Australia's National Science Agency

MD-WERP Activity T1.TK4

Values and vulnerability of the Murray-Darling Basin - Basin-wide rapid assessment

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July 2023

Murray–Darling Water & Environment Research

Citation

Wahid S, Nolan M, Dunlop M, Watto MA, Robertson DE, Jalilov S, Pirzl R, Lyons P, Bettini Y and Harper R (2023). Values and vulnerability of the Murray-Darling Basin – Basin-wide rapid assessment. CSIRO, Australia.

Acknowledgement of Country

The authors acknowledge the Traditional Owners of the lands and waters of Australia, and in particular the Traditional Owners of the lands and waters of the Murray–Darling Basin. The river and its tributaries are known by many names including Millewa (Ngarrindjeri name for the main Murray channel in South Australia), Baarka (Barkindji; Darling River, inland New South Wales (NSW)), Warring (Taungurung; Goulburn River, Victoria), Kolety (Wamba Wamba; Edwards River, inland NSW), Kalari (Wiradjuri; Lachlan River, inland NSW), Murrumbidjeri (Wiradjuri; Murrumbidgee River, inland NSW) and Guwayda (Kamilaroi; Gwydir River, northern NSW), amongst others. While the European names are used in this report, the authors recognise the important associations and history of the Indigenous names for rivers and streams in the Basin. The authors express our respect for Elders, past and present, amongst the Nations of the Murray–Darling Basin.

Acknowledgements

The authors take this opportunity to thank the following staff of the MDBA and CSIRO who have worked closely with the authors to deliver on this activity: Joel Bailey, Alex Meehan, Neville Crossman, Peta Braedon, and Minh Nguyen. In addition to the provision of data to the CSIRO team, they have provided valuable insights and context for the work; and reviewed and provided valuable feedback on the progress of the study.

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Glossary

Adaptive capacity	The adaptive capacity represents the set of resources available for adaptation. These resources may be social, economic, environmental, or cultural, including access to ecosystem services, information, expertise, and social networks.
Asset	Assets (capitals) are resources a community or region draws on to make a living. Assets can be categorised as social, economic, environmental, and cultural. Individual or unit assets are grouped (e.g., species in an ecosystem) in the way the community or region draws on to make a living.
Attributes	Properties of an asset that are sensitive or underpin adaptive capacity. Flow change may affect some attributes and not others. Different people may value attributes differently. Indicators can be used to measure objective attributes.
Climate change	A statistically significant variation in the climate's mean state or its variability persists for an extended period (typically decades or longer). Climate change may be due to natural internal processes, external forcing, or persistent anthropogenic changes in the atmosphere's composition or land use.
Exposure	Exposure refers to hydroclimate changes that the community or region will likely experience.
Flow	Flow (change) refers to changes in natural runoff in sub-Basins due to climate change. It does not include impacts of water entitlement, allocation, and trade of river flow.
Impact	The consequence for communities or regions of exposure and sensitivity to that change (e.g., a community dependent on irrigation will be poorly impacted due to a reduction in water availability). It is a function of exposure and sensitivity and may be harmful or beneficial.
Indicator	Indicators measure past, current or future conditions of assets and values (economic, social and cultural) or exposure or adaptive capacity.
Region	A population or ecosystem; or a grouping of natural resources, species, infrastructure, or other assets. In this report, regions are often used to refer to Surface Water Resource Plans Areas (SW-WRPA).
Resilience	Capacity to recover from variation or change, often the amount or extent of change a community or region can undergo, and still retain the same function and structure while maintaining options to develop.

Risk	Risk refers to the probability of occurrence of ‘exposure’ events or trends multiplied by the impacts if these events or trends occur. It recognises the uncertainty of ‘exposure’ events or trends to occur and the diversity of values.
Sensitivity	The degree to which a community or region is sensitive to a change (e.g., a community that makes no use of water in a local river will be unaffected by reductions in water yield and/or availability compared with a community that uses a lot of water).
Values	Refer to an organised set of preferential assumptions and beliefs that influence much of the communities’ perceptions of climate change impact and their coping behaviour. Values are not a property of valued asset or the community valuing it but a co-product.
Vulnerability	The degree to which assets, values or regions are susceptible to climate change impact. It is a function of a community or region's sensitivity and adaptive capacity. It is a relative term differentiating vulnerability among socioeconomic groups, communities, or regions rather than an absolute measure of susceptibility.

Acknowledgments

This work was undertaken as a part of the Murray-Darling Basin Water and Environment Research Program (MD-WERP) Climate Adaptation Theme. The MD-WERP is an Australian Government initiative to strengthen scientific knowledge of the Murray–Darling Basin that is managed through a partnership between the Department of Climate Change, Energy, the Environment and Water, the Commonwealth Environmental Water Holder and the Murray–Darling Basin Authority. The Climate Adaptation Theme brings together CSIRO, Deakin University and eWater researchers.

The authors pay respect to the Traditional Owners and their Nations of the Murray−Darling Basin. We acknowledge their deep cultural, social, environmental, spiritual and economic connection to their lands and waters.

Summary

The assessment focus and framework. The assessment focus is understanding economic, social, cultural, and environmental vulnerabilities through the ‘values’ lens (what matters most to communities). It is delivered in two stages. The first stage is a basin-wide rapid assessment of relative vulnerabilities of the water resource plan areas (WRPAs) across the Basin – this report. The second stage assessment will be conducted through case studies to capture the complex water-society-ecosystem dynamics of values and vulnerabilities in more detail, which are challenging to assess and present in the basin-wide rapid assessment.

The rapid assessment identified the major factors that describe the long-term sensitivity of the communities’ values directly or indirectly related to flow change (*exposure*) and used various exploratory indicators to assess them. The indicators were identified by tracking various Flow-Asset-Values (FAV) pathways. The pathways link flow to assets and the associated attributes that people in the community value and the community's ability to adapt to changes in flow while maintaining the values they derive from the assets. The FAV pathways helped us navigate the complexities of values and vulnerability.

Two types of exploratory indicators were used: flow and socioecological. The exploratory flow indicator data were generated through hydrological modelling at CSIRO. The socioecological exploratory indicators were identified by extensively searching the credited and acknowledged sources. Indicator data were collected from various sources, including research repositories, databases, surveys, and publications from various government and academic sources. The socioecological indicator data were delineated and re-mapped based on area or population correspondence between the original spatial units (e.g., SA2, LGA) and WRPAs.

Climate change will stress communities’ water-sensitive values. The climate change in the Basin will likely change rainfall patterns and river flow characteristics, creating additional challenges to managing Basin’s water resources. Based on climate change projections, it is likely that droughts and floods will become more intense and frequent, which will add stress to the communities and their water-sensitive values. This is especially relevant for 13% of all the addresses within 500 meters of major water courses in the Basin and thus closely connected to the Basin’ waters. Since droughts are recurring features of the overall Basin climate, with a significant impact on communities and their values, Basin communities may need to adapt significantly to long-term climatic and flow changes.

Flow change will impact economic and social values differently across the Basin. Communities are likely to be vulnerable to the impacts of climate change and flow changes in different ways, depending on where they are, their livelihoods and what they value. We note that economic values in the regions that have a higher number of agricultural businesses and employment in agricultural-related jobs, such as the Namoi, Namoi, Gwydir and Condamine-Balonne regions in the northern basin and the Lachlan, Murrumbidgee, Northern Victoria and Wimmera-Mallee regions in the southern Basin might be more sensitive to changes in flow. A warmer-drier scenario may affect remote regions dependent on agriculture more than regions with more mixed economies.

Social values heavily depend on communities' confidence in the long-term water future, access to sufficient and reliable water supplies for domestic and recreational use and community wellbeing. Generally, communities in the outer and remote regions of the Basin have less access to affordable food/groceries and attractive natural places and may need to adapt significantly to live well under the impending changes in these or similar regions. The basin has close to 20 million overnight visitors per year and decreasing river flows might make it challenging to maintain recreational and other public and tourist benefit values while meeting the consumptive demands.

All regions demonstrate some adaptive capacity to cope with short-term flow variability, but the long-term efficacy of these capacities to confront climate change remains unclear. The adaptive capacity of communities in the different regions varies depending on various factors, including remoteness, economy, infrastructure, access to services and socio-economic conditions. While some communities have higher adaptive capacity due to diversified economies and water trading, others are more socially connected and have greater access to infrastructure and services. Access to services will help communities face future short-term economic and social values sensitivity. Communities in the Victorian Murray, Northern Victoria and Eastern Mount Lofty Ranges regions have relatively higher proportions of more reliable security water entitlement. These regions are also economically diverse, which will help communities adapt to sensitivities related to economic values. Communities in New South Wales Murray and Murrumbidgee regions reported a greater sense of belonging and involvement in local community activities, providing a bulwark against risks to social values. However, this does not suggest that these regions are devoid of challenges.

Despite the variety of adaptive mechanisms apparent across the Basin - economic diversity, reliable water entitlement, access to services, and robust social and community fabric - it remains uncertain how effective these might be in facilitating adaptation to sustained climate change impacts on flow. This multifaceted perspective underscores the inherent complexity of the Basin's socioeconomic landscape, highlighting the necessity of factoring these nuances into any future planning and decision-making endeavours. It also emphasises the potential implications of climate change, suggesting that more research is needed to comprehend the long-term effectiveness of regional adaptive capacities and strategies.

Changes in flow regimes and flooding will affect wetlands, waterbodies, and waterways. The wetlands, waterbodies and waterways in the Basin are home to waterbirds (including migratory species), native vegetation, and native fish. These habitats rely on particular flow regimes, including periodic flooding, to support multiple species' survival, health, and breeding events. Under a warmer-drier scenario, reduced flooding will negatively affect important bird sites in the Victorian Murray, Wimmera-Mallee surface water, and the South Australian Murray regions; native vegetation in the New South Wale Murray and the Gwydir regions; and wetland fish species in the Queensland Border Rivers Moonie and the Condamine-Balonne and the South Australian Murray Region. A warmer-wetter climate, with more flooding, may benefit the environmental values associated with wetlands. Still, extreme flooding can lead to economic and social impacts.

A planned and structured data-gathering and reporting process is needed to improve understanding of First Nations' cultural values and vulnerability. First Nations Peoples have a profound cultural and spiritual connection to water, which affects many aspects of their lives. Changes in river flows and water availability can impact food and fibre production, cultural practices, and preserving species integral to their values. The sensitivity of First Nations' cultural values is hard to measure due to the lack of Basin-wide consistent data. Examples show that efforts are being made to increase formal roles in decision-making processes and recognise traditional and cultural knowledge and wisdom in water management. First Nations enterprises reliant on water might face challenges with the increasing frequency and severity of drought and floods. Assessing or establishing the First Nations' adaptive capacity to adjust to a warmer and drier or wetter basin is hard. Much will depend on planned and structured data-gathering and reporting to improve First Nations Peoples' meaningful participation in water policy, regulatory mechanisms, and programs to secure outcomes that align with their different sets of values and rights.

Caveats and compatibility with realistic policy settings. The Rapid Assessment of Values and Vulnerability is a preliminary integrated analysis of values and vulnerability. It combines exposure, sensitivity, and adaptive capacity into an overarching basin-wide assessment. Nevertheless, data deficit and limited specific understanding of local values mean that the outcomes are exploratory and should not be used for planning or prioritising management actions. We recommend case studies in multiple locations. These studies would offer a granular view of the complex relationships between flow changes and values indicators. They would also shed light on critical immediate coping decisions that have a long lifetime to account for the effects of climate change.

1. Introduction

The Murray-Darling Basin (MDB) flow-related values and vulnerabilities assessment is aligned with MD-WERP research question 1. *Which of the Basin's economic, social, environmental, and cultural values are most vulnerable to the flow-related impacts of climate change*?.

The study is undertaken in two stages (Figure 1), drawing on relevant studies and the experience of the joint CSIRO-MDBA team.

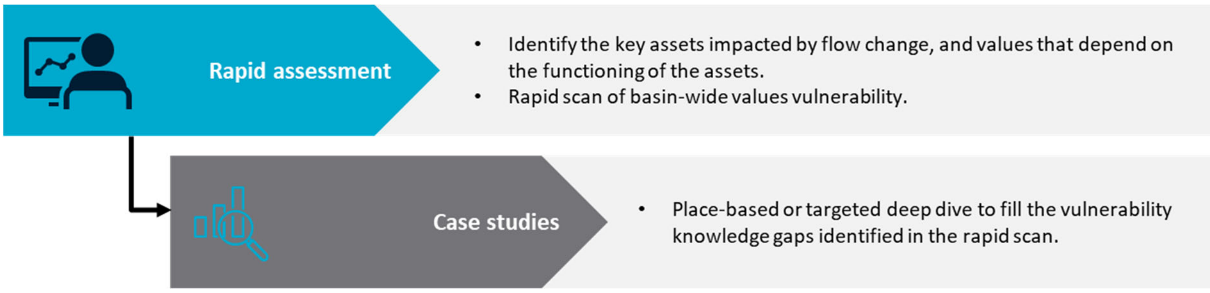

Figure 1 Values and vulnerability assessment stages.

This report presents the findings of the first stage of the study - a rapid Basin-wide assessment of flow-related values and vulnerabilities. The outputs of the first stage will identify the values and vulnerabilities that are challenging to report/represent in a Basin-wide assessment and the knowledge gaps. The second stage assessment will build on the first stage and undertake place-based or targeted case studies to fill the knowledge gaps.

The document has several sections. The first and second sections introduce the study, vulnerability context and underlying socioeconomic and cultural conditions (where are we now). The third section is a novel Flow-asset-values (FAV) framework to assess the values and vulnerability. It sets out the steps in establishing and running the assessment that considers "values" (what matters most to whom now). The fourth section identifies the critical assets impacted by flow change, sensitivities of values that depend on the functioning of the assets, and communities' ability to cope with change.

Objective of the study

The Murray-Darling Basin (MDB) is Australia's largest river system, spanning over 1.1 million km^2, the size of France and Spain combined. Over 2.6 million people live in the Basin. The Basin economy supports over 9,000 irrigated agriculture businesses. Around 40% of Australia's agricultural produce by gross value comes from the Basin, including 100% of rice, 96% of cotton, and 74% of grapes (MDBA n.d.). The Basin is home to many First Nations peoples and has significant diversity of ecosystems.

The hydroclimate of the MDB is changing. The future will likely be warmer and drier, with more severe droughts. These changes threaten the Basin's sustainable management as they are likely to significantly impact water availability in the Basin, and the type of flow-dependent agricultural production, communities, and environmental outcomes that can be achieved. Adapting to these changes is challenging because: (i) water is a cross-cutting issue connected to many sectors and across bioregions: (ii) there are competing needs from different water users and water sharing is contentious; and (iii) the Basin's future water projections are highly variable (Zhang *et al.* 2020a).

The 2020 assessment report on the social and economic conditions in the Basin (Sefton *et al.* 2020) notes that a combination of technological changes, shifts in consumer demand, changing trade patterns, and climate change, along with water reforms has resulted in a complex set of factors that are significantly affecting businesses and communities in the Basin. These changes are occurring rapidly, surpassing their capacity to adapt effectively. Even the First Nations people, who have been adapting to climate changes for millennia, will need substantial support to improve their adaptive capacity due to the large scale and fast pace of change. There is a relative shortage of knowledge and understanding of climate change impacts on assets and values in the MDB. Therefore, it is crucial to effectively inform authorities and develop solutions and adaptation plans in response to climate change impacts. By expanding our understanding, we can better address these challenges and make informed decisions for a sustainable Basin future.

The objective of the values and vulnerability assessment study is to provide insights into how the values people hold for the social, economic, environmental, and cultural assets in the Basin will be impacted by anticipated flow regime changes (MDBA Feedback on WERP Values Vulnerabilities Work plan dated 3 November 2021) and identifying knowledge gaps to inform current and future adaptation planning activities for the Murray-Darling Basin Authority (MDBA) and government, industry and communities that rely on a healthy working Basin.

Scope and limitations

This study targets only those values potentially linked to flow change. It acknowledges that people live and perform within a human-natural (or social-ecological) system and make individual, community, and regional decisions based on shared values. However, we recognise that sectoral and societal interactions are complex, interdependent, change over time and space, and are challenging to explain through reductionist analysis approaches. As such, the findings of the rapid assessment, based on overlaying and analysing various exploratory indicators of future exposure of values and current sensitivity and adaptive capacity, provide snapshots of potential vulnerabilities and may not capture site-specific nuances and complexities of values and vulnerabilities.

We want to highlight that the available data do not currently allow Basin-wide assessment of absolute vulnerability, especially those related to social and cultural values. We also did not analyse the likely trends and scenarios for the socioeconomic conditions or values in the future. As such, the sensitivity and adaptive capacity in this rapid scan represent only the status of the communities today. Therefore, information is provided on regions that might be more vulnerable today than others (relative vulnerability) to enable future detail exploration of the sources of vulnerability.

In short, we reiterate that significant further work should be undertaken, based on case studies, to understand the interactions between water-related and other assets. Therefore, the rapid assessment results presented in this report should be interpreted with regard to the above limitations and should not be used beyond an exploratory context. In particular, the results are not well-suited for informing detailed planning or management actions without additional information and analysis.

2. Vulnerability context

The Murray-Darling Basin is vulnerable to the impacts of climate change. The impending climate changes are expected to increase the frequency and severity of extreme events such as droughts, reduce water availability, and increase the risk of flooding in the area with serious economic, social, cultural, and environmental repercussions. This section provides an overview of the MDB's socioeconomic, cultural, and environmental settings to set up the vulnerability context and our approach to the rapid assessment. Sub-sections on socioeconomics, First Nations, environment and water management further set the scene for why we measure vulnerability and focus on values. The section does not provide an exhaustive review of the existing conditions of the MDB but is more focused on providing a brief overview of the context to situate the assessment results.

Socioeconomics

The Murray-Darling Basin is a region of significant socio-economic vulnerability, with rural and First Nations communities particularly vulnerable to climate change and water insecurity. The knowledge about the socio-economic impacts of climate change, needed to inform adaptation to transformative change, is growing but currently limited. Lately, an assessment report on the social and economic conditions in the Basin (Sefton *et al.* 2020) highlights how technological change, consumer demand shifts, trade pattern changes, climate change, and water reform have greatly impacted businesses and communities, surpassing their ability to adapt. Low rainfall and prolonged drought have also made communities more vulnerable to bushfires and other natural disasters. In addition, many of the communities in the Murray-Darling Basin are economically challenged. The region is heavily reliant on agriculture and tourism, and the impacts of climate change will likely have a significant impact on these industries. Furthermore, the region is also home to a large Indigenous population, particularly vulnerable to water insecurity and socioeconomic disadvantage. There is considerable anthropological evidence that Indigenous people in the Murray-Darling Basin have long adapted to gradual climate change over thousands of years (Green et al., 2010). They have never encountered such a rapid environmental change they are recently facing (Nikolakis *et al.* 2016).

