Executive Summary

The climate of the Murray–Darling Basin is changing. Average temperatures are increasing, droughts are occurring more often and the volume of inflows into the Murray–Darling Basin have decreased over the last 20 years.

In this context, after the worst drought in recent history, the Basin Plan was developed and began in 2012. It represents a significant advance in Australian water management and provides a consistent water policy across five state and territory governments. At its core, it seeks to ensure environmental outcomes are realised and balance all interests. The Basin Plan currently addresses the risks of climate change. Water rights and markets are stronger, climate risks in water resource plans are comprehensively assessed and more water has been secured as an ongoing entitlement for the environment. The Basin Plan also includes mechanisms that ensure the Basin Plan settings can be reviewed as new science comes to hand. However, more needs to be done to deal comprehensively with a changing climate. The MDBA is responsible for ensuring a healthy working Basin and ensuring that settings under the Basin Plan provide long-term resilience to a changing climate.

With the Basin Plan settings still being put in place, we need to understand whether current policies can be improved to assist the environment, communities and irrigators to adapt to a future with potentially even less water than planned in 2012. We need to further understand specifically what climate change is likely to mean for the hydrology of our rivers, the way we operate them, the effect on water quality and water-dependent ecosystems and how water markets and trade will operate in the future.

This paper outlines:

- what we know about climate change and the Murray–Darling Basin
- how the Basin Plan currently addresses climate change risks
- how those risks might have changed since 2012
- the challenges ahead and what further Basin-specific research is required to translate these risks into Basin-specific risks, and
- the MDBA’s climate change research program.

The MDBA is open to feedback from all stakeholders on this paper and the questions it poses.

We look forward to working with all stakeholders on this key issue.
Climate change and the Murray–Darling Basin

The Basin’s climate is changing. The atmosphere is warming, rainfall patterns are shifting, and extreme weather events such as storms, droughts and floods are becoming more frequent and intense. These changes are attributed to increasing concentrations of greenhouse gases in the atmosphere associated with human activities, in particular, growing emissions of carbon dioxide (IPCC, 2014). Climate change is expected to impact water availability in the Murray–Darling Basin, and the communities, businesses and ecosystems which depend on them (CSIRO, 2008; MDBA, 2010; CSIRO et al., 2016; Steffen et al., 2018).

Observed changes

Temperature

Australia’s climate is changing in response to a warming global climate system (BOM and CSIRO, 2018). Temperatures across Australia are now 1°C hotter (on average) relative to 1910 (Figure 1) and further increases are expected (BOM and CSIRO, 2016; 2018).

Figure 1: Mean temperature change in Australia relative to 1910. (BOM and CSIRO, 2016)

Temperatures in the Basin reflect this national trend, with annual mean temperatures continuing to increase above the long term average (1910 to 2017), year after year. Figure 2 demonstrates that temperature increases in the Basin are particularly evident over the last 20 years.
Rainfall

Multiple large-scale weather patterns influence the Basin’s climate. Dynamic interactions between these systems results in a highly variable climate, and extreme variations in rainfall both spatially and temporally. This variability makes it difficult to determine the exact effect climate change is having on rainfall. Nevertheless, scientists agree that rainfall patterns are changing as a result of climate change.

Rainfall patterns vary between the Basin’s north and south. The climate in the southern Basin receives more consistent, rain-bearing weather systems, such as the Southern Annular Mode (SAM). Historically, this system brings regular winter rainfall to south-east Australia and is often responsible for the majority of inflows entering the Basin in a given year. Inter-annual variability in this weather system is common, and associated with interactions between the SAM, Indian Ocean Dipole (IOD) and ENSO systems (Hope et al., 2017; BOM & CSIRO, 2018).

Southern Basin

Over the last 20 years, there has been an observed shift in the amount of rainfall in south-east Australia, particularly via the SAM. Less rainfall is falling during the winter and spring, and slightly more rainfall is falling during autumn. Overall, the southern Basin is receiving less annual rainfall.
compared to the long term average. These changes are attributed to climate change (Hope et al., 2017; BOM & CSIRO, 2018).

Northern Basin

The northern Basin has a more variable and intermittent rainfall pattern, with long dry periods and droughts interspersed with intense rainfall events. Rainfall in the northern Basin is generated by a more complicated mix of weather systems than in the southern basin, giving rise to greater variability and unreliability (Ekström et al., 2015; BOM & CSIRO, 2018). Over the last 20 years the northern Basin has also seen a shift in rainfall patterns, with declines in winter and spring rainfall, and increases in summer and autumn rainfall. Differences in the summer and winter rainfall over the past 20 years (relative to the long term average) for Australia are shown in Figure 3.
Figure 3: Winter rainfall: April to October rainfall deciles for the last 20 years (1998–99 to 2017–18). Summer rainfall: October to April rainfall deciles for the last 20 years. A decile map shows where rainfall is above average, average or below average for the recent period, in comparison with the entire national rainfall record from 1900. (BOM and CSIRO, 2018)
Climate change projections

Governments and research institutions are continually improving the understanding of how global climate change will influence the Australian climate. This research applies up to 40 global climate models that represent the relationship between greenhouse gas concentrations, global temperatures and global circulation patterns. Using these models, scientists are able to project the impacts of global climate change in the Australian context. Significant variation between projected outcomes makes it difficult to precisely forecast the effect of climate change on future weather patterns, nevertheless these models remain highly useful tools to examine the potential range of future impacts due to climate change.

