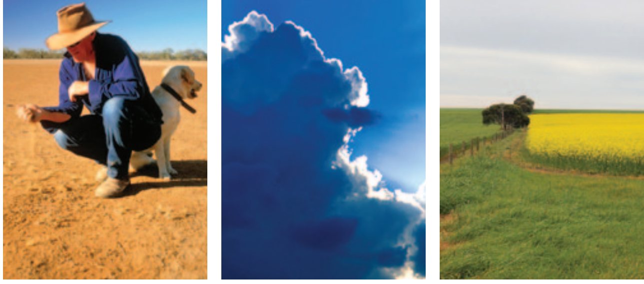
South Eastern Australian
Climate Initiative



The South Eastern Australian Climate Initiative

Phase 2 of the South Eastern Australian Climate Initiative (SEACI) is a three-year (2009–2012), $9 million research program investigating the causes and impacts of climate variability and change across south-eastern Australia.

SEACI is a partnership between the CSIRO Water for a Healthy Country Flagship, the Bureau of Meteorology, the Murray–Darling Basin Authority, the Victorian Department of Sustainability and Environment, and the Australian Government Department of Climate Change and Energy Efficiency.

The SEACI region includes the Murray–Darling Basin, the state of Victoria and southern South Australia, as illustrated in Figure 1.

The program of research for Phase 2 of SEACI builds on the outcomes of Phase 1, in which significant advances were made in our understanding of the key drivers influencing the climate of south-eastern Australia. Phase 2 includes studies of climate variations on time scales ranging from weeks to decades, providing information which is relevant to a range of policy and water management stakeholders.

Research is conducted through three related themes.

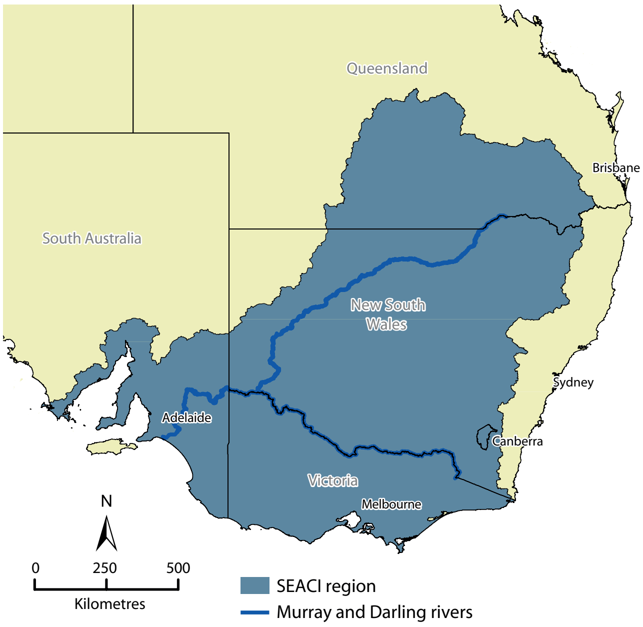


Figure 1. South Eastern Australian Climate Initiative (SEACI) region

Theme 1: Understanding past hydroclimate variability and change in south-eastern Australia

Research in Theme 1 is leading to a better understanding of the factors that drive climate across south-eastern Australia, and how these impact on the water balance.

This theme seeks to describe the relationships between the large-scale climate factors which affect south-eastern Australia, including the Hadley circulation and the sub-tropical ridge, and is undertaking an assessment of the ability of climate models to capture these observed relationships.

This research is determining the extent to which observed changes in climate can be attributed to enhanced greenhouse gas concentrations, and aims to determine the cause of the greater-than-expected decline in streamflow which was observed across south-eastern Australia throughout the Millennium Drought (1997–2009).

Further details can be found in Factsheet 2 of 4: *The Millennium Drought and 2010/11 Floods.*

Theme 2: Long-term hydroclimate projections in south-eastern Australia

Research in Theme 2 is leading to improved future hydroclimate projections in south-eastern Australia.

Research in this theme seeks to improve projections of future climate across south-eastern Australia, and the impact of climate variability and change on future water availability and river flow characteristics.

This research is further refining appropriate greenhouse gas emission and global warming scenarios for water resources impact assessment, and is assessing the ability of global climate models to simulate the observed large-scale atmospheric drivers of south-eastern Australian climate.

Research is also being undertaken to improve the understanding and estimation of streamflow sensitivity to rainfall and temperature, and to improve hydrological models in order to adequately capture potential changes in climate–runoff relationships and dominant hydrological processes. This is providing updated and more accurate projections of the impact of climate change on water availability across south-eastern Australia.