A reduction in rainfall-runoff might disproportionally affect farms and communities in some irrigation districts, for example, as entitlements are traded from regions with lower-value irrigation activities. Analysis by ABARES found that future water market scenarios are estimated to have allocation prices that are an average of 28% higher compared with the current market scenario, and above $200 per ML in eight out of the ten years in the southern Basin. Under drier conditions, allocation prices could be 50% higher on average than what is currently being seen in the market (Gupta *et al.* 2020). Water markets will also be challenged by uncertainty related to climate change. Water markets offer a resilient and flexible decentralised approach to cope with climate and drought conditions (Debaere and Li 2022). However, it is expected that use of water markets is likely to be crucial in mitigating the effects of future climate change. Nevertheless, water market adaptation can be impacted by the uncertainties associated with present and future climate change (Loch *et al.* 2013). In an era of increasing water scarcity, water trading can be an important instrument to assist in water sharing, reallocation and farm adaptation to climate change (Wheeler 2022).

The 2020 Basin Plan Evaluation suggests that small and remote towns in Australia are the most vulnerable to climate change (MDBA 2020). Smaller and more remote towns will find holding and growing their populations even more difficult in a drier, more extreme climate, undermining the sustainability and growth potential of their local and regional economy.

The social and economic objectives of the Basin Plan are dependent on the achievement of the plan’s ecological objectives, as functioning ecosystems provide a range of services and benefits to communities and industries to support a healthy working Basin. For example, maintaining connectivity flows throughout the river system maintains water quality by keeping salt, sediment and nutrients mobile and flushing them from the system. In turn, good water quality supports fishing activities that provide social and economic benefits for communities, such as connection to Country for First Nations, and recreational and tourism activities. Poor water quality has significant technological and financial implications for potable water treatment. The cost-benefit assumptions inherent in the Basin Plan rely heavily on the maintenance of ecosystem services over the coming decades to provide these cumulative benefits. However, the benefits will be compromised by prolonged dry periods with low flows, connectivity issues and limited water available for environmental watering to maintain or support improvements in ecosystem services. The cumulative benefits to amenity, tourism, recreation, and agriculture from ecosystem services are, therefore highly vulnerable to declining ecosystem health.

Environment

The Murray-Darling Basin is one of the world's most important and ecologically diverse river systems, being home to over 40 species of native fish, hundreds of species of birds, mammals and reptiles, and numerous species of plants. However, the Basin has been facing increasing environmental vulnerabilities due to the impacts of climate change. Climate change has been identified as a major threat to the Basin’s ecosystems and species. Population growth and land clearing can also lead to increased demand for water resources, resulting in over-extraction of the available water resources and degradation of aquatic habitats, as well as increased sedimentation and nutrient runoff into waterways. Decades of water extraction and river regulation have impacted the Basin's environmental assets. Climate change will add to these existing environmental vulnerabilities. Fortunately, knowledge of environmental watering requirements continues to develop, and watering events are providing real outcomes for Basin species and ecosystems (MDBA 2020). However, there are knowledge gaps of ecosystem interdependencies and species watering requirements, including how ecological communities will persist under new climate averages, and recover from the expected hydroclimate extremes. The response of the environment to water availability and related pressures is complex and often poorly understood. Combining hydrological modelling with ecosystem response modelling (ecohydrological models) provides a means to understand the response of ecosystems or ecological assets to changes in water regimes (Tharme 2003; Poff *et al.* 2010). While this has been done in some places, ecological response models are often local scale or focus on habitats, and the development of these models is data intensive. In the MDB case, conceptual ecological response functions (e.g., hypothesised response to drought) have been used to overcome the high data requirements (Grafton *et al.* 2012; Connor *et al.* 2013). For example, to explore the potential ecological benefits of increasing environmental water trading, (Connor *et al.* 2013) developed a hydro-economic simulation model to represent the exponential increase in ecological damage in the Murrumbidgee catchment within the Murray-Darling Basin. In addition, future hydroclimate conditions will be novel, therefore outside of the domain of the observations and measurements used to calibrate many models. As a result, detailed information is very patchy across the MDB system.

It is also imperative to consider broader-scale perspectives that align with the scale at which water management decisions are made. Nevertheless, this is challenging. It is difficult to extend beyond the local scale at which most assessments of ecological responses are conducted, to a more regional or Basin-wide view. As there are more than 77,000 kms of rivers and water courses and > 30,000 wetlands in the Murray-Darling Basin (Water Act 2007 – Basin Plan 2012), the system is too large for an assessment of the ecological responses of each component. Conceptual response functions based on a single ecological asset often fail to represent the reality that within a management area, there are generally multiple and potentially competing assets (e.g., river reaches, wetlands, and floodplains), each with its own set of indicators of ecosystem health (Settre *et al.* 2017). Generalisable models for larger spatial scales tend to produce different outputs than those designed for specific habitats, places, or species. Generally, case-study based response functions are often limited in their generalisability (Webb *et al.* 2015).

Although these factors mean that it is difficult to ascertain the vulnerability of ecological assets and gain a complete regional or Basin-wide view, approaches to work with imperfect knowledge and significant knowledge gaps are required, to provide sufficient information and understanding of regional or Basin-wide vulnerability, to match the scale at which some water planning decisions are made. Several examples of approaches designed with regional/Basin-wide application in mind can be overlaid with ecological information to determine ecological responses. Poff et al. (2010) developed the ELOHA (ecological limits of hydrologic alteration) framework based on reach-based environmental responses to flow regime changes and classification of river reaches to extend the framework for the broader-scale application. (Swirepik *et al.* 2016) proposed the UEA (umbrella environmental asset) approach based on sites with detailed information about ecological responses to flow called hydrologic indicator sites and inferred requirements for other sites.

First Nations

Cultural vulnerability in the Murray-Darling Basin is a growing concern. First Nations (Indigenous communities), are traditionally dependent on the river for sustenance, face increased pressure to adapt to changing environmental conditions and manage water resources sustainably. Current trends in climate change threaten the cultures and livelihoods of First Nations people in the Murray-Darling Basin (Nikolakis *et al.* 2016).

For millennia, First Nations people have been adjusting to changes in the climate and their effects on the environment. They have faced many challenges in nurturing their culture, sustaining their way of life, and taking care of Country, and they have been successful because of their cultural knowledge and strong social networks.

First Nations people are considered uniquely vulnerable to the impacts of climate change, as distinctive cultural, socio-economic, and geographical factors contribute to an elevated level of exposure and sensitivity to the impacts of climate change. The current scale and pace of environmental change mean that First Nations communities will need substantial support to improve their adaptive capacity.

The Indigenous and Torres Strait Islander concept of 'Connection to Country' intricately ties First Nations peoples' relationship to their land and waters with their identity and culture (Hartwig and Jackson 2020). More than 40 First Nations are in the Basin with strong cultural and spiritual connections to the Country. They have varied interests regarding water and are responding in distinct ways to address water management issues in their traditional territories. Scarcity and over-allocation of water resources in the Murray-Darling Basin have strained First Nations people to secure their consumptive and non-consumptive water supplies amid growing competition from other users (Jackson *et al.* 2009). The complex nature of water rights and management in the Basin and the difficulty of reconciling traditional cultural practices and environmental protection make it difficult for communities to respond effectively to these changes.

First Nations adaptation to change is further complicated by the fact that many communities have not been effectively included in the decision-making process concerning the river basin management. This lack of representation is leading to a lack of recognition of Indigenous knowledge and practices and a lack of understanding of how traditional practices can help in the sustainability of the river. Consequently, climate change and its impact on the ecosystem are likely to significantly impact the wellbeing of First Nations communities connected to them. So, this is important to recognise the importance of traditional cultural practices and knowledge in the management of the river.

Despite limited knowledge of how climate change will impact First Nations people, it is certain that the complex and multidimensional interaction between climate and existing social and economic disadvantages, such as lower levels of health, income, and education, are likely to exacerbate the sensitivity of First Nations peoples to climate change. Therefore, specific focus will need to be given to understanding the vulnerabilities of First Nations people.

Water management

The Murray–Darling Basin supports a variety of industries, including agriculture, tourism and energy. However, it is increasingly vulnerable to climate change, water shortages, and other environmental pressures. Warmer temperatures, reduced rainfall, and extreme weather events are leading to decreased river flows, increased drought frequency and severity, increased salinity levels, decreased water quality, and reduced crop yields in some years. This results in higher food prices and shortages, economic losses for farmers and other industries, and an increased risk of water infrastructure failure. To protect the Basin and its inhabitants, improved management of water resources, increased investment in water infrastructure, and better adaptation to climate change are essential for its long-term sustainability. Over the past 100 years, significant efforts were devoted to the establishment of irrigation districts and water infrastructure to optimise economic outputs from agriculture. In November 2012, the Basin Plan was passed into law for a healthier Basin that supports farming and other industries (MDBA 2020).

The central feature of the Basin Plan is the re-balancing of how water is shared between consumptive and environmental uses, specifically, increasing the amount of water allocated to the environment and building a framework that can adaptively manage this balance in a variable climate. The Basin Plan's adaptive instruments consist of water trade, adjustable sustainable diversion limits (SDLs), risk management requirements, including managing water for critical human water needs in extreme events, and protections for environmental water, groundwater systems, and connections between surface water and groundwater. There are also water-sharing arrangements set out in the MDB agreement. Sustainable diversion limits are the amount of water that, on average, can be withdrawn and used by the Basin towns, industries and communities while securing water for the river's health and reliant ecosystems. Water recovery to meet the SDLs has been achieved through purchasing consumptive water entitlements and implementing water use efficiency measures by irrigation schemes and primary producers. Various mechanisms to further adjust the SDLs are also being implemented. These mechanisms include improvements to water infrastructure and river operations to deliver equivalent environmental outcomes with smaller water volumes and reduce the amount of water diverted for irrigation.

Water Resource Plans (WRPs) set out the rules for how water is used at the catchment level, including limits on how much water can be taken from the system, how much water will be made available to the environment and how water quality standards can be met. The WRPs also describe water management during specified types of extreme events. If a change in the likelihood of these events is likely to occur, such as those expected due to climate change, then the concerned Basin governments and authorities must consider whether water resources would be managed differently. All the relevant Basin governments are responsible for complying with water resource plans (33 surface and groundwater resource plan areas). The Basin governments also develop long-term watering plans that identify priority environmental assets in the water resource plan areas and the requirements needed to meet ecological objectives and guide environmental watering at the catchment scale. Considering climate risks, including improving knowledge of climate change impacts on water requirements and Basin water resources, is also required when reviewing the Basin Plan. The Basin Plan includes a cycle of regular review, including reviews of its subsidiary plans, such as the Basin-wide Watering Strategy.

Water in the MDB can be bought and sold either permanently or temporarily. This water is traded through well-established water markets – within catchments, between catchments (where possible) or along with river systems. This form of water trading allows users to buy and sell water in response to their individual needs. Water trading has become a vital business tool for many irrigators.

The first full-fledged Basin Plan evaluation was undertaken in 2020 (MDBA 2020) . An initial vulnerability assessment was conducted to support the Basin Plan evaluation. This assessment sets out a high-level subjective scan of how Basin Plan objectives relating to Basin communities, water-dependent industries, water markets, ecological outcomes, and First Nations people may be vulnerable to the impacts of climate change. The report states that the climate science for the Murray–Darling Basin now predicts with high-level confidence that temperatures will rise, and, in the southern Basin, winter rainfall will decline.

Projected reductions in water available for consumptive use and environmental flows are exacerbated in several ways by the other impacts of climate change. In particular:

- Increased variability (longer droughts, more intense wet periods, and other extreme events) will challenge water users and ecosystems to sustain themselves at low water availability levels for longer and adapt to the impacts of more extreme weather events.
- High evapotranspiration rates mean there will be less water in the landscape and more water will be required to irrigate crops effectively.
- Water quality issues, particularly salinity and hypoxic black water events, are expected to be more prevalent, reducing the water supply's fit-for-purpose nature and impacting communities, industry, and the environment.

Further, as the climate changes, landscape water dynamics, including interactions between runoff, vegetation, groundwater, rivers and wetlands, will increasingly be novel and may not be well represented in current models.

These changes mean that the environment, industries, businesses, and communities that have depended on the historical hydrology of the Basin for their development and survival must also change. While water management measures are designed to function across a range of water availability, the system might be vulnerable because it is untested under the full range of scenarios climate change may present.

3. Assessment approach

Assessment framework

The study extends the use of the term 'values' beyond its narrow focus on monetary worth, relative worth, or fair return on exchanges to encompass subjective and nonmaterial values of communities and cultures affected by change. Thus, the study refers to 'values' as an organised set of preferential assumptions and beliefs that influence much of communities' values system or principles that guide their behaviour shaped by cultural, religious, or personal factors. Thus, values are a co-product of the assets valued and the communities valuing it - it is not a property of either on their own.

What matters to people, that is, what is valued, can be expressed in many ways. To simplify the values understanding and identify the shared values of the Commonwealth, we looked at similar elements of the Basin Plan (2012). Chapter 5 of the Basin Plan (2012) articulates a set of common values concerning the Basin. The overarching outcome in article 5.02 (2) of the Plan can be considered as a values statement, which is 'healthy and working Murray-Darling Basin', described in more detail as:

> communities with sufficient and reliable water supplies that are fit for a range of intended purposes, including domestic, recreational, and cultural use; and
>
> productive and resilient water-dependent industries, and communities with confidence in their long-term future; and

healthy and resilient ecosystems with rivers and creeks regularly connected to their floodplains and, ultimately, the ocean.

We used the Basin plan outcome statements to identify Basin values in "quadruple-bottom line" terms: economic, social, cultural and environmental values (Figure 2).

Figure 2 Values for a healthy and working Murray-Darling Basin

Economic values

- Productive water-dependent industries and communities with confidence in their long-term income.

Social values

- Resilient communities with confidence in their long-term future and with sufficient and reliable water supplies for domestic and recreational use.

Cultural values

- First Nations communities with sufficient and reliable access to water for cultural use.

Environmental values

- Healthy and resilient ecosystems.

We define "vulnerability" as the degree to which assets or values are susceptible to climate change impacts. It is a function of a community or region's exposure, sensitivity and adaptive capacity. We use a novel Flow-asset-values (FAV) framework to examine the three key components of vulnerability i.e., exposure, sensitivity, and adaptive capacity (Figure 3) (Fritzsche *et al.* 2014).

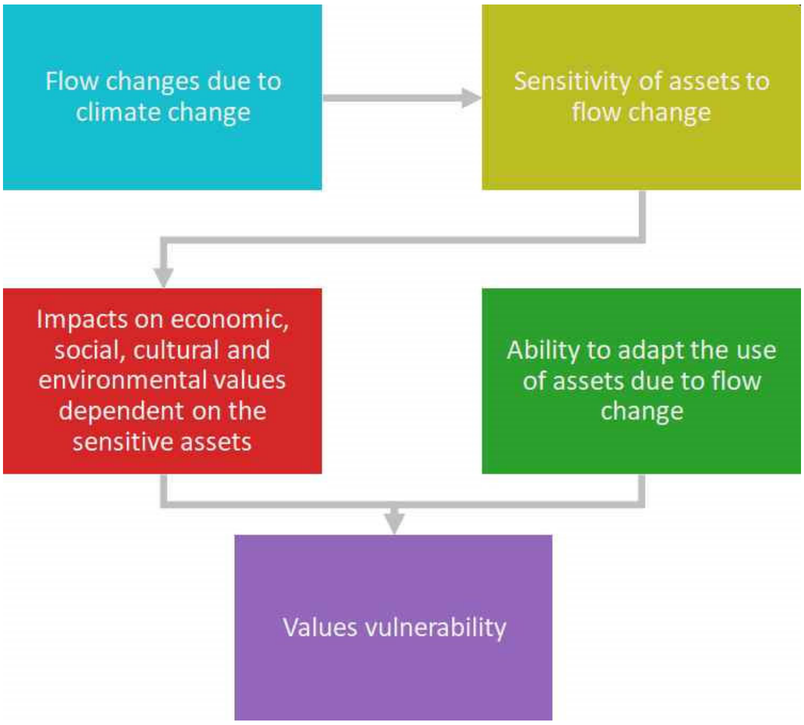

Figure 3 Flow-asset-values (FAV) framework

We used the FAV framework (Figure 3) to identify indicators that measure regional or community exposure, state of sensitivity, and adaptive capacity (Nguyen *et al.* 2016). This is necessary as there is no standard unit of measurement for values vulnerability and quantifying absolute vulnerability is impossible. Thus, we consider vulnerability a relative term differentiating vulnerability among communities or regions or representing circumstances changing over time rather than being an absolute measure of susceptibility. Indicators provide a measurable or observable simplified means to explore the exposure, sensitivity of asset or values and coping properties. Flow change may affect some properties of a particular sensitive asset, not others, and different people may value properties differently.

In the FAV framework, sensitivity refers to how much values are affected by changes in flow. Ideally, measures of this would relate to the change in values as a function of change in flow, for example, how much a unit change in irrigation water availability affects a community's wellbeing or how much reduced flows impact the recreational and aesthetic value of a wetland. However, these direct measures are generally not readily available for most values and exploratory *indirect* indicators are used in this rapid scan. For example, we included measures related to the quantity of the water-dependent asset that gives rise to a benefit, or in some cases, the quantity of water typically applied to the asset or other measures of the asset's productivity. The rationale for this is that the greater the amount of a sensitive asset in a region, the more values associated with that asset will be affected by changes in flow. However, this *assumes* that impacts on values are linearly related to changes in flow. We acknowledge that the sensitivity of values to flow will be much more complicated within context-specific dynamics, including thresholds.

Caution is exercised to avoid overly rigidly interpreting any vulnerability components (Preston and Stafford-Smith 2009). For example, existing adaptation strategies at the national level can alter the sensitivity and adaptive capacity at the Basin or catchment levels, and that in turn, can affect individuals or communities. The systems' nested, dynamic, and looped nature aspects make vulnerability 'complex' in a technical sense (Snowden 2003; Preiser *et al.* 2018). Therefore, broad boundaries for terms and concepts associated with vulnerability components are considered in this study for undertaking the values-based assessment in the most meaningful way (see Glossary for definitions of terms used in the document).

Spatially, data is organised in Water Resource Plan Areas (WRPA). The WRPAs represent the main spatial scale for water planning in the Basin. The Basin governments worked closely with local communities, including First Nations groups, to prepare the WRPs. The WRPAs follow the hydrological catchment boundaries, and it makes sense to generate flow change data at this spatial scale.

The time horizon for the study is 2050. The time horizon is identified considering Basin Plan timelines, the global communities strive to limit warming below 2°C by 2050, and this timeframe represents a balance between Basin-level water planning and policy and when climate impacts may become more significant.

Rainfall in the Basin is highly variable over time and space, challenging the concept of an identifiable 'average' flow condition under future climate change. To address the uncertainty related to future rainfall, we used the storyline approach of the Plausible Hydroclimate Futures for the Murray-Darling Basin (Zhang *et al.* 2020a). This study describes plausible what-if scenarios around a 2°C warming, effectively communicating climate change risk to the public and policymakers in a more accessible and comprehensive way.