Over the past decade, several studies have applied global climate models to identify potential changes in the Basin’s climate, and estimate the scale of potential impacts on water availability. Two such investigations, the Murray–Darling Basin Sustainable Yields (MDBSY) project and the South Eastern Australian Climate Initiative (SEACI), both found a greater likelihood of declining rainfall at the basin-scale, and that water availability in the southern basin would continue to decline.

The MDBSY study projected the average volume of available surface water could decline 11% by 2030 under the median climate scenario. Subsequent projections by SEACI found a 1°C increase in the mean global temperature (by 2030) could lead to changes in mean annual runoff by between −2 and −22% in the southern Basin, and −29 and +12% in the northern Basin (CSIRO, 2010, 2012). Work under the Climate Change in Australia initiative indicates the Australian climate will experience longer dry periods and more severe droughts (comprising more frequent and intense heat waves) in the future.

The combination of model uncertainty and unpredictable phenomena (such as El Niño and La Niña events) means the capacity to predict future temperatures and rainfall patterns is limited (BOM and CSIRO, 2018). However, consistency between temperature and rainfall patterns and climate change projections provides confidence that climate models represent the key processes driving the warming trend (BOM and CSIRO, 2018). This also provides confidence that several climatic trends are likely to emerge (Table 1).
Table 1: Synthesis of trends associated with climate change impacts in the Murray–Darling Basin (adapted from CSIRO et al., 2016)

<table>
<thead>
<tr>
<th>Temperature metrics</th>
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<tbody>
<tr>
<td>Average temperature</td>
<td>Increasing</td>
<td></td>
</tr>
<tr>
<td>Daily maximum temperature</td>
<td>Increasing</td>
<td></td>
</tr>
<tr>
<td>Daily minimum temperature</td>
<td>Increasing</td>
<td></td>
</tr>
<tr>
<td>Number of hot days</td>
<td>Increasing</td>
<td></td>
</tr>
</tbody>
</table>

| Water yield Metrics      |               |     |
| Cool season rainfall     | Decreasing    |     |
| Snowfall                 | Decreasing    |     |
| Soil moisture            | Decreasing    |     |
| Evapotranspiration       | Increasing    |     |
| Runoff                   | Decreasing    |     |

| Water extreme metrics    |               |     |
| Intensity of extreme rainfall| Increasing |     |
| Time in drought          | Increasing    |     |
| Frequency of severe drought| Increasing  |     |

Implications and risks of climate change for the Basin

The impacts of climate change on Basin water resources are wide ranging and significant. Higher average temperatures will increase the amount of water lost to evaporation and reduce soil moisture. This means more rainfall will be absorbed into the soil, resulting in less runoff, reduced river flows and less water being stored and regulated by dams.

Higher temperatures are also expected to lead to an increased dependency on river flows, as crops and native vegetation have less access to soil moisture and suffer increased losses from transpiration. This may be further compounded by increased growth rates associated with higher concentrations of carbon dioxide. Studies have shown that ‘carbon dioxide fertilisation’ can further reduce catchment inflows by as much as 28% (Ukkola et al., 2015).

Research indicates climate change will influence weather systems differently in the northern Basin, compared to the southern Basin.
Projections indicate a small increase in total annual rainfall in the northern Basin is more likely in the medium to long-term (Ekström et al., 2015; BOM & CSIRO, 2018; NARClim, 2019), whereas decreasing winter and spring rainfall is consistently predicted to occur in the southern Basin over the rest of this century (Hope et al., 2017, BOM & CSIRO, 2018).

Climate change can be expected to increase river salinity levels (where control measures are not present) as a result of more frequent and longer periods of low or zero flow. Longer periods of low flow with higher temperatures will also increase the likelihood of blue-green algal blooms, with potentially devastating impacts on native fish and town water supplies. Storages, such as Lake Hume, are subject to increases in bloom formation under drought conditions and if dry conditions become more frequent, so too will water quality issues.

Reduced rainfall and streamflow, and increased temperature will also impact on the natural cycle of floods and droughts, changing the hydrology of the river system. Animals and vegetation have both temperature and watering requirements (and tolerances) and these are less likely to be met under climate change, with adverse outcomes, like species extinction, occurring more often.

The risks identified have significant consequences for the environmental health of the Murray–Darling Basin. This is also true for the communities living in the Basin, and the industries and agribusinesses reliant on the river system for their water supply.

Climate change will have significant implications in the Basin, increasing pressure on the health of the Basin’s environment, its communities and its economy. It is also likely that the management, sharing and delivery of the basin water resources will become significantly more complex, and contested.

Climate change is expected to increase production risks to agriculture, through reduced water availability, higher evapotranspiration and higher temperatures. Agricultural industries have been adapting to these risks through changes in business and operating models. Highly water-dependent industries (e.g. irrigation industries) are also adapting to the reality of less water and will continue to do so.