Further details can be found in Factsheet 4 of 4: *Understanding future changes in climate and streamflow*.

Theme 3: Seasonal hydroclimate prediction in south-eastern Australia

Research in Theme 3 is exploring the predictability of streamflow, leading to improved seasonal climatological and hydrological forecasts.

Phase 1 of SEACI contributed to the development of a statistical streamflow forecasting model which utilised climate forecasts from the Predictive Ocean Atmosphere Model for Australia (POAMA). In Phase 2, SEACI research is further improving the ability of POAMA to predict rainfall at lead times ranging from several weeks to nine months. Outputs from the statistical streamflow forecasting model are being improved by better accounting for large-scale drivers such as the El Niño – Southern Oscillation and the Indian Ocean Dipole.

SEACI research has contributed to the development of a seasonal streamflow forecasting service which provides predictions of streamflow for three months ahead. The service is available at: <http://www.bom.gov.au/water/ssf/index.shtml>.

Research in Phase 2 of SEACI is further developing modelling approaches and assessing the utility of seasonal forecasts, which will improve the skill of hydrological modelling for south-eastern Australia.

Further details can be found in Factsheet 3 of 4: *Predicting seasonal climate and streamflow*.

National Research FLAGSHIPS
Water for a Healthy Country
CSIRO

Australian Government
Department of Climate Change and Energy Efficiency
Bureau of Meteorology

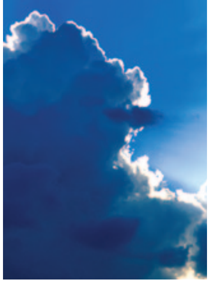
MURRAY–DARLING BASIN AUTHORITY

State Government Victoria
Department of Sustainability and Environment

FACTSHEET 1 OF 4

The suite of four factsheets is available from www.seaci.org or by emailing seaci@csiro.au

South Eastern Australian
Climate Initiative



The Millennium Drought and 2010/11 Floods

The recent drought in historical context

Between 1997 and 2009, south-eastern Australia experienced the most persistent rainfall deficit since the start of the 20th century. Annual rainfall during the so-called 'Millennium Drought' was 73 mm below average (or 12.4% below the 20th century mean) for the years 1997–2009 inclusive.

Other significant dry periods occurred throughout the 20th century, however they were not as dry for as long. The period 1932–1945 was the next driest 14 years on record, however this period had a rainfall deficit of just 6.9% – around half that observed throughout the Millennium Drought.

The 1932–45 dry period (encompassing the WWII drought) had a geographical character which saw it spread across most of the continent. The Millennium Drought differed from this significantly in that it was largely limited to south-eastern and south-western Australia while the bulk of the continent experienced above average rainfall, as shown in Figure 1.

The Millennium Drought was also distinctive with regards to its seasonality. The rainfall decline occurred between March and October with around two-thirds of the rainfall deficit occurring in autumn, with smaller reductions throughout the rest of the year. By comparison, during the WWII drought, rainfall declines tended to be greatest in the spring months.

The 2010/11 La Niña event and the flooding across south-eastern Australia

In 2010/11, the world experienced one of the strongest La Niña episodes on record. Comparably strong La Niña events had not been recorded since the 1970s, and while there were a few La Niña events throughout the Millennium Drought, they did not bring significant rainfall to south-eastern Australia.

As a result of this strong La Niña, significant and widespread increases in rainfall were observed across Australia. The episode produced widespread flooding across south-eastern Australia, with the largest impact occurring in the north of the region. The Murray–Darling Basin experienced its largest annual rainfall total on record. South-eastern Australia recorded its fourth highest annual rainfall with 810 mm.

The statistics in this factsheet were derived using the latest gridded rainfall observations as developed by the Bureau of Meteorology – as part of the Australian Water Availability Project (AWAP) – averaged over continental Australian south of 33.5°S and east of 135.5°E (depicted as red rectangle in Figure 1).

Data are publicly available at: <http://www.bom.gov.au/cgi-bin/silo/cli_var/area_timeseries.pl>.