We used two scenarios in this study to explore exposure to changes in flow: a 'Warmer and drier' Basin and a 'Warmer and wetter' Basin. The warmer Basin refers to 2°C temperature rise with a corresponding 7% potential evapotranspiration increase from the historical baseline. The drier and wetter world refer to 5% less or 10% more rainfall across the MDB, respectively.

Data sources

For this study, we explored a variety of data sources, including research repositories, databases, and publications from various government and academic sources. After an extensive search of credited and acknowledged sources, meetings and discussions with experts from the Murray-Darling Basin Authority (MDBA), WERP users' advisory group, and others WERP themes and Climate Change COP, the following indicator data sources were selected.

1. ABS, 1270.0.55.005 - Australian Statistical Geography Standard (ASGS): Volume 5 - Remoteness Structure, July 2016.
2. ABS, 2016-Census of Population and Housing.
3. ABS, 2020- Customised extraction for Tourism Research Australia (TRA).
4. ABS, 4618.0 - Water Use on Australian Farms, 2015-16.
5. ABS, 7121.0 - Agricultural Commodities, Australia, 2015-16.
6. ABS, 7503.0 - Value of Agricultural Commodities Produced, Australia, 2015-16.
7. ABS, Census Working Population Profile, 2015-16.
8. Brookes (2017), Australian National Aquatic Ecosystems (ANAE) v3.0

9. ABARES (2022), National Land Use Map, 2015-16
10. Basin-wide Environmental Watering Strategy, MDBA, 2019.
11. Cunningham SC, White M, Griffioen P, Newell G and Mac Nally R, (2013) Mapping floodplain vegetation types across the Murray-Darling Basin using remote sensing. Murray-Darling Basin Authority, Canberra.
12. Hartwig, L.D., & Jackson, S. The status of Aboriginal water holdings in the Murray-Darling Basin, 2020
13. http://www.bom.gov.au/water/dashboards/#/water-markets/mdb/eoi
14. https://data.gov.au/data/dataset/murray-darling-Basin-fish-and-macroinvertebrate-survey
15. Ramsar wetlands of Australia, Commonwealth of Australia, 2018
16. Tourism Research Australia, 2020, Summation options by stopover Local Government Area
17. 2020 Regional Wellbeing Survey data tables, Version 1.0, Sept 2021
18. Zhang, L, Zheng, HX, Teng, J, Chiew, FHS, and Post D (2020). Plausible Hydroclimate Futures for the Murray-Darling Basin.

The socio-ecological indicator data were available at multiple spatial units (e.g., SA2, LGA etc.). We re-mapped the indicator data to WRPAs, where appropriate, based on the correspondence of areas or populations between the original spatial units and the WRPAs. For example, for water volume applied, the data collection and remapping process involved the following steps:

1. Calculate the mapped irrigated area of each SA2 spatial unit.
2. Create a spatial union of the SA2 spatial units and the WRPA's.
3. Calculate the mapped irrigated area for each part of the SA2 that is in multiple WRPA's.
4. Calculate the ratio of each part of the irrigated area of the SA2 to the total area of mapped irrigation in the SA2.

These ratios were used when an SA2 crosses over multiple WRPA's to distribute the total SA2 reported indicator to each part. The SA2 boundaries were then dissolved, and the values for each WRPA's parts were summed up to the WRPA level. The same process is followed when the indicator is related to agriculture, such as agricultural-related employment, but the ratio is determined using all mapped agricultural areas.

Similarly, population-based correspondence was used for the proportion volunteering indicator. Population counts reported by mesh blocks, the smallest statistical spatial unit, were used to estimate the number of persons in each part of the indicator reporting units straddling more than one WRPA. The population ratio in each part to the reported population was used to apportion the reported number of volunteers to each part and then summed to arrive at a WRPA estimate. A similar approach was also used to estimate the weighted WRPA mean for the economic diversity, percentage of off-farm income, household income and personal income indicators.

Each of these methods of indicator spatial re-mapping introduces error and uncertainty. However, they provide the best estimates of the situation of the WRPA's. Annex C lists how data on sensitivity and adaptive capacity were re-mapped.

4. Key findings

Economic values

Productive water-dependent industries and communities with confidence in their long-term income

Agricultural primary producers (farmers)

The Murray–Darling Basin is a water source for over 3 million people and provides a basis for an impressive agricultural landscape. The Basin is also important because it is home to over 50,900 farms, which account for 40% of all farms in Australia. The Basin contributes about 50% of Australia's irrigated produce, which brings $19 billion share to the national economy annually. These numbers underscore the Murray-Darling Basin's significant contribution to securing the livelihoods of farmers residents, and contributing to the national economy (MDBA n.d.).

Exposure

In recent decades, Australia has experienced a shift towards higher temperatures and lower winter rainfall, which has significantly impacted many farmers and their businesses (Hughes and Gooday 2021). Rising temperatures and increased evaporation will contribute to reduced water inflows even for any given level of precipitation. Cai and Cowan (2008), project that a 1°C rise in temperature will lead to a 15% reduction in annual inflow, even if rainfall does not change within the Basin. There have already been witnessed significant reductions in average streamflow linked to climate change in the Southern Murray-Darling Basin (Cai and Cowan 2008). Climate change is expected to significantly impact agricultural primary producers (farmers) income by reducing their crop yields. For example, (Kirby *et al.* 2014) reported a significant reduction in the production of cotton, rice, dairy and meat in area during the millennium drought. Given these precedents, it is predicted that as temperatures continue to rise, heat waves may become more frequent and intense, and pests and diseases can spread to new areas, causing crop and livestock damage and increasing the risk of bushfires. Decreased rainfall and evapotranspiration increases can directly affect crop and pasture production, and declining catchment inflow can reduce water availability for irrigation and livestock. Changes in rainfall patterns are likely to shift the hydrological cycle, skewing rainfall distribution over time and space, which can affect crop growth and water availability. Concurrent reductions in soil moisture, temperature increases, and nutrient dynamics changes can reduce soil fertility and crop yields.

We assess the flow-related exposure of farmers' income through the following three indicators.

1) **Mean annual runoff**. Integrates impacts of changes in rainfall (amount and variability), temperature and potential evaporation. Changes affect water availability for rainfed crops and pastures and inflows to dams that determine irrigation water allocations. It is a primary variable considered in water resources planning, and most climate impact studies report on changes in mean annual flow (Zhang *et al.* 2020a).
2) **Runoff for floodplain inundation**. Daily runoff not exceeding 95% of the time describes high-runoff events contributing to floodplain inundation (Zhang *et al.* 2020a).

3) **Seasonal runoff change**. The ratio of runoff (Jun-Nov)/ runoff (Dec-May) describes the impact of change in rainfall seasonality.

The changes (%) of factors influencing long-term flow characteristics of farms in the two scenarios are shown in Table 1 and Table 2. While the changes (%) of factors indicate reductions in mean annual runoff, it is important to note that these changes do not vary substantially among different WRPAs.

Table 1 Changes in flow characteristics related to farmers' long-term income between warmer-drier and historical baseline scenarios.

Murray-Darling Basin Water Resource Plan Areas (WRPAs)	Changes from historical baseline (1898-2018)		
	Mean annual runoff	Runoff for floodplain inundation (Q95)	Runoff-Jun-Nov/Runoff Dec/May
Victorian Murray	-20%	-18%	3%
Northern Victoria	-19%	-19%	4%
Wimmera-Mallee (surface water)	-20%	-20%	3%
South Australian Murray Region	-22%	-23%	2%
Eastern Mount Lofty Ranges	-24%	-24%	-1%
Lower Darling	-23%	-25%	-1%
New South Wales Murray	-22%	-22%	1%
Murrumbidgee	-22%	-22%	1%
Lachlan	-26%	-25%	1%
Macquarie-Castlereagh	-24%	-25%	0%
Intersecting Streams	-23%	-25%	0%
Namoi	-26%	-27%	1%
Gwydir	-21%	-24%	0%
New South Wales Border Rivers	-22%	-25%	0%
Queensland Border Rivers-Moonie	-25%	-28%	0%
Condamine-Balonne	-22%	-25%	0%
Warrego-Paroo-Nebine	-21%	-22%	0%

Table 2 Changes in flow characteristics related to farmers' long-term income between warmer-wetter and historical baseline scenarios.

Murray-Darling Basin Water Resource Plan Areas (WRPAs)	Changes from historical baseline (1898-2018)		
	Mean annual runnoff	Runoff for floodplain inundation (Q95)	Runoff-Jun-Nov/Runoff Dec/May
Victorian Murray	18%	18%	4%
Northern Victoria	18%	20%	2%
Wimmera-Mallee (surface water)	18%	20%	3%
South Australian Murray Region	20%	21%	-1%
Eastern Mount Lofty Ranges	22%	25%	7%
Lower Darling	21%	23%	-2%
New South Wales Murray	19%	21%	4%
Murrumbidgee	20%	23%	1%
Lachlan	23%	23%	-1%
Macquarie-Castlereagh	22%	23%	-3%
Intersecting Streams	20%	23%	-2%
Namoi	21%	22%	0%
Gwydir	**16%**	19%	0%
New South Wales Border Rivers	18%	20%	-1%
Queensland Border Rivers-Moonie	21%	24%	-2%
Condamine-Balonne	20%	21%	-2%
Warrego-Paroo-Nebine	28%	26%	-2%

Table 1 shows a 5% decline in rainfall, reducing the mean annual runoff by 19% to 26% in the different catchments of the Basin. The reductions in mean annual runoff tend to be lower in the Northern Victoria region where the agricultural industry is an important contributor to the Australian economy with a gross value of agricultural production exceeding $2,600 million (ABS 2021). Conversely, the largest reductions in the mean annual runoff under a warmer-drier scenario are in the Namoi region, where agricultural output and economic well-being highly depend on water availability for irrigation (Sharp and Curtis (2012). A 2012 Deloitte report indicates that a drop in every mega litre of irrigation water will result in a consecutive decline of Namoi's economy by approximately $750 (Deloitte Access Economics 2012). Adjusted for inflation, this translates to $945 in 2022 (Reserve Bank of Australia 2023).

Changes in the runoff seasonality in warmer-drier scenario have led the southern parts of the Basin, like Victorian Murray, Northern Victoria, and Wimmera-Mallee regions, to experience a greater proportion of runoff occurring in the wetter half of the year (June-November) from the historical average. This also means drying will be less severe in the southern Basin in warmer-drier scenario. The rest of the Basin may not experience changes in the runoff seasonality.

Under the warmer-drier scenario, the runoff related to events that historically inundate floodplains decreases in magnitude, indicating that less frequent inundation is expected. Reductions in these high-flow events tend to be larger for the WRPAs in the northern Basin than those in the south. A similar pattern occurs for the runoff events related to instream habitats, with an overall decline in event magnitude and larger declines in the north relative to the south. In unregulated parts of the system, reductions in high flow events are likely to reduce riverine connectivity required to fill pools and waterholes, and may constrain the ability of water users to access water.

Under a warmer-wetter scenario of a 10% increase in rainfall, all indicators reflect increased water availability across the entire Basin. Exposure indicators suggest that the percent increases in exposure tend to be higher in the WRPAs where baseline runoff indicators are lower, notably in the northern and central parts of the Basin. However, these changes' exact nature and magnitude are still uncertain and subject to ongoing research.

Sensitivity

The impending climate changes (Whetton and Chiew 2021) are anticipated to affect agricultural production in the Basin (Quiggin 2011). Agricultural primary producers (farmers) derive income from cropping, horticulture, grazing and animal production, which depend on the quality of farmland and pastures, among other things. Farmers also use water for domestic purposes. There are a variety of factors that can influence the long-term income sensitivity of farmers. Some of these include:

1. **Market conditions**: The Basin exports a significant amount of its agricultural produce to other nations (MDBA 2020). While food security may not be a concern for all major importers of Australian food products, the export of these goods makes a substantial direct and indirect contribution to stabilising the global food market and ensuring the food security of importing nations (Qureshi, Hanjra, *et al.* 2013). Farmers are sensitive to world markets. The level of competition in the global and domestic markets for a farmer's produce can affect their income. If many other farmers produce similar goods, prices may be lower, leading to lower income for the farmer. In some markets, there may be a premium for higher quality produce or other desirable characteristics, such as organic or locally grown produce.
2. **Production costs**: Inputs such as seeds, fertiliser, and fuel can impact a farmer's income. If these costs are high, farmers may have lower incomes. Implementing adjustments to cropping systems in response to changing conditions represents medium to long-term measures that entail significant adaptation expenses and subsequently increased overall costs of food production (Qureshi, Hanjra, *et al.* 2013).
3. **Farming technology**: Modern farming technology can improve crop yields and increase efficiency, leading to higher incomes for farmers.
4. **Government policies**: Australian and overseas government policies, such as tariffs, subsidies, and regulations, can also affect a farmer's income.
5. **Access to credit and finance**: The availability of credit and finance can affect a farmer's ability to invest in their business and grow their income.
6. **Farm size**: The size of the farm may also impact a farmer's income sensitivity. Larger farms may have economies of scale that allow them to produce crops more efficiently and at a lower cost, leading to higher income. This trend has been observed by Telford and Jennings (1997)

regarding the dairy farming sector, which is experiencing a consolidation trend, with farms merging and expanding in size, resulting in a decline in the total number of dairy farms.

7. **Seasonal/Weather conditions**: Drought, heavy rain, floods, storms, hail, heatwaves, and frost can impact the yield of a farmer's crops and animal productivity and wellbeing, and thus farm income. A recent study by ABARES has reported that the recent changes in seasonal conditions have affected the profitability of Australian farms (Hughes and Gooday 2021). Figure 4 shows that many of the farms affected the most due to seasonal/weather changes are concentrated in the Murray-Darling Basin.

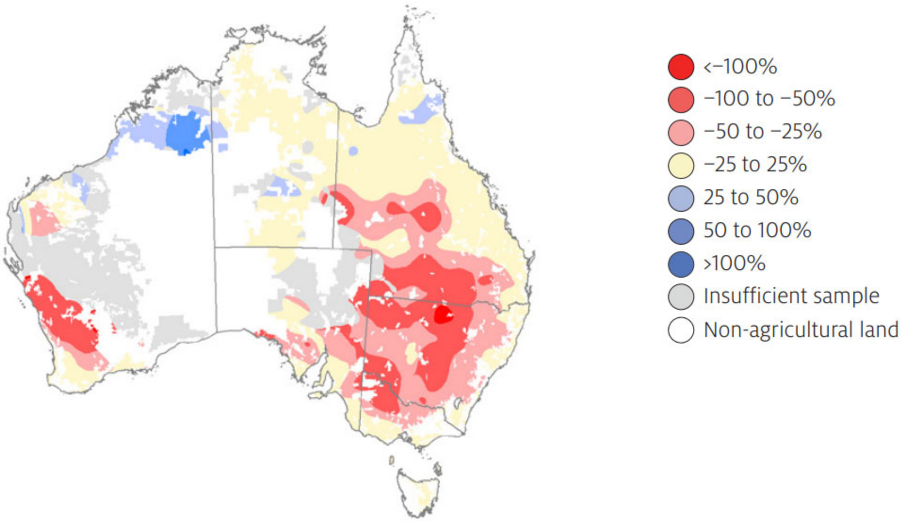

Figure 4 Effect of recent (2001 to 2020) seasonal conditions on farm profit (Source Hughes and Gooday 2021)

8. **Climate change**: Scientific evidence suggests that the inter-annual and multiyear variability of streamflow is very high in the Murray–Darling Basin, which is higher than in rivers in regions with similar hydroclimates elsewhere in the world (Chiew and McMahon 2002; Peel *et al.* 2004). Although the Basin has historically witnessed periods of low flow, the frequency of low flows has increased in recent decades e.g., the unprecedented Millennium Drought in the southern Basin from 1997 to 2009. This drought resulted in a significant decline in reservoir storage levels, several years of severe water restrictions in regional towns, and prolonged low water allocations to irrigators (Van Dijk and Podger 2005; Young and Chiew 2011). Similarly, the intense droughts during 2017–2019 in the northern and central Basin significantly impacted agricultural and domestic water supplies (Vertessy *et al.* 2019). Long-term weather changes are likely to have cumulative impacts on farm production and viability, in some cases alleviating climatic constraints and, in other cases, overwhelming existing capacities to accommodate climatic variability.

9. **Water availability**: Decreased water availability may reduce agricultural production and impact farm income, where fixed farm costs are high. However, declines in regional output can lead to increases in produce prices which may decrease the net impact on income, especially for farmers with more-reliable sources of water and lower fixed costs. Water availability to individual farms depends on rainfall, allocations, and water markets (and trade). Dryland farming depends on seasonal rainfall. A minimum amount is required to fill the soil and support basic plant growth, with additional water supporting crop yield. Irrigated agriculture

requires seasonal allocation of irrigation water for crop or pasture productivity. Livestock producers need seasonal allocation of water for stock of sufficient quality. Farms with perennial crops rely on a minimum irrigation volume to keep crops alive. Some farms rely on stockfeed derived from irrigated and dryland grain or fodder crops. Some farms rely on floodplain flooding for crop and pasture production.

The first six factors related to farmers' income could be measured through surveys/interviews or in-depth case studies. However, detailed measurement approaches are beyond the scope of the rapid assessment. We used the g*ross value of agricultural production, agricultural related employment, and agricultural businesses number* as integrative indicators of farmers' income sensitivity (Table 3). For example, a region with a greater *gross value of agricultural production* would likely have more income sensitive to flow changes.

Table 3 Indicators used to assess farmers' long-term income sensitivity.

Factors influencing farmers' long-term income sensitivity	Integrative indicators used to assess income sensitivity
Market conditions Production costs Farming technology Government policies Access to credit and finance Farm size	Gross value of agricultural production, GVAP ($m) Agricultural related employment Agricultural businesses number
Weather conditions Climate change Water availability	Total water applied (ML) Area of floodplain (ANAE) grazing (ha)

We use *total water applied (ML) and area of floodplain (ANAE) grazing (ha)* as indicators for regions sensitivity associated with weather conditions, climate change and water availability.

Table 4 provides the indicator values of farmers' income exposure, sensitivity, and adaptive capacity; they are described afterwards.

Table 4 Farmers' income exposure, sensitivity, and adaptive capacity indicator values.

