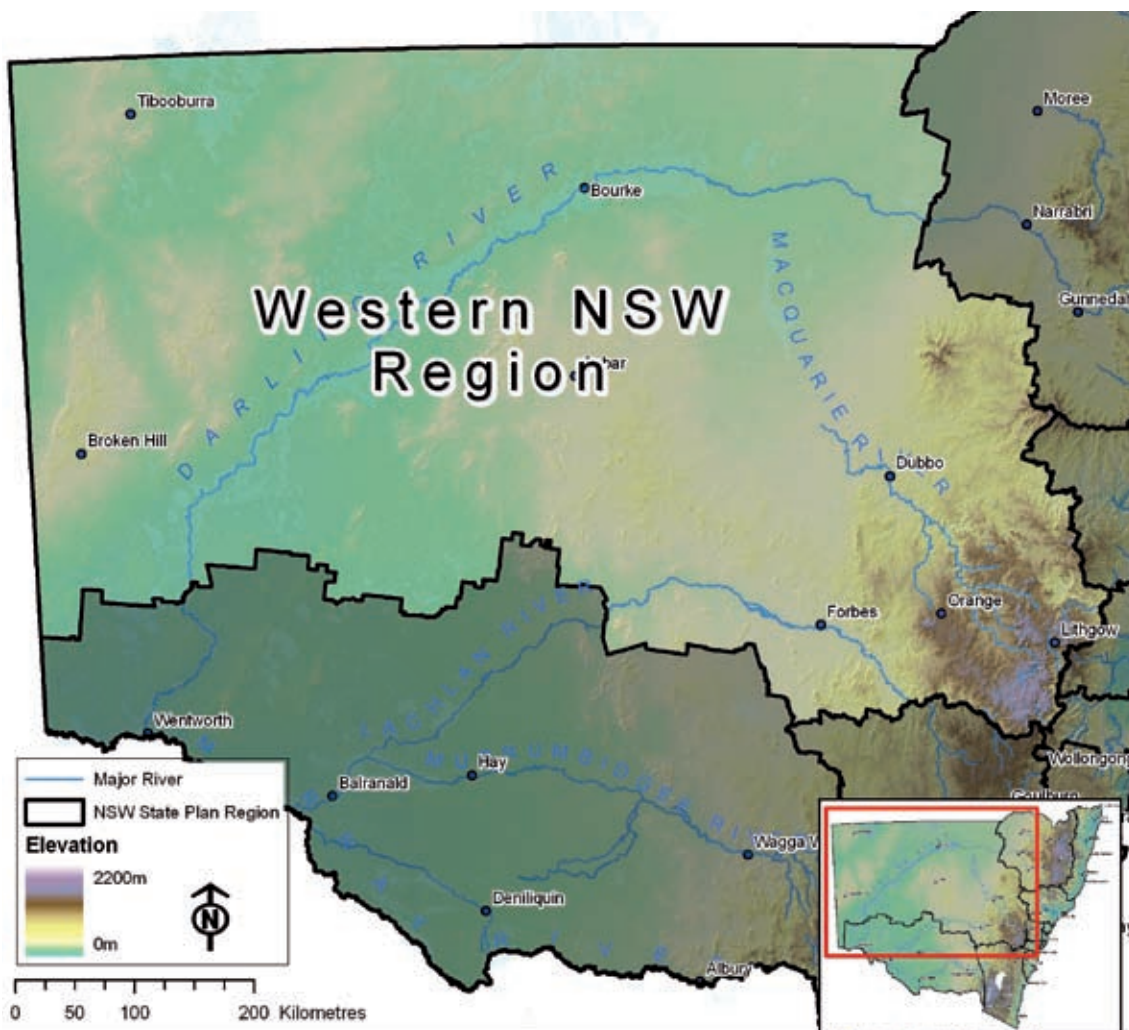
The region includes a wide range of climatic zones. Overall average annual rainfall is about 360 mm, ranging from 180–250 mm in the arid far west, to about 400 mm on the semi-arid plains in central NSW, to about 600 mm on the slopes and over 1000 mm on the highlands in the extreme south-east of the region. Rainfall is greater in summer than in other seasons, particularly in the central and western parts of the region. The wetter eastern parts have winter-dominated run-off, whereas the drier western parts have summer-dominated run-off.

Settlements and industry

The region has several major regional centres including Dubbo, Broken Hill, Bathurst, Orange, Lithgow, Cowra, Mudgee, and numerous smaller towns and localities. The Western region has several large mines and some highly productive agricultural lands, particularly on the tablelands and on the western slopes and adjacent plains, where most of the native vegetation has been replaced by agriculture. Extensive floodplains support irrigated and dryland cropping, horticulture and grazing and also retain significant ecological values that are reliant on flooding. Grazing is widespread throughout the region.

Natural ecosystems

Biologically, the region has a high level of species diversity as a result of its broad climatic expanse and diverse ecosystems. Major wetlands, including the internationally significant Macquarie Marshes, Narran Lake and Paroo River Wetlands, occur on the Darling floodplain and at Lake Pinaroo in the Bulloo catchment. A small percentage of the region is reserved in national parks. Major conservation reserves include Sturt (340,000 ha), Paroo–Darling, and Mutawintji national parks, Pilliga and Macquarie Marshes nature reserves and the western parts of Wollemi, Blue Mountains, Kanangra Boyd and Gardens of Stone national parks.



Expected regional climatic changes

Temperatures are virtually certain to rise

Average daily minimum temperatures are very likely to rise by between 0.5–2.0°C depending on the season. Average daily maximum temperatures are likely to increase by 1.5–3.0°C.

Evaporation is likely to increase throughout the year in most parts of the region

The greatest increases in evaporation are projected to occur during spring, when increases of more than 50% are likely in the far north-west of the region. Substantial increases are likely for the rest of the region during the spring months and throughout the region during summer. In autumn, evaporation is likely to increase most in the west (20–50%), with smaller increases likely in the east of the region (10–20%). In winter, a slight increase in evaporation is likely in the north-east of the region, while the south-western areas are likely to experience a moderate decrease.

Rainfall is likely to increase in summer and decrease in winter

A moderate increase in rainfall is likely in summer over most of the region, with a substantial increase in the tablelands and central west. This increase is likely to be offset by moderate to substantial decreases in rainfall during winter.

In spring and autumn, rainfall is likely to decrease slightly in the south-west of the region, grading to a slight increase in the north-west. No significant change in rainfall is likely in the central parts of the region during these months.

The impact of the El Niño–Southern Oscillation is likely to become more extreme

Our current understanding of how climate change may influence major drivers of climate variability such as the ENSO phenomenon is limited (PMSEIC 2007). However, current scientific literature indicates that the pattern of climate variability associated with ENSO will continue under enhanced greenhouse conditions. This assessment assumes that the ENSO phenomenon will continue to drive climatic variability across NSW.

This assessment assumes that ENSO years will continue to be drier than average but also become hotter, leading to more extreme impacts. La Niña years are likely to continue to be wetter than average but will also become warmer. In El Niño events, water stress is likely to be more intense because of higher temperatures.

Summary of temperature and rainfall changes in the Western region to 2050				
Season	Minimum temperatures	Maximum temperatures	Precipitation	Evaporation
Spring	1.5–2.0°C warmer	2.0–3.0°C warmer	5–10% decrease in the south-west <i>grading to</i> 5–10% increase in the north-east No change in central parts of the region	More than 50% increase in the far north-west <i>grading to</i> 20–50% in the rest of the region
Summer	1.0–1.5°C warmer in the west 1.5–2.0°C warmer in the central tablelands	1.5–2.0°C warmer in the east 2.0–3.0°C warmer in the west	10–20% increase over most of the region 20–50% increase in the tablelands and central west	20–50% increase
Autumn	1.0–1.5°C warmer in the south and west <i>grading to</i> 1.5–2.0°C warmer in the north and central tablelands	2.0–3.0°C warmer	5–10% decrease in the south-west <i>grading to</i> 5–10% increase in the north-east No change in the central parts of the region	10–20% increase in the east <i>grading to</i> 20–50% increase in the west
Winter	0.5–2.0°C warmer, particularly in the north	2.0–3.0°C warmer, particularly in the north	10–20% decrease over most of the region 20–50% decrease in the south	5–10% increase in the north-east <i>grading to</i> 10–20% decrease in the south-west

Examples of projected climate change in the Western region by 2050

1. Orange

The current average daily maximum temperature in summer is 25.2°C.
This is very likely to increase to between 26.7°C and 27.2°C.

The current average rainfall over summer is 216 mm.
This is likely to increase to between 259 mm and 324 mm.

The current average rainfall over winter is 295 mm.
This is likely to decrease to between 235 mm and 265 mm.

2. Dubbo

The current average daily maximum temperature in summer is 31.9°C.
This is very likely to increase to between 33.4°C and 33.9°C.

The current average rainfall over summer is 173 mm.
This is likely to increase to between 190 mm and 259 mm.

The current average rainfall over winter is 142 mm.
This is likely to decrease to between 113 mm and 128 mm.

3. Wilcannia

The current average daily maximum temperature in summer is 34.6°C.
This is very likely to increase to between 36.1°C and 37.6°C.

The current average rainfall over summer is 98 mm.
This is likely to increase to between 108 mm and 147 mm.

The current average rainfall over winter is 59 mm.
This is likely to decrease to between 30 mm and 53 mm.

4. Tibooburra

The current average daily maximum temperature for summer is 35.6°C.
This is very likely to increase to between 37.6°C and 38.6°C.

The current average rainfall over summer is 83 mm.
This is likely to increase to between 91 mm and 99 mm.

The current average rainfall over winter is 48 mm.
This is likely to decrease to between 38 mm and 46 mm.

Expected physical responses

Increased evaporation is likely to lead to drier soil conditions throughout the year

As a result of increased temperature and evaporation, soil conditions are likely to be drier in all seasons.

A minor increase in annual average run-off is projected as a result of increases during summer and autumn

A minor increase in average annual run-off is about as likely as not and run-off is likely to be redistributed across the seasons, with increases in summer and autumn and decreases in spring and winter. The average of modelled changes in run-off are shown in Figure 5.6 and listed (with the range of projected changes) in Table 5.6.

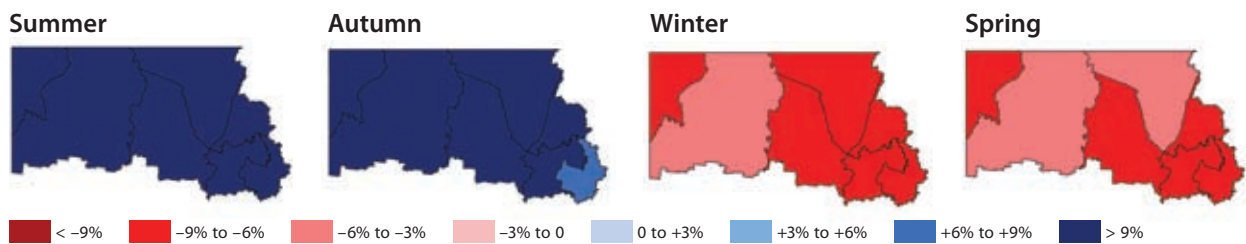


Figure 5.6 Estimated four-model mean percentage change in seasonal run-off for the Western region for projected 2030 climatic conditions⁶

The severity of hydrological droughts will about as likely as not remain similar to current levels

The modelled run-off totals show significant variation, and there are no clear patterns about whether short, medium or long duration droughts are going to be more or less severe. The estimates range from 15% drier to 15% wetter. The averaged results indicate there will about as likely as not be no significant change compared to current drought severity.

Flooding behaviour is likely to change

Increases in the intensity of flood-producing rainfall events are likely to change flood behaviour, but catchment conditions at the time of each rainfall event (soil moisture conditions and levels in major water storages) will affect the degree of change.

Fire regimes are likely to change, but changes to fuel availability are uncertain

Existing fire frequency in this region is highly variable with fire cycles of 20–50 years common in the mallee shrublands and forest/woodland remnants in the eastern slopes/tableland fringe and longer in the Western Division woodlands. Reduced fuel availability due to increasing dryness will more likely than not decrease fire frequency towards the year 2050. Fire dangers peak in summer with the season more likely than not to commence earlier (spring) along with an intensification of fire danger within the season.

Historically, the region experiences over 30 very high to extreme fire danger days a year, with higher number further west. Very high to extreme fire danger days are projected to increase by 10–50% and the conditions conducive to large and intense fires (such as prolonged drought, low humidity, number of days with high temperature and high wind speeds) will more likely than not increase.

Future change in fuel availability is the least certain of all the factors that drive fire. Projected decreases in available moisture will possibly reduce fuel availability; however, projections of fuel availability are presently regarded as highly speculative.

⁶ Run-off projections are for 2030, rather than 2050, as they are based on an existing study (Vaze *et al.* 2008). The 2030 projections are considered indicative of the direction and magnitude of hydrological changes by 2050 (see Section 2.3 and Appendix A for further details).

Table 5.6 Modelled changes in run-off in the Western region

Period	Run-off depths			Magnitude of high flows			Frequency of occurrence of current levels of low flows		
	Magnitude ¹ and direction of projected changes	Degree of agreement ²	Range of projected change	Magnitude ¹ and direction of projected changes	Degree of agreement ²		Magnitude ¹ and direction of projected changes	Degree of agreement ²	
Spring	Moderate decrease	Likely	-23% to +6%	Moderate decrease	Likely		Moderate increase	About as likely as not	
Summer	Substantial increase	Likely	-1% to +42%	Substantial increase	Very likely		Slight decrease	Likely	
Autumn	Substantial increase	About as likely as not	-9% to +30%	Substantial increase	About as likely as not		Slight decrease	About as likely as not	
Winter	Minor decrease	Likely	-17% to +11%	Slight decrease	Likely		Moderate increase	About as likely as not	
Annual	Minor increase	About as likely as not	-9% to +19%	N/A	N/A		N/A	N/A	

Changes in run-off depths and stream flows were estimated using results from each of the four GCMs selected for this assessment. Run-off projections are for 2030, rather than 2050, as they are based on an existing study (Vaze *et al.* 2008). The 2030 projections are considered indicative of the direction and magnitude of hydrological changes by 2050 (see Section 2.3.3 and Appendix A for further details).

The range of the estimates and their degree of agreement are presented in this table.