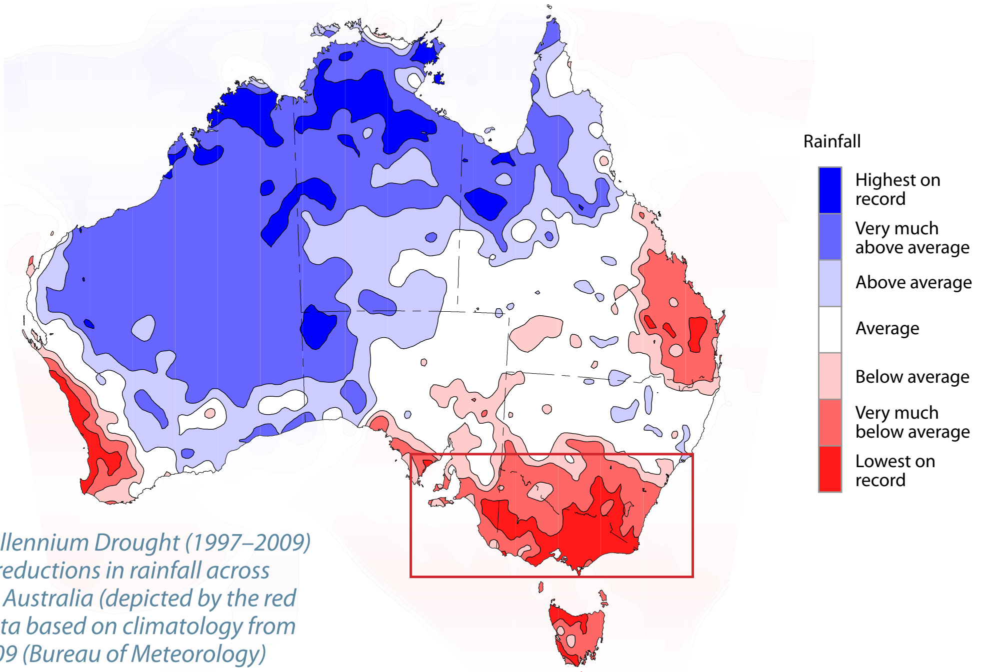


Figure 1. The Millennium Drought (1997–2009) saw major reductions in rainfall across south-eastern Australia (depicted by the red rectangle). Data based on climatology from 1900 to 2009 (Bureau of Meteorology)

SEACI is a partnership between the CSIRO Water for a Healthy Country Flagship, the Bureau of Meteorology, the Murray–Darling Basin Authority, the Victorian Department of Sustainability and Environment, and the Australian Government Department of Climate Change and Energy Efficiency.

The greatest positive rainfall anomalies for 2010 were located in the northern half of south-eastern Australia, with a significantly lower impact occurring south of the Great Dividing Range, where tropical influences such as La Niña are reduced.

Throughout this La Niña episode the greatest rainfall anomalies in south-eastern Australia were recorded in spring (247 mm, or 60% above the 20th century average) and in the 2010/11 summer when 303 mm was recorded (150% above the 20th century average). This is the largest summer total ever recorded by a considerable margin.

The impact of the strong La Niña was exacerbated by the Southern Annular Mode (SAM), which reached record positive values in late spring and early summer of 2010. In addition, one of the largest negative Indian Ocean Dipole (IOD) events of the last 50 years was recorded in 2010 (Figure 2).

Despite the La Niña episode, below-average rainfall (192 mm, 11% below the 20th century average) was recorded in April–July 2010, continuing the established pattern of below-average rainfall during the autumn months. This trend has continued into 2011, with rainfall throughout April to June 2011 being 25% below the 20th century average.

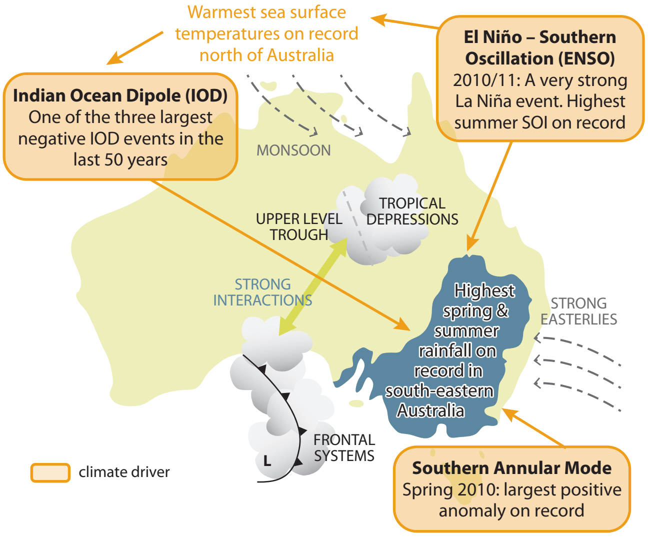


Figure 2. In 2010/11, south-eastern Australia recorded record-breaking rainfall in spring and summer due to the combination of the positive phase of all large-scale modes of variability known to contribute to the year-to-year variability of rainfall: ENSO, IOD and SAM

The sub-tropical ridge (STR)

The sub-tropical ridge is a belt of high pressure stretching across the mid-latitudes. It is the surface signature of the Hadley Cell which is the most fundamental component of the global climate system. It is the process by which heat from the sun, which falls mainly in the tropics, is transported from equatorial zones to the mid-latitudes in the atmosphere.