Murray-Darling Basin Water Resource Plan Areas (WRPAs)	Exposure			Sensitivity					Adaptive Capacity			
	warmer-drier basin											
	Mean annual runoff	Runoff for floodplain inundation (Q95)	Runoff -Jun-Nov/ Runoff Dec-May	GVAP (million AUD)	Employment in agriculture related jobs (%)	Agricultural businesses (No.)	Total water applied (ML)	Area of floodplain (ANAE) grazing (ha)	Percentage of reliable water entitlement	Percentage off-farm income	Economic diversity	Remoteness
Victorian Murray	-20%	-18%	3%	1,076	13	1,843	489,048	8,502	65	14	0.62	3
Northern Victoria	-19%	-19%	4%	2,662	13	5,319	776,203	18,001	52	16	0.66	4
Wimmera-Mallee (surface water)	-20%	-20%	3%	2,219	25	3,147	358,660	9,904		10	0.49	3
South Australian Murray Region	-22%	-23%	2%	1,665	26	2,025	335,555	22,526	100	11	0.49	2
Eastern Mount Lofty Ranges	-24%	-24%	-1%	315	15	533	40,779	2,042	100	18	0.72	4
Lower Darling	-23%	-25%	-1%	331	13	492	66,685	439,741	2	13	0.46	2
New South Wales Murray	-22%	-22%	1%	601	9	1,008	344,886	120,230	8	10	0.67	3
Murrumbidgee	-22%	-22%	1%	2,760	15	4,628	1,102,636	226,490	10	13	0.56	3
Lachlan	-26%	-25%	1%	2,098	26	3,865	258,868	393,861	4	12	0.47	2
Macquarie-Castlereagh	-24%	-25%	0%	1,420	11	3,466	158,909	570,808	2	15	0.60	2
Intersecting Streams	-23%	-25%	0%	270	21	451	38,915	1,201,942		10	0.25	1
Namoi	-26%	-27%	1%	1,095	14	1,885	240,948	84,175	1	17	0.58	3
Gwydir	-21%	-24%	0%	973	31	1,019	192,519	112,735	3	11	0.45	3
New South Wales Border Rivers	-22%	-25%	0%	580	28	935	77,641	35,287	0	19	0.53	3
Queensland Border Rivers-Moonie	-25%	-28%	0%	1,045	27	875	122,791	28,260	1	13	0.36	3
Condamine-Balonne	-22%	-25%	0%	1,993	11	2,914	241,114	111,133	1	19	0.65	2
Warrego-Paroo-Nebine	-21%	-22%	0%	461	28	517	84,744	575,655		8	0.44	1

Gross value of agricultural production, GVAP ($m) (Figure 5). *Farmers' GVAP* in Northern Victoria, Wimmera-Mallee (surface water), Murrumbidgee, Lachlan, and Condamine-Balonne WRPAs are the highest in the MDB. The GVAP in each one of these WRPAs has over $2,000 million worth of production.

Flow changes may impact the total income from farms in these WRPAs in absolute terms. However, we note that the *gross value of agricultural production* indicates the sensitivity of individual farmers, and farmers in other regions may be more sensitive to % change in flow. Indicators of the sensitivity of individual farms are important but beyond the scope of this rapid assessment.

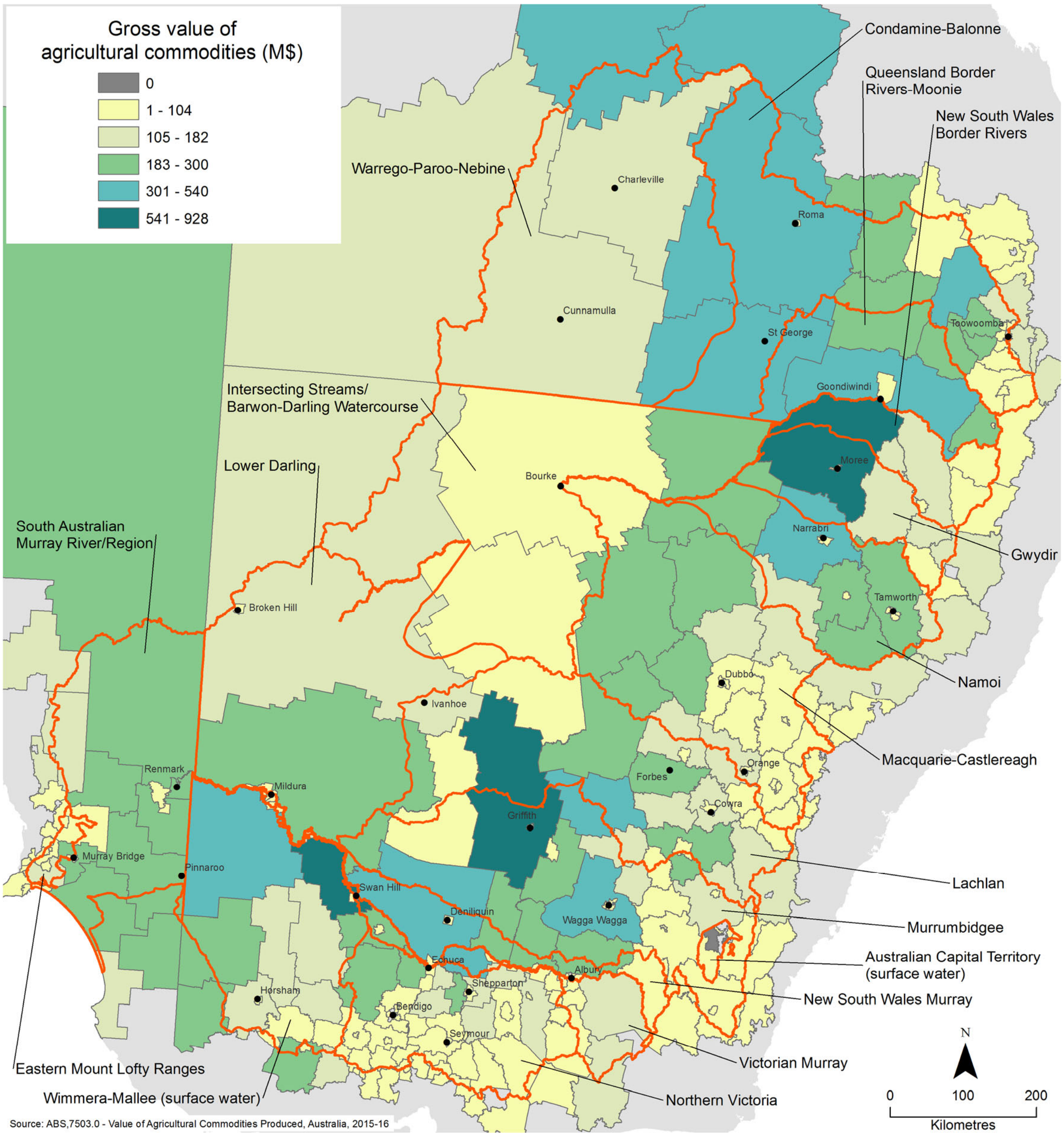

Figure 5 Map showing the gross value of agricultural production in the Murray Darling River Basin.

Total water applied (ML) (Figure 6). The Murrumbidgee region has one the largest irrigated agriculture area in the Murray Darling Basin. It accounts for more than 22% of the Basin's surface water withdrawals. Murrumbidgee Irrigation Area grows wheat, grapes, rice, cotton, corn, oats, and barley; rice, soybeans, corn, wheat, barley, and irrigated pasture are grown in Coleambally Irrigation Cooperative Limited, and wheat, canola, rice, cotton, and corn are produced in "private" diversions from the upper tributaries of the Murrumbidgee River along the Yanco Creek system. Other industries include poultry, almond, walnut, citrus, stone fruit, wine grapes and rice. The Murrumbidgee region often experiences drought and water shortages (Van Dijk *et al.* 2013). This can significantly impact crop yields and livestock production. Even a 5% rainfall reduction might lead to 22% reduction in annual runoff and consequential financial losses for farmers and impact food security for the region.

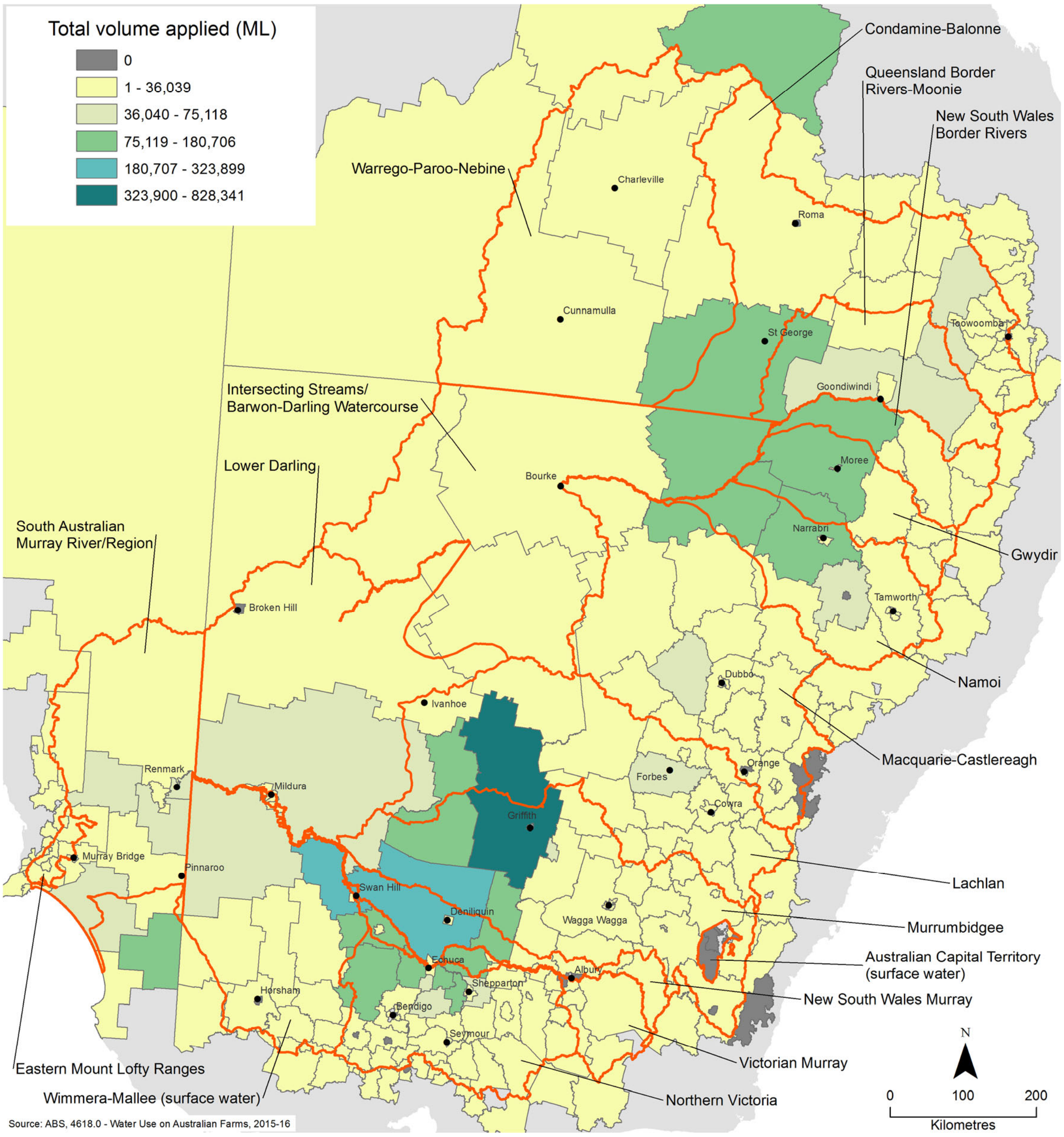

Figure 6 Map showing total volume applied (ML) in the Murray Darling River Basin.

Area of floodplain (ANAE) grazing (ha) (Figure 7). Floodplain grazing provides a valuable forage for livestock during the dry season, when other grazing land may be scarce. Changes in rainfall and overbank flow can impact the productivity of floodplain grazing. Barwon-Darling Watercourse has the largest area of floodplain grazing. It is the dominant land use activity in the Barwon-Darling valley (78% of the total land area), and the potential climate change impact on forage availability might challenge the regional economy.

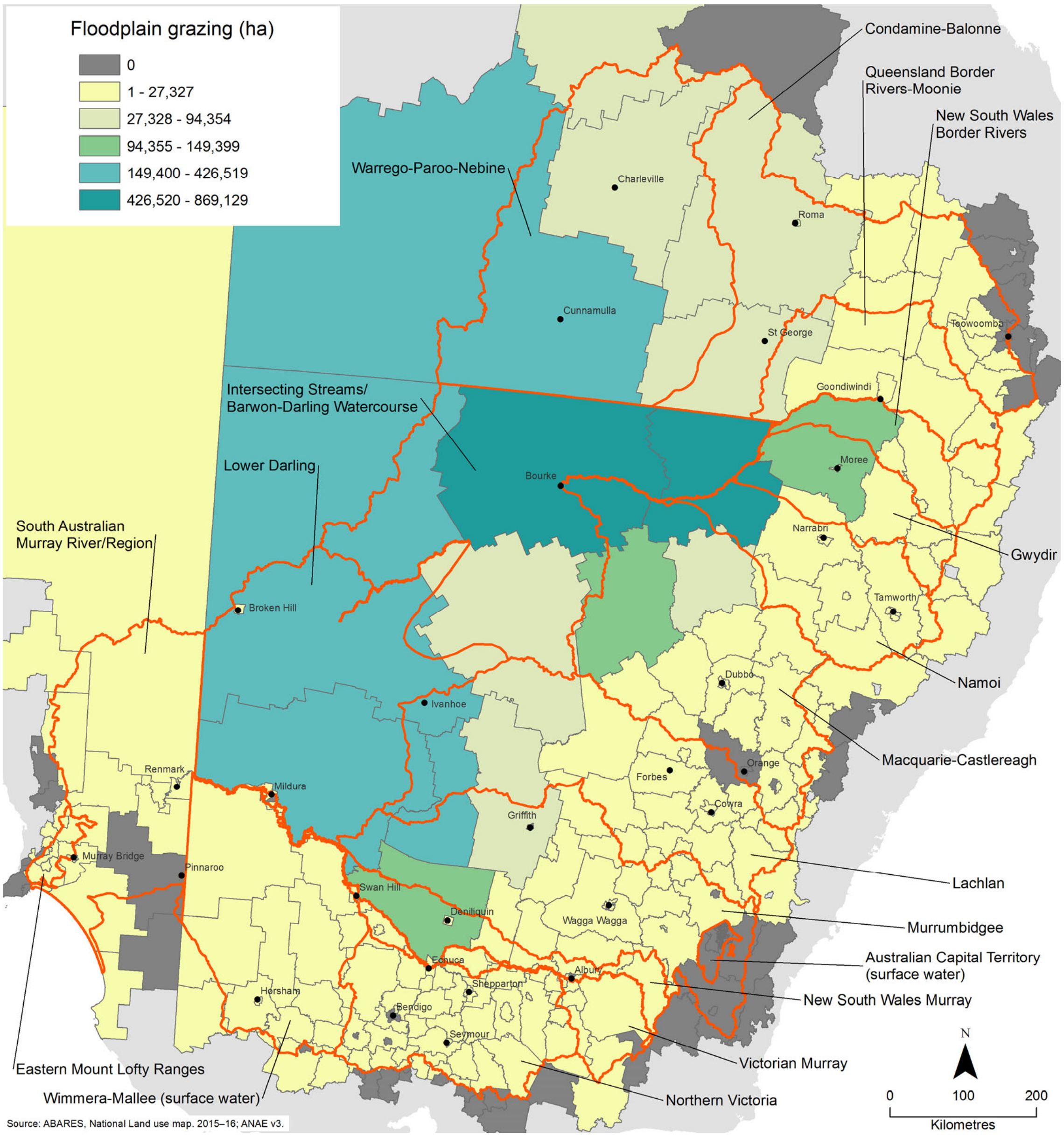

Figure 7 Map showing the area of the floodplain (ANAE) grazing (ha) in the Murray Darling River Basin.

Agricultural related employment (Figure 8). The ratio of agricultural-related employment to total employment varies within WRPA's, however looking at the larger regional picture the Wimmera-Mallee (surface water), South Australian Murray and Lachlan in the southern Basin have higher overall proportion of the workforce in agriculture and agricultural related work. In the northern Basin the Warrego-Paroo-Nebine, Gwydir and both Queensland and New South Wales Border Rivers have a high proportion of agricultural related employment.

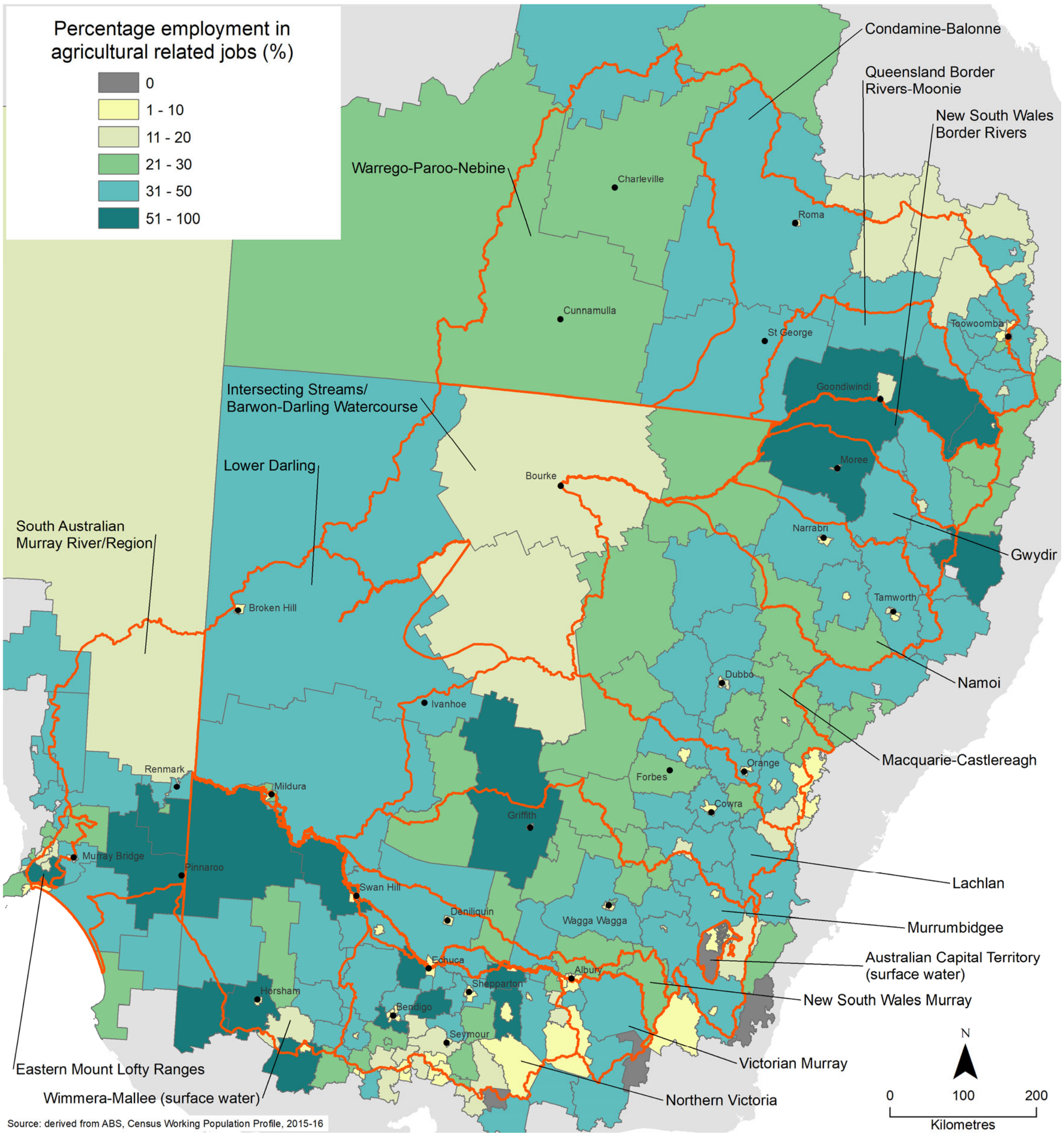

Figure 8 Map showing the percentage employment in agricultural related jobs in the Murray Darling River Basin.