Some of the responses by irrigators to future climate changes include:

- A change of crop types such as:
  - a shift to more drought tolerant or water efficient varieties
  - a spatial shift in where crops are grown
  - a reduction in total permanent plantings and an increase in annual crops under a future of reduced water availability. Annual crops allow for greater inter-annual flexibility in water use because perennial planting require water every year. The shift to annual crops could be substantially more if the current irrigation footprint is maintained.
- A possible shift in the irrigation season from summer to autumn/spring – such changes have already been observed in the southern basin dairy industry.
- A reduction in both annual and permanent crop types under the more severe climate change scenarios that see substantial reductions in water availability.
There are also other businesses indirectly impacted by reducing water availability. For example, tourism, fishing and recreation-based enterprises that depend on healthy rivers and wetlands are likely be impacted by drier climatic conditions and the prevalence of stressed ecosystems. There could be implications for other types of ecosystem services provided by healthy rivers, wetlands and floodplains, such as flood and soil erosion risk mitigation, climate regulation (via carbon sequestration) and water purification, that also affect the welfare of communities across the Basin.

As well as water-dependent economic sectors in the Basin, there are many communities that also rely on a healthy river system for their sense of healthy living. This may link to things such as particular cultural needs or identities; a desire for a particular aesthetic; or a sense of wellbeing or psychological health that river systems can support.

We are all, in some way, susceptible to the impacts of climate change.
The Basin Plan

In the early 2000s there was widespread agreement across governments that a plan was needed to manage our water carefully and protect the Basin for future generations. The Murray–Darling Basin Plan was developed to manage the Basin as a whole and connected system. The Basin Plan aims to restore the Basin back to a healthier and more environmentally sustainable level, while continuing to support farming and other industries for the benefit of the Australian community.

The Basin Plan, amongst other things, sets limits (known as sustainable diversion limits or SDLs) on the amount of water that can be taken from the Basin each year, leaving more water for our rivers, lakes and wetlands, and the plants and animals that depend on them. Figure 4 provides a summary of the main elements of the Basin Plan.

Development of the Basin Plan

Understanding the effects of climate change on the Murray–Darling Basin is a complex undertaking. Broadly, the task can be divided into two fields of investigation: understanding how each aspect of the climate will change; and anticipating how these changes will affect the natural and human developed components of the Basin.

At the time of Basin Plan development (2009–12), there was significant uncertainty in both fields of study. As outlined by Neave et al. (2015), the models designed to forecast the specific climatic impacts displayed significant range and uncertainty. Overall, there was a broad understanding of the
impacts of climate change at the global scale (e.g. a warming atmosphere, changing patterns of rainfall), but it was more difficult to anticipate exactly how these changes would play out at smaller scales such as across the Murray–Darling Basin. Translating these uncertain climatological and hydrological changes through to matters relevant to stakeholders and decision-makers (such as water availability, ecosystem health, water quality, and agricultural production) was also subject to much uncertainty and the difficulties associated with separating a global warming signal from the high natural climate variability.

In 2009, the Authority sought advice from the CSIRO regarding selection of climate change inputs to three elements of the Basin Plan modelling program: a climate baseline to describe the Basin’s water resource, future climate scenarios to examine climate change risks to water availability and climate sequences to support operational planning.

The CSIRO recommended the MDBA use the longest possible climate record for hydrologic modelling to encapsulate a range of climate conditions, noting the South Eastern Australia Climate Change Initiative also suggested a running baseline based on the past 30 years data was also appropriate. Guided by this advice, in 2009 the Authority selected the 114-year climate history (1895–2009) as the climate baseline for the Basin Plan modelling. This was considered the most scientifically credible option available at that time. A key strength of long climatic sequences is that they take into account the extremes of climate experienced in the past, including three prolonged drought periods—the ‘Federation’ drought (1895–1903), the ‘World War Two’ drought (1939–1945) and the ‘Millennium’ drought (1996–2010). This scenario also includes climatic extremes similar to what we can expect under the range of climate change projections. The 114-year climate sequence also has similar mean annual rainfall and mean annual runoff as both the 30 years preceding the Basin Plan and the 1961–2008 IPCC climate baseline (Table 2).

To examine climate change risks, the 2030 dry, median and wet climate change scenarios recommended by CSIRO were adopted and extended by the MDBA in 2010 to assess the risks to the Basin’s water resources from climate change (MDBA, 2010). It was not considered necessary to apply the CSIRO’s suggested scaling method in other modelling activities given the climate baseline was deemed sufficiently robust. It was also not feasible to represent natural and human responses to different levels of water availability (associated with each climate change scenario) in a scientifically robust and defensible way.

Climate sequences to inform operational planning scenarios (next 10 to 15 years) over the period of the Basin Plan’s implementation recommended by the CSIRO consisted of short and medium-term sequences that consider the recent climate period (past 10 to 20 years). However, time limitations and the significant uncertainties at that time regarding Basin Plan implementation (i.e. Northern Basin Review and Sustainable Diversion Limit Adjustment Mechanism) diminished the value of pursuing this work, and short term planning scenarios were not pursued.
Table 2: Mean annual rainfall and runoff over the southern MDB averaged over different climate periods prior to Basin Plan modelling (modified from Chiew et al., 2009).