The relationship with global warming

SEACI researchers have analysed the observed climate record and found that the El Niño – Southern Oscillation and other large-scale modes of variability cannot explain the observed decline in autumn and early-winter rainfall in south-eastern Australia.

SEACI researchers have, however, found a strong relationship between the rainfall decline in south-eastern Australia and the intensity of the sub-tropical ridge (STR), with the decrease in rainfall strongly associated with increasing surface pressure in the latitudes of the STR. The strengthening of the STR is estimated to account for around 80% of the recent rainfall decline in south-eastern Australia.

Research indicates that there are changes in the Hadley Cell (and hence changes in the STR) associated with global warming. In particular, the STR has intensified with increasing global surface temperature. This result implies that the rainfall decline in south-eastern Australia may have some link to global warming. To investigate this, SEACI researchers conducted simulations of the global climate over recent decades using a global climate model and different external forcings (natural and anthropogenic). In these simulations, the climate model was only able to reproduce STR increases and other modifications of the Hadley Cell when anthropogenic forcings (e.g. greenhouse gases) were present in the simulation along with the natural forcings.

This gives confidence that there is a link between the rainfall decline across south-eastern Australia and increasing greenhouse gas concentrations in the atmosphere.

National Research FLAGSHIPS
Water for a Healthy Country
CSIRO

State Government Victoria
Department of Sustainability and Environment

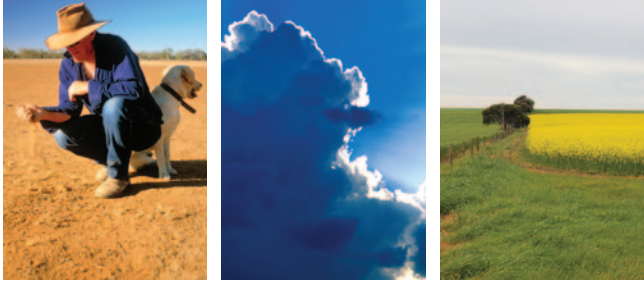
Australian Government
Department of Climate Change and Energy Efficiency
Bureau of Meteorology

MURRAY–DARLING BASIN AUTHORITY

FACTSHEET 2 OF 4

The suite of four factsheets is available from www.seaci.org or by emailing seaci@csiro.au

South Eastern Australian
Climate Initiative



Predicting seasonal climate and streamflow

Seasonal climate drivers

Rainfall prediction across south-eastern Australia relies upon an understanding of how various large-scale climate factors affect rainfall patterns across the region. Prediction of seasonal rainfall across the region is derived from strong associations with El Niño – Southern Oscillation (ENSO), the Indian Ocean Dipole (IOD) and the Southern Annular Mode (SAM).

The impact of the ENSO and IOD on rainfall is relatively well understood and provides a degree of confidence when developing seasonal predictions. The SAM however, has a shorter time scale than that of the ENSO and the IOD, and therefore its contribution to forecast skill only tends to occur in the first month of the forecast.