Number of agricultural businesses (Figure 9): A potential increase in the frequency and severity of extreme weather events due to climate change, such as floods and droughts, will impact agricultural businesses. In the southern Basin, the Northern Victoria and the Murrumbidgee WRPAs have the highest number of agricultural businesses and are expected to have regional economies that significantly benefit from servicing agriculture. The Murrumbidgee has the second-highest number of agricultural businesses, but is the leading wheat, rice, and irrigated cotton-producing region and has the highest reported number of sheep as compared to any other WRPA in the basin. The Murrumbidgee region supports one the largest irrigated agriculture area in the Murray Darling Basin, accounting for more than 22% of the total Basin's surface water use/withdrawals. In the northern basin, Macquarie-Castlereagh has the highest number of agricultural businesses. Macquarie-Castlereagh is known for its farming and livestock production and is the second-largest beef cattle producer. After the Macquarie-Castlereagh, the Condamine-Balonne in the southern basin has the second highest number of agricultural businesses and supports the largest beef cattle industry in the Murray-Darling Basin.

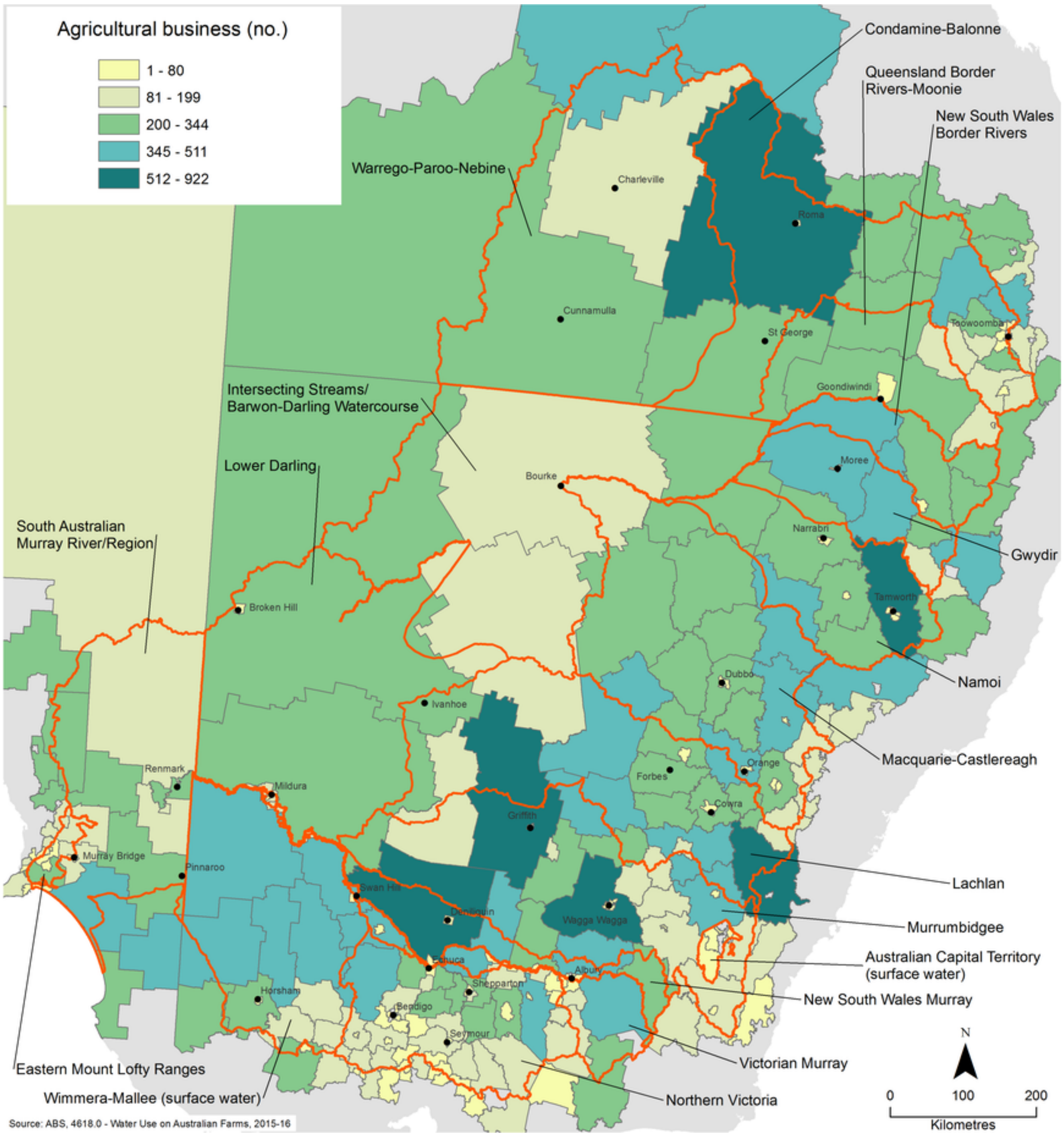

Figure 9 Map showing agricultural businesses in the Murray Darling River Basin.

Adaptive capacity

Farmers in the MDB have been coping with droughts and floods and adapting to changing water availability since farming began in Australia. They change crop types, and cropping intensity, adjust herd sizes, move stock, temporarily move to other livelihoods, and, more recently, trade water as temporary coping strategies. The ability to sustain a viable business through periodic years of low to nil production with off-farm income has become an important strategy for many farming enterprises. Strategies used to cope with climate variability are likely to become more important in the face of climate change. In addition, it should be recognised that permanent changes in water availability, especially reductions, would likely require additional, potentially transformational, adaptation strategies undertaken across the system not just by individual enterprises (Howden *et al.* 2007). These could include new water infrastructure, allocation rules and water management changes, and support for alternate livelihood options at farm and regional scale. Here we describe indicators of short-term adaptive capacity in different parts of the Basin.

- *Water market and trading*. Reliable water entitlement (highest priority for water allocation) allows farmers to generate cash flow by trading or carrying it over for use in subsequent years. These mechanisms enable farmers to make better production planning and get the most value from allocated water. Data obtained from the Bureau of Meteorology (BOM) Water Information and ABS show that Victorian Murray, Northern Victoria, South Australian Murray Region, Eastern Mount Lofty Ranges, Lower Darling, and New South Wales Murray regions have more than 40% of their agribusiness irrigating and also have a larger proportion of reliable water entitlements. The Lower Darling and New South Wales Murray regions have large irrigating business percentages but have less reliable water entitlement. The effectiveness of water trading in the MDB is currently restricted by a range of institutional and governance challenges (Wheeler 2022). Figure 10 shows volumes of temporary water purchases reported by the 2016 agricultural census (ABS, 2017).

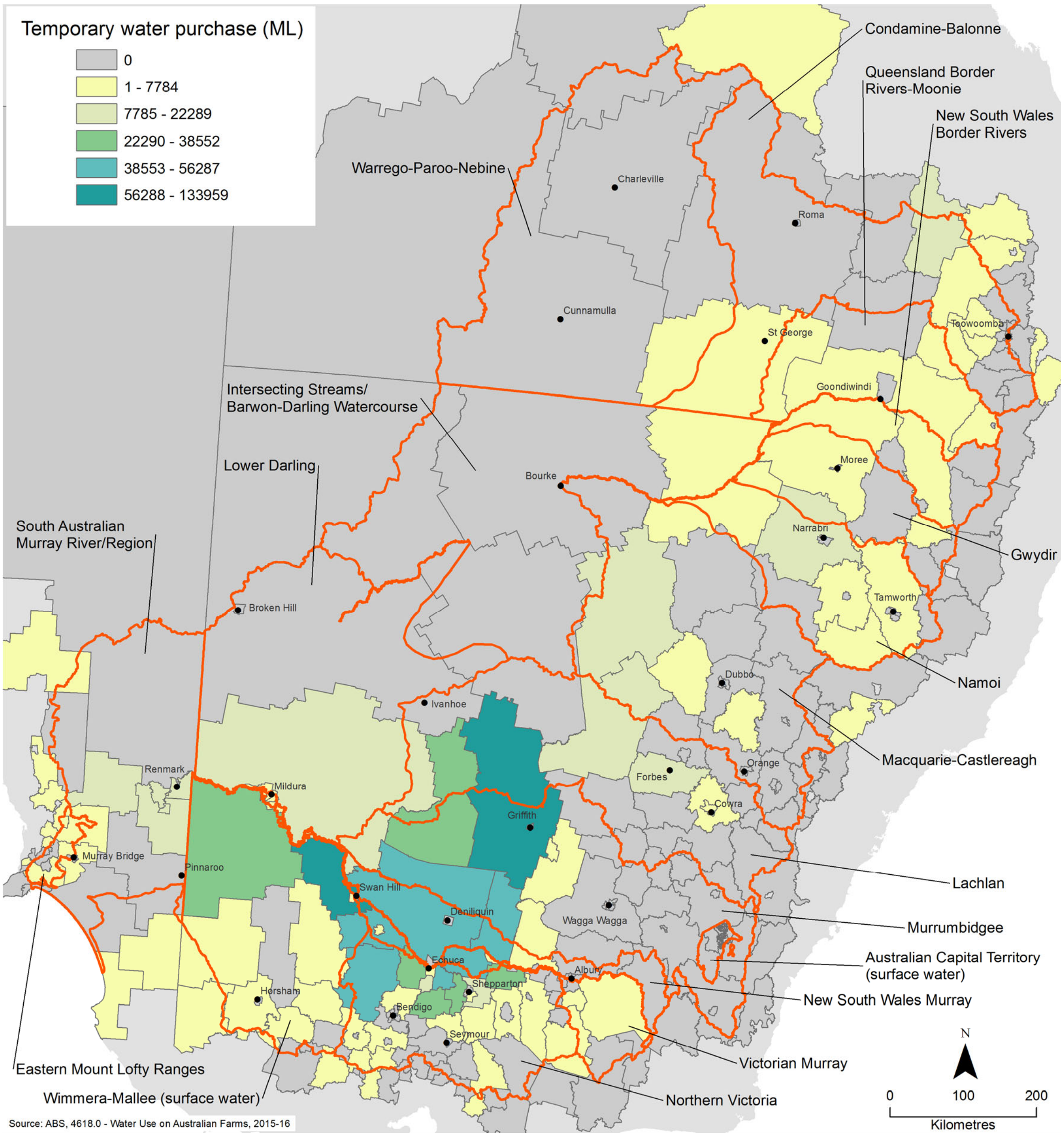

Figure 10 Map showing temporary water purchase (ML).

- *Off-farm income*. Off-farm income is an important component of farmers' adaptive capacity and a driver of farm's financial status (Yazd *et al.* 2019). Working a part-time job, running a small business, renting out property, family members working outside of agriculture, and so on can be an important source of cash flow to maintain the viability of their enterprises through periods of low farm production. ABS data show that the average off-farm income of farming families in the entire Basin is about 14%. The percentage of off-farm income varies within each WRPA, taking a weighted mean approach in order to compare across WRPA's, the Warrego-Paroo-Nebine has less than 10% off-farm income, while Wimmera-Mallee (surface water), New South Wales Murray, and Intersecting Streams have a 10% share of the household income from off-farm income. Eastern Mount Lofty Ranges, New South Wales Border Rivers and Condamine-Balonne regions have greater percentage of off-farm income. Farmers in regions with less access to off-farm income may face difficult livelihood situations in the face of reductions in water availability.

- *Economic diversity*. The economies in the South Australian Murray Region, Lachlan, Gwydir and Queensland Border Rivers-Moonie WRPAs are relatively less diverse than the rest of the Basin, 26-31% of the total jobs in these regions are agriculture-related. More significant employment in agriculture may mean farmers have less opportunity for off-farm income generation. However, tourism might (e.g., the Gwydir region has several national parks and nature reserves, such as the Gwydir Wetlands) provides temporary respite during the challenging time on the farms.
- *Remoteness*. In times of crisis, farmers often diversify farming and adapt their production methods and crops to stay competitive. They need access to diverse skills and workforce and improve efficiency and productivity. Mapping of remoteness measured using the Accessibility/Remoteness Index of Australia Plus (ARIA+), produced by the Hugo Centre for Population and Migration Studies at the University of Adelaide and published by the ABS show the majority of Intersecting Streams and Warrego-Paroo-Nebine regions as very remote, with Lower Darling, Lachlan, Macquarie-Castlereagh and Condamine–Balonne containing significant areas classed as either very remote or remote (ABS, 2016). Farmers in these regions may find it harder to access diverse skill sets and thus have a lower economic adaptive capacity.
- *Social and community factors*. Social and community factors, such as public perceptions of farming and the availability of labour, can affect the ability of farmers to adapt to changing conditions.
- *Community Leadership and Collaboration*: Community leadership and collaboration, such as community-led initiatives, efforts, and collaborative decision-making, can help communities make their social values and assets more resilient and adaptive to changing circumstances. Community-level collaboration can help identify options and mobilise resources to build capacity and make decisions for preserving social values and assets.

Businesses reliant on the farming communities

Exposure

Besides impacting agricultural production (Quiggin *et al.* 2010), climate change could also affect the businesses and industries that rely on the agriculture sector in the region. If climate change constrains crop and livestock production, the businesses that depend on agriculture for their raw materials could face difficulties in sourcing their products and higher costs. Likewise, many non-agricultural businesses that rely on farming communities (Figure 11) might also be affected because of decreasing income from agricultural production. Considering that the businesses reliant on farming communities are influenced by the performance of the agriculture sector and by the income level of primary agricultural producers (farmers), we measure the flow-related exposure of businesses reliant on farming communities using the same indicators as used to measure the exposure of farmers' income, i.e., annual catchment runoff, runoff for floodplain inundation, and seasonal runoff change. The changes (%) of factors influencing long-term water availability in various parts of the Basin under the two scenarios are presented above in Table 1 and Table 2.

Sensitivity

The Murray-Darling Basin is home to a range of businesses that rely on farming communities in one way or another. For example, agricultural and livestock supply companies, processing and packaging companies, logistic companies, banks, insurance companies, and small retailers etc. are all associated with the agriculture sector in the Basin. These businesses derive income by providing different goods and services to farmers, such as seeds, fertiliser, veterinary supplies, farm consultation, transportation, storage, etc. Besides these, local rural businesses, such as fuel stations, restaurants, and grocery stores, also rely on farmers for their customer base. These businesses are sensitive to several factors, including climate change, and water availability etc., as changes in water flow could impact agricultural production and farmers' income and so also impact these businesses. Several factors can influence the long-term sustainability of businesses that rely on farming communities. For example:

- Market conditions: Businesses reliant on farming communities are sensitive to market conditions, e.g., price fluctuations, supply, and demand-related issues. Decreasing prices of agricultural commodities could force farmers to reconsider their resource allocation and agricultural production decisions, creating a supply and demand gap for agricultural commodities and raw materials that support businesses that rely on agriculture. Reduced profitability of agricultural enterprises, especially those more dependent on flows, could affect the level of dependence on agricultural enterprises, e.g., the proportion of businesses that come from supplying raw materials to farms. Businesses that also trade with non-agricultural businesses may be less sensitive to changes in agricultural production due to changes in flow.
- Government policies: Changes in government policies and regulations can also affect the bottom line of many businesses as they might affect how they operate. Some policies and regulations could affect farmers' ability to provide a consistent and reliable supply of goods to agricultural and non-agricultural businesses. Similarly, lifting government subsidies and incentives to farmers could also affect different inputs and output prices, affecting the profit margins for businesses that rely on farming communities.
- Access to credit and finance: Credit and finance constraints could affect farmers' and other investors' ability to invest in different businesses and grow their off-farm income.
- Weather: Extreme weather conditions could also lead to disruptions in the supply chain for agricultural and non-agricultural businesses.
- Climate change: Climate change and its impacts on weather patterns and crop yields could affect the long-term sustainability of businesses that rely on the farming community.

Given the lack of information about how sensitive businesses reliant on farming communities may be to changes in agricultural production, we have selected indirect indictors that relate to how important agriculture may be to those businesses.