<table>
<thead>
<tr>
<th>Climate period</th>
<th>Mean annual rainfall (mm)</th>
<th>Mean annual runoff (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1895–2006 Historical climate in MDBSY</td>
<td>436</td>
<td>42</td>
</tr>
<tr>
<td>1895–2008 Historical climate in MDBSY extended to 2008</td>
<td>435</td>
<td>42</td>
</tr>
<tr>
<td>1961–1990 IPCC climate period</td>
<td>461</td>
<td>48</td>
</tr>
<tr>
<td>1961–2008 IPCC period extended to 2008</td>
<td>446</td>
<td>43</td>
</tr>
<tr>
<td>1979–2008 30 years</td>
<td>432</td>
<td>40</td>
</tr>
<tr>
<td>1989–2008 20 years</td>
<td>429</td>
<td>37</td>
</tr>
<tr>
<td>1994–2008 15 years</td>
<td>398</td>
<td>30</td>
</tr>
<tr>
<td>1999–2008 10 years</td>
<td>390</td>
<td>27</td>
</tr>
</tbody>
</table>

Initial thinking was to include a uniform 3% allowance for climate change into the sustainable diversion limit, based on a proportion of the estimated average 10% decline in water availability under a median 2030 climate scenario. This was criticised by CSIRO because it oversimplifies climate change projections. Instead, it was recommended that further analyses should be undertaken to understand environmental water requirements and ecological responses under future climate scenarios. These were carried out in the process of setting the Environmentally Sustainable Level of Take (ESLT) and informed the final Basin Plan settings (Swirepik et al., 2015). More detailed exploration of climate change effects can be considered in future reviews of the Basin Plan.

Water management in a changing climate

Managing a complex river system with a highly variable climate such as the Murray–Darling Basin is a dilemma for decision-makers. Scientific understanding generally contains a level of uncertainty, and yet significant investments in policy reforms are more easily justified when the evidence base is more certain. For example, the impacts of climate change in the Murray–Darling Basin are intertwined with the natural variability of the system. The timing and magnitude of long term climate changes remain uncertain and difficult to identify and measure separately from natural variability.
Taking action to address future risks can have immediate costs, which need to be weighed up against future benefits, which are less clearly understood.

The MDBA’s response to climate change in 2012, was to ensure the Basin Plan recommended the immediate action of recovering additional water for the environment which, combined with refinements to existing water sharing arrangements, would buffer the system from stress under a drying climate. Secondly, the Basin Plan was designed to be adaptive, and regularly reviewed and updated with the best available science and emerging knowledge about climate change (Neave et al., 2015).

The Basin Plan itself is designed to adapt to new knowledge. The settings made in 2012 were based on the best available information. Regular reviews are built into the Plan to allow for changes as the knowledge base improves. This includes the requirement for the MDBA to conduct future reviews with an updated assessment of climate change risks. The first major review point for the Basin Plan is in 2026. The objective of the MDBA’s climate change program is to build our understanding of, and capacity to analyse, climate change impacts to inform this review.
The adaptive approach employed by the Basin Plan also gives effect to the requirements of the Water Act 2007 (Cth), which includes:

- improved water resource monitoring and accounting
- requirements for Basin governments and the MDBA to monitor the outcomes of environmental flows and the condition of key environmental assets
- periodic evaluation and review of the outcomes of water management arrangements that may be used to adapt operations, water sharing arrangements or policy.

The Basin Plan also requires that, where appropriate, climate risks to the implementation of these policies must be identified, and where possible, addressed by water resource plans. In this way, future water sharing arrangements, policies and management practices, along with the broader water reform package will deliver a healthy working Basin that is more resilient to the threats posed by climate change.

The Sustainable Diversion Limits (SDLs) are a key element of the Basin Plan, and deliver on several Basin Plan policy objectives simultaneously, including addressing the risks of climate change. These limits determine how much water, on average, can be used in the Basin by towns and communities, farmers and industries.

Sustainable diversion limits are estimates, using a formula to determine how much water can be taken for consumptive purposes in any given year. These formulas consider inflow volumes, water allocation policies, user behaviours, water trades, and infrastructure.

Water usage patterns in the Basin are diverse. Usage varies year-to-year depending on climatic conditions, rainfall, trade, infrastructure development and individual business decisions. The new system of limits will consider both the water available for use, the water expected to be used and the actual amount of water used. Water accounting occurs following the end of each water year.

Under the existing system of entitlements and allocations, water is allocated based on availability—in a dry year less water is allocated and available for use, in a wet year there is more available for use. The allocations system is therefore naturally adaptive to climate variations, and adjusts year-to-year.

![Figure 6: water allocations and usage in different climatic conditions](image-url)
A number of other Basin Plan policy provisions also address climate change. These are given effect through the Plan’s policies for water accounting, water quality and salinity, environmental water management, and water trade policies and elements contained in water resource plans.