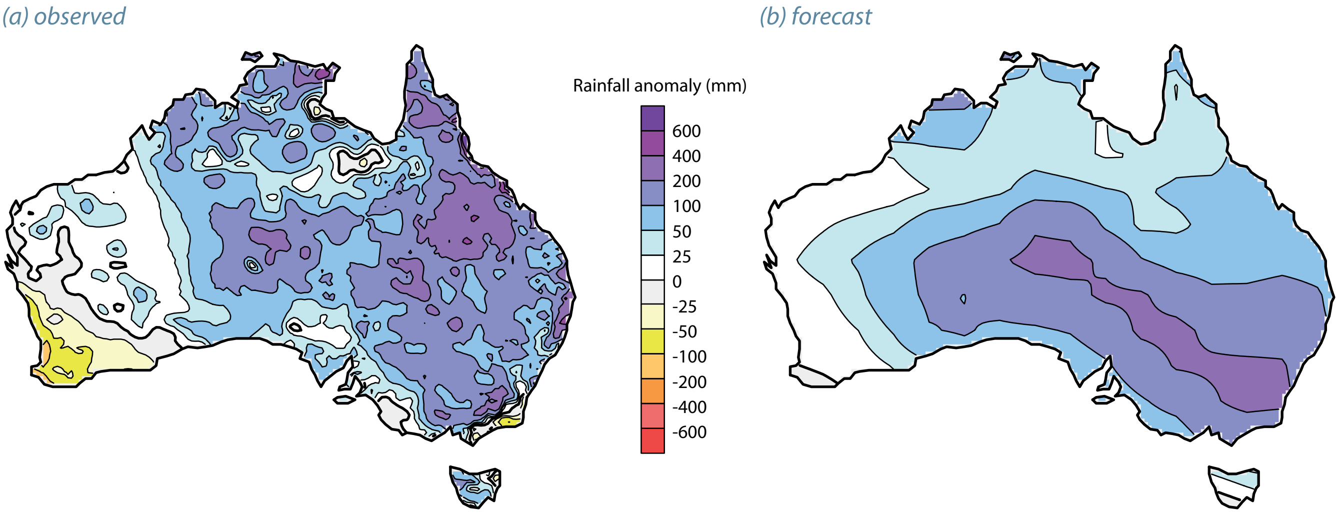
Regional variations in the nature of impacts from these large-scale factors must also be taken into account when developing predictions for south-eastern Australia. For example, the IOD mainly affects the southern part of the Murray–Darling Basin (MDB) from mid-winter to mid-spring. However, El Niño events that have their largest amplitude in the eastern Pacific Ocean tend to reduce rainfall in the southern MDB in late spring to early summer. By comparison, El Niño events that have their largest amplitude in the central Pacific Ocean tend to reduce rainfall in the northern MDB in late autumn to winter.

Progress with seasonal climate prediction

POAMA2, the new coupled ocean–atmosphere seasonal forecast system, is routinely run at the Bureau of Meteorology to forecast seasonal climate with lead times of up to nine months. The new POAMA2 system can now predict the occurrence of El Niño events up to nine months in advance, though predictability of IOD events is still limited to lead times of less than three months.

POAMA2 successfully translates the good predictions of El Niño and IOD into high quality predictions of rainfall in south-eastern Australia at three-month lead times. For instance, the likelihood of receiving above average rainfall across south-eastern Australia during winter and spring is correctly predicted between 55% and 70% of the time for lead times of three months.

A good forecast from POAMA2 was made for the record wet spring in 2010 (Figure 1). This rainfall forecast was a result of POAMA2 correctly predicting the strong La Niña conditions in the Pacific Ocean at a six-month lead time which, together with a negative IOD and a very strong positive SAM, contributed to large rainfall accumulations across most of Australia.



(a) observed

(b) forecast

Figure 1. (a) Observed and (b) forecast rainfall anomalies for spring season 2010. The forecast is the POAMA2 seasonal forecast that was initialized on 1 September 2010 and provided a good forecast of observed conditions (Bureau of Meteorology)

SEACI is a partnership between the CSIRO Water for a Healthy Country Flagship, the Bureau of Meteorology, the Murray–Darling Basin Authority, the Victorian Department of Sustainability and Environment, and the Australian Government Department of Climate Change and Energy Efficiency.

Research in Phase 2 of SEACI indicates that there are good prospects for improving the prediction of seasonal rainfall at longer lead times. Currently, systematic model biases are preventing the predictions of El Niño and the IOD from being properly translated into good rainfall predictions at lead times greater than three months. These model biases have been identified and are being addressed for the next version of POAMA.

Progress with seasonal streamflow forecasting

Skilful forecasting of seasonal streamflow for south-eastern Australia is dependent upon two sources of predictability. The dominant source is knowledge of the condition of the catchment soil and groundwater storages at the initial forecast date. Knowledge of climate variations during the forecast period – principally rainfall accumulation – is the other key source of predictability.

Statistical forecasts of streamflow can be made using antecedent streamflow (if available) or antecedent rainfall totals (in the absence of streamflow observations in near real-time) to represent the initial catchment soil and groundwater storage conditions. Rainfall variations for the forecast period are then inferred from some key climate indices at the initial forecast time.

The use of monthly water-balance model simulations to represent the initial catchment conditions has, on average, had little impact on forecast skill. Using these simulations does however reduce the chances of skill estimates based on forecasts of historical events being artificially inflated by predictor selection, and also reduces the computation requirements to establish forecasting models.

Replacing selected climate indices at the initial forecast time with rainfall forecasts from POAMA2 produces mixed results: the skill of streamflow forecasts increases in some seasons and decreases in others. The skill of these streamflow forecasts is related to the accuracy of the POAMA2 rainfall forecasts. Using all methods, the forecast probability distributions are reliable for all seasons with the exception of autumn, where to date no predictors have adequately described the impact of the rainfall decline since the mid-1990s.