Notes:

- 1 The magnitude of the changes from the four GCMs (see Box 4.1 for definitions)
 - 2 The degree of agreement is based on the number of GCMs (out of four) which agree with the direction of projected average change (see Box 4.1 for definitions)
- N/A Not applicable (not modelled)

Regionally significant impacts

The climate changes and physical responses described above are expected to result in the following impacts on land, settlements and natural ecosystems.

Impacts on land

Reduced vegetation cover, caused by poorer growing conditions, is likely to leave many soils vulnerable to increased erosion. This risk is likely to be exacerbated by heavy downpours during more frequent intense storms. Vulnerable areas include some surface soils on the alluvial plains, and gullies on the slopes and plains. Conversely, drier soil conditions are likely to reduce gully erosion in some areas on the tablelands. Acidification hazards are likely to be reduced for the tablelands and slopes. Salinity hazards are likely to change, but the degree and direction cannot be determined at this time.

Plant cover is likely to decline on the slopes and plains but to increase on the tablelands

Lower rainfall in winter and increased evaporation are likely to result in less soil moisture. The slopes are predicted to be worst affected, but the plains are also likely to be drier during spring and winter. Soil drying is likely to lead to reduced plant growth and cover on these areas, thereby increasing the risk of soil erosion. Warmer temperatures are likely to improve plant growth on the central tablelands, where winter rainfalls are higher and can balance the increased evaporation.

Sodic surface soils are at particular risk

Sodic soils are highly vulnerable to erosion, and occur mainly in parts of the slopes, the more western clay plains, the central alluvial plains of the Macquarie River, the environs of the Bogan River and areas along the Darling River. Sodic surface soils require vegetation cover to maintain and develop soil structure, and are likely to be affected by vegetation declines on the clay plains. Problems of sodic surface soils on the plains are likely to be exacerbated by an increase in summer rainfall and in the intensity of storms.

Sheet, rill and gully erosion are likely to ease on the tablelands and worsen on the slopes and plains

Historically, sheet and rill erosion have been major land degradation issues in the region. These forms of erosion are likely to ease on the central tablelands, where plant cover is likely to increase, but become worse on the slopes and plains where plant cover is likely to decline. Gully erosion has been a serious problem on both the cropping lands of the slopes and areas with vulnerable subsoils on the tablelands. Drier periods in winter are expected to reduce the amount of water draining through the soil, with reduced through-flow, seepage flow and deep drainage. This reduction is likely to lessen some forms of gully erosion on the tablelands, particularly in areas where sodic soils occur on granites and metasediments. In contrast, gully erosion on the slopes and plains is likely to increase because of increased run-off from summer rainfall with more heavy downpours. The increased risk of erosion on the far west plains, in the vicinity of Broken Hill, is of particular concern in an area where ground cover is often low.

Wind erosion is likely to increase in the far west

Wind erosion is currently a problem in some western areas, especially on sandy soils or mallee, and is likely to increase in these drier parts of the region. Reductions in ground cover and dryer soils in the western parts of the region are likely to exacerbate the risk of wind erosion regardless of any possible changes in wind patterns and intensity.

Acidification hazards are likely to ease

Acidification is currently a serious problem for agricultural lands on the tablelands and slopes. Climate change is likely to reduce acidification hazards because there is likely to be less potential for leaching in winter and summer rain is likely to be enough to maintain perennial plants. However, acidification is likely to remain a problem because leaching is only one of its causes. Land use is also an important factor in its development.

The potential effects of climate change on salinity are unclear

Salinity is a major land degradation and water quality issue for this region, and predictions of wetter summers combined with drier winters have implications for salinity hazards. The mobilisation and evaporation of salts from discharge sites are likely to increase the extent of saline sites, but these processes are complex and vary between catchments. The effects of climate change on regional salinity cannot be predicted at present, but localised changes to salinity risk are very likely.

Changes to rainfall and run-off are likely to affect Aboriginal cultural heritage values

The Western region includes a variety of sites, places and objects that are culturally significant to Aboriginal people, including ceremonial sites, stone artefacts, burial sites, fish traps, hearths, stone and ochre quarries and scarred trees. Decreased rainfall, decreased run-off and increased erosion are likely to result in the loss of culturally significant trees and damage to ceremonial sites.

Impacts on settlements

Despite the likelihood of drier conditions for much of the year, flood-producing rainfall events are likely to increase in frequency and intensity. Whether these changes lead to an increase in flooding of property will depend on catchment moisture levels and water levels in major storages at the time of the event. Changes in short, intense rainfall events are likely to increase flooding from smaller urban streams and drainage systems and may also exceed the capacity of stormwater systems through levees.

Changes in the risk of flooding of property cannot be predicted yet

Many settlements 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.

Local government has reported that the areas in this region subject to inundation in a flood of the size that occurs on average once every 100 years are Forbes, Broken Hill, Narromine and Orange. The local impact of flooding varies with terrain and is influenced by man-made structures such as roads, embankments, bridges and culverts. On the headwaters of the streams 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. The frequency and intensity of flood-producing rainfall events in the region are likely to rise. This may result in increases in the extent and frequency of flooding of property. However, flood levels also depend on the catchment conditions before each flood-producing rainfall event, including soil moisture and water levels in reservoirs such as Wyangala and Burrendong. Drier soils and lower reservoir levels will lessen the flood impact of this flood-producing rainfall. Catchment conditions are likely to change 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 be determined yet.

The risk of flooding from urban streams is likely to increase

Increases in rainfall intensities, particularly in short duration storms, are likely to cause additional flooding from local streams in towns such as Broken Hill, Cobar, Dubbo and Coonamble. Floodwaters are likely to rise more rapidly, potentially increasing the danger of these local floods to the community.

Rural floodplain management plans are likely to need review

Floods also impact on small rural communities, individual rural properties and agricultural production. Rural floodplain management plans that coordinate development to minimise flood risk, while allowing flood access for flood-dependent ecosystems, have been adopted or are under development on a number of floodplains in the Lachlan, Macquarie and Darling catchments. These plans are likely to require review to respond to changes in floodplain hydrology, ecology and land use induced by climate change.

Water supplies are likely to be affected by hydrological changes

Run-off from this region, particularly in the eastern parts, contributes inflows to major tributaries of the Murray–Darling Basin, including directly to the Darling River. The Darling also receives major inflows from catchments outside this region. If future run-off is at the drier end of the range of estimates, inflows to water storages are likely to decrease by 10–15% during drier periods. This will have most impact on towns with small storages. Pumping from streams is likely to be possible less often, but towns and irrigators with higher security water from major rivers are likely to be buffered against reductions in flows.

Impacts on ecosystems

Hotter and drier conditions are likely to have impacts on all natural ecosystems in the region. The worst affected are likely to be those already under substantial threat and some riverine and wetland ecosystems. Pests, weeds and the occurrence of major wildfires are likely to have an increasing impact. Some native species are likely to be reduced in numbers, contract in range or be lost from the region altogether, while hardier species persist. Ecosystem processes such as nutrient cycling are also likely to be affected.

Increases in temperature and drier conditions are likely to cause major impacts

The combination of increased temperatures, greater temperature extremes, favourable conditions for pests and weeds and large wildfires is likely to impact on the region's natural ecosystems. These changes will add to the substantial impacts on biodiversity already stemming from past and current land uses such as unsustainable water extraction and overgrazing. Hardy, unpalatable, or mobile species adapted to high temperatures are likely to be more resistant to the effects of climate change. The resilience of ecosystems to climate change impacts is likely to be enhanced by improvements to current land-use practices.

Noxious pests and weeds are likely to invade or increase in distribution and abundance in this region

Highly noxious species such as the cane toad (*Bufo marinus*), Coolatai grass (*Hyparrhenia hirta*), mimosa bush (*Acacia farnesiana*), and lippia (*Phyla canescens*) are likely to spread in the region, bringing with them a wave of local extinctions and destabilising regional ecosystems.

Riverine and wetland ecosystems are likely to degrade

Riverine and wetland ecosystems, particularly those fed by flows from the Great Dividing Range, are likely to be affected by a cascade of impacts. Longer periods between major over-bank floods, due to lower spring and winter inflows, flow regulation and water extraction, have already caused major losses of river red gums (*Eucalyptus camaldulensis*), coolabah (*Eucalyptus coolabah*), black box (*Eucalyptus largiflorens*) and other trees fringing rivers and wetlands, and this loss may worsen under the predicted climate changes. Fringing vegetation is expected to contract to channel edges or be lost entirely in some places. Losses of fringing vegetation are likely to result in major reductions of habitat for numerous species of water birds, owls, bats, fish, frogs, reptiles, bees, moths and other invertebrates. Declines in these species will affect the functions they perform such as pollination and predation on insect pests. The loss of trees is also likely to intensify bank destabilisation and collapse, erosion and lack of shading, which in turn are likely to result in a decline in water quality. Warmer water during periods of lower flows is likely to increase outbreaks of toxic cyanobacteria. Mosquito numbers are likely to increase because of wetter, warmer conditions in summer and declines of natural predators such as fish, dragonflies, bats and birds.

Wetland-dependent colonial birds are likely to be reduced in numbers

The extensive wetlands in the Greater Darling Floodplain, such as Narran Lake and the Macquarie Marshes, provide foraging and breeding areas for several trans-equatorial colonial bird species as well as many Australian species such as brolgas (*Grus rubicunda*). Drier catchment conditions, substantially reduced winter and spring run-off, and river regulation may cause increased periods between winter/spring floods and shorter duration flooding. These conditions are likely to reduce the breeding success of these birds, the available habitat

for breeding and possibly also the population numbers if the period between flood events exceeds the life expectancy of many individuals. Extended hot periods are likely to cause heat stress and death of nesting birds, and have a substantial effect on local populations.

Productivity and nutrient cycling are likely to be affected

The primary productivity of most ecosystems is expected to decline. Increased temperatures are likely to exceed the physiological limits of many soil-crust lichens and cryptogams, especially in the northern parts of the region. Soil crusts form a major component of ground cover and have a large effect on soil stability, nitrogen and carbon fixation and soil fertility. In the southern parts of the region, lower rates of plant growth due to hotter, drier conditions, especially in winter, are likely to result in reduced foliage biomass. However, foliage biomass is likely to increase in the north and east of the region because of increases in spring, summer and autumn rainfall. Leaf palatability is likely to decrease throughout the region as a result of elevated CO₂ levels, leading to changes in plant-eating and detritivorous invertebrates such as termites, earthworms, mites, slaters and burying beetles. These insects make up most invertebrate biomass, play a key role in organic matter turnover, and are also a major food resource for vertebrates. Entire food webs are therefore likely to be affected, as well as processes such as nutrient cycling. The impacts are likely to vary through the region, being most negative in the south because of severe reduction in winter rainfall. The north-eastern parts of the region are likely to have more primary productivity because of increased rainfall.

Ecosystems currently threatened by grazing pressure are at high risk

Climate change is likely to place additional pressure on grazing-sensitive ecosystems. Grazing and browsing by introduced and native herbivores has had a major impact on many ecosystems in this region, in particular those dominated by palatable plant species such as myall (*Acacia pendula*), rosewood (*Heterodendrum oleifolium*), brigalow (*Acacia harpophylla*) and nelia (*Acacia loderi*). Regeneration in ecosystems currently hindered by heavy grazing and browsing is likely to be further constrained by adverse climatic conditions, contributing to their ongoing decline.

Highly fragmented grasslands and grassy woodlands on the central western slopes and plains are particularly vulnerable to degradation

Communities that are relatively widespread are better able to withstand disturbances. A wider distribution increases the chances of patches surviving extreme events, and where species loss occurs locally, re-colonisation from neighbouring patches or refuges can proceed rapidly. Conversely, highly fragmented ecosystems are more vulnerable to disturbances, and many in this region are already under stress from weed invasion, pasture improvement, cropping and other edge effects. These communities are likely to be less resistant and resilient to the impacts of climate change. For example, grasslands and grassy woodlands on fertile soils on the western slopes, such as those around Wellington, have been heavily cleared, most remnants are small and isolated, and almost all are degraded by weed invasion and other changes. Heavy grazing of many remnants has caused changes in species abundances and composition and prevented the regeneration of trees. Climate change is likely to add yet another pressure on these already highly stressed ecosystems, with many species that cannot cope with the increase in temperature disappearing from lower altitudes.

Fire and drought are likely to reduce seed and nectar production and affect granivores and nectarivores, including pollinators

Nectar-feeding vertebrates such as honeyeaters, gliders, possums and flying foxes are important pollinators of many plants, and in turn rely on the flowering of eucalypts in the dry forests and woodlands, particularly on the western slopes and plains in this region. Extensive fire and drought reduce the flowering of eucalypts, and hence impact on nectarivores. Such environmental conditions are likely in the predicted warmer El Niño periods, threatening nectarivore populations and pollination. In many eucalypt and casuarina species, fire and drought conditions also reduce seed production, decreasing food resources for specialist granivores such as the glossy black cockatoo (*Calyptorhynchus lathami*) at Pilliga and Goonoo.

More frequent major wildfires are likely to alter fire-sensitive ecosystems

The combination of higher summer rainfall and higher temperatures increases the possibility of very large wildfires sparked by lightning strikes in vegetation types previously unable to support large fires, such as the bumble box, cypress pine and mulga woodlands of the Cobar Penneplain and the floodplain woodlands of the Darling Riverine Plains.

Many species are unlikely to tolerate future maximum temperatures

The intensification of extreme temperatures in the region is likely to reduce the foraging periods of many species that are usually active at dusk or dawn or during the day. Those with high metabolic requirements are likely to have insufficient time to gather enough energy to survive, particularly when food is scarce. Species likely to face increased risk of extinction include those at the edges of their climatic ranges, those with narrow distributions or sedentary habits, and those with specialised habitat, ecological or thermal requirements, including malleefowl (*Leipoa ocellata*), bulloo grey grass-wrens (*Amytornis barbatus barbatus*), dusky hopping mice (*Notomys fuscus*), bats and koalas. Bats are highly sensitive to roosting temperatures, particularly in maternity colonies, and extremely hot days can wipe out a whole colony. Koala populations in the more open forests and woodlands of areas such as West Pilliga and along the Darling River are vulnerable to heat stress and death over long hot spells. Dramatic population decline is likely in some places.

Some of the more widespread and northerly species are likely to persist or widen their distributions

Some species are likely to be advantaged by the predicted changes. These include the more hardy, unpalatable, perennial and generalist species with broad geographic ranges indicative of broad climatic tolerances, such as hardy shrubs and herbs. Mitchell grasslands and species that depend on summer rain, such as some burrowing frogs, are likely to benefit from wetter summers and warmer conditions. Highly mobile species that can disperse when conditions are poor (e.g. red kangaroos and some birds), and those with lower metabolic rates that can endure prolonged periods of poor conditions (e.g. reptiles), are likely to cope better with the changes.