<table>
<thead>
<tr>
<th>Provision</th>
<th>Basin Plan</th>
<th>Description of Provision</th>
</tr>
</thead>
<tbody>
<tr>
<td>Refining existing arrangements</td>
<td>Chapter 6</td>
<td>The Basin Plan continues to support and strengthen States’ annual allocation process. The process is responsive to climate variability and change.</td>
</tr>
<tr>
<td>Hydrological modelling covering extremes of climate</td>
<td>Chapter 6</td>
<td>Modelling to support development of SDLs using an extended climate sequence (1895-2009) and therefore captured all the dry and wet periods of this 114 year period.</td>
</tr>
<tr>
<td>Strengthening existing water trading framework</td>
<td>Chapter 12</td>
<td>The Basin Plan refines and strengthens the existing water trading framework, allowing the most productive use of scarce water in dry times.</td>
</tr>
<tr>
<td>Buffering the system from stress</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SDLs provide additional water to support healthy ecosystems</td>
<td>Chapter 5 &amp; 6</td>
<td>Recovery of additional water (average of 2,730 GL/year) from consumptive use for environmental purposes will help to build the resilience of water-dependent ecosystems in the face of a drying climate.</td>
</tr>
<tr>
<td>Inclusion of groundwater and interception in SDL framework</td>
<td>Chapter 6</td>
<td>The Basin Plan brings groundwater diversions and interception activities into SDLs.</td>
</tr>
<tr>
<td>Protection of planned environmental water</td>
<td>$10.29</td>
<td>The Basin Plan requires States to ensure there is no net reduction in protection of planned environmental water when updated water resource plans are developed.</td>
</tr>
<tr>
<td>Enhancing with new arrangements</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Identification of risks, and strategies to address those risks</td>
<td>$6.02(2)(g)(ii) $4.03(2)(y)(v)</td>
<td>The Basin Plan identifies climate change as a risk to the condition and continued availability of water resources and provides that new knowledge about its impacts is required.</td>
</tr>
<tr>
<td>Setting an environmental objective and outcome that considers climate change</td>
<td>$5.02(1)(d) $5.02(2) $1.04(1) $5.07(1)(a) $5.04(2)(a)</td>
<td>A Basin Plan objective is ensuring that water-dependent ecosystems are resilient to climate change (Chapter 5, 6 and 9), and an outcome is that water-dependent ecosystems have strengthened resilience to climate change (Chapter 5).</td>
</tr>
<tr>
<td>Setting a water trade outcome that considers climate change</td>
<td>$5.07(2)(c)(ii)</td>
<td>A Basin Plan outcome is the creation of a more efficient and effective market that enables water-dependent industries to strengthen their capacity to adapt to future climate change.</td>
</tr>
<tr>
<td>Annual environmental watering priorities based on prevailing climatic conditions</td>
<td>$8.23-$8.31</td>
<td>The annual environmental watering priorities are determined from an assessment of the amount of water likely to be available in the year in question.</td>
</tr>
<tr>
<td>Maximising the benefits of environmental watering</td>
<td>$8.35(1)</td>
<td>Environmental watering is to be undertaken in a way that incorporates strategies to deal with a variable and changing climate.</td>
</tr>
<tr>
<td>Arrangements to meet human water needs under extended dry periods</td>
<td>Chapter 11</td>
<td>The Basin Plan has identified the volume of water required to deliver and meet critical human needs on the shared River Murray system, and has arrangements to manage the risks that this cannot be provided.</td>
</tr>
<tr>
<td>Water resource plans to develop strategies to address the risk of climate change, protect groundwater systems and manage extreme dry conditions</td>
<td>Chapter 10</td>
<td>States must consider the risks of climate change and determine how to respond. States must consider what rules are required to protect groundwater-dependent ecosystems and the productive base of groundwater. States must describe how an extreme dry period will be managed, and consider whether management should change if new science about climate change suggests a change in the chance of such events occurring.</td>
</tr>
<tr>
<td>Adapting to future changes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Discrete-point adaptation</td>
<td>$6.06</td>
<td>The Basin Plan must be reviewed at least every 10 years (Water Act s50) and reviewed under s6.06 of the Basin Plan must be undertaken having regard to the management of climate change risks and include an up-to-date assessment of those risks. The Environmental Watering Plan and water quality and salinity targets in the Water Quality and Salinity Management Plan must be reviewed every 5 years (Water Act s62).</td>
</tr>
<tr>
<td>Continuous adaptation</td>
<td>$8.17 $8.31</td>
<td>The Basin-wide environmental watering strategy can be reviewed at any time and at least every five years, and the Basin’s environmental watering priorities are determined annually and can be updated at any time.</td>
</tr>
<tr>
<td>Monitoring and evaluation</td>
<td>Schedule 12 Item 3817</td>
<td>The matters for evaluation of the Basin Plan include the protection and restoration of water-dependent ecosystems and ecosystem functions, including for the purposes of strengthening their resilience in a changing climate, and the effectiveness of the water resource plan in providing a robust framework under a changing climate.</td>
</tr>
</tbody>
</table>

Figure 7: Actions taken in the Basin Plan that address climate change/variability (Neave et al., 2015)
The challenges ahead

The implementation of the Basin Plan has already benefitted the environment, industry and Basin communities in the face of a changing climate. The Basin Plan will continue to evolve to address the impacts of climate change into the future. This is achieved by using the best available science to underpin the way in which the Plan is implemented, evaluated and reviewed—a key reason the Basin Plan was designed to be adaptive. Regular review points are built in to ensure each component is evaluated, reviewed and improved over time. This requires continual investment in new science, knowledge and capacity.

With responsibility for Basin Plan policy, compliance and river operations, the MDBA must be prepared to adapt to risks of climate change at multiple timeframes, including:

- **Short term** adaptations for river operations
- **Medium term** adaptations to optimise social-economic and environmental outcomes – progressed through five-yearly evaluations of major Basin Plan policies (commencing in 2020), and
- **Long term** adaptations to optimise social-economic and environmental outcomes through a review of the Basin Plan – including by investing in new science, knowledge and capacity to evaluate adaptations to climate change (commencing with the first Basin Plan review in 2026).

To inform the development of these strategies, governments need to ensure that the right information is available to identify adaptations and their appropriate scale.

The MDBA, in partnership with Basin governments and scientific research bodies, is working to improve its understanding of the links between climate change, Basin Plan policy and outcomes in the Basin. The Sustainable Diversion Limit Adjustment Mechanism and the Northern Basin Review are both examples of adaptation built into the Basin Plan, embedding improvements in understanding and science in the Basin Plans implementation. Adaptation is key to ensuring water is managed in the interests of all Australians.