Table 5 Indicators used to assess the long-term income sensitivity of the businesses reliant on farming communities

Factors influencing the long-term sensitivity of businesses rely on agriculture	Integrative indicators used to assess businesses' sensitivity
Market conditions Incentives and subsidies Government policies Access to credit and finance	Agricultural related employment Number of agricultural businesses Business count non-agricultural

Table 6 Changes in flow characteristics (between warmer-drier scenario and historical baseline) influencing businesses reliant on farming communities, and their income sensitivity indicator values

Murray-Darling Basin Water Resource Plan Areas (WRPAs)	Exposure			Sensitivity	Adpative capacity	
	warmer-drier basin					
	Mean annual runoff	Runoff for floodplain inundation (Q95)	Runoff - Jun-Nov/ Runoff Dec-May	Businesses count non-agriculture (No.)	Economic diversity	Remoteness (reversed rating)
Victorian Murray	-20%	-18%	3%	3,007	0.62	3
Northern Victoria	-19%	-19%	4%	8,488	0.66	4
Wimmera-Mallee (surface water)	-20%	-20%	3%	1,119	0.49	3
South Australian Murray Region	-22%	-23%	2%	1,145	0.49	2
Eastern Mount Lofty Ranges	-24%	-24%	-1%	956	0.72	4
Lower Darling	-23%	-25%	-1%	378	0.46	2
New South Wales Murray	-22%	-22%	1%	1,897	0.67	3
Murrumbidgee	-22%	-22%	1%	4,045	0.56	3
Lachlan	-26%	-25%	1%	1,564	0.47	2
Macquarie-Castlereagh	-24%	-25%	0%	3,775	0.6	2
Intersecting Streams	-23%	-25%	0%	167	0.25	1
Namoi	-26%	-27%	1%	1,584	0.58	3
Gwydir	-21%	-24%	0%	373	0.45	3
New South Wales Border Rivers	-22%	-25%	0%	524	0.53	3
Queensland Border Rivers-Moonie	-25%	-28%	0%	388	0.36	3
Condamine-Balonne	-22%	-25%	0%	3,983	0.65	2
Warrego-Paroo-Nebine	-21%	-22%	0%	183	0.44	1

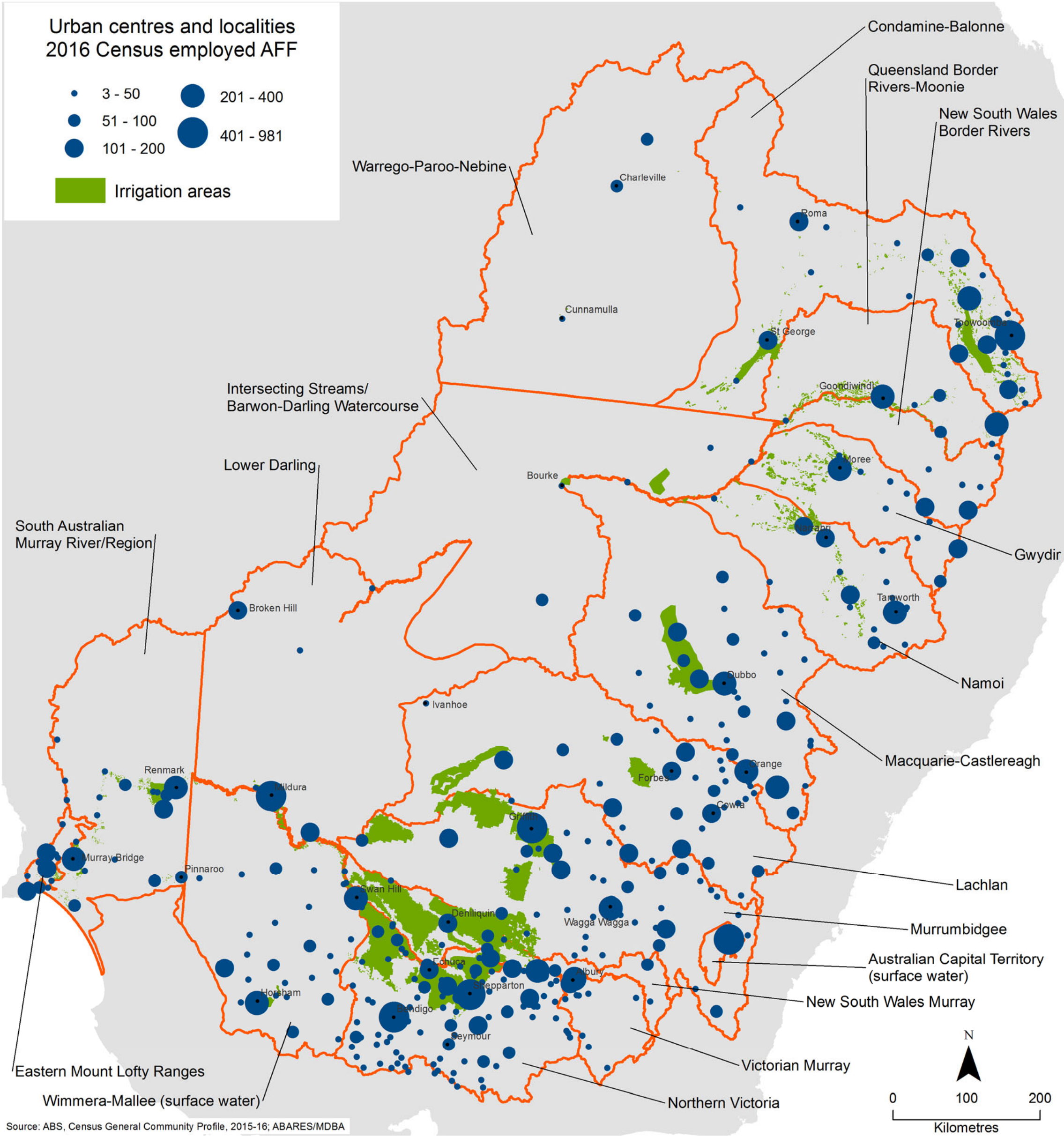

Figure 11 Map showing urban centres and localities 2016 Census employed in Agriculture, Fisheries and Forestry (AFF).

Business count non-agricultural (Figure 12): It is an a priori expectation that the agriculture-based businesses and activities influence the non-agricultural businesses in regions predominantly reliant on agriculture-based economies. Interestingly, like the number of agricultural businesses, Northern Victoria has the highest number of non-agricultural businesses, followed by Murrumbidgee, Lachlan, and Wimmera-Mallee (surface water) in the southern basin. The Macquarie Castlereagh and Condamine-Balonne have the highest number of non-agricultural businesses in the northern basin due to large regional centres including Orange, Dubbo and Toowoomba.

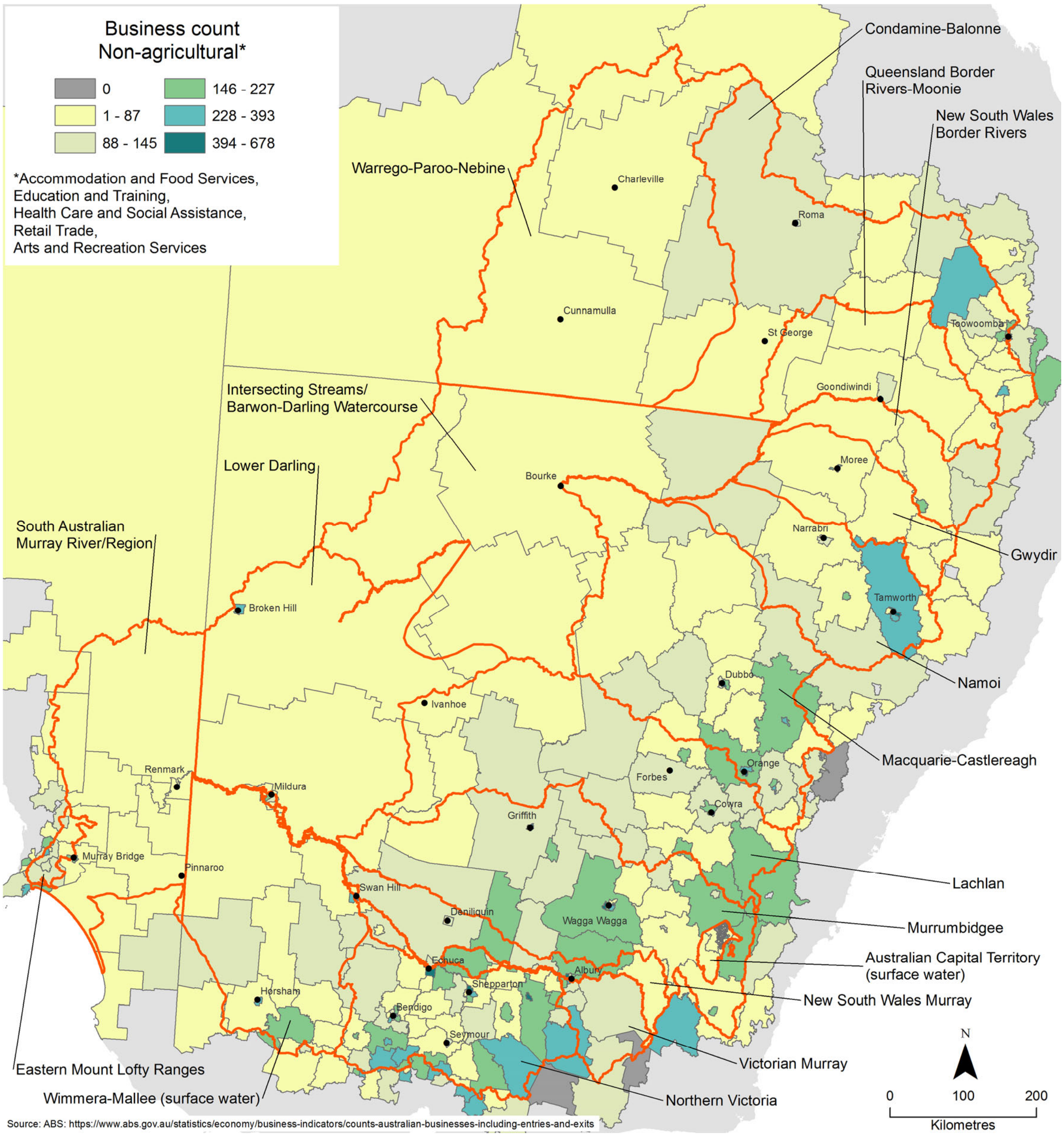

Figure 12 Map indicating non-agricultural business count in the Murray Darling River Basin.

Adaptive Capacity

Businesses that rely on farming communities can adapt to changing environmental conditions by adopting innovative techniques, technologies, and smart strategies. The state and local governments can help these businesses develop innovative strategies and to help improve their adaptive capacities, such as by aiding these businesses through financial incentives and technical assistance. Furthermore, establishing collaborative networks and partnerships between farmers, industry, and governments could also help improve the adaptive capacity of these businesses. We describe indicators that impact the business's short-term adaptive capacity reliant on farming communities in the basin.

Economic diversity. Economic diversity can help businesses that rely on farming communities to adapt better. It helps them hedge against risks associated with changing environmental circumstances by creating alternate business opportunities. The calculated economic diversity index compares the proportion of the workforce employed in the 19 identified industry sectors to that of the entire Murray–Darling Basin (the closer an Economic Diversity Index score for a region to 1.0, the closer its employment distribution is to the Basin as a whole, and the more diverse its economy). The economic diversity index indicates that the Lachlan, Wimmera-Mallee, and South Australian Murray WRPAs are economically less diverse than the other WRPAs. In the northern part, Intersecting Streams, Queensland Border Rivers-Moonie, Warrego-Paroo-Nebine, and Gwydir regions are economically less diverse.

Remoteness. Remoteness can limit access due to longer distances from major markets and cities, thus making it difficult for businesses to access different products and services they need and offer. People live and work in remote areas in the Intersecting Streams, Lachlan, Macquarie-Castlereagh, Condamine–Balonne, and the Warrego-Paroo-Nebine regions. In these areas, businesses reliant on farming communities may find it difficult to access new markets and thus, like the farmers, could have lower economic adaptive capacity.

Access to local government services: Local government services could support the farming communities and the businesses reliant on them with advice and resources to help them adjust according to the changing circumstances.

Access to financial and professional services: Increasing access to financial and professional services and other resources to support innovative and smart business strategies could help businesses become more resilient to changes demand for their goods and services due to changes in the agricultural sector.

Tourism and ecosystem-based enterprises

Exposure

The Murray-Darling basin is a popular domestic tourist destination in Australia. Many state and national parks rely on Basin water resources to sustain environmental health and attract visitors. The tourism value in the basin includes opportunities to explore the region's rivers, waterways, wetlands, and many iconic and historic sites. The region is also home to some of Australia's natural attractions, abundant wildlife, and vibrant regional and cultural heritage. The basin provides a unique combination of cultural, recreational, and educational activities and experiences, making it a popular destination among visitors.

The most popular tourist activities include fishing, camping, bushwalking, birdwatching, mountain biking, canoeing, kayaking, etc. The basin is a significant source of revenue generated from tourism-based businesses. For example, the region is known for its quality wines, particularly Shiraz, Chardonnay and Cabernet Sauvignon, which attract visitors to taste and purchase the local wines produced in the region. The basin's rich cultural heritage is also a significant tourist attraction. Many First Nations communities offer cultural tours and experiences like traditional storytelling, bush tucker tours, and art and craft workshops.

Tourism contributes $11 billion annually to the basin's economy (MDBA n.d.). However, drought and reduced river flow in the basin challenge tourism and ecosystem-based businesses. The reduced river flows affect communities and businesses that depend on the water, especially many tourist attractions are particularly vulnerable to the consequences of climate change (MDBA 2020). The MDBA recently reported that the recreational uses and activities that support the basin's significant eco-tourism industry could be challenged under conditions of reduced water flows (MDBA 2020).

We assessed the exposure of tourism and ecosystem-based enterprises/business to changes in water flows through indicators such as annual catchment runoff, runoff for floodplain inundation, and seasonal runoff change (the same as exposure for agriculture). The indicators are measured for two scenarios: a "Warmer and drier" world and a "Warmer and wetter" world. The changes (%) of factors influencing long-term water availability in various parts of the Basin under the two scenarios are presented above in Table 1 and Table 2.

Sensitivity

The basin's tourism and ecosystem-based businesses depend on several environmental assets, including approximately 400,000 water-dependent ecosystems and internationally recognised (Ramsar) wetlands (Hart *et al.* 2021). These water-dependent environmental assets support the tourism business by creating opportunities for various activities, such as fishing, kayaking, camping, bird watching, wine tasting, and many others. Water flow changes could impact a region's attractiveness to visitors, affecting how many come, how long they stay, and the activities they undertake, affecting the regional tourism industry. Several factors could, directly and indirectly, influence the long-term income sensitivity of tourism and ecosystem-based businesses in the basin.

Some of these factors include:

- Water availability: The basin's environmental assets, including 400,000 water-dependent ecosystems and wetlands, are supported by ~3,000 giga litres (GL) of environmental water (Hart *et al.* 2021). However, decreasing river flows make it challenging to meet the environmental demands and maintain social, cultural, Indigenous, and other public benefit values (Williams *et al.* 2022). Droughts and increased temperatures can lead to decreased water levels in rivers which could make it difficult for many tourism-based businesses and activities, such as fishing and boating. In addition, reduced water flows are also deteriorating water quality and thus impacting the region's native species, which could make it less attractive for tourists.
- Weather: Weather is an important factor in determining tourism-based business in a region. Extreme weather can discourage tourists from visiting a destination and impact tourism businesses' bottom line. The Murray-Darling Basin area is vulnerable to droughts, floods, heat waves and bushfires, which could hurt tourism. Extreme weather can also disrupt the infrastructure and make it difficult for tourists to access attractions and amenities. Recently, the findings of the Aboriginal Weather watchers project of the MDBA First Nations peoples have indicated a significant increase in the frequency of dust storms, an extreme weather event fuelled by dry conditions and low rainfall in many parts of the basin (MDBA 2020).
- Natural amenity: The basin's natural environment provides excellent value, such as scenic beauty, clean air, and water, which attract people to the region. Improvements in environmental conditions can contribute to increased amenity and recreational opportunities, jobs, and income growth in the tourism sector. However, environmental degradation and loss of ecological condition can decrease the basin's natural values and attractiveness.

- Quality of life and regional economic conditions: Tourism heavily relies on the overall quality of life and availability of high-quality services such as accommodation and restaurants. In the Murray-Darling Basin, a decline in these due to climate change could impact tourist visitation and income associated with tourism.
- Economic conditions: Economic or market conditions could significantly affect the income of tourism-based businesses. Increased economic growth might lead to more disposable income, which could create demand for travel and tourism in the region. However, in an economic downturn, it becomes difficult for people to travel, which could result in less tourism activity and income.
- Government policies: Different policies intended to protect and restore the Basin's natural environment and wildlife could impact tourism-based businesses and the dwellers' income.
- Infrastructure: A well-developed road and transportation infrastructure could make it easier for tourists to access the region, making it more attractive. Similarly, improved water infrastructure can create opportunities for more recreational activities and help minimise the environmental impact of tourism, allowing for a more sustainable tourism industry. However, extreme weather events such as drought, heavy rains, winds, floods, and bushfires can disrupt the infrastructure, making it difficult for tourists to access the region.

We use *domestic overnight spend per trip* and *tourism business number* as indicators of the amount that the regions benefit from tourism which flow changes could directly or indirectly impact. The indicators related to water availability and weather had been discussed earlier and are not repeated here.

Table 7 Indicators used to assess long-term income sensitivity based on tourism and ecosystem-based enterprises.

Factors influencing long-term income sensitivity of tourism ecosystem-based enterprises	Integrative indicators used to assess tourism and ecosystem-based income sensitivity
Natural amenity Quality of life Economic conditions Government policies Infrastructure	Tourism (Domestic overnight spend per trip) Tourism business number

The sensitivity of regions in terms of tourism and ecosystem-based businesses of the selected indicators are described here.

- *Tourism business number* (Figure 13): In the southern part of the basin, the Northern Victoria, Wimmera-Mallee (surface water), Eastern Mount Lofty Ranges, and the Murrumbidgee and in the northern Basin, the Macquarie-Castlereagh, Namoi, Gwydir, and the Queensland Border Rivers-Moonie WRPAs have a higher number of tourism businesses.

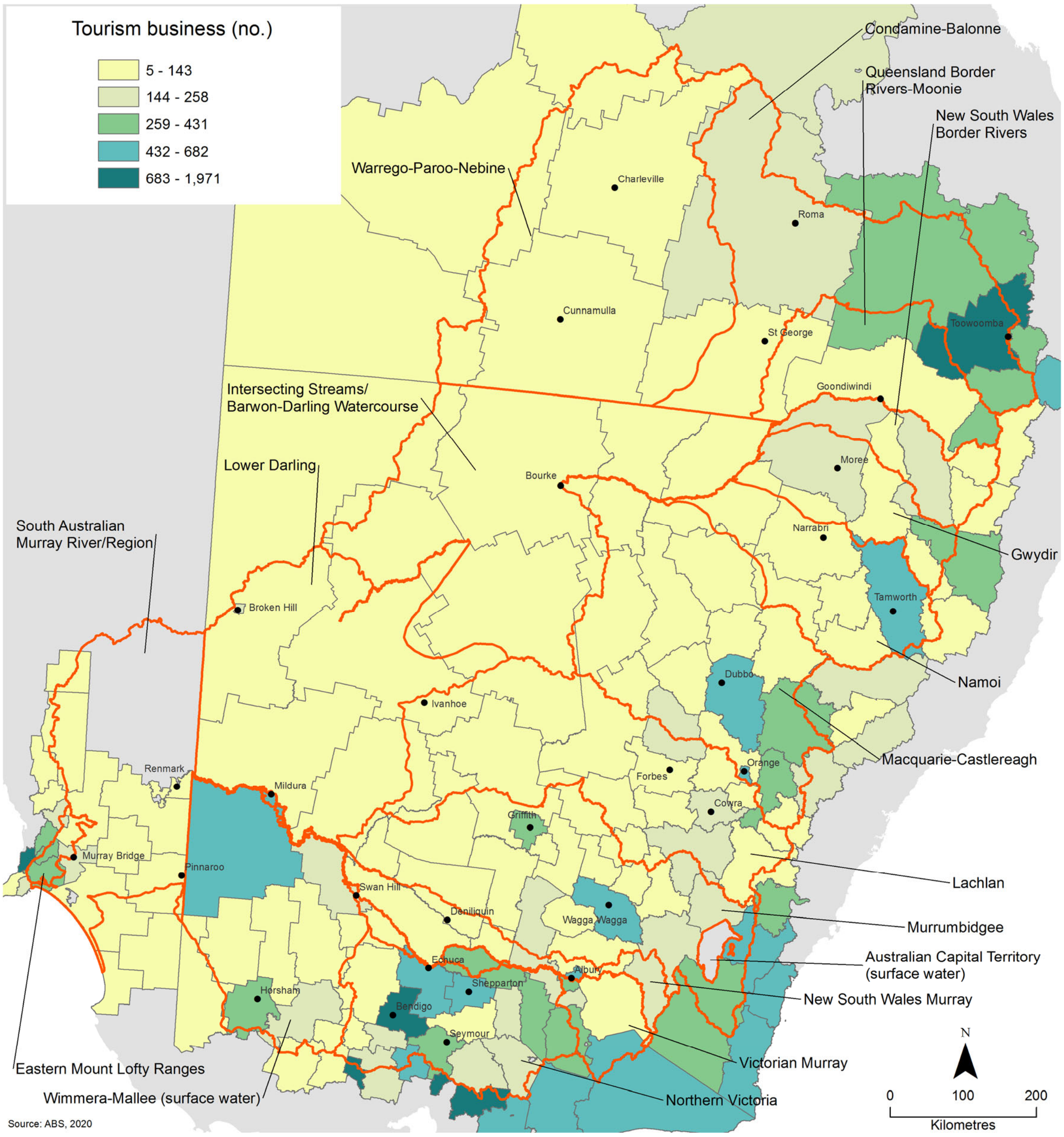

Figure 13 Map showing number of tourism businesses in different WRPAs in the Murray Darling River.