Climate change is likely to alter the size and frequency of plague locust outbreaks

Increased summer rainfall and warmer minimum temperatures are likely to favour the earlier breeding and hatching of the Australian plague locust, *Chortoicetes terminifera*, particularly in favourable years (e.g. La Niña years), with consequent impacts on vegetation cover. However, more humid summer conditions are also likely to favour parasites and diseases that control plague locusts. The broadscale use of pesticides to control locust outbreaks has the potential to impact on invertebrate and vertebrate fauna through primary or secondary poisoning.

5.7 The South East region

Note: The changes described in this section should be reviewed in conjunction with the terminology in Box 4.1.

- By 2050, the climate is virtually certain to be hotter, with a likely rainfall increase in summer and decrease in winter. Snowfall is likely to decrease. However, changes in weather patterns that cannot be resolved by the climate models mean that rainfall in coastal parts of the region is difficult to simulate.
- Run-off and stream flow are likely to decrease in spring and winter, particularly in the west, and increase during summer.
- Sea level is virtually certain to keep rising.
- The rate of erosion is likely to increase on some soils. Coastal agricultural soils are likely to be inundated and acidification is likely to increase.
- Sea level rise coupled with increased flooding is virtually certain to pose an increased risk to property and infrastructure in coastal areas. Developments near coastal lakes and estuary entrances and on coastal floodplains are vulnerable.
- Widespread changes to some natural ecosystems are very likely. Those most at risk are alpine ecosystems, low-lying coastal ecosystems and those sensitive to fire.

Characteristics of the region

Local Government Areas: *Bega Valley; Bombala; Boorowa; Cooma-Monaro; Eurobodalla; Goulburn Mulwaree; Harden; Palerang; Queanbeyan; Snowy River; Upper Lachlan; Yass Valley; Young.*

Location and topography

The region is topographically diverse, covering approximately 60,900 square kilometres of the south-eastern corner of NSW, from the south-western slopes across the Snowy Mountains and tablelands of the Great Dividing Range to the coast, with more than 200 km of coastline stretching from Durras Lake north of Bateman's Bay to Cape Howe on the Victorian border. It includes Australia's highest mountains and the sources of the Snowy, Murray, Murrumbidgee and Lachlan rivers. The region is characterised by relatively short beaches between rocky headlands, the large coastal embayments of Batemans Bay and Twofold Bay and a variety of estuary types including large rivers, coastal lakes and lagoons and numerous small coastal creeks.

Climate

The region is climatically diverse, and consequently its climate projections are harder to interpret than those for some other regions. Overall, the present climate is predominantly cool temperate, with the higher elevation inland parts having greater daily extremes, colder winters and hotter summers than coastal areas.

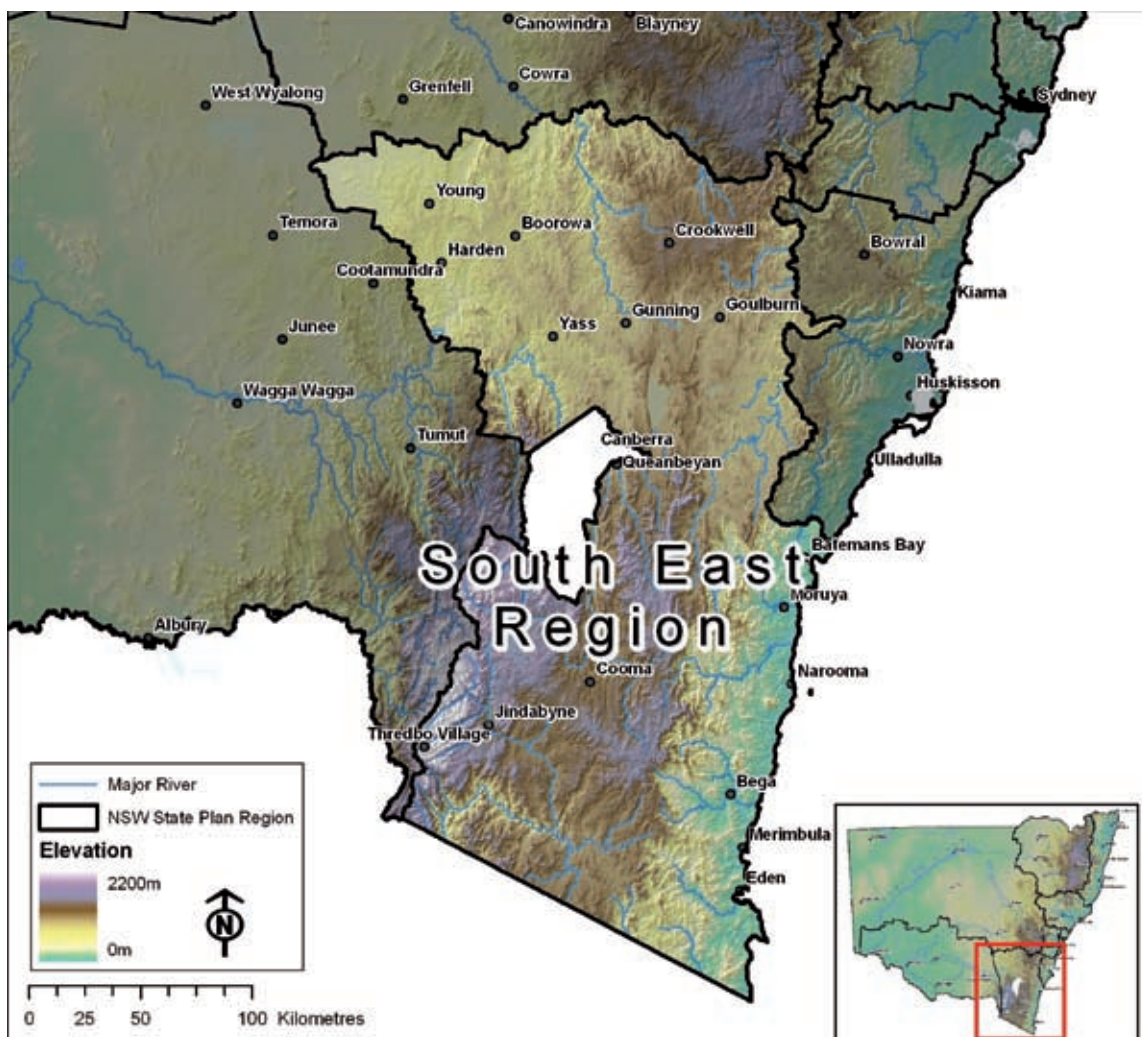
Annual rainfall averages 730 mm for the whole region and is highest on the Snowy Mountains at over 2000 mm. Annual totals are also high on the south coast and hinterland (nearly 900 mm), but lower on the western slopes (more than 600 mm). Rainfall seasonality is variable across the region. Rain is fairly uniformly distributed among seasons in the northern parts, slightly dominant in summer and autumn on the south coast, and dominant in spring and winter in the Monaro, Snowy Mountains and southern slopes and plains. Run-off has a distinct winter peak. Winter snowfall in the alps is crucial to the hydrology, soils, ecology and economy of the region.

Settlements and industry

The main population and service centre for the region is Canberra–Queanbeyan although Canberra falls outside the region, being in the Australian Capital Territory. Other regional centres include Goulburn and Cooma on the tablelands, Batemans Bay, Bega and Eden on the coast and Yass, Gundagai and Young on the western slopes. Tourism is widespread on the coast and in the Snowy Mountains. Primary industries including wool, cereal crops, dairying, forestry, fisheries and aquaculture provide an important economic base for the region.

Natural ecosystems

The southern tablelands and south-western slopes in this region, which have been extensively cleared for agriculture, support some of the sparsest cover of natural vegetation in the state. Conversely, the south coast and escarpment are relatively undeveloped, with large areas of state forest and national park. The region contains many temperate grassland and alpine ecosystems and species not found elsewhere, including the internationally significant (Ramsar) wetland Blue Lake in the Snowy Mountains. Significant protected areas include Kosciuszko National Park, containing Australia's largest and highest alpine areas, the South East Forests and Deua-Wadbilliga national parks on the escarpment, and Nadgee Nature Reserve on the far south coast. The state's only pristine estuary, Nadgee Inlet, is located in the region.



Expected regional climatic changes

Temperatures are virtually certain to rise

Average daily maximum temperatures are very likely to increase by 2.0–3.0°C in autumn, winter and spring and 1.5–2.0°C in summer. Average daily minimum temperatures are very likely to increase from 1.0–3.0°C, depending on the season, with greater increases in the east of the region than in the west.

Rainfall is likely to increase in summer and decrease in winter; a reduction in snow cover is likely in the alps

Most of the region is likely to receive a substantial increase in summer rainfall. Conversely, winter rainfall is projected to decrease by up to 50%, with the decline likely to be greatest in the north and west of the region. However, changes in weather patterns that cannot be resolved by the climate models mean that rainfall in coastal parts of the region is difficult to simulate.

A greater proportion of precipitation in the alps is likely to fall as rain rather than snow, because of higher temperatures. This change, combined with less rainfall in spring and winter, is likely to result in a significant reduction in snow cover in the region.

Increased evaporation is likely in spring and summer

Evaporation is likely to increase moderately in the northern part of the region during spring and throughout the region during summer. There is no clear pattern in projections for autumn and winter.

The impact of the El Niño–Southern Oscillation is likely to become more extreme

Our current understanding of how climate change may influence major drivers of climate variability such as the ENSO phenomenon is limited (PMSEIC 2007). However, current scientific literature indicates that the pattern of climate variability associated with ENSO will continue under enhanced greenhouse conditions. This assessment assumes that the ENSO phenomenon will continue to drive climatic variability across NSW. It is noted, however, that ENSO is a weaker influence on annual average rainfall in coastal areas than in inland areas.

This assessment assumes that ENSO years will continue to be drier than average but also become hotter, leading to more extreme impacts. La Niña years are likely to continue to be wetter than average but will also become warmer. In El Niño events, water stress is likely to be more intense because of higher temperatures.

Summary of temperature and rainfall changes in the South East region to 2050				
Season	Minimum temperatures	Maximum temperatures	Precipitation	Evaporation
Spring	1.5–3.0°C warmer, particularly in the east	2.0–3.0°C warmer	5–20% increase in the central and southern tablelands No change in the ACT and southern coast 5–20% decline in the alps and Monaro	10–20% increase in the north No change in the south
Summer	1.5–2.0°C warmer	1.5–2.0°C warmer	20–50% increase	10–20% increase
Autumn	1.0–3.0°C warmer, particularly in the east	2.0–3.0°C warmer	No change in central and southern tablelands 5–10% increase on the south coast 5–20% decrease from the ACT south, including the alps and Monaro	No clear pattern
Winter	1.0–3.0°C warmer, particularly in the east	2.0–3.0°C warmer	20–50% decrease in the central and southern tablelands, alps and Monaro No significant change on southern coast	No clear pattern

Examples of projected climate change in the South East region by 2050

1. Moruya Heads

The current average daily maximum temperature for summer is 23.2°C.
This is very likely to increase to between 24.7°C and 25.2°C.

The current average rainfall over summer is 275 mm.
This is likely to increase to between 660 mm and 413 mm.

The current average rainfall over winter is 203 mm.
This is likely to decrease to between 182 mm and 101 mm.

2. Cabramurra (Snowy Mountains)

The current average daily maximum temperature in winter is 4.1°C.
This is very likely to increase to between 6.1°C and 7.1°C.

The current average daily minimum temperature in winter is -1.1°C.
This is very likely to increase to between 0.9°C and 1.9°C.

The current average rainfall over winter is 609 mm.
This is likely to decrease to between 305 mm and 548 mm.

Expected physical responses

Sea level is virtually certain to rise

This study assumed a sea level rise of 0.4 m above the 1990 mean sea level by 2050 and a 0.9 m rise by 2100 consistent with the A2 emissions scenario adopted (refer to Section 2 for details).

Increased evaporation is likely to result in drier conditions in the southern tablelands and alps

Increased evaporation, combined with projected changes in rainfall, is likely to result in drier soil conditions in the southern tablelands and alps, particularly in spring and winter.

Spring run-off is very likely to decrease substantially and summer run-off is very likely to increase substantially

A decrease in spring rainfall is very likely to cause a substantial decrease in average spring run-off across the region, with the size of the change increasing westward. An increase in summer rainfall is very likely to cause a substantial increase in average summer run-off and a moderate increase in the magnitude of high flows.

Overall, there is likely to be a slight decrease in average annual run-off. The average of modelled changes in run-off are shown in Figure 5.7 and listed with the range of projected changes in Table 5.7.

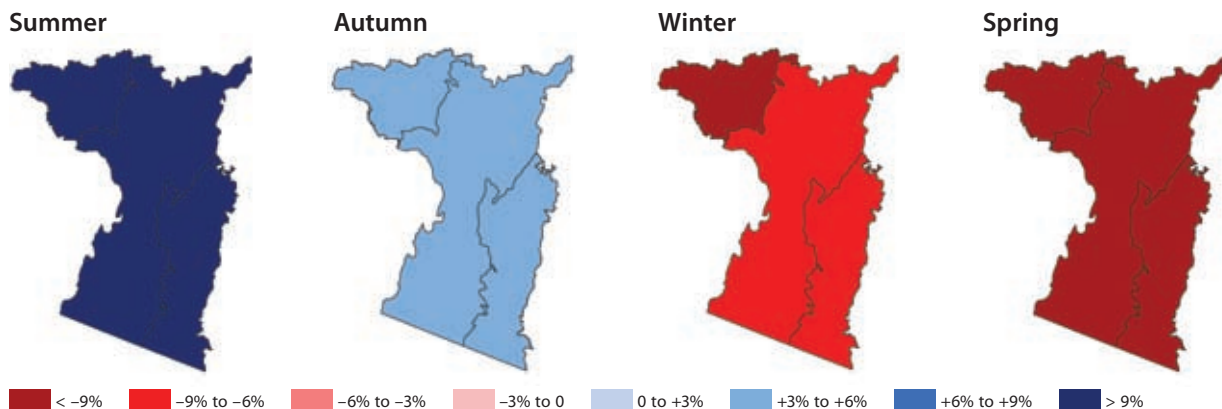


Figure 5.7 Estimated four-model mean percentage change in seasonal run-off for the South East region for projected 2030 climatic conditions⁷

Hydrological droughts are likely to become more severe

Short, medium and longer duration droughts are all likely to become more severe with most of the models predicting a decrease in run-off during these periods. The model results mostly indicate an increase in severity, with estimates ranging to a 15% decrease in total run-off. The averaged results indicate that there is likely to be around a 5% decrease in total run-off during droughts.