The findings from this research are being used to improve the Bureau of Meteorology's operational seasonal streamflow forecasting service. An example forecast is shown in Figure 2. Here, historical conditions suggested that the streamflow for the three months from July to September 2009 could fall within a large range of conditions. The forecast however suggested that streamflow would be quite low, which was what in fact was observed, with flows just over 400 GL.

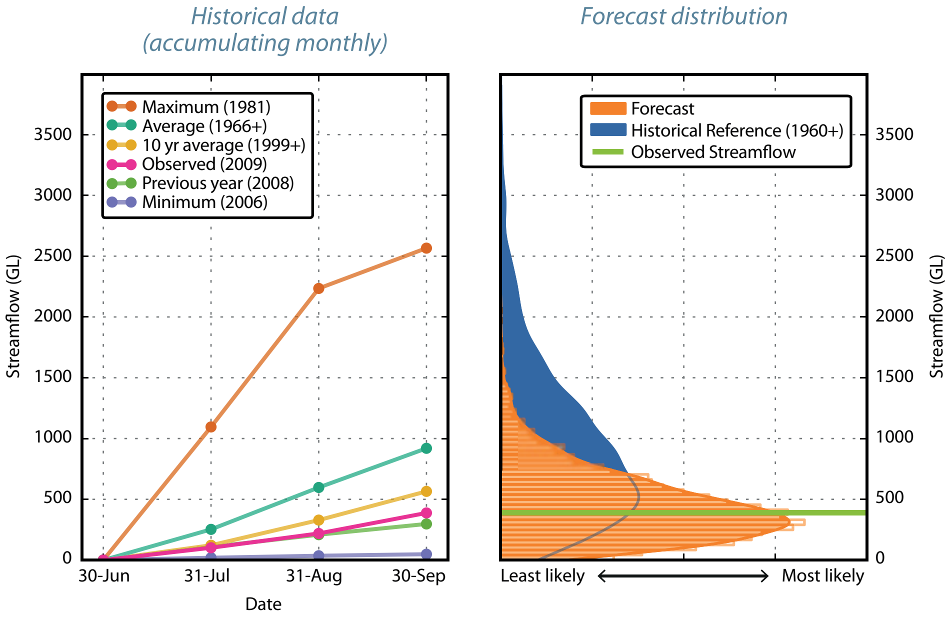


Figure 2. Seasonal streamflow forecast issued by the Bureau of Meteorology in July 2009 for total flows of the Ovens River to the Murray River for July to September 2009 (Bureau of Meteorology)

National Research FLAGSHIPS
Water for a Healthy Country
CSIRO

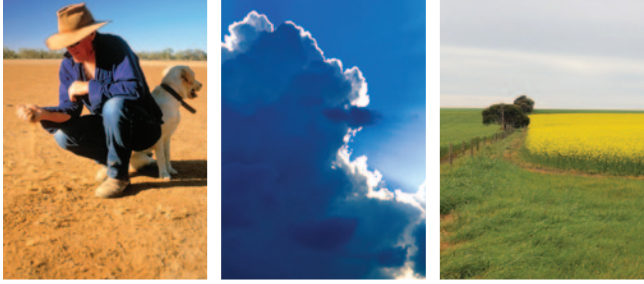
State Government Victoria
Department of Sustainability and Environment

Australian Government
Department of Climate Change and Energy Efficiency
Bureau of Meteorology

MURRAY–DARLING BASIN AUTHORITY

FACTSHEET 3 OF 4

The suite of four factsheets is available from www.seaci.org or by emailing seaci@csiro.au



Understanding future changes in climate and streamflow

Estimating climate change impact on future climate and streamflow

Estimating future streamflow under a changed climate involves three main components as summarised in Figure 1. Firstly, global climate models are used to project future climate change. Secondly, the results from the global climate models are 'downscaled' to the region of interest and its weather patterns. Finally, the downscaled future climate series are used to drive hydrological models to estimate future streamflow.

There is uncertainty in each of the modelling components. The first source of uncertainty is the future level of greenhouse gas emissions. The second is how the global climate (in particular global temperature) will respond to these emissions. To quantify and reduce the uncertainty, SEACI researchers have assessed the global climate models used by the Intergovernmental Panel on Climate Change (IPCC), and place more weight on the projections from the better models.

The global climate models operate on a very coarse spatial resolution. For example, Victoria is typically represented by less than five grid cells. For regional and catchment hydrological modelling, SEACI researchers use statistical and dynamic downscaling models to downscale daily rainfall and other climate variables to the catchment scale. A third source of uncertainty therefore is how regional and local climates (in particular rainfall) will respond to the changes in the global climate.