- *Tourism (Domestic overnight spend per trip)* (Figure 14): In terms of the number of domestic overnight spend per trip, local government areas with river towns such as Renmark and Berri in the South Australian Murray, Mildura and Echuca in Victoria and Albury in NSW are reported to be some of the most popular destinations among domestic visitors as compared to other parts of the basin. These regions may be susceptible to overall declines in tourism resulting from flow changes.

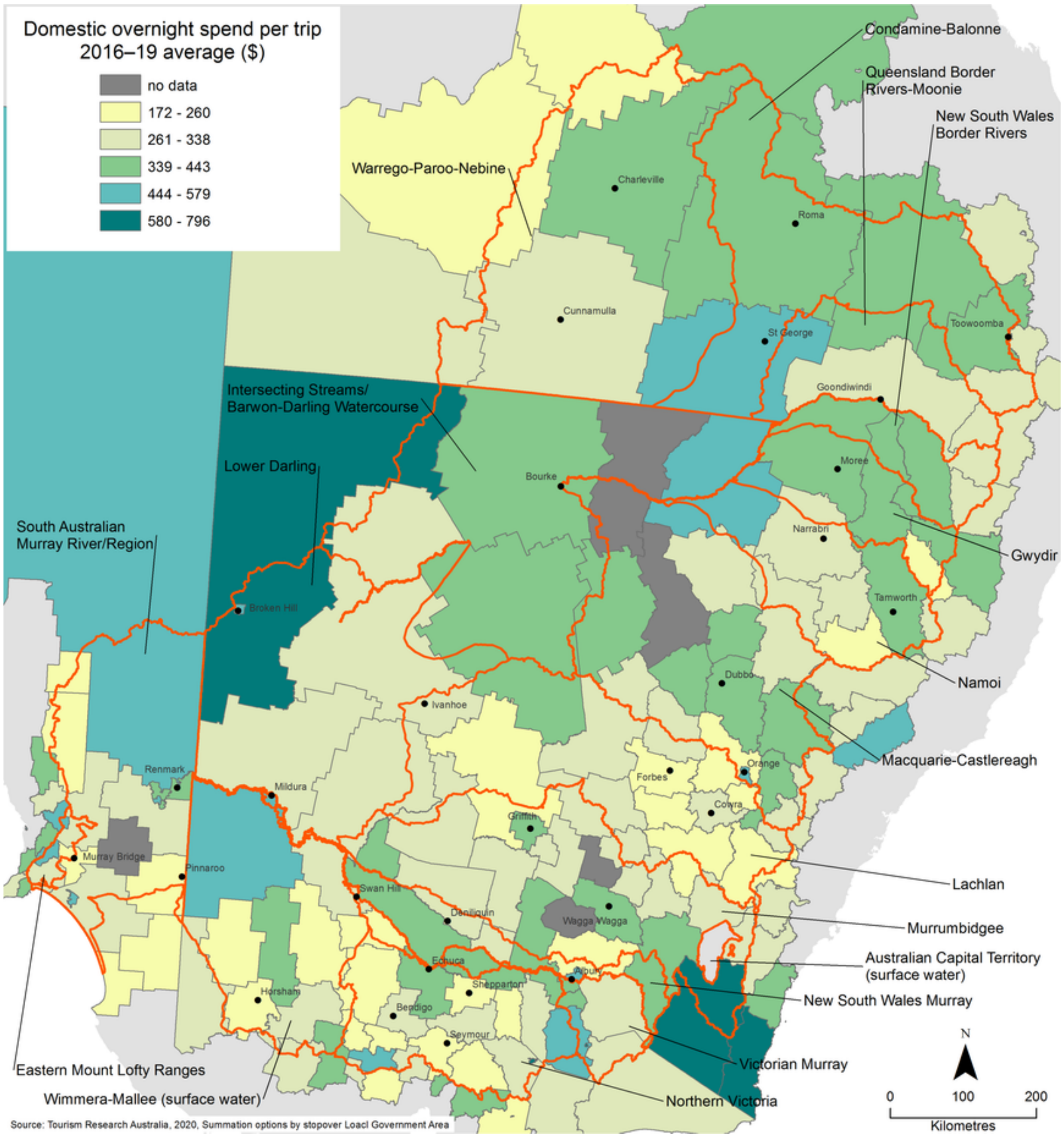

Figure 14 Map showing domestic overnight spend per trip in the Murray Darling River Basin.

Table 8 Changes in flow characteristics (between warmer-drier scenario and historical baseline) influencing tourism and ecosystem-based enterprises and their income sensitivity indicator values[1].

Murray-Darling Basin Water Resource Plan Areas (WRPAs)	Exposure			Sensitivity		Adaptive Capcity	
	warmer-drier basin						
	Mean annual runoff	Runoff for floodplain inundation (Q95)	Runoff -Jun-Nov/ Runoff Dec-May	Tourism business number	Tourism (Domestic overnight spend per trip)	Economic diversity	Remoteness (reversed rating)
Victorian Murray	-20%	-18%	3%	1	2	0.62	3
Northern Victoria	-19%	-19%	4%	3	2	0.66	4
Wimmera-Mallee (surface water)	-20%	-20%	3%	3	3	0.49	3
South Australian Murray Region	-22%	-23%	2%	1	4	0.49	2
Eastern Mount Lofty Ranges	-24%	-24%	-1%	3	2	0.72	4
Lower Darling	-23%	-25%	-1%	1	3	0.46	2
New South Wales Murray	-22%	-22%	1%	2	3	0.67	3
Murrumbidgee	-22%	-22%	1%	3	3	0.56	3
Lachlan	-26%	-25%	1%	2	2	0.47	2
Macquarie-Castlereagh	-24%	-25%	0%	3	3	0.60	2
Intersecting Streams	-23%	-25%	0%	1	3	0.25	1
Namoi	-26%	-27%	1%	3	3	0.58	3
Gwydir	-21%	-24%	0%	3	3	0.45	3
New South Wales Border Rivers	-22%	-25%	0%	2	3	0.53	3
Queensland Border Rivers-Moonie	-25%	-28%	0%	3	2	0.36	3
Condamine-Balonne	-22%	-25%	0%	2	3	0.65	2
Warrego-Paroo-Nebine	-21%	-22%	0%	1	3	0.44	1

[1] Tourism numbers reported in the table are rankings based on visual interpretation with 1 indicating smallest and 4 the highest number of tourism businesses or domestic overnight spend per trip by WRPA.

Adaptive capacity

Factors such as diversifying tourism to attractions and experiences that are less water or flow-dependent and focussing nature-based experiences on more resilient ecosystems will determine how well tourism-based businesses adapt to changing environmental conditions in the Basin. (Amelung and Nicholls 2014) suggest that destinations may need to invest in indoor amenities or infrastructure to accommodate potential increases in visitation. Similarly, access to local government and professional services, social capital, and the willingness of local communities to embrace tourism as an economic development option could also affect the adaptive capacity of tourism in the basin. We report indicators that describe the short-term adaptive capacity of tourism in various parts of the basin.

- Economic diversity. Economically diverse regions can attract more tourists by offering various activities. It can help the tourism sector to adapt to the changing environmental circumstances, such as creating opportunities for ecotourism, sustainable tourism, or green tourism or help tourism operators diversify the tourism activities that are less flow dependent. Similarly, economic diversity can help operators offer different services and attractions in the region to make it more attractive to a wider range of visitors. Economic diversity (based on Stenekes *et al.* 2012) in South Australian Murray Region, Lachlan, Gwydir, and Queensland Border Rivers-Moonie WRPAs is less compared to the rest of the Basin. However, tourism is an important economic indicator in most of these regions (e.g., the Gwydir region has several national parks and nature reserves, such as the Gwydir Wetlands), indicating that tourism in these regions is likely to have less coping capacity. The Intersecting Streams region has the lowest economic diversity as compared to other WRPAs, which can impede the adaptive capacity of tourism businesses in this region.
- Remoteness. On the one hand, remoteness can be a potential attraction for tourism operators to offer a unique experience to the visitors, it can affect many tourism businesses to adapt to change. Although remoteness can promote sustainable tourism practices and help preserve the area's Indigenous culture and history, accessing different amenities can be difficult in remote locations, affecting the tourism businesses' adaptive capacity. The most remotely located regions in the Murray-Darling Basin include the Intersecting Streams and the Warrego-Paroo-Nebine region.
- Access to local government services. Better access to local government services can help tourism businesses to diversify offerings (e.g., flexible wildlife tours that can be modified based on weather conditions etc.) or develop climate-resilient infrastructure, such as elevated boardwalks, flood barriers, and building designs that can withstand hotter weather. Better access to local government services means better opportunities for the operators to offer diverse services and facilities to visitors.
- Social and community factors. Social and community factors, such as the level of social cohesion and other forms of social capital, can affect the ability of tourism-based businesses to adapt to the changing environmental conditions.
- Community leadership and collaboration. Community leadership and collaboration, such as community-led initiatives, efforts, and collaborative decision-making, can help communities make their tourism-based businesses more resilient and adaptive to changing

circumstances. Community-level collaboration can help identify options and mobilise resources to help tourism businesses adapt to the changing conditions.

Key insights

Warmer-drier Basin:

A Basin-wide 2°C temperature, 7% potential evapotranspiration (PET) increase, and 5% rainfall decline from the historical mean might reduce the mean annual runoff by 19% to 26%. The Lachlan and Namoi regions under the modelled warmer and dryer scenario have higher *mean annual runoff* reduction than other WRPA's in the basin. Chiew (2006) reported that streamflow is more sensitive to rainfall where there is smaller effective catchment storage (less vegetation or smaller effective soil store). The Lachlan region has a higher gross value of agricultural products and 26% of its agriculture employment, making it particularly sensitive to changes in agricultural activity. The Namoi region is traditionally known for its high-quality soil and dryland cropping. About 19% of the agricultural area is used for dryland crops. Under this scenario the region might witness one of the highest (27%) reductions in flow for floodplain inundation, making its traditional agricultural production vulnerable. Both the Lachlan and the Namoi regions have lower percentages of high-security water entitlement, indicating that the reduced river flows could further impact this entitlement, impacting the overall adaptive capacity of agricultural farming (Deloitte Access Economics 2012; Sharp and Curtis 2012). However, in recent years a wider variety of irrigated crops such as fruit and vegetables have been grown, which helps diversify the region's agricultural income and provides some flexibility to adapt to changing water availability.

Considering that the Lachlan and Namoi regions under this exposure scenario have higher mean annual runoff reduction than other WRPA's in the basin, agricultural businesses reliant on farming communities might be more sensitive to reduced water availability in these regions than the WRPAs. The Lachlan has one of highly concentrated agricultural businesses count. A 5% rainfall decline from the historical mean might affect these businesses in the Lachlan region. These industries are likely to be affected by reductions in water availability, meaning that water efficiency will be increasingly important (CSIRO 2007; Lukasiewicz *et al.* 2012). Higher temperatures may also lead to inadequate winter chilling for some fruit trees, reducing fruit yield and quality (Hennessy and Clayton-Greene 1995). Economic diversity can help adapt these businesses under the reduced river flows in these regions especially in the Namoi region, which has a higher percent of economic diversity than the average percent economic diversity in the Basin. The Lachlan region, however, has lower percent economic diversity. In contrast, remoteness and social and community factors can compromise the adaptive capacity of the businesses reliant on agricultural communities in these regions.

The northern Victoria WRPA is expected to face the lowest reductions (19%) in the mean annual runoff in a Basin-wide 2°C temperature, 7% potential evapotranspiration (PET) increase, and 5% decline in rainfall. Although the region has the highest number of agricultural businesses, agricultural-related employment is only 13%-the second lowest in all WRPAs. The region also has the highest number of non-agricultural businesses. Higher economic diversity and access to reliable water entitlement could help the region's agricultural-reliant businesses adapt to changing water availability.

Floodplain harvesting is a common practice in the Queensland Border Rivers-Monnie region. The region might witness a 28% reduction in flow for floodplain inundation with a consequent negative impact on the region's 27% agriculture-related employment.

The numbers on tourism businesses and the number of domestic overnight spend per trip indicate that tourism is less developed in the Lachlan and the Namoi WRPAs. As both the Lachlan and Namoi might have higher mean annual runoff reduction than other WRPAs in the basin, the less developed tourism might be more sensitive to the changes in water flows. Although economic diversity could help the region's tourism businesses, especially in the Namoi region and provide some flexibility to adapt to changing water availability, social and community factors such as community-led initiatives and efforts can help the tourism sector's adaptive capacity in these regions.

Warmer-wetter Basin:

In a warmer and wetter scenario, Basin-wide 2°C temperature, 7% potential evapotranspiration (PET) and 10% increase in rainfall from historical mean might increase the mean annual runoff by 16% to 28%.

Warrego-Paroo-Nebine and Lachlan might have the highest increase in the mean annual runoff compared to the other WRPA's in the basin. The Warrego-Paroo-Nebine region might observe the highest increase (26%) in flow for floodplain inundation. The region has the second largest area of floodplain grazing and the third highest beef cattle producing region amongst all WRPAs. A 10% increase in rainfall and the resultant increase in flow for floodplain inundation will help to support beef cattle production in the Warrego-Paroo-Nebine region.

The Gwydir region is expected to have the least increase in the annual mean runoff and flow for floodplain inundation. Although the Gwydir region supports one of the largest irrigated cotton-producing areas in the Basin, the region's 30% dryland cropping system is the second largest among all WRPAs. An increase in rainfall is likely to benefit the region's dryland farming, potentially reducing reliance on irrigation. However, flooding can be a problem, as was recently experienced by the cotton growers in the region. The Lachlan has one of the highest number of agricultural businesses, whereas the Warrego-Paroo-Nebine has one of the lowest. However, both the regions have high agricultural related employment (26-28%). Any incremental changes in water flows, might help both WRPAs expand the businesses reliant on farming communities.

The number of tourism businesses and domestic overnight spend per trip indicate that tourism is relatively less developed in the Warrego-Paroo-Nebine and the Lachlan regions. The Warrego-Paroo-Nebine and the Lachlan might have a higher mean annual runoff so that it might offer opportunity for the tourism sector. Social and community factors such as less community-led initiatives and efforts can also help the tourism sector adapt to change.

Social values

Resilient communities with confidence in their long-term future and with sufficient and reliable water supplies for recreational use

Exposure

Over 2.6 million people in the Basin depend on its waters for drinking, agricultural and industrial, and recreational purposes (Nikolakis *et al.* 2016). Rural communities in the Basin are geographically dispersed and diverse in their economic, geographic, and social settings (Nelson *et al.* 2010). Analysis of the geocoded national address data from Geoscape Australia (2021) found that 13% of all the addresses are within 500 meters of major water courses in the Basin (excl. ACT) and thus closely connected to the Basin's waters (Figure 15).

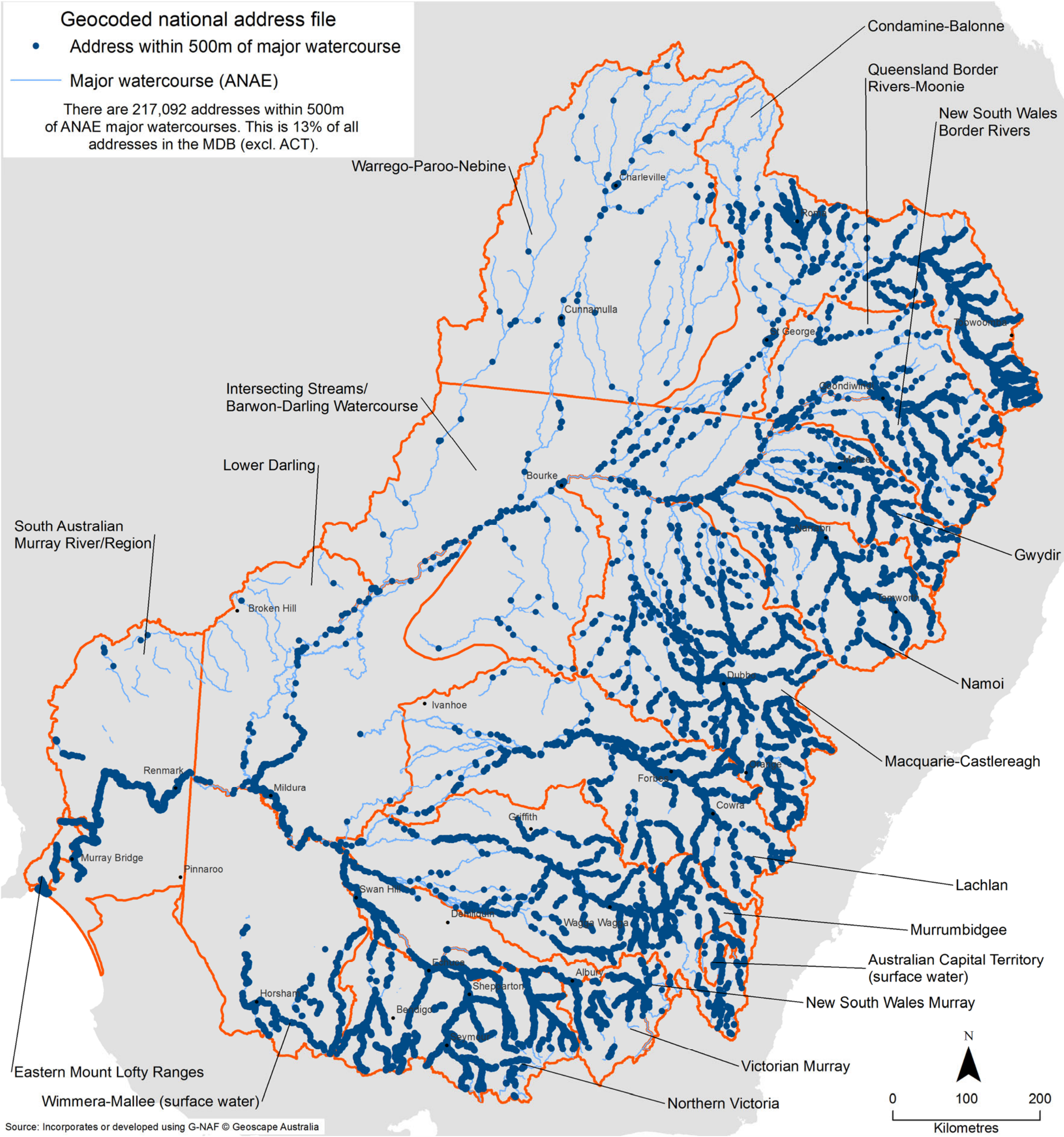

Figure 15 Map showing addresses within 500m of the major watercourse.