Flooding behaviour is likely to change

The combination of rising sea levels and catchment-driven flooding is likely to increase flood frequency, height and extent in the lower areas of the coastal floodplains. Increases in the intensity of flood-producing rainfall events are likely to change flood behaviour everywhere, but catchment conditions at the time of each rainfall event (soil moisture conditions and levels in major water storages) will affect the degree of the change.

Fire regimes are likely to change, but changes to fuel availability are uncertain

Higher temperatures and changes to rainfall patterns will more likely than not lead to increased fire frequency towards the year 2050, but the return period of fires is considered likely to remain within the current domain of acceptable fire intervals of 10–50 years for woodlands and forests. Wetter forests in high altitudes or escarpments, along with sub-alpine and alpine vegetation, currently have longer fire-cycles, and the grasslands of the Monaro have irregular fires, but again the frequency of fires is expected to stay within existing ranges. Fire dangers in the region currently peak in summer and no major change is expected, although the fire season may extend longer into spring.

Historically, the near coastal and higher mountain areas of the region experience an average of fewer than 10 very high to extreme fire risk days a year, while inland areas have between 10 and 15, and sub-alpine areas less than one day a year. Very high to extreme fire danger days are projected to increase by 10–50% and the conditions conducive to large and intense fires (such as prolonged drought, low humidity, number of days with high temperature and high wind speeds) may increase.

Future change in fuel availability is the least certain of all the factors that drive fire. Projected decreases in available moisture will possibly reduce fuel availability; however, projections of fuel availability are presently regarded as highly speculative.

⁷ Run-off projections are for 2030, rather than 2050, as they are based on an existing study (Vaze *et al.* 2008). The 2030 projections are considered indicative of the direction and magnitude of hydrological changes by 2050 (see Section 2.3 and Appendix A for further details).

Table 5.7 Modelled changes in run-off in the South East region

Period	Run-off depths			Magnitude of high flows		Frequency of occurrence of current levels of low flows	
	Magnitude ¹ and direction of projected changes	Degree of agreement ²	Range of projected change	Magnitude ¹ and direction of projected changes	Degree of agreement ²	Magnitude ¹ and direction of projected changes	Degree of agreement ²
Coastal subregion							
Spring	Substantial decrease	Very likely	-18% to -6%	Moderate decrease	Very likely	Moderate increase	Very likely
Summer	Substantial increase	Very likely	+1% to +31%	Moderate increase	Very likely	Slight decrease	Likely
Autumn	Minor increase	About as likely as not	-5% to +19%	Slight increase	About as likely as not	Slight decrease	Very likely
Winter	Moderate decrease	Very likely	-14% to -2%	Moderate decrease	Likely	Slight increase	About as likely as not
Annual	Slight decrease	Likely	-9% to +7%	n/a	n/a	n/a	N/A
Inland subregion							
Spring	Substantial decrease	Very likely	-31% to -7%	N/A	N/A	N/A	N/A
Summer	Substantial increase	Likely	-5% to +26%	N/A	N/A	N/A	N/A
Autumn	Slight increase	About as likely as not	-9% to +18%	N/A	N/A	N/A	N/A
Winter	Substantial decrease	Very likely	-20% to -2%	N/A	N/A	N/A	N/A
Annual	Moderate decrease	Very likely	-16% to +5%	N/A	N/A	N/A	N/A

Changes in run-off depths and stream flows were estimated using results from each of the four GCMs selected for this assessment. Run-off projections are for 2030, rather than 2050, as they are based on an existing study (Vaze *et al.* 2008). The 2030 projections are considered indicative of the direction and magnitude of hydrological changes by 2050 (see Section 2.3.3 and Appendix A for further details).

The range of the estimates and their degree of agreement are presented in this table.

Notes:

1 The magnitude of the average of the changes from the four GCMs (see Box 4.1 for definitions)

2 The degree of agreement is based on the number of GCMs (out of four) which agree with the direction of projected average change (see Box 4.1 for definitions)

N/A Not applicable (not modelled)

Regionally significant impacts

The climate changes and physical responses described above are expected to result in the following impacts on land, settlements and natural ecosystems.

Impacts on land

Sea level rise is virtually certain to cause coastal recession and inundation of agricultural soils on coastal plains. Heavier summer rainfalls are likely to increase the rate of sheet, rill and gully erosion. Dryland salinity, currently a problem in parts of the region (especially in the lower rainfall areas of the southern tablelands), is likely to be exacerbated by changed groundwater hydrology. Higher temperatures are likely to increase the activity of soil micro-organisms in sub-alpine areas, leading to significant loss of organic matter.

Rising sea level is virtually certain to increase coastal recession

Sea level rise and storms are virtually certain to increase coastal inundation and erosion, causing the erodible coastline to recede by 20–40 m by 2050 and 45–90 m by 2100, but could fall outside this range depending on local factors. Impacts will be locally intensified or reduced by changes in other factors such as rainfall patterns, storm intensities and frequencies, river flows, and wind and wave action. Shoreline retreat is very likely to be higher in estuaries and on beaches with lower gradients, particularly where the ocean breaks through or washes over coastal dunes. Seawalls behind beaches, while protecting the area landward, can cause the loss of sandy recreational areas unless beach replenishment programs are put in place. Erosion is virtually certain to affect sandy beaches along the whole south coast.

Coastal dune erosion and soil decline are likely to increase

Coastal dunes are stabilised by specialised vegetation in what is a hostile environment for most plants, with low nutrient levels, low structural stability and high leaching. Wind erosion and nutrient leaching on dunes are likely to increase. The barrier dunes and back-barrier flats behind many of the region's beaches are likely to come under increasing pressure from the interaction of sea level rise and soil decline. Compared to the extensive coastal floodplains of the north coast, many south coast estuaries and lagoons are relatively small and protected by headlands. However, the relatively minor protective barriers on the south coast estuaries are more vulnerable to sea level rise.

Salt water from increased sea levels is likely to affect subsoils on the coastal plain

Significant increases in saline incursions into coastal plain subsoils are likely as a result of sea level rise. Saline water is likely to intrude locally into currently fresh groundwater (aquifers). The quality and condition of the soils of the region's coastal plains are likely to come under increasing threat from major changes in soil hydrology due to sea level rise.

Sheet and rill erosion are likely to increase; gully erosion is likely to increase in summer but decrease in winter

Significant changes in the character of sheet, rill and gully erosion are likely because of increased heavy downpours, with a significant threat in late summer, especially along the coast and immediate hinterland. A decrease in available water in winter is likely to be offset by high carry-over of soil moisture from summer and autumn, allowing for good ground cover in most years. High minimum temperatures in spring and autumn are also likely to improve ground cover, especially in frost hollows on the tablelands and mountains where temperature sometimes limits plant growth. Increased run-off and water drainage through the soil (because of greater rainfall in summer) is likely to increase gully erosion in vulnerable areas, although this impact may be offset to some extent by better ground cover. Conversely, lower soil moisture levels in winter are likely to mitigate gully erosion.

Increased erosion is likely on stream banks near the coast and in the immediate hinterland

Stream bank erosion and stream channel instability are likely to be affected by changes in run-off to streams, the intensity of storms, bank-stabilising vegetation and watertables on the lower coastal floodplains. The risk of increased stream bank erosion is likely to be greatest in late summer, with the larger, east-flowing rivers likely to be most vulnerable. There is likely to be some offset from revegetation of river banks, where vegetation is likely to regenerate during the periods of lower stream flows during winter.

Acidification is likely to decrease across the region

Acidification usually occurs in high-rainfall areas or in association with lighter textured soils with low acid-buffering capacity. Winter-dominant rainfall zones are also more prone to soil acidification. The expected shift to summer-dominant rainfall in this region, coupled with a significant decrease in winter rainfall, is likely to reduce acidification risk, especially on the western slopes and tablelands.

Problems of acid sulfate soils are likely to increase in the short term but decrease in the longer term

Acid sulfate soils (ASS) are a localised problem on the region's coasts. They are confined to low-lying coastal floodplains, estuaries and back-barrier flats, especially where imposed drainage has occurred. Changes in ASS will occur where groundwater hydrology changes, for example where higher sea levels inundate coastal plains and where watertables rise to meet ASS. Higher watertables reduce the frequency with which potential acid sulfate soils (PASS) progress to actual acid sulfate soils (AASS), but rehabilitation of AASS will occur only where fresh water inundates subsoils, as in areas where higher sea levels cause extension of freshwater flooding. Significant structural decline can occur where saline water inundates soils. Ultimately, higher sea levels are likely to reduce ASS, although seasonal changes in soil hydrology are likely to cause local development of AASS, regardless of sea level rise. Warmer temperatures are likely to promote mangrove growth, which increases the development of PASS on the south coast.

Increased erosion of sodic soils is likely

Soils with a high sodium content (sodic soils), derived from granites and metasediments, are highly erodible. Increased rainfall in summer is likely to impact on many of the region's sodic soils, especially on the tablelands, but reduced winter rain is likely to reduce seepage and hence alleviate some forms of gully erosion on these soils.

Declines in the organic content of alpine soils are extremely likely, but elsewhere the change is difficult to predict

Organic matter is important in maintaining soil structure and nutrient availability for plants. The accumulation of organic matter in soil is influenced by such factors as the rate of plant growth, nutrient levels in foliage, the activity of soil micro-organisms and erosion. Climate change can create conditions that both enhance and impede the accumulation of organic matter, and the overall effect is difficult to predict. In coastal and hinterland areas of the region, projected climate change is likely to maintain or slightly increase organic matter levels. In the alps, higher temperatures and reduced winter rainfall are likely to cause humus soils to lose a significant amount of their organic matter.

Soil nutrient levels are likely to decrease in salinised coastal areas and tablelands

Soils most at risk of a decline in nutrient levels are agricultural soils on the coastal plains that are vulnerable to inundation by saline water, and soils on the tablelands and slopes where lower winter rainfall is likely to engender the concentration of salts in saline scalds, as well as reducing plant cover. The loss of large areas of alpine humus soils is very likely to reduce nutrient retention in sub-alpine areas, and lead to substantial nutrient flows into reservoirs such as Lake Jindabyne.

Mass movement of soil is likely to increase in localised areas

Increased summer rainfall is likely to increase the risk of mass movement of soil (e.g. slumps and landslips) in all currently vulnerable slopes in coastal hinterlands. Drier winters are likely to mitigate this effect to some degree and mass movement is likely to be restricted and localised. Significant loss of organic matter in alpine humus soils is likely to reduce vegetation cover and increase the risk of mass movement.

Changes in dryland salinity are difficult to predict

Dryland salinity is a substantial degradation issue on low-rainfall parts of the southern tablelands and slopes. Any modification of groundwater hydrology is very likely to have an impact on salinity because watertable fluctuations move and concentrate salts. Further investigation is needed to forecast whether the salinity risk will increase or decrease under an altered climate, but the regional shift to summer-dominant rainfall, coupled with significantly reduced winter falls, is more likely than not to exacerbate salinity risks.

Sea level rise and flooding are likely to affect Aboriginal cultural heritage values

The South East region includes a variety of sites, places and objects that are culturally significant to Aboriginal people, including stone artefacts, ceremonial sites, middens, stone and ochre quarries and rock shelters. Sea level rise, decreased rainfall, and decreased run-off are likely to result in the loss of or damage to middens and other coastal sites.

Impacts on settlements

Major impacts on settlements are likely from erosion and flooding caused by sea level rise and intense rainfall. Many low-lying settlements near estuaries and the coast are at risk. Residential, commercial and public property and infrastructure are vulnerable, including roads, water supplies and sewerage systems.

Rising sea level is virtually certain to increase the threat of saltwater intrusion and erosion to many settlements near estuaries and beaches

Settlements on low-lying floodplains and those near estuaries are vulnerable to seawater intrusion and beach recession. Developed sand spits that lie between the ocean and estuaries are extremely likely to be at increased risk of breaching by the combined effect of sea level rise and more intense rainfall. Built assets extremely likely to be affected include dwellings, outbuildings, stormwater infrastructure, roads and sewerage infrastructure.

Community assets, residential property and associated infrastructure are virtually certain to be at risk from inundation or recession

Most coastal villages are near estuary entrances or beaches and are likely to be affected by sea level rise. Estuaries with settlements particularly vulnerable to sea level rise include the Clyde River (Batemans Bay), Wagonga Inlet (Narooma), Coila Lake (Tuross Head), Merimbula Lake and Back Lake (Merimbula) and Wallaga Lake (Regatta Point and Beauty Point). Various built assets within settlements are at risk, including dwellings, outbuildings, stormwater infrastructure, sewerage infrastructure and roads.

Sea level rise is likely to threaten some properties

Dwellings, caravan parks, surf clubhouses, beachfront roads and associated infrastructure in the region are likely to be threatened by sea level rise by 2050. The most significant threats are around the developed foreshores of Batemans Bay and beaches to the south, including parts of Maloneys Beach, Long Beach, Surfside Beach, Corrigans Beach and Caseys Beach. Other areas where assets are likely to be at risk include Beares Beach, Cuttagee Beach, Tathra Beach, Pambula Beach, Aslings Beach and Legges Beach.

Most property boundaries referenced to the high water mark will change

An important consequence of sea level rise is that beachfront or waterfront property boundaries referenced to the mean high water mark will move inland over time.

Flood risk in coastal areas is virtually certain to be exacerbated, and elsewhere the risk is likely to be variable

Local government has reported that parts of the Bega, Eurobodalla and Queanbeyan local government areas are subject to inundation in floods that occur on average once every 100 years. The exposure of individual properties to flood risk depends on catchment conditions, local terrain and man-made structures such as roads, embankments, bridges and culverts in key locations. On the coast, sea level rise and increased intensity and frequency of flood-producing rainfall are likely to substantially increase the frequency of flooding, the extent of flooding and the number of properties affected. Currently, four trained river entrances and eight coastal lakes and lagoons in the region have entrance management policies that deal with flooding.

Flooding from urban streams is likely to increase

Increases in rainfall intensities, particularly in short duration storms, are likely to cause additional flooding from local streams. Floodwaters are likely to rise more rapidly, potentially increasing the danger of these local floods to the community.