The downscaled future daily climate series are then used to drive hydrological models which estimate future streamflow. Runoff and streamflow are mainly influenced by rainfall, with a 1% change in mean annual rainfall in south-eastern Australia generally amplified as a 2% to 3% change in mean annual runoff. Runoff will also be affected by changes in potential evaporation, dominant hydrological processes, vegetation response, and surface–atmosphere feedbacks in a warmer and higher CO_2 environment. The uncertainties associated with these changes in runoff therefore represent a fourth source of uncertainty. Ways of reducing these uncertainties are being investigated by SEACI researchers.

Future rainfall and streamflow projections for south-eastern Australia

The majority of global climate model simulations indicate that south-eastern Australia will, on average, be drier in the future, particularly across the far south of the region. This is consistent with the expected changes in the large-scale atmospheric and oceanic drivers of rainfall in this region in a warmer world. Although the average rainfall and streamflow in south-eastern Australia are projected to decline, extreme rainfall events are likely to be more intense because warmer temperatures will provide stronger

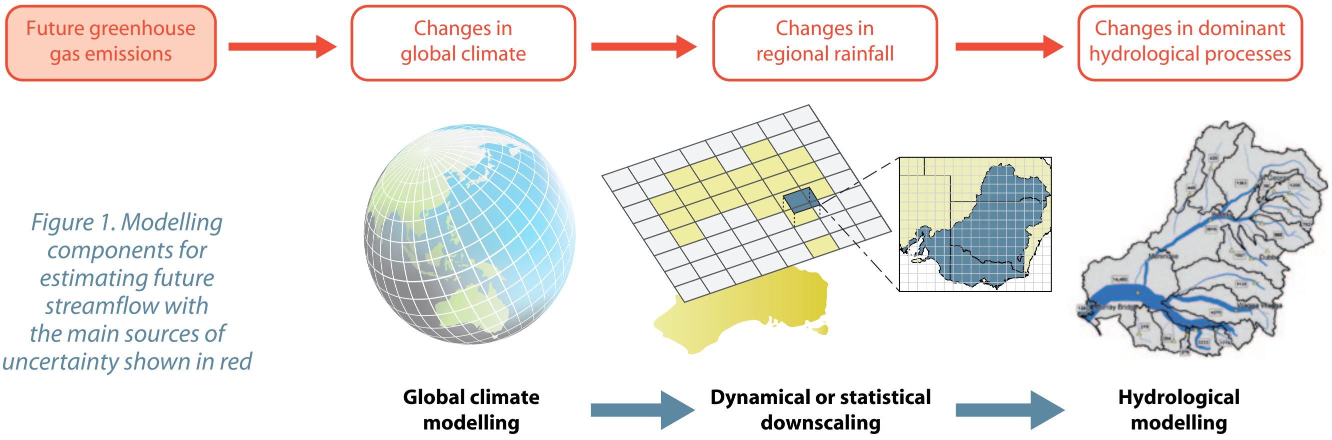


Figure 1. Modelling components for estimating future streamflow with the main sources of uncertainty shown in red

SEACI is a partnership between the CSIRO Water for a Healthy Country Flagship, the Bureau of Meteorology, the Murray–Darling Basin Authority, the Victorian Department of Sustainability and Environment, and the Australian Government Department of Climate Change and Energy Efficiency.

convection and an increased capacity for moisture to be held in the air. These higher-intensity storms will increase flood risks, cause greater storm and sewer runoff in urban areas, and increase erosion and nutrient delivery to waterways, particularly during high-runoff events following dry periods.

Figure 2 shows the projected changes in future average annual rainfall and runoff modelled by SEACI researchers using future climate series downscaled from the global climate model projections. The plots show the change in average annual rainfall and runoff for a 1°C global warming (the projected warming by ~2030 relative to ~1990). Projected declines in rainfall and runoff will be greater for higher global warming and for the more distant future.

The wet, median and dry estimates in Figure 2 show the range of projected change representing the uncertainty.

Averaged across the northern half of the region (north of 33°S; corresponding to the latitude just north of Sydney), the median estimate is a decline in average annual rainfall of 3% (range of –12% to +4%) and decline in runoff of 10% (range of –30% to +14%). Averaged across the southern half of the region (south of 33°S) the median reductions in rainfall and runoff tend to be larger and are more consistent across the vast majority of projections, with a median decline in average annual rainfall of 4% (range of –9% to 0%) and decline in runoff of 12% (range of –24% to –1%).

The future climate for south-eastern Australia will be one that still produces droughts and floods, but where the average annual rainfall and runoff is likely to be lower. The low river flows experienced during the Millennium Drought may be expected to recur more frequently in the future.