Improved science will be vital for ongoing adaptive management of the Plan. As the science improves there is likely to be difficult questions that must be answered.

One of the fundamental questions is, are the current macro settings of the Basin Plan, such as the sustainable diversion limits, adequate to ensure a healthy working Basin under climate change? The more difficult question that follows is, if not, should these macro settings be changed? Or should the expectations of what the Basin Plan can achieve be tempered? Or is it a combination of each?
There are other Basin Plan implementation instruments which must also be examined as climate science continues to strengthen, such as the environmental management framework. This framework (described in Chapter 8 of the Basin Plan) outlines the long-term ecological aims of the Basin Plan (through the Basin-wide Environmental Watering Strategy and long-term watering plans), and details the year-to-year environmental watering actions (the annual watering priorities) necessary to achieve these long-term aims. This framework will be reviewed by the end of 2020. This review will examine whether the guidance provided by the framework is effective. As part of the proposed 2022 review of the Basin-wide Environmental Watering Strategy, consideration will be given to whether the expected ecological objectives and outcomes are still relevant given future climate projections, and also whether the timeframes for achieving those outcomes are still realistic.

The challenges of climate change in the Murray–Darling Basin are complex. The MDBA will engage actively with expert agencies and researchers to ensure the MDBA is accessing the latest climate science; understanding the implications and risk for the Basin; and exploring management strategies and possible policy changes that will work to build Basin resilience in a drier, hotter future climate.

Hydrology and ecology

Focus questions
- What will the macro hydrological settings of the Basin Plan deliver in terms of a healthy working Basin?
- Under climate change, and the water management measures in place, what are the likely trajectories for the Basin’s environmental health?
- What management and operational measures can be put in place to improve the resilience of the Basin’s environmental assets?
- What other changes to the Basin Plan might need to be considered, and how effective might they be in delivering a healthy working basin?

The MDBA is committed to improving knowledge about climate change impacts on the hydrology of the Basin. There is still uncertainty over the precise impacts climate change will have on the hydrology and ecology in the Basin. However, we need to start preparing for these impacts now, and climate science is at the point where some trends are becoming apparent and some impacts can be anticipated. As in 2012, the MDBA will use a multiple-lines-of-evidence approach to best anticipate and manage these impacts. It has also partnered with the University of Melbourne to develop a method for testing the effect of altered quantities and patterns of water availability (due to climate change) on the ecology of the Basin’s water-dependent ecosystems.

Climate change may also mean that protection or restoration of some ecological sites/values is not feasible and so alternate strategies may need to be developed (e.g. adaptation) to sustain these values. In order to achieve Basin Plan objectives, the MDBA is investigating ecological climate adaption options and is identifying potential climate refuges in the Basin—places in the Basin that will be less affected by climate change and may be able to continue supporting vulnerable flora, fauna and ecosystems. As stated by Neave et al. (2015):
A drying climate would lead to some ecosystems moving to a new state (e.g. from river red gum forest with a flood-dependent understorey to river red gum woodland with a flood-tolerant understorey). A better understanding of ecological responses to climate change will have a bearing on the water requirements of water-dependent ecosystems and consequently on how reductions in water availability due to climate change are shared between users and the environment.

Climate change is expected to reduce water resources, altering the pattern of flow in rivers. Climate science is confirming the trend of declining April-to-October rainfall and run-off in the southern Basin, and indicates it will continue to decrease further (Hope et al., 2017). Similarly, a recent study by the MDBA found that climate change is one contributor to the reduced flows experienced by the northern Basin since the year 2000 (MDBA, 2018). These climate change induced reductions in flow will affect all aspects of Basin condition and raise new management issues.

For example, work by CSIRO (2008) indicates that water not held in entitlements (planned environmental water or ‘PEW’) is particularly susceptible to reductions in water availability from climate change. This occurs because rules in state water plans have the effect of partly shielding consumptive users and environmental water holders from these reductions. Under a drying climate, the reduced quantity of planned environmental water will have to be factored into the determination of an environmentally sustainable level of take.

The Water Act envisages the inherent complexity of the river system and makes it clear that the Basin Plan is to serve environmental purposes, and is also to provide for the use and management of the Basin water resources in a way that optimises economic and social outcomes. This poses two challenges for the MDBA. First, measuring and assessing each of these outcomes involves a diversity of research disciplines, research methods and evidence, including community and Aboriginal knowledge and learnings. Secondly, it requires a holistic approach, in which communities and their associated activities are considered to be part of the system. This approach requires that relationships between parts of the system, including interdependencies and trade-offs, are understood.

New research, including updated climate change science, will be crucial to the 2026, or earlier, review.

**Water quality**

Focus question:
- As water quality risks change under climate change, what strategies can be implemented to ensure that water quality remains fit for purpose across the Basin?

Water quality is managed in partnership with the Basin state and territory governments, with a key management arrangement being the Basin Salinity Management 2030 strategy (MDBMC, 2015) which sets out clear objectives and targets for managing salinity in rivers. It remains critical that the right information is collected to inform adaptive management toward these objectives.
While salinity is managed through existing control measures implemented along the River Murray, lower flows present salinity issues in other areas such as the Darling River and Lower Lakes where there is potential for large saline groundwater ingress.