The degree of change in the risk of flooding of property above tidal influence cannot yet be determined

The frequency and intensity of flood-producing rainfall events in the region are likely to rise. This may result in increases in the extent and frequency of flooding of property. However, away from coastal influences affected by sea level rise, flood levels will also depend on the catchment conditions before each flood-producing rainfall event, including soil moisture and water levels in reservoirs. Drier soils and lower reservoir levels will lessen the flood impact of this flood-producing rainfall. Catchment conditions are likely to change as a result 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 be determined yet.

Major infrastructure such as highways and airports in the coastal zone will more likely than not be affected by sea level rise and flooding

Key infrastructure is likely to be affected as water levels rise, potentially including airports at Moruya Heads and Merimbula. At times the Princes Highway is likely to be flooded in low-lying places such as Coila Lake, Tuross Lake, Corunna Lake, Nangudga Lake and Wagonga Inlet. Other roads such as George Bass Drive and Main Road 272 are likely to be affected in several places.

Some water supply and sewerage systems are likely to be threatened

Coastal groundwater supplies and surface supplies from areas near current tidal limits, such as those at Tuross and Bega, are likely to be vulnerable to sea level rise. On-site sewage disposal systems are also likely to be affected at locations such as Durras and Wallaga lakes. Sewerage infrastructure, such as pumping stations at Kianga and Wallaga lakes, is likely to require upgrading to avoid risks to water quality. Dune filtration systems at several locations are vulnerable to coastal erosion.

Declining rainfall and increased evaporation are likely to reduce water supplies, particularly for urban areas on the tablelands and slopes such as Goulburn, Queanbeyan and Canberra. If future run-off is at the drier end of the range of estimates, pumping from streams will be possible less often and inflows to water storages are likely to decrease by about 10% during drier periods, impacting particularly on towns with small storages. Towns and irrigators supplied with higher security water from the major storages in the Murrumbidgee and Lachlan valleys are likely to be buffered against reductions in inflows, but reductions in divertible volumes are likely for general security users.

A more detailed study looking specifically at the potential impacts of climate change on Sydney's water supply and demand is currently underway. This study, being conducted as part of the Sydney Metropolitan Water Plan, covers all of Sydney's hydrological catchment, which encompasses part of the South East region. The study will take into account local conditions in drinking water catchments, as well as projected customer demand, under climate change scenarios.

Impacts on ecosystems

Sea level rise, increased temperatures, loss of snow cover, and changes in water availability, rainfall seasonality, drought and fire regimes are very likely to cause widespread changes in natural and semi-natural ecosystems. Snow-dependent ecosystems and many unique alpine species are very likely to disappear. Low-lying coastal ecosystems are very likely to be vulnerable to inundation and saline intrusion into the watertable. Productivity is likely to decline on the tablelands and slopes.

Many alpine ecosystems and species are very likely to become extinct

In the Snowy Mountains, higher temperatures, lower winter precipitation and the replacement of snowfall by rainfall are very likely to cause the extinction or severe contraction of snow-dependent or cold-adapted ecosystems such as Fjaeldmark and sphagnum bogs and species such as the corroboree frog (*Pseudophryne* spp.) and mountain pygmy possum (*Burramys parvus*). Their place is likely to be taken by more common and widespread cool-climate ecosystems and species.

Increased bushfire frequency and intensity, particularly in the alpine and sub-alpine zone, are very likely to cause major changes to ecosystems

The impacts of larger and more frequent fires, particularly those caused by lightning strikes from summer storms in areas that seldom burn, are likely to be substantial in the alpine and sub-alpine zones. Organic alpine soils are flammable when dry, and in 2003 soils in some alpine areas burnt for weeks. Reduced soil moisture, due to hotter conditions, and reduced precipitation are likely to increase the incidence of similar events, causing irreparable damage. Disturbances of ground cover from fires, grazing, and patch deaths are all likely to favour noxious weeds, most notably hawkweed (*Hieracium* spp.). Recently found in the Snowy Mountains, hawkweed has the capacity to become a major pest and displace numerous native species. Alpine ash (*Eucalyptus delegatensis*) forests are sensitive to fire. When burnt adult trees die, regeneration is from seed in the soil. A second fire can eliminate alpine ash if it occurs before young trees mature and produce seed, which can take more than 20 years. About half of all alpine ash in NSW burnt in the 2003 wildfires, and many areas are virtually certain to be lost to repeated burns by 2050. In addition, alpine ash seeds require about six weeks of chilling in order to germinate, a cool period that will become less frequent as temperatures rise. This phenomenon has already been observed with regeneration poorer than expected following the 2003 fires.

Sea level rise is likely to threaten some estuarine communities

Sea level rise and shoreline retreat are likely to induce a large-scale modification or loss of intertidal and subtidal communities as water depth, turbidity, sedimentation, pH, temperature and salinity change. The region has large areas of seagrasses, mangroves and salt marshes at sites such as the Clyde and Moruya rivers, Merimbula Lake, Coila Lake, Wagonga Inlet, Back Lagoon and Bournda Lagoon. Seagrasses are likely to be displaced from some of their current extent and their ability to re-colonise is difficult to predict. Mangroves and salt marshes are also likely to be displaced but new mangrove habitat should form in other places, including areas currently occupied by salt marsh. Salt marsh is slow to colonise however, and its establishment in new habitats is likely to be limited by the rapidity of sea level rise and increased rates of sediment movement. Changes in the species composition of estuarine invertebrate communities are likely to adversely affect estuarine food webs and result in declines in some fish populations. The re-establishment of estuarine ecosystems is virtually certain to be impeded by infrastructure and development in places such as Batemans Bay, Narooma and Merimbula.

Inundation and saline intrusion are virtually certain to impact on low-lying coastal ecosystems

Low-lying ecosystems near the foreshore and estuaries are highly vulnerable to inundation following tidal and storm surges, and to saline intrusion into the groundwater table. The extent of some ecosystems is likely to be greatly reduced by coastal recession and loss of sandy habitats. Those ecosystems trapped between the coast and infrastructure or agricultural barriers are at most risk of being lost. The tidal and saline limits of estuaries are likely to migrate inland, and estuarine and marine plants and animals are likely to follow.

In coastal areas, saltwater intrusion into the groundwater, inundation and erosion are virtually certain to reduce the extent and integrity of littoral rainforest, coastal grasslands, rock platform communities, salt marshes and dry sclerophyll communities on coastal dunes. Many specialised plants such as the endangered salt marsh species *Wilsonia rotundifolia*, and invertebrate and vertebrate fauna, are extremely likely to decline in association with ecosystem changes. Seagrass habitats in estuaries such as Back Lagoon and Bournda Lagoon are particularly vulnerable to increases in ocean water levels. Freshwater wetlands close to the coast are likely to be completely transformed by increased salinity, resulting in the loss of flora and fauna restricted to these habitats.

Climate change is likely to reduce shorebird habitat and reduce shorebird numbers

Salt marshes, sand flats and mudflats provide important roosting and foraging habitat for a suite of shorebirds, including some species that migrate seasonally to other parts of the world. Important areas include Montague Island, Tuross Head and the Bega River mouth. Refuges for shorebirds are being reduced globally along migratory routes by human modification of coasts, and climate change is likely to exacerbate this trend.

Wetlands such as Lake George, Lake Bathurst, Rows Lagoon, Nunnock Swamp, Bega Swamp and Wingecarribee Swamp are known to be sensitive to changes in water balance, grazing and other disturbances, with contractions already attributed to increased evaporation and reduced rainfall. As drying accentuates, the plants in these wetlands are at risk of being lost to competition from species adapted to drier soils. Wetlands are often areas of very high productivity in relatively unproductive landscapes, and many animal species depend on them for foraging, grazing and breeding.

Lower primary productivity is likely to change many ecosystem processes

Many parts of the tablelands are likely to become significantly drier than in the past, especially during winter. This shift is likely to limit the primary spring season of plant growth that depends on moisture stored in the soil after winter rainfall. Water stress, particularly during drought years, is likely to kill many trees in woodlands and forests, and stressed trees are also likely to die from additional pressure from insect attack and disease. A decline in plant growth and survival is likely to lead to an overall drop in productivity, affecting all other forms of life through reduced flowering and production of foliage and seed. Such impacts are likely to be most severe for resident species or those with low dispersal capacity and high metabolic rates, including many of the threatened woodland birds and small mammals such as the black-chinned honeyeater (*Melithreptus gularis gularis*), diamond firetail (*Stagonopleura guttata*), hooded robin (*Melanodryas cucullata cucullata*), glossy black (*Calyptorhynchus lathamii*) and gang gang (*Callocephalon fimbriatum*) cockatoos, squirrel glider (*Petaurus norfolcensis*) and smoky mouse (*Pseudomys fumeus*). While warmer and wetter summers are likely to compensate somewhat for winter drying in some years, substantial impacts such as tree deaths are likely to occur in drought years that are hotter than at present.

Climate change is likely to increase stress on fragmented and degraded ecosystems and on threatened species

Across the region, many ecosystems are highly stressed by factors such as land clearance, fragmentation effects, conflicting land uses, pests and weeds. They include the box gum woodlands of the tablelands and slopes and the lowland grassy woodlands of the south-east corner and river floodplains (e.g. the Bega Valley). These ecosystems and their constituent species are likely to be put under greater pressure through climate change, resulting in a further reduction in their extent, diversity and integrity. Species already seriously threatened by other factors are likely to be extremely vulnerable to changes, for example the spotted tree frog (*Litoria spenceri*) and booroolong frog (*Litoria booroolongensis*) which have been brought close to extinction by the pathogenic chytrid fungus. The few isolated locations where these species can still be found are likely to undergo major habitat changes such as the drying of once-perennial streams, leaving no refuge populations to re-establish after adverse climatic events.

Changes in rainfall patterns are likely to intensify seasonality, increase grazing pressure from native herbivores, and alter plant communities

The annual boom-and-bust cycle on the tablelands of high growth in spring and autumn and no growth during winter is likely to intensify as rainfall seasonality changes. This change is likely to increase the browsing and grazing impacts of the large kangaroo population and other herbivores on grasslands and grassy woodlands during drier winter periods. Frost-hollow tussock grasslands are likely to decline with the incursion of trees. Summer-growing C4 grasses such as wallaby grass and red grass, and weeds such as African lovegrass (*Eragrostis curvula*), St John's wort (*Hypericum perforatum*) and Chilean needle grass (*Nassella neesiana*), are likely to expand and displace palatable native species such as poa tussocks (*Poa* spp.).

5.8 The Sydney/Central Coast region

Note: The changes described in this section should be reviewed in conjunction with the terminology in Box 4.1.

- By 2050, the climate is virtually certain to be hotter, with a likely increase in summer rainfall and a decrease in winter rainfall. However, changes in weather patterns that cannot be resolved by the climate models mean that rainfall in coastal regions is difficult to simulate.
- Sea level is virtually certain to keep rising.
- Changes in rainfall are likely to increase sediment shedding from the hinterland, potentially causing changes to stream channels including bank erosion.
- Sea level rise, coupled with increased flooding, is virtually certain to pose an increased risk to property and infrastructure. Developments near estuary entrances and beaches and on coastal floodplains are most vulnerable.
- Sea level rise is virtually certain to alter estuarine and coastal lowland ecosystems. Seasonal drying is likely to degrade freshwater wetlands and higher temperatures are likely to cause many ecosystems to change or contract. Altered fire regimes have the potential to cause major changes in ecosystems.

Characteristics of the region

Local Government Areas: Ashfield; Botany Bay; Burwood; Canada Bay; Canterbury; Hornsby; Hunter's Hill; Hurstville; Kogarah; Ku-ring-gai; Lane Cove; Leichhardt; Manly; Marrickville; Mosman; North Sydney; Pittwater; Randwick; Rockdale; Ryde; Strathfield; Sutherland; Sydney City; Warringah; Waverley; Willoughby; Woollahra; Auburn; Baulkham Hills; Blacktown; Blue Mountains; Hawkesbury; Holroyd; Parramatta; Penrith; Bankstown; Camden; Campbelltown; Fairfield; Liverpool; Wollondilly; Gosford; Wyong.

Location and topography

The Sydney/Central Coast region is a lowland coastal plain covering 13,800 square kilometres. It is fringed by escarpments and dissected sandstone plateaux, including the Blue Mountains and the Woronora, Yengo and Wollemi plateaux. The region's coastline of about 120 km extends from the Royal National Park to the southern shores of Lake Macquarie, and its numerous estuaries include drowned rivers such as Broken Bay, Sydney Harbour, Botany Bay and Port Hacking, the large Tuggerah Lakes system, and numerous bays and small lagoons such as Wamberal Lagoon, Narrabeen Lakes and Manly Lagoon.

Climate

Most of the region has a warm temperate climate. Average annual rainfall in greater Sydney is slightly less than 950 mm, ranging from more than 1200 mm near the coast to slightly less than 800 mm in the west. The Central Coast has an average annual rainfall slightly above 1100 mm. Rainfall throughout the region is greatest in summer and autumn, with a slightly higher proportion of winter rainfall on the coast than inland. Because evaporation and transpiration are lowest in autumn and winter, run-off is highest in autumn and winter and lowest in spring.

Expected regional climatic changes

Temperatures are virtually certain to rise

The mean daily maximum and minimum temperature are virtually certain to increase in all seasons. The magnitude of projected increases ranges from 1.5–3°C.

Rainfall is likely to increase in all seasons except winter

Summer rainfall is likely to increase substantially across the region, with smaller increases likely in autumn and spring. Winter rainfall is likely to decrease moderately across much of the region. However, changes in weather patterns that cannot be resolved by the climate models mean that rainfall in coastal regions is difficult to simulate.

Increased evaporation is likely in spring and summer

Evaporation is likely to increase moderately in spring and summer. There is no clear pattern in projections for autumn and winter.

The impact of the El Niño–Southern Oscillation is likely to become more extreme

Our current understanding of how climate change may influence major drivers of climate variability such as the ENSO phenomenon is limited (PMSEIC 2007). However, current scientific literature indicates that the pattern of climate variability associated with ENSO will continue under enhanced greenhouse conditions. This assessment assumes that the ENSO phenomenon will continue to drive climatic variability across NSW. It is noted, however, that ENSO is a weaker influence on annual average rainfall in coastal areas than in inland areas.

This assessment assumes that ENSO years will continue to be drier than average but also become hotter, leading to more extreme impacts. La Niña years are likely to continue to be wetter than average but will also become warmer. In El Niño events, water stress is likely to be more intense because of higher temperatures.