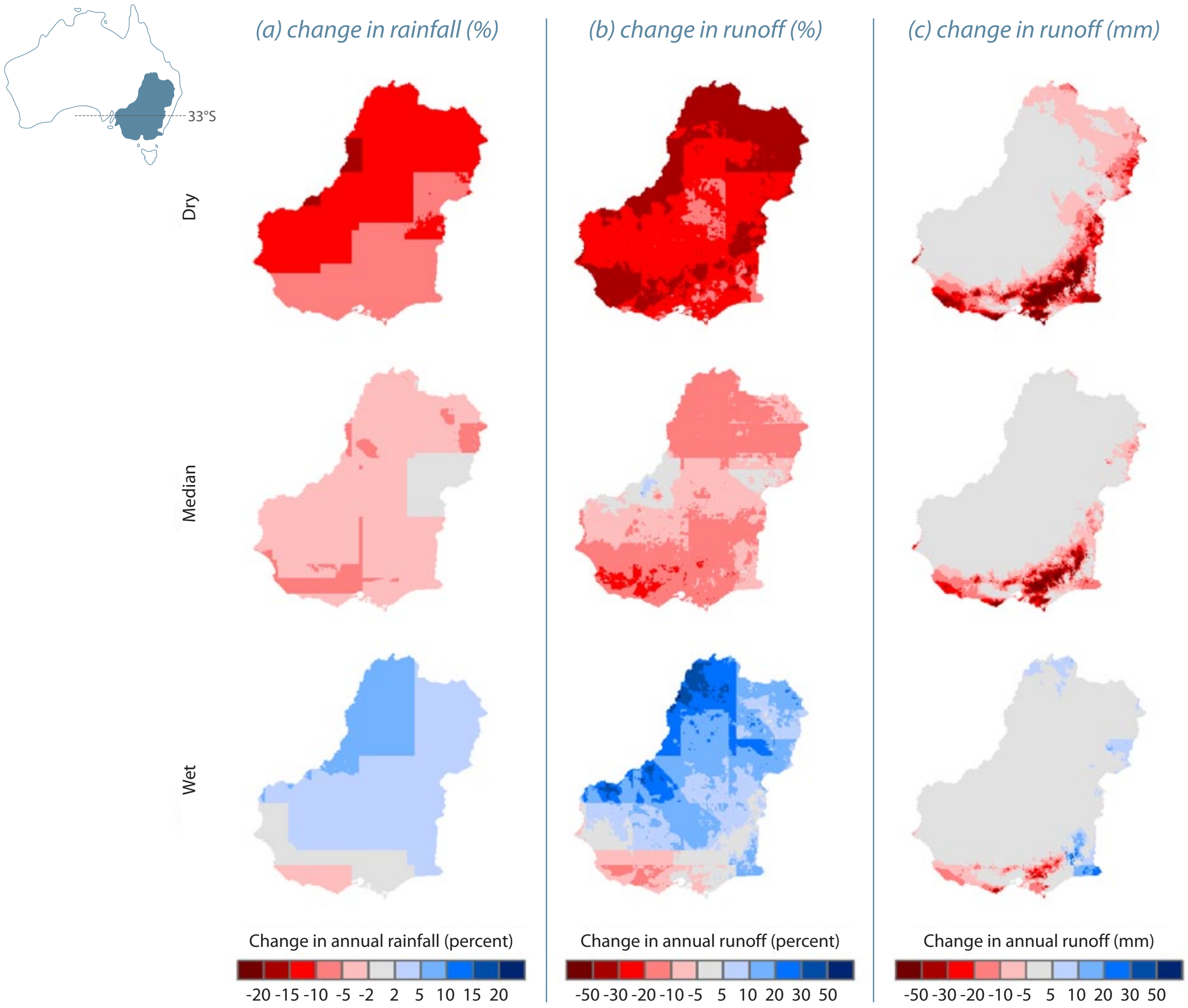


Figure 2. Changes in modelled mean annual runoff (for ~2030 relative to ~1990 global temperature) across south-eastern Australia (Murray–Darling Basin and Victoria) showing the median result and the wet and dry extremes of the possible range for (a) rainfall, and runoff: (b) percent, (c) millimetres

National Research FLAGSHIPS
Water for a Healthy Country
CSIRO

Australian Government
Department of Climate Change and Energy Efficiency
Bureau of Meteorology

MURRAY–DARLING BASIN AUTHORITY

State Government Victoria
Department of Sustainability and Environment

FACTSHEET 4 OF 4

The suite of four factsheets is available from www.seaci.org or by emailing seaci@csiro.au