In recent years, blue-green algal blooms in the Murray River are becoming more frequent with five major blooms occurring in the last 13 years, compared to at most four in the preceding 65 years (Joehnk et al., 2018). These blooms have significant environmental, economic and social impacts as they cause disruptions to drinking water supplies, the environment, recreational activities, tourism and agriculture.

The mass fish kills that occurred in the Darling River downstream of Menindee in January 2019, triggered by algal bloom die-offs and low dissolved oxygen, are a clear example of these potential impacts.

In recent years, some river reaches have seen hypoxic blackwater events and low dissolved oxygen events. Low dissolved oxygen events are generally associated with very low flows and hot weather conditions, while blackwater events result from inundating floodplains that have remained dry for an extended period (i.e. multiple years) and have accumulated high levels of eucalyptus leaf litter. The effects of blackwater are highly dependent on temperature, with warmer weather greatly exacerbating their effects. Given predicted climate change scenarios, maintaining adequate minimum flow rates where practical, particularly in warmer weather, and re-commencing flows with sufficient dilution will be important measures for managing or ameliorating low dissolved oxygen events. Blackwater events are a more difficult phenomenon to manage, given the only known way to ameliorate them, at present, is regular flooding of floodplains—a generally unfeasible measure in a river system increasingly constrained by user demands and climate change. Research into alternate ways of managing or ameliorating blackwater may be needed.

There is also need to expand our knowledge of the influence of water temperature itself on animal and plant populations. High water temperatures are potentially harmful for animals and plants. For example, the iconic Murray cray (Euastacus armatus) has a long term maximum temperature tolerance of 27 degrees (Geddes et al., 1993) and future heatwave conditions may see these thresholds exceeded in some southern Murray–Darling Basin habitats. Thresholds for other species that are either iconic and/or essential for ecosystem functioning may be approached in the future e.g. river prawn larvae (Macrobrachium australiense) struggle to survive at water temperatures approaching 35 degrees (Lee and Fielder, 1981). Another issue is sub-lethal thresholds that impact on population viability, e.g. the possibility of pre-spawning egg failure in Murray cod if spring water temperatures substantially exceed 21 degrees (Lake, 1967).

It is clear that flow is a key driver of water quality issues, both in terms of drought and low or no flow conditions leading to increased salinity, increased frequency of algal blooms and the potential for low dissolved oxygen events, and at the other extreme large floods causing excessive carbon loading and hypoxic blackwater events. Key knowledge priorities include:

- Salinity planning and management—an improved understanding of floodplain processes and salinity impacts from changed flow regimes, including from climate change.
• Algal blooms—an improved understanding of the impact of climate change on triggers and conditions leading to algal blooms in key storages and locks and weirs and along the river.
• Hypoxic blackwater and low dissolved oxygen events—to increase capacity to understand the risk of hypoxic blackwater and other low dissolved oxygen events occurring under different climate change scenarios, to inform river management and water use planning decisions.

The Independent Assessment of Lower Darling fish kills, which commenced on 22 January 2019, may also give insights into future monitoring requirements or knowledge needs.

Irrigated agriculture, Basin economies, trade and the water market

Focus questions:
• Will existing trade rules continue to be effective in achieving productive and resilient water-dependent industries and communities under a changing climate?
• What are the business risks to irrigators, and what strategies can irrigators adopt to adapt to a future with less water availability?
• What are the climate change risks to other economic sources in the Basin, and will changes to sustainable diversion limits be needed to ensure the future flow of ecosystem services and economic benefits?

The introduction of water trade and a water market that was separate from land holdings allowed water to be bought and sold as a commodity. Consequently, water can be directed to its highest value uses and irrigators have the flexibility to use water allocated to them; or not use water and sell the allocations (trade) as an alternative income source in any given water year. Conversely, people who need more water do not have to go to without water and can buy more water.

Research by Jiang and Grafton (2012) demonstrated that inter-regional water trade in periods of a much reduced water availability can mitigate the on-farm impacts of climate change and improve on-farm profit reductions caused by climate change. For example, under an extreme dry scenario, water trade improved the profit reductions by 7% (Jiang and Grafton, 2012). Qureshi et al. (2018) also showed that the ability to trade water from low value crops to high value crops can result in economic losses that are much lower than the proportional decline in water availability during periods of drought.

Loch et al. (2013) conclude that irrigators can use water markets in a number of ways to adapt to less water availability under climate change. The use of water markets by irrigators can be transformational (e.g. selling all water entitlements and relocating or switching to dryland) or incremental (e.g. trading water allocations, using carry-over, changing water management techniques).

Under declining water availability, the water market products offered by states need to remain fit-for-purpose. Inter-regional trade rules and limits need to be responsive to and sufficiently flexible to allow irrigators to trade water to mitigate risks associated with an increasingly warmer and drier
climate. The reliability of water being able to be delivered to market users, particularly during an increasingly drier and low water availability future, needs to be well-understood. Research is needed into how production and financial risks of irrigators change and how irrigators may then respond to these changing risks (e.g. changing the extent, types and timing of crop plantings). Better understanding of these risks to irrigation will have implications for river operations with water management and planning decisions, and will reveal whether current water market rules are able to support irrigators mitigating and adapting to climate change risks.