Summary of temperature and rainfall changes in the Sydney/Central Coast region to 2050				
Season	Minimum temperatures	Maximum temperatures	Precipitation	Evaporation
Spring	2.0–3.0°C warmer	2.0–3.0°C warmer	10–20% increase	10–20% increase
Summer	1.5–3.0°C warmer	1.5–2.0°C warmer	20–50% increase	10–20% increase
Autumn	1.5–3.0°C warmer	1.5–3.0°C warmer	No significant change	No clear pattern
Winter	1.5–3.0°C warmer	2.0–3.0°C warmer	10–20 % decrease	No clear pattern

Examples of projected climate change in the Sydney/Central Coast region by 2050

1. Parramatta

The current average daily maximum temperature for summer is 27.7°C.
This is very likely to increase to between 29.2°C and 29.7°C.

The current average rainfall over summer is 307 mm.
This is likely to increase to between 365 mm and 456 mm.

The current average rainfall over winter is 207 mm.
This is likely to decrease to between 165 mm and 186 mm.

2. Norah Head

The current average daily maximum temperature in summer is 24.4°C.
This is very likely to increase to between 25.9°C and 26.4°C.

The current average rainfall over summer is 302 mm.
This is likely to increase to between 362 mm and 453 mm.

The current average rainfall over winter is 306 mm.
This is likely to decrease to between 275 mm and 245 mm.

3. Katoomba

The current average daily maximum temperature in summer is 22.3°C.
This is very likely to increase to between 23.8°C and 24.3°C.

The current average rainfall over summer is 402 mm.
This is likely to increase to between 483 mm and 603 mm.

The current average rainfall over winter is 269 mm.
This is likely to decrease to between 215 mm and 242 mm.

4. Peats Ridge

The current average daily maximum temperature in summer is 26.2°C.
This is very likely to increase to between 27.7°C and 28.2°C.

The current average rainfall over summer is 377 mm.
This is likely to increase to between 452 mm and 565 mm.

The current average rainfall over winter is 254 mm.
This is likely to decrease to between 203 mm and 229 mm.

Expected physical responses

Sea level is virtually certain to rise

This study assumed a sea level rise of 0.4 m above the 1990 mean sea level by 2050 and a 0.9 m rise by 2100 consistent with the A2 emissions scenario adopted (refer to Section 2 for details).

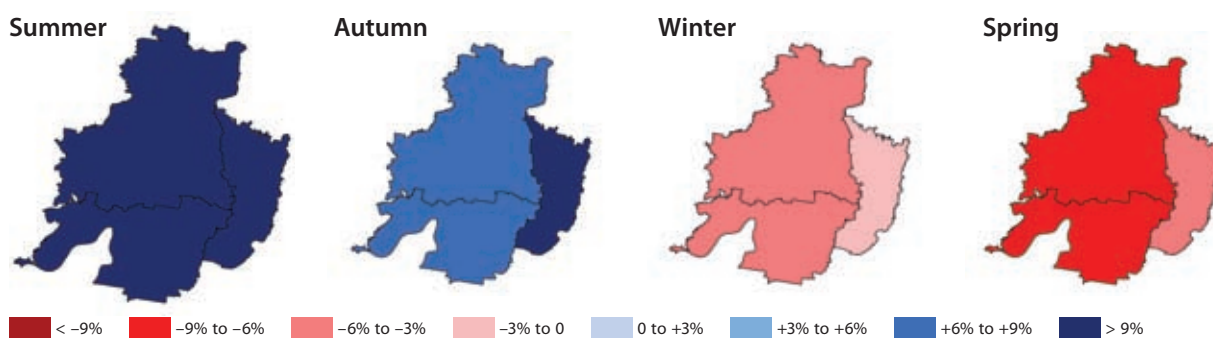
Increased evaporation is likely to lead to drier conditions in spring

As a result of increased temperatures and evaporation, soil conditions in spring are likely to be slightly drier.

A minor increase in annual average run-off is projected; summer run-off is very likely to increase substantially

Some redistribution of run-off across the seasons is likely, with increases in summer and autumn and decreases in winter and spring. A substantial increase in summer run-off is very likely throughout the region, and a minor decrease in average annual run-off is about as likely as not. The average of modelled changes in run-off are shown in Figure 5.8 and listed with the range of projected changes in Table 5.8.

Sydney Subregions



Central Coast Subregions

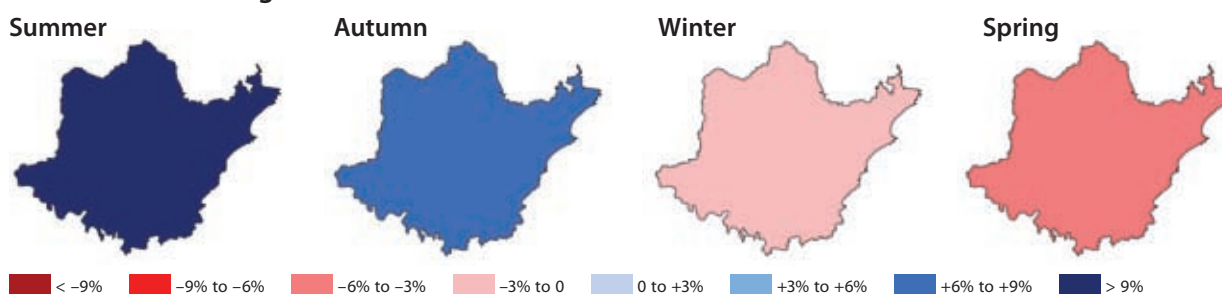


Figure 5.8 Estimated four-model mean percentage change in seasonal run-off for the Sydney and Central Coast subregions for projected 2030 climatic conditions⁸

⁸ Run-off projections are for 2030, rather than 2050, as they are based on an existing study (Vaze *et al.* 2008). The 2030 projections are considered indicative of the direction and magnitude of hydrological changes by 2050 (see Section 2.3 and Appendix A for further details).

Short-term hydrological droughts are projected to become more severe, while medium and long-term droughts are projected to become less severe

Estimates of the change in total run-off during short-term drought periods range from 20% drier to 25% wetter compared to historical conditions. The corresponding estimates for medium to long-term drought periods range from 10% drier to 20% wetter. The average of the four modelled results indicates that short-duration droughts are likely to become more severe, and medium to long-term droughts are about as likely as not to be slightly less severe.

Flooding behaviour is likely to change

The combination of rising sea levels and catchment-driven flooding is likely to increase flood frequency, height and extent in the lower portions of coastal floodplains. Increases in the intensity of flood-producing rainfall events are likely to change flood behaviour, but catchment conditions at the time of each rainfall event (soil moisture conditions and levels in major water storages) will affect the degree of the change.

Fire regimes are likely to change, but changes to fuel availability are uncertain

Higher temperatures and changes to rainfall patterns will more likely than not lead to increased fire frequency, but the return period of fires is considered likely to remain within the current domain of acceptable fire intervals of 10–30 years towards the year 2050. Peak fire dangers in the 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. The fire season will more likely than not be longer, extending into late winter and lengthening into late summer. Very high to extreme fire danger days are projected to increase by 10–50% and the conditions conducive to large and intense fires (such as prolonged drought, low humidity, number of days with high temperature and high wind speeds) will more likely than not increase.

Future change in fuel availability is the least certain of all the factors that drive fire. Projected decreases in available moisture will possibly reduce fuel availability; however, projections of fuel availability are presently regarded as highly speculative.

Table 5.8 Modelled changes in run-off in the Sydney/Central Coast region

Period	Run-off depths			Magnitude of high flows			Frequency of occurrence of low flows		
	Magnitude ¹ and direction of projected changes	Degree of agreement ²	Range of projected change	Magnitude ¹ and direction of projected changes	Degree of agreement ²	Magnitude ¹ and direction of projected changes	Degree of agreement ²	Magnitude ¹ and direction of projected changes	Degree of agreement ²
Sydney subregion									
Spring	Moderate decrease	Likely	-18% to +5%	N/A	N/A	N/A	N/A	N/A	N/A
Summer	Substantial increase	Very likely	0% to +34%	N/A	N/A	N/A	N/A	N/A	N/A
Autumn	Moderate increase	Likely	-5% to +23%	N/A	N/A	N/A	N/A	N/A	N/A
Winter	Minor decrease	Likely	-13% to +7%	N/A	N/A	N/A	N/A	N/A	N/A
Annual	Minor increase	About as likely as not	-7% to +13%	N/A	N/A	N/A	N/A	N/A	N/A
Central Coast subregion									
Spring	Minor decrease	Likely	-12% to +8%	Slight decrease	About as likely as not	Moderate increase	About as likely as not	Moderate increase	About as likely as not
Summer	Substantial increase	Very likely	+6% to +28%	Substantial increase	Very likely	No significant change	Very likely	No significant change	Very likely
Autumn	Moderate increase	About as likely as not	-5% to +19%	Moderate increase	Likely	Slight decrease	About as likely as not	Slight decrease	About as likely as not
Winter	Slight decrease	Likely	-14% to +12%	Slight decrease	Likely	Slight increase	About as likely as not	Slight increase	About as likely as not
Annual	Minor increase	About as likely as not	-4% to +16%	N/A	N/A	N/A	N/A	N/A	N/A

Changes in run-off depths and stream flows were estimated using results from each of the four GCMs selected for this assessment. Run-off projections are for 2030, rather than 2050, as they are based on an existing study (Vaze *et al.*, 2008). The 2030 projections are considered indicative of the direction and magnitude of hydrological changes by 2050 (see Section 2.3.3 and Appendix A for further details).

The range of the estimates and their degree of agreement are presented in this table.

Notes:

1 The magnitude of the average of the changes from the four GCMs (see Box 4.1 for definitions)

2 The degree of agreement is based on the number of GCMs (out of four) which agree with the direction of projected average change (see Box 4.1 for definitions)

N/A Not modelled for this subregion

Regionally significant impacts

The climate changes and physical responses described above are expected to result in the following impacts on land, settlements and natural ecosystems.

Impacts on land

Sea level rise and resulting inundation and erosion are virtually certain to have major impacts on the coastline. Changes in rainfall are likely to increase sediment shedding from the hinterland, potentially causing changes to stream channels including bank erosion. Problems of acid sulfate soils are likely to lessen in the longer term.

Rising sea level is virtually certain to increase coastal recession

Sea level rise and storms are virtually certain to increase coastal inundation and erosion, causing the erodable coastline to recede, typically by 20–40 m by 2050 and 45–90 m by 2100 but could be outside this range depending on local factors. Impacts will be locally intensified or reduced by changes in other factors such as rainfall patterns, storm intensities and frequencies, river flows, and wind and wave action. Shoreline retreat is very likely to be higher in estuaries and on beaches with lower gradients, particularly where the ocean breaks through or washes over coastal dunes. Where beaches are backed by seawalls and promenades, as is commonly the case in the developed Sydney Basin, there is very likely to be a narrowing and potential loss of sandy recreational areas unless beach replenishment programs are put in place.

Salt water from sea level rise is likely to affect soils on coastal plains

Interactions among saline incursions caused by sea level rise, increased flood flows and higher watertables are likely to cause saline waters to move into new areas of the coastal plains. Soil structural decline is likely in some low-lying areas near the tidal reaches of the upper Parramatta River and smaller estuaries.

Higher rainfall is likely to increase the risk of mass movement of soils in vulnerable areas

Higher rainfalls are likely to accelerate all forms of soil erosion across the region, and to increase the risk of mass movement on vulnerable slopes in coastal hinterlands, such as the Razorback Range. However, freeze-thaw effects at higher elevations such as the Blue Mountains are likely to become rarer because of higher winter minimum temperatures, leading to greater slope stability in these areas.

Gully erosion is likely to increase in vulnerable areas; river banks are likely to become less stable

Greater run-off and high seepage flows are likely to increase gully erosion in vulnerable areas. However, this effect is likely to be offset to some extent by increased cover of ground vegetation arising from generally higher moisture levels in soils. Higher winter minimum temperatures are likely to enhance ground cover, especially in frost-hollow areas in the west of the region where temperature sometimes limits winter grass growth. The streams most vulnerable to river bank erosion are likely to be the larger, unregulated tributaries of the Hawkesbury River, such as the MacDonald River, which have floodplain sediments dominated by sands.

Dryland salinity is likely to increase

Dryland salinity is a major soil degradation issue in western Sydney, particularly associated with some Wianamatta-group rocks. Higher watertables associated with increased summer and spring rainfall may cause local saline outbreaks. However, it is also likely that higher rainfall will flush more salts from streams such as South Creek.

Problems of acid sulfate soils are likely to continue in the short term but decrease in the longer term

Acid sulfate soils (ASS) are likely to remain a problem in locations such as the tidal foreshores of the upper Parramatta River and low-lying areas of the Central Coast, but ameliorate over time. Initial rises in sea level are likely to cause saline waters to inundate some areas with ASS, leading to a structural decline of the soil. Over time, the interaction of a continuing rise in sea level and catchment-driven flooding are likely to lead to more freshwater inundation on floodplains, resulting in an improvement in ASS. However, most of the areas prone to ASS in the region are with urban infrastructure, so any improvements associated with climate change will also depend on urban development and its impact on groundwater hydrology.

Organic matter in soils is likely to increase in most areas, but decline in coastal swamps

Organic matter in soils is important in maintaining structure and nutrient availability for plants. Several factors influence the accumulation of organic matter in soil, including the rate of accumulation of leaf litter and debris, the activity of soil micro-organisms, soil moisture and erosion. In general, higher CO₂ concentrations, temperatures and rainfall are likely to increase biomass production in almost all coastal areas. This increase is likely to lead to rises in organic matter accumulation and soil carbon levels, provided that extra inputs are not offset by higher decomposition rates or lost through burning. Likely exceptions are those coastal swamps that lose organic matter as a consequence of sea level rise and saltwater incursion.

Sea level rise and flooding are likely to affect Aboriginal cultural heritage values

The Sydney/Central Coast region includes a variety of sites, places and objects that are culturally significant to Aboriginal people, including stone artefacts, rock art, middens, grinding grooves, rock shelters and ceremonial sites. Sea level rise and extreme rainfall events are likely to result in the loss of or damage to middens and other coastal ceremonial sites.

Impacts on settlements

Settlements near estuaries and beaches are likely to be most vulnerable to the effects of climate change. Sea level rise and more heavy downpours are likely to increase flood risks. Urban streams are likely to flood more frequently and the risk of some levees being overtopped is likely to increase.

Sea level rise is virtually certain to affect many settlements near estuaries and beaches

Residential and commercial beachfront development in the region are virtually certain to be threatened by either ocean inundation or coastline recession. Dwellings, tower blocks, commercial premises, registered clubs, caravan parks, surf clubs, beachfront roads and associated infrastructure will be potentially at risk by 2050.

Areas at risk include Collaroy, Narrabeen, North Entrance and Avoca

Areas at Collaroy/Narrabeen and Wamberal are currently at risk from ocean inundation or coastline recession. At Collaroy/Narrabeen, residential tower blocks, residential beachfront development and associated infrastructure are potentially threatened by current coastal processes and are likely to have enhanced risk by 2050. At Wamberal, residential beachfront dwellings are currently at risk. Other areas of concern likely to have increasing risks by 2050 include The Basin, Patonga, Macmasters Beach, Avoca, Forresters Beach, Blue Bay, North Entrance, Cabbage Tree Harbour and Hargraves Beach, Mona Vale, Newport, Bilgola, Avalon, Whale Beach, Palm Beach, Pearl Beach, Shelley Beach, Toowoan Bay, The Entrance, Soldiers Beach and Lakes Beach.

Infrastructure at risk includes major ports, airports and sewerage works

Low-lying settlements have a wide range of vulnerable built assets. Many public boat ramps, recreation jetties and wharves are likely to be affected by sea level rise, as well as local roads, parks and reserves. Low-lying sewerage infrastructure is at risk, posing potential risks to water quality and public health. Major public infrastructure that is likely to be affected includes Port Jackson, Port Botany, the Sydney fishing port, ferry terminals and the runways of Sydney Airport.

Most property boundaries referenced to the high water mark will change

An important consequence of sea level rise is that beachfront or waterfront property boundaries referenced to the mean high water mark are virtually certain to move inland over time. About 50,000 properties are likely to be affected state-wide, but regional figures are not available.

Existing coastal protection structures are likely to be affected

For much of the region, infrastructure is already protected by seawalls and revetments, which are likely to require ongoing maintenance as sea levels rise. Sea walls and revetments protect beaches such as Cronulla, Maroubra, Coogee, Bondi, Manly, Curl Curl, Dee Why and Terrigal.

The frequency, intensity and extent of flooding are likely to increase

Local government has reported that more than 100,000 urban buildings in the region are currently exposed to inundation in a flood of the size that occurs on average once every 100 years. Many of these buildings are on the Central Coast and in the catchments of the Hawkesbury–Nepean and Georges rivers. Higher sea levels and an increased frequency of intense rainfall events are likely to significantly increase the frequency of flooding, the depth of flooding and the number of properties affected. Impacts will vary locally according to terrain and the influence of man-made structures such as roads, embankments, bridges and culverts. In coastal areas, particularly below the tidal limit, the way in which river and estuary entrances change as sea levels rise will affect flood behaviour. Seven lakes and lagoons in the region currently have estuary management strategies that reduce flood impacts.

Urban streams are likely to flood more frequently

Increases in rainfall intensities, particularly in short duration storms, are likely to cause additional flooding from local streams. Floodwaters are likely to rise more rapidly, potentially increasing the danger of these local floods to the community. Areas with potential for significant increases in overland flooding include Fairfield and parts of Gosford.

Settlements on estuaries and coastal lakes are vulnerable

Estuaries and coastal lakes with settlements that are vulnerable to flooding from sea level rise and catchment run-off include Tuggerah Lakes, Brisbane Waters, the Hawkesbury River, Narrabeen Lakes, Manly Lagoon, Port Jackson, the Cooks River, the Georges River and coastal creeks in the Pittwater area. The degree of impact will depend on the influence that sea level has on flood levels and behaviour and the exposure of the settlements. For example, in Narrabeen Lagoon, which is heavily influenced by ocean level, flood damage has the potential to increase more than five-fold due to sea level rise predicted by 2100. On smaller lagoons in the region, such as Manly Lagoon, the potential increase in damage may be significantly higher by 2100.

Some levees are likely to become less effective at protecting property from floods

Local government reports the existence of over 40 km of levees in the region, many in western Sydney. Although levees provide some flood protection to areas behind them, changes in flood-producing rainfall events are likely to reduce the protection provided by some existing works, resulting in increases in the frequency of damage and the need for evacuation.

Water supplies are likely to be affected by hydrological changes

If future run-off is at the drier end of the range of estimates, inflows to water storages are likely to decrease by about 10%. This will have most impact on towns with small storages.

A more detailed study looking specifically at the potential impacts of climate change on Sydney's water supply and demand is currently underway. This study, being conducted as part of the Sydney Metropolitan Water Plan, will take into account local conditions in drinking water catchments, as well as projected customer demand, under climate change scenarios.

Box 5.5 Ozone levels in Sydney under climate change

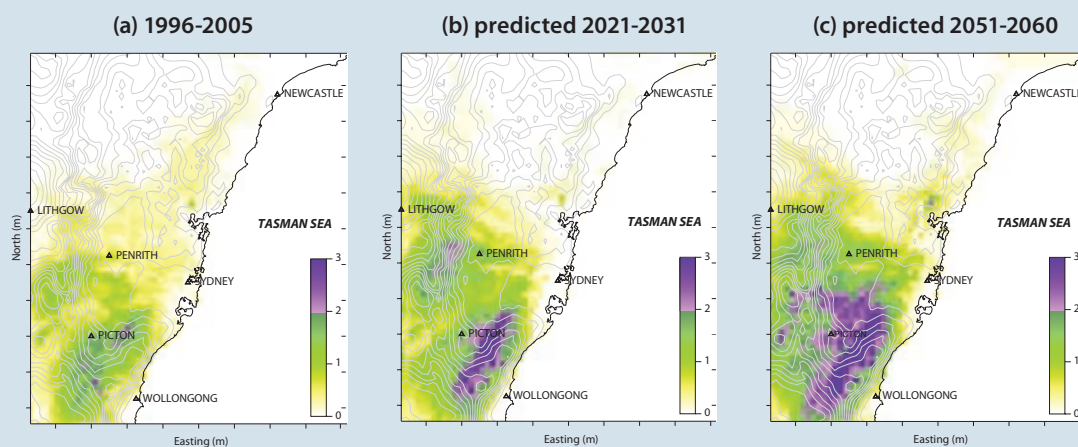
Under the Clean Air Research Program, the Australian Government Department of Environment, Water, Heritage and the Arts (DEWHA) funded the Clean Air Research Project 11: 'A methodology for determining the impact of climate change on ozone levels in an urban area' (CSIRO 2008). This project was undertaken by CSIRO Marine and Atmospheric Research with the support of DECC. It provides an insight into the impact of climate change on ozone levels in Sydney in 20 and 50 years' time, and estimates the decrease of emissions which may be needed to maintain ozone levels below the current air quality standard. It is called the National Environment Protection Measure for Ambient Air Quality.

Climate change projections for NSW suggest significant increases in the frequency of drought, increases in the frequency of hot days and increases in the frequency of high fire risk weather. Sydney currently experiences temperatures above 30°C on 15 days per year. Studies have highlighted that by 2030 this is predicted to increase to between 18 and 31 days per year and by 2070 to between 22 and 117 days per year. This has important ramifications for air pollution and health, with ozone pollution events linked to the frequency of hot, sunny days, and with the highest particle pollution concentrations linked to the presence of bushfire smoke in the Sydney region.

Impact of temperature rise alone

Ozone concentrations in the Sydney region were compared for three 10-year periods: 1996–2005, 2021–2030 and 2051–2060. The figure below shows the impact of the predicted increase in temperature across the three decades on the spatial distribution of the 4-hour ozone exceedence. It can be seen that the size of the ozone footprint increases across the three decades. This result is also reflected in the 1-hour exceedence data.

The modelling results also demonstrate that the increase in temperature will result in an increase in the number of exceedences of the 1-hour ozone standard in the Sydney region of 27% by 2021–2030 and 45% by 2051–2060 (compared with the 1996–2005 period). The average number of exceedences of the 4-hour ozone standard increased by 30% by 2011–2030 and 92% by 2051–2060.



Ozone concentrations in the Sydney region, indicating the average number of days per season with a 4-hour ozone level exceeding 80ppb: (a) 1996–2005; (b) predicted 2021–2030; (c) predicted 2051–2060

Source: CSIRO 2008

Impact of temperature rise and emissions growth

The study also looked at the impact of temperature increases coupled with growth in emissions. Sydney emissions were aligned with the energy assumptions inherent in the A2 emissions scenario (see Box 2.1), so the impact on ozone concentrations of this predicted change in emissions, coupled with the predicted temperature increases for the 2051–2060 period, could be investigated.

Again, the results show that the size of the ozone footprint increases for the 4-hour ozone exceedences. The results also highlight that, based on current technologies, overall emission reductions of the order of 70% by 2060 would not achieve compliance with the ozone standards.

While this study is a preliminary investigation into the impact of climate change and associated temperature increases on air quality in the Sydney region, it demonstrates that a rise in temperature alone, without any changes to current technology, has the potential to increase peak ozone concentrations and increase the size and duration of the ozone footprint, raising the population's exposure to elevated ozone concentrations.

Impacts on ecosystems

Ecosystems on foreshores are likely to be affected by coastal recession and rising waters, and other low-lying coastal ecosystems are at risk from saltwater intrusion into watertables and up-river systems. Increased temperatures and altered fire regimes are also likely to impact on ecosystems across the region. Highly cleared and fragmented ecosystems such as those on the Cumberland Plain are likely to be at greater risk than more intact ecosystems.

Sea level rise is likely to threaten coastal ecosystems

Rising watertables and saltwater intrusion are likely to affect lowland ecosystems in the coastal zone. Saline intrusion is likely to eliminate salt-intolerant vegetation in areas near the present tidal limit such as some of the freshwater and forested wetlands on the Hawkesbury–Nepean floodplain and the Wyong River. In permeable substrates such as the sand plain supporting the Botany Wetlands, salt water intruding into watertables is likely to push fresh water upwards, increasing freshwater volumes at or near the surface. Salt water is likely to approach or reach the surface in lower parts of the landscape, converting freshwater ecosystems into types adapted to more saline conditions. Ecosystems that establish in affected areas are extremely likely to contain a reduced structural complexity and diversity of species, particularly in more fragmented landscapes. Affected ecosystems are likely to include coastal swamp forests, coastal floodplain wetlands, littoral rainforest, coastal heath swamps and coastal-dune dry sclerophyll forest. Lowland forests and heathlands contain flowering trees and shrubs that are important to nectarivores and insectivores such as honeyeaters, flying foxes, micro-bats and arboreal mammals like pygmy possums.

Sea level rise is likely to threaten some estuarine communities

Sea level rise and shoreline retreat are likely to induce a large-scale modification or loss of intertidal and subtidal ecosystems as water depth, turbidity, sedimentation, pH, temperature and salinity change. Tuggerah Lakes and other barrier estuaries contain most of the region's larger seagrass beds, and the region also has large areas of mangroves and salt marshes at sites such as the Towra Point, the Hawkesbury River, Homebush Bay, Brisbane Water and Port Hacking. Seagrasses are likely to be displaced from some of their current extent and their ability to re-colonise is difficult to predict. Mangroves and salt marshes are also likely to be displaced but new mangrove habitat should form in other places, including areas currently occupied by salt marshes. Salt marsh is slow to colonise however, and its establishment in new habitats is likely to be limited by the rapidity of sea level rise and increased rates of sediment movement. Changes in the species composition of estuarine invertebrate communities are likely to adversely affect estuarine food webs and result in declines in some fish populations. It is virtually certain that infrastructure and development will impede the re-establishment of estuarine habitats in some places, such as the Parramatta River and Brisbane Water.

Climate change is likely to reduce migratory shorebird habitat and populations

Rock platforms, sand spits, mudflats and salt marshes provide important foraging and nesting areas for a suite of shorebirds, including some species that migrate seasonally along the East Asian–Australasian Flyway. Estuaries in the region such as Towra Point and Homebush Bay are internationally significant while Brisbane Water, the Tuggerah Lake system and rocky coasts also provide important habitat for the shorebirds of the region (e.g. little terns, red-capped plovers and sooty oystercatchers). Many migratory shorebird populations have already declined because of habitat modification along migratory routes, and climate change is likely to exacerbate this trend.

Altered fire regimes are likely to cause widespread changes in many ecosystems

An increase in more intense or extensive fires is likely to cause contraction of the most fire-sensitive ecosystems. Rainforest and wet sclerophyll forests, which occur in much of the region in sheltered pockets among the widespread dry forests, are likely to contract to mesic refuges or disappear altogether. Even in fire-adapted ecosystems, more intense, extensive fires can cause subtle but widespread changes in species composition and vegetation structure. Altered fire regimes can influence litter depth and structure, litter breakdown by invertebrates and decomposition by microbes, plant regeneration and recruitment and fauna populations. Examples of species at risk include Deane's blue gum (*Eucalyptus deanei*), Blue Mountains ash (*Eucalyptus oreades*) and ground parrots (*Pezoporus wallicus*). The numbers of hollow-bearing trees, important for many mammals and birds, are likely to be reduced. Changes in fire regimes are likely to interact with climatic changes. For example, the opening of the canopy by fire, together with warmer temperatures and wetter summers, is likely to advantage weeds such as lantana (*Lantana camara*).

Fire and drought are likely to affect nectarivores and granivores

Nectar-feeding vertebrates such as honeyeaters, gliders, possums and flying foxes are important pollinators of many plants, and in turn rely on the flowering of plants such as banksias and eucalypts in the dry forests and heaths of the region. Extensive fire and drought reduce the flowering of these plants, and hence impact on nectarivores. Such environmental conditions are likely in the predicted warmer El Niño periods, threatening nectarivore populations and pollination. In many eucalypt and casuarina species, fire and drought conditions also reduce seed production, decreasing food resources for specialist granivores such as gang gang (*Callocephalon fimbriatum*) and glossy black (*Calyptorhynchus lathamii*) cockatoos.