Other water-dependent economic sectors in the Basin also face risks and uncertainty under climate change. For example, tourism, fishing and recreational based enterprises that depend on healthy rivers and wetlands may be impacted by drier climates that place stress on ecosystems. Other types of ecosystem services provided by healthy rivers, wetlands and floodplains, such as flood and soil erosion risk mitigation, climate regulation (via carbon sequestration) and water purification, all have direct economic benefit to Basin communities. These economic benefits are also at risk from an increasingly warmer and drier climate, but very little is understood about the impacts of climate change on these ecosystem services in the Basin (Alamgir et al., 2014). Furthermore, how much environmental water will be needed and how will it need to be managed to sustain these other water-dependent economic sectors under climate change?

**River Murray operations**

**Focus question:**
- What more can be done to adapt the operation of the Murray River in response to the changing climate and how can we work with all other river operators in the Basin to help adaptation?

The MDBA operates and manages the water resources of the River Murray upstream of the South Australian border on behalf of the governments of Victoria, New South Wales, South Australia and the Commonwealth. In this role, the MDBA is responsible for managing water storages to maximise water conservation, ensuring that state water entitlements are delivered as ordered, and that the water is shared between the states in accordance with the agreed rules. The MDBA is also responsible for the management of key infrastructure along the river and the management and operation of the salt interception schemes. The River Murray system downstream of the SA border is managed by the South Australian government.

The shift in water ownership, arising from trading of water between irrigation areas and through the transfer of water to environmental water holders as a result of the Basin Plan, has increased the complexity of river operations. Dealing with this complexity within the current operating framework has, on occasions, been challenging.

Climate change is expected to bring additional challenges to river operations in the form of larger floods, prolonged droughts, more intensive heatwaves driving spikes in demands and more regular water quality incidents. Although the system experiences these types of events already, the frequency, size and extent of these events may change and challenge existing approaches.
The framework that guides River Murray Operations is designed, by necessity, to allow for adaptable operations—as every day, month and year on the river can be markedly different. This flexibility is supported by the state allocation frameworks that adjust allocations according to water availability. However there are some areas of the operating framework and water sharing rules that may require refinement or adjustment if they are to remain relevant under a changed future climate and achieve the intended outcomes.

For example, minimum passing flows in the river and the tributaries may not be sufficient under a warming climate to keep the system in good shape. Another relevant example is the hard coded access rules regarding the operation and control of the Menindee Lakes and the assumption that 480 GL of water in storage is sufficient drought protection until the next major inflow.

Improvements in climate, streamflow and demand forecasting will provide much needed intelligence for day to day operations. The ability to assess the probabilities of various scenarios occurring will improve operational decision making. Front-line operators will be better able to manage the impacts of climate change using forecasts rather than depending only on the historic record, as they are already beginning to do.

Any change to the operating framework for the River Murray will require the approval of the joint governments. Thus the focus should also be to support and bolster the adaptive framework that is already built into the operating framework such that when Basin propose changes to operations and water sharing rules, these are supported by informed decision makers.
MDBA climate change research program

The Basin Plan adapts to new information. Adaptation has been occurring since the Basin Plan’s inception in response to the changes in rainfall and streamflow patterns. Adaptations are also occurring over the medium term, building in the knowledge gained through periodic evaluations, like the 2017 Evaluation of the Basin Plan.

Effective adaptation over the short, medium and long term relies on accurate and timely information and an understanding of the current and forecast implications of climate change on the Murray–Darling Basin.

The complexity of climate science, the inherent climate variability of the Basin, and the multitude of water users within the Basin means that the MDBA must progress its climate change forward work program, in partnership with key agencies and the scientific research community. The MDBA will ensure we are well placed to incorporate new climate change science into elements of adaptive management.

This includes working alongside independent and eminent scientists, such as those on the MDBA’s independent Advisory Committee on Social, Economic and Environmental Sciences to ensure we access the best available science for our investigations and assessments.

We will also be working with government, industry, First Nations people, community stakeholders and partners to identify opportunities to enhance water management in the Basin.

The MDBA climate change program aims to enhance understanding of:

- global climate change patterns and trajectory predictions
- potential climate change impacts on the hydro-climatic conditions in the Basin
- potential impacts and risks to social, environmental and economic outcomes in the Basin
- opportunities and strategies to improve the arrangements within the Basin Plan

The program will be developed collaboratively, but as a starting point the MDBA considers the following five elements important for early consideration:

1. Continued collaboration with the Bureau of Meteorology, CSIRO and other research partners to understand and utilise the latest climate change science.
2. Review of adaptation actions implemented by Basin governments and environmental water holders, and working with these stakeholders to create a unified approach to identifying and addressing climate risks.
3. Work with policy institutions, eminent scientists and governments to advance discussions around difficult policy questions arising from climate change impacts.
4. Assessment of progress to addressing climate change risks through state water resource plans.
5. Enhance our capacity to assess climate change impacts on the Basin; refine the way we test policy robustness; develop planning and operational tools to support decision making; and explore alternative strategies to provide for a better future.
As this work evolves, the MDBA will continually improve what it delivers across all timescales (annually, five yearly, etc.). The program will be sequenced to ensure major milestones are delivered in time for the 2026 Basin Plan review.

As a next step, the MDBA will work the MDBA’s independent Advisory Committee on Social, Economic and Environmental Sciences, and other stakeholders, to articulate a climate change work plan for the MDBA. The workplan will be endorsed and publicly available by mid-2019. The workplan is the first step in the climate change work program for the MDBA.
References


CSIRO (2010). Climate variability and change in south-eastern Australia: A synthesis of findings from Phase 1 of the South Eastern Australian Climate Initiative (SEACI). CSIRO, Australia.


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