High-altitude species are likely to contract in the lower parts of their ranges

Few areas rise much above the general elevation of the region's sandstone plateaux, and consequently cold-adapted species inhabiting the plateaux have few high-altitude refuges and are susceptible to temperature rises. A number of plant species typically occur above 1,000 m, some of which are either threatened, endemic or concentrated around upland swamps. These species include *Eucalyptus gregsoniana* (Wolgan snow gum), *Celmisia longifolia* (snow daisy), *Persoonia hindii*, *Boronia deanei*, *Derwentia blakelyi* and *Dillwynia stipulifera*. A suite of vertebrates is found only above 600 m, including the regionally endemic Blue Mountains water skink (*Eulamprus leuraensis*) and the highland copperhead (*Austrelaps ramsayi*), bold-striped cool-skink (*Bassiana duperreyi*), tussock cool-skink (*Pseudemoia entrecasteauxii*), southern brown tree frog (*Litoria ewingi*), blotched bluetongue (*Tiliqua nigrolutea*), gang gang cockatoo, flame robin (*Petroica phoenicea*) and false pipistrelle (*Falsistrellus* spp.). All of these species are likely to contract in the lower-elevation parts of their ranges.

Highly fragmented ecosystems are likely to come under added pressure from climate change

The grassy woodlands and forested wetlands of the Cumberland Plain are highly fragmented and listed as endangered ecological communities. Edge effects, arson, weeds and lack of recruitment are the main factors threatening these ecosystems. Climate change is likely to exacerbate these existing impacts, with increased temperatures creating harsher microclimates at ecosystem edges. Drought stress and fire associated with warmer El Niño periods are likely to lead to weakening and eventual loss of some old, hollow-bearing trees. Stressed trees are also more susceptible to insect attack, which will also contribute to tree loss.

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Glossary

acid sulfate soils: a mix of low-lying coastal clays and sands that contain sulphur-bearing compounds at concentrations above 0.5% in clays and 0.01% in sands

albedo: The fraction of the total light striking a surface that gets reflected from that surface

alluvial: arising from sediments deposited from flowing water

anthropogenic: Produced or caused by human activity

biodiversity: The variety of all life forms: the different plants, animals and micro-organisms, the genes they contain and the ecosystems they form

biomass: The total mass of living material occupying a specific part, or the whole of, an ecosystem at a given time

biophysical environment: The biological and physical elements of an environment

climate: the synthesis of the day-to-day weather conditions in a given area; the actual climate is characterised by long-term statistics of the state of the atmosphere in an area

colonial birds: bird species which congregate in large numbers to feed or nest

domain of acceptable fire intervals: specifies the upper and lower limits of fire intervals, beyond which significant decline of species populations and local extinction is likely; a decline in biodiversity can occur as a result of either too infrequent (above maximum limit or threshold) or too frequent burning (below minimum threshold) (Kenny *et al.* 2004)

East Coast Low: an intense low-pressure system which occurs on average several times each year off the eastern coast of Australia; can cause gale or storm force winds, heavy widespread rainfall, and very rough seas and prolonged heavy swells

ecological community: an aggregation of organisms characterised by a distinctive combination of two or more ecologically related species

ecosystem: a functional system which includes communities of living organisms and their associated physical, non-living environment, which interact to form an ecological unit, such as a tidal rock pool, wetland or forest

El Niño–Southern Oscillation: a natural oscillation in the state of the ocean–atmosphere system that leads to substantial changes in atmospheric circulation throughout the Asia-Pacific region and generally drier conditions in eastern Australia; *see also* La Niña

erosion: the loosening and transportation of soil and other material, chiefly by wind and running water; *see also* gully erosion, rill erosion, sheet erosion

generalist species: species that are able to thrive in a wide variety of environmental conditions and can make use of many different resources

general security users: those who have ‘regulated river (general security) access licences’ under the *Water Management Act 2000*; general security users have lower priority of access to water compared with environmental water, ‘regulated river (high security) access licences’, stock and domestic and town water supply water

geomorphological: relating to the Earth’s form, especially the surface and physical features, and the relationship of these to the geological structures beneath

global climate model: mathematical tool for simulating the climate system; based on the physical, chemical and biological properties of the climate system and their interactions

greenhouse gases: atmospheric gases, including carbon dioxide, methane, chlorofluorocarbons, nitrous oxide, ozone and water vapour, which trap heat reflected from the Earth’s surface

groundwater: water that occurs beneath the ground held in or moving through saturated layers of soil, sediment or rock

gully erosion: form of erosion involving the formation of deep sided channels or gullies

Indian Ocean Dipole: ocean–atmosphere phenomenon in the Indian Ocean; defined by an index that is the difference between sea surface temperature in the western (50°–70°E, 10°S–10°N) and eastern (90°–110°E, 10°–0°S) tropical Indian Oceans

intertidal: between the levels of low and high tide

La Niña: the extensive cooling of the central and eastern Pacific Ocean; in Australia (particularly eastern Australia) associated with an increased probability of wetter conditions

ozone: a gas made of three oxygen atoms, occurring naturally in the stratosphere where it protects life on Earth from harmful levels of solar ultraviolet radiation; ozone at ground-level is formed from anthropogenic emissions and is a major component of photochemical smog

Ramsar Convention: common name for the *Convention on Wetlands of International Importance Especially as Waterfowl Habitat*, signed in Ramsar, Iran in 1971

Ramsar wetland: a wetland classified as internationally important under the Ramsar Convention

rill erosion: soil erosion resulting in the formation of shallow drainage lines less than 30 cm deep; occurs when surface water concentrates in depressions or low points

run-off: water that flows across the land surface and does not soak into the ground; can be a major agent of soil erosion and can carry pollutants

salinisation: the accumulation of salts in the soil; leads to degradation of soils and vegetation

salinity hazard: the extent to which natural physical characteristics, excluding land cover, predispose a landscape to salinisation; relevant characteristics include topography, soils, geology, climate

sheet erosion: the removal of the upper layers of soil by raindrop splash and/or run-off

sodic soils: soils containing a high proportion of sodium; sodic soils cause poor physical conditions for plant growth and are susceptible to erosion

soil acidification: a reduction in soil pH (increase in acidity)

specialist species: species that can only thrive in a narrow range of environmental conditions

storm bite: the volume of beach sand that can be eroded from the visible part of the beach and dunes during a storm

southern Annular Mode: north–south movement of the strong westerly winds in the middle to higher latitudes of the Southern Hemisphere

weather: the day-to-day state of the atmosphere and its short-term variation

Appendix A: Assessment of hydrological impacts

Run-off projections

The GCMs used as part of the IPCC's work are the best available tools for modelling future climate scenarios. However, temperature and rainfall results produced by GCMs are at too coarse a spatial resolution (typically $\approx 200 \text{ km} \times 200 \text{ km}$) to allow for an appropriate analysis of hydrologic impacts.

In order to manage water resources for the future, the NSW Department of Water and Energy (DWE) undertook a study to investigate how future projections for temperature and rainfall were likely to impact on run-off and water availability for all of New South Wales.

The method used was to firstly generate a reference (no climate change) time series of run-off estimates for $5 \text{ km} \times 5 \text{ km}$ areas of land at daily time steps for the period 1895–2006. The run-off estimates were generated using the historical daily rainfall record and estimated evaporation applied to rainfall run-off models calibrated to over a hundred gauged catchments in NSW.

Comparable time series of climate change run-off estimates at a reference date of 2030 were then generated for the 15 GCMs that had daily data available for the A1B emissions scenario for the current and future time periods. A daily scaling method was used to adjust the historical daily rainfall record. The daily scaling method applies different scaling factors based on ratios of seasonal distributions of daily rainfall totals. (For full details of this method refer to the original report: Future climate and run-off projections (~2030) for New South Wales and Australian Capital Territory (2008).) The method adjusts daily rainfall totals on a seasonal basis to be higher or lower than the historical, and maintains the inter-annual and inter-decadal patterns.

The method applied to results from the 15 GCMs produced a range of changes to rainfall and resulting run-offs, from significantly wetter to significantly drier futures, reflecting the current level of uncertainty of rainfall projections (but there is greater consensus for temperature projections). However, the model assessment and selection of the four best GCMs by UNSW has narrowed the range of results and associated uncertainty study quite significantly.

There are a couple of important differences between the results from this work and work for the other components of the regional impacts study:

- This study used a different emissions scenario (A1B instead of A2) and assessment date (2030 instead of 2050). This was because the modelling was completed before the design of the regional impact study. Given the overall strengths of this work, these differences are considered to be minor compared to the uncertainty of GCM outputs.
- The daily scaling method and the longer modelling period used to estimate rainfall and run-off changes (112 years compared to 20 years) may result in some statistical differences in the results of mean seasonal changes.

Analysis of run-off estimates

Modelled run-off estimates across the State Plan regions were extracted for the 112-year modelling period, for the historical reference period and the four selected GCMs from the database created for the project discussed in the previous section. These results were analysed for the following:

- percentage change in average seasonal run-off depths, and
- percentage change in total run-off depths for the driest period of record during the 112-year record for period durations of 0.5, 1, 2, 3, 4, 5, 6 and 7 years.

In addition, modelled historical reference and GCM run-off estimates were extracted for gauged catchments for which the rainfall run-off models had been calibrated. The catchments with the best reproduction of historical flow distributions were analysed for changes in:

- the magnitude of high flows (the flow rate currently exceeded 1% of the time), and
- the frequency of occurrence of low flows (the flow rate currently exceeded 90% of the time).

Analysis of drought severity

Hydrological drought is associated with the effect of extended periods of low rainfall on the amount of water entering rivers, lakes and other water bodies. The important issue in analysing hydrologic drought is the amount of run-off generated by rainfall, and not the amount of rainfall itself.

The minimum amount of run-off over a continuous period is important in understanding, for example, how much water needs to be stored to ensure there is water available to supply to water users during droughts. The amount of water stored is generally a socio-economic decision, and may be based on lowest run-off for a short duration (e.g. six months) or for a longer duration (e.g. seven years).

This study analysed the modelled daily run-off results from Vaze *et al.* (2008) to understand whether hydrologic droughts of different lengths of time are likely to be more or less severe than they have been historically. The total run-off for a given continuous length of time was calculated from the 112-year period of results, and the lowest total over that period recorded. For example, the lowest run-off for any period of one year may have been 50 mm, and occurred between 18 July 1902 and 17 July 1903, whereas the lowest run-off for any seven-year period may have been 200 mm, occurring between 21 February 1941 to 20 February 1948.

These calculations were done for each region, for eight different lengths of time including short durations (0.5 and 1 year), medium durations (2, 3, and 4 years) and longer durations (5, 6, and 7 years), and for the historical period, as well as for each GCM. The changes in drought severity for any particular duration were the percentage change for the GCM results compared to the historical period.

Presentation of analysis

Each GCM resulted in a different estimate of run-off changes. The reporting of these results is based on the following characteristics:

- the magnitude of the average of the changes from the four GCMs
- the full range of changes (from lowest to highest percentage change)
- the degree of agreement between the four GCMs regarding the direction of change.

For the magnitude of changes, the following descriptions were used for the average increase or decrease:

Description	Range for % change in:		
	Run-off depths	High flow magnitude	Low flow frequency
Slight	0–3	0–5	0–10
Minor	3–6	N/A	N/A
Moderate	6–9	5–10	10–20
Substantial	>9	>10	>20

Terminology for the degree of agreement is as follows:

Description	Number of GCMs agreeing on direction of average change
Very likely	4
Likely	3
About as likely as not	2
Possibly	1

Reasons for differences in reported rainfall changes and run-off results

Changes in rainfall have been estimated using two different methods for different impact assessment in this report, and in some cases produce different results. This will be apparent where ‘expected regional climate change’ results reported at the beginning of each regional section do not fully correspond to reported changes in seasonal run-off.

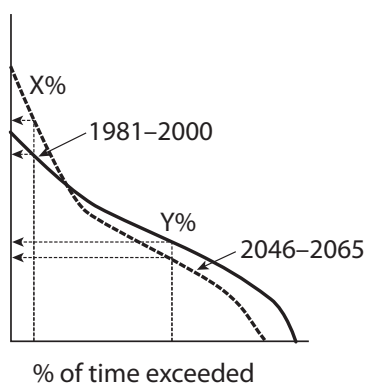
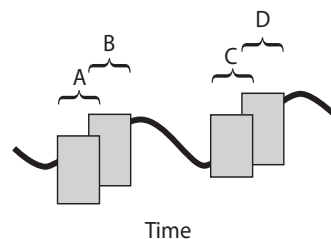
There are several reasons for this, including that the hydrology was estimated for the A1B emissions scenario at a 2030 assessment date, whereas the regional climate change was estimated for the A2 emissions scenario at a 2050 assessment date. The effect of this would be that the changes estimated for the hydrology would be smaller. A further reason for the different results is because different methods were used to estimate rainfall. A brief explanation of these methods follows.

The expected regional rainfall changes are calculated directly from GCM modelled results. The first step was to calculate the ratio of seasonal rainfall for the respective current and future sample dates. Daily data is stored for twenty-year periods centred around 1990 and 2055, so the percent change in rainfall (P) is calculated as

$$\% \text{ Change}_{(\text{season})} = 100 * \frac{\overline{P}_{(\text{season}, 2046 \rightarrow 2065)}}{\overline{P}_{(\text{season}, 1981 \rightarrow 2000)}}$$

These ratios were then averaged for the four models, and interpolated from the native GCM resolution of around 200 km to a finer resolution of 50 km, and averaged within each region.

The first step is a source of uncertainty because of the natural decadal scale variability of rainfall. The diagram to the right illustrates this. The decadal natural variability is represented by a smoothed line. The calculated change for future climate will in part depend on the selection of the current period (A or B) and the future period (C or D). A change represented by C/B would be much smaller than that calculated by D/A.



The method used to estimate rainfall for changes in hydrology, described in Chiew *et al.* (2008), is quite different. Rainfall for future climatic conditions was estimated using the same data set (GCM modelled daily rainfall for 1981–2000 and 2046–2055).

The first step in the method calculates the ratio of daily modelled rainfalls with the same exceedence probability for each season. In the example shown, the higher daily rainfalls with low exceedence probabilities (X%) increase, and the lower daily rainfalls with higher exceedence probabilities (Y%) decrease.

The next step is to rescale these factors to account for the assessment date of 2030 compared to the data date of 2055. These factors are scaled by the ratios of the average temperature increase of 1990 → 2030 compared to 1990 → 2055. These re-scaled factors for each percentile rainfall for each season are then used to scale daily rainfall from the Bureau of Meteorology’s SILO database for all data sets within the GCM grid cell for the period 1895–2006, and these re-scaled daily rainfall data sets used in calibrated rainfall run-off models.

The hydrology uses a much longer data set of rainfall examples of wet and dry periods. Different subsets of this may show either an increase or decrease in rainfall totals, depending on whether it is a wet period or dry period.

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