Many of these communities depend on a diverse population of native animals, fish, and water birds for their social values, cultural aspirations, food, recreation, amenity, tourism etc. (King *et al.* 2023). Therefore, any changes in the Basin's hydrological characteristics and water flows due to climate change (Whetton and Chiew 2021) will impact the communities' social values.

The distribution and magnitude of socio-economic impacts will not be even, with different groups and communities impacted more than others, either positively or negatively (AITHER 2017). Decreasing water availability (Qureshi, Whitten, et al. 2013) or changing flow characteristics (runoff for floodplain inundation, runoff for in-stream habitats, runoff for pools and water holes in rivers, low flow days and changes in flow seasonality) could exert more pressure on the Basin's assets associated with social values such as native vegetation, fish, waterbirds, access to local healthy food, and fair and transparent water allocation. Many of these assets are also associated with environmental values of the Basin and are discussed in the environmental values section of this report.

Sensitivity

The Murray Darling Basin is a hub for social and recreational activities. Families can fish, exchange information about their activities, and learn about their cultural practices (Jackson and Nias 2019). The Basin is also a place for swimming and camping, allowing people to relax and find solace (Mooney and Tan 2012). Many recreational activities rely on the water. Here we describe the major factors that explain the long-term sensitivity of the communities' social values that are directly or indirectly related to a flow change.

1. **Regional demographics and diversities:** Water availability and flow change can significantly impact regional demographics and diversity. At the same time, demographics can affect the use of water-related assets and how water is managed for economic, social, and cultural purposes. For example, in 2006, around 3.4 million people (17% of the Australian population) lived in or around the Basin and depended on the Basin's water for economic, social, and economic purposes (ABS/ABARE/BRS 2009). Although the Basin's overall population is increasing, the population growth in regional areas is slow, and the population is aging.

   According to the ABS population data, the regional areas of the Basin have witnessed a modest population growth since 2011 (7.8%). Over the same period, the population growth across regional Australia was reported to be 10.0% (AITHER 2022). Besides these 3.4 million individuals, there is a large population of Australians who derive benefits from the Basin by consuming the produce of the Basin or by visiting the recreational places of the Basin (ABS/ABARE/BRS 2009). The regional and demographic conditions vary across the Basin for different measures and indicators. For example, nearly one-third of the Basin population live in regions where infrastructure and services are below the regional Australian average (Sefton *et al.* 2020).

2. **Economic development:** Economic development extracts resources for financial gains that can impact the regional social ecosystem and how regional communities use and value the area and the resources. Economic growth also increases competition for limited water resources among various users, which could affect the region's regional biodiversity and social values.

3. **Community well-being:** The extent of community well-being indicates how individuals can interact and engage in social events, promoting a sense of ownership and value for their culture and community. Better community well-being offers individuals access to social assistance services and resources, which can help them improve their quality of life and draw values for their spiritual renewal. However, poor social well-being can incapacitate individuals and communities and make their social values sensitive to changing environmental conditions.

4. **Anthropogenic factors:** Science-based evidence suggests that rapid environmental change in the Basin directly results from modern anthropogenic activity (Nikolakis *et al.* 2016). Different anthropogenic activities, such as pollution from agricultural and industrial activities, have impacted and can further impact soil, vegetation, and water resources, affecting the Basin ecosystem and the associated cultural and social values.

We used various integrative indicators to describe the major factors related to the sensitivity of communities' social values (Table 9).

Table 9 Indicators used to assess the long-term sensitivity of communities with confidence in their long-term future and with sufficient and reliable water supplies for recreational use.

Factors describing long-term sensitivity of communities' social values	Integrative indicators used to assess social values
Regional demographics and diversities Economic development Community well-being Anthropogenic factors	Access to affordable food/groceries at local shops Attractive natural place – availability Overall community wellbeing index

Access to affordable food/groceries at local shops (Figure 16): Communities in the Basin enjoy healthy food and consider access to affordable food/groceries vital for their wellbeing. However, access to affordable food/groceries vary across the Basin for different measures and indicators.

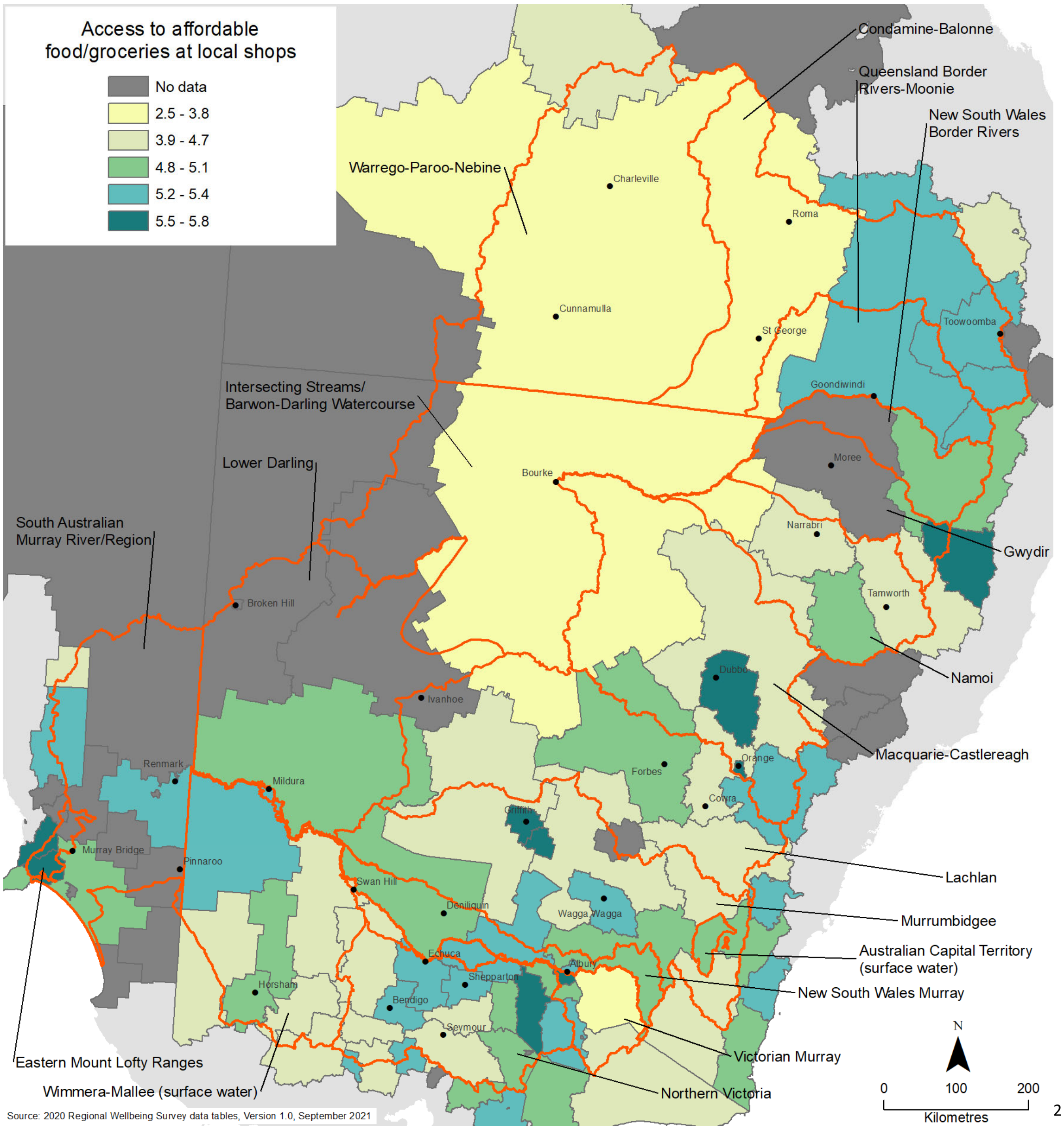

Figure 16 Map showing access to affordable food/groceries at local shops (higher score indicating better access).

Attractive natural place (Figure 17): The 2020 Regional Wellbeing Survey asked communities to scale if attractive natural places (e.g., parks) exist. Access to attractive natural places can significantly impact a person's happiness, satisfaction, and fulfilment. We assume that regions where communities think they have less attractive natural places are more sensitive to flow change in terms of erosion of social wellbeing. The communities around Dubbo (Macquarie-Castlereagh) and Swan Hill (Wimmera-Mallee) areas reported access to fewer attractive natural places. The hydrological projections indicate that these regions will likely witness greater mean annual runoff changes, potentially impacting the natural places' health. Thus, the social values of the communities in such regions could be more sensitive to change.

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[2] Numbers in Figure 16 are rating given on the 2020 Regional Wellbeing Survey data

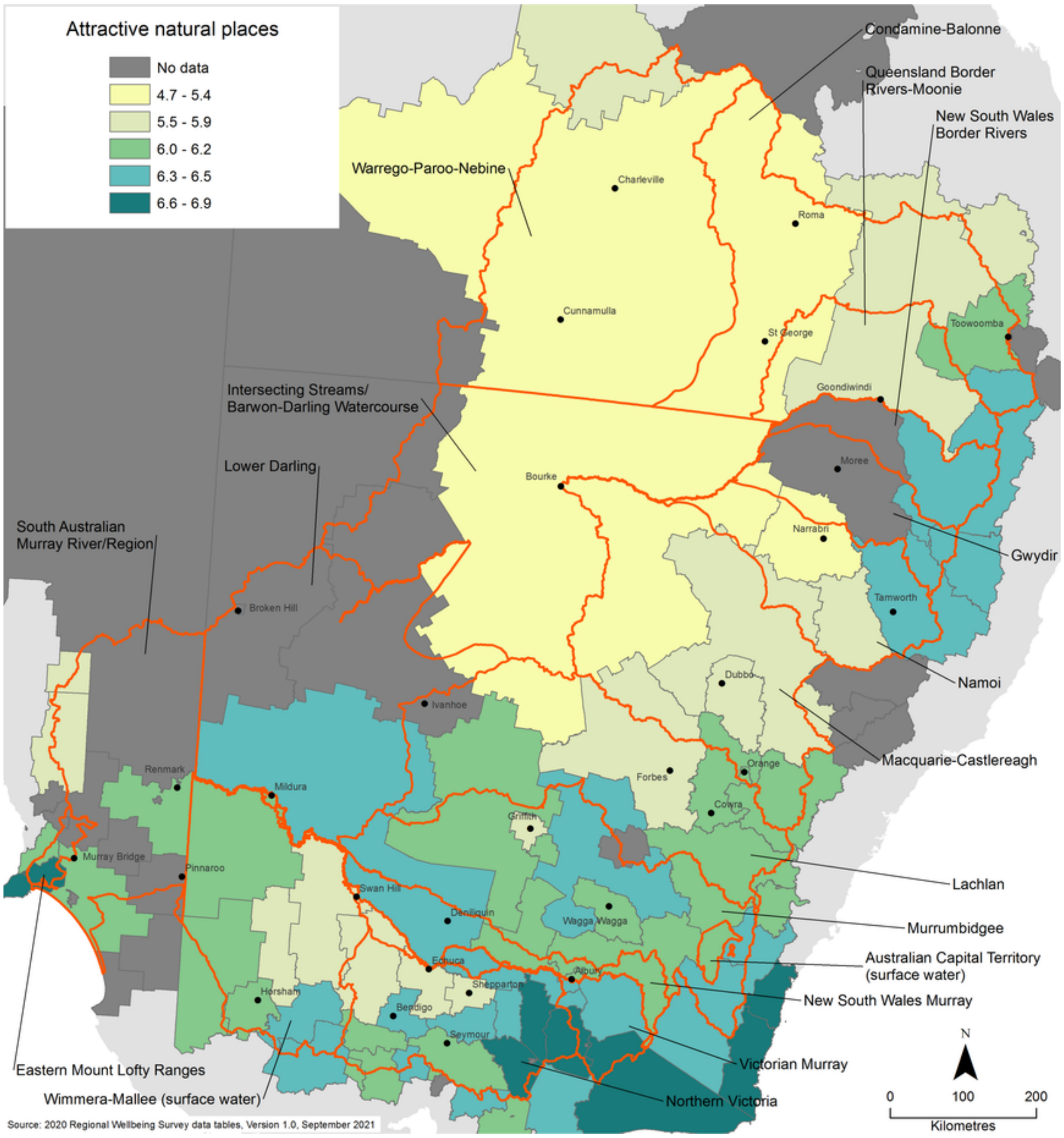

Figure 17 Map showing attractive natural places in the Murray-Darling River Basin (a higher score means more attractive natural places for the communities).

Overall community wellbeing (Figure 18): The University of Canberra Regional Wellbeing Survey provides consistent basin-wide data on community wellbeing. They measured overall community wellbeing by asking survey participants how much they agreed with the following four statements, from 'strongly disagree' (1) to 'strongly agree' (7): (i) This community copes pretty well when faced with challenges; (ii) This community has a bright future; (iii) If I could, I would shift to live in another community; (iv) I would recommend my community to others as a good place to live.

Variations within WRPA's exist however, southern and eastern parts of the Basin report higher scores. Regions in the north-west of the Basin report lower overall community wellbeing compared with regional Australia and may indicate a greater sensitivity to reductions in flow and reductions in floodplain inundation.

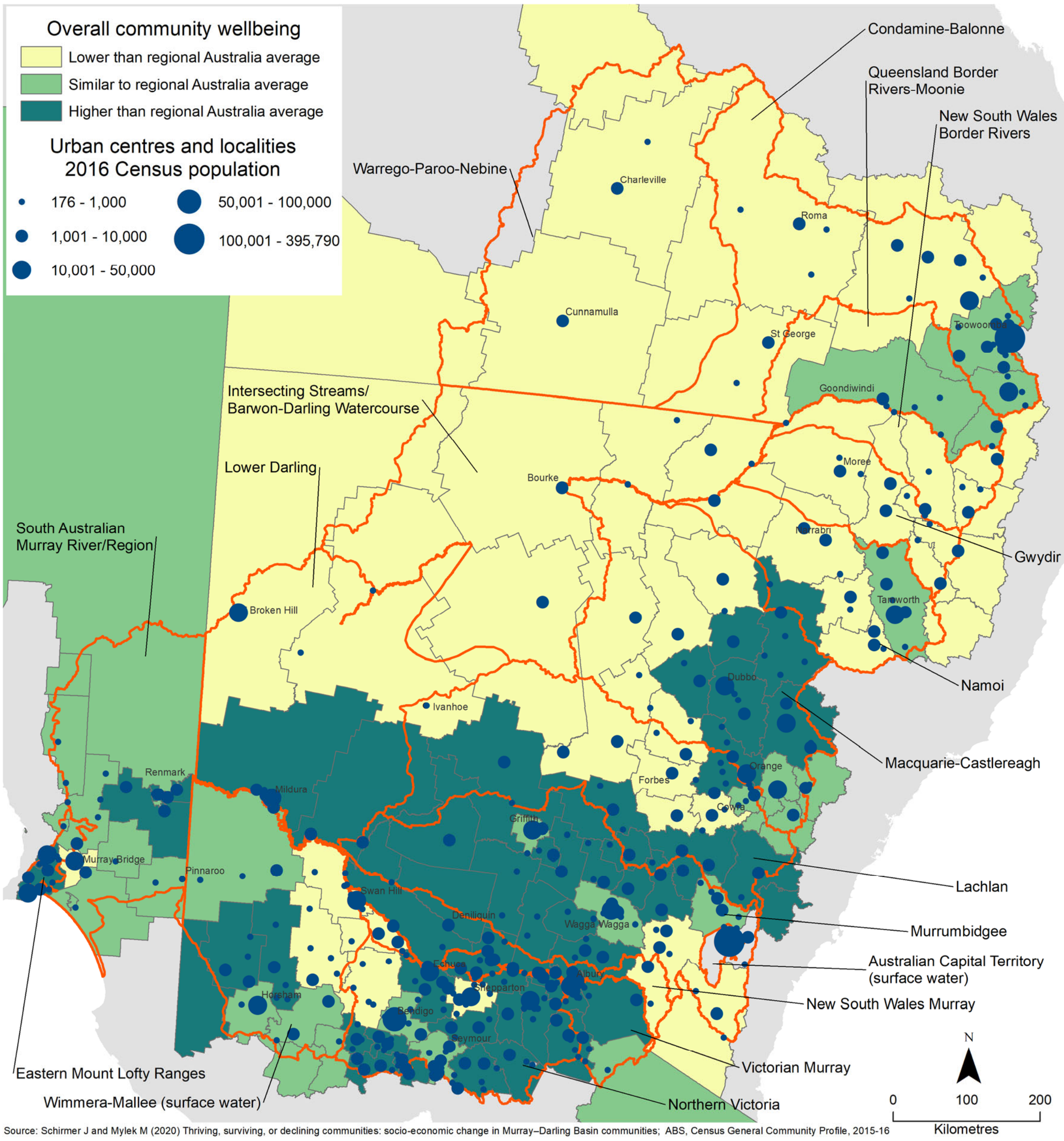

Figure 18 Overall community wellbeing, Regional Wellbeing Survey, University of Canberra.

Adaptive capacity

Next, we describe indicators related to the short-term adaptive capacity to cope with the erosion of social values.

Household weekly income: Household income is an important determinant of their adaptive capacity to climate change (Akter et al. 2022). Households with higher incomes usually have better access to resources and information, which can help them better adapt to environmental changes. Conversely, households with lower incomes have limited capacities to access resources and information and adapt to the changing environmental conditions (Chu et al. 2017). In Australia, some of the most vulnerable rural communities with less adaptive capacity are extensively reliant on sheep grazing for their household income (Nelson et al. 2010), which might affect the economic as well as social adaptive capacity of these communities.

Social and community factors: Social and community factors such as the extent of opportunities for social networking and social assistance, can affect the ability of the communities and their social values to adapt to the changing environmental conditions. Communities need several social networks for support and wellbeing, such as volunteers, local community groups, friends, and family. These factors can help communities living in the Basin preserve their social values and increase their adaptive capacity to cope with different challenges, e.g., environmental challenges. Social cohesion can also enable communities to work together and develop sustainable strategies to preserve their values and conserve resources.

Community leadership and collaboration: Community leadership and collaboration such as community-led initiatives, efforts, and collaborative decision-making, can help communities make their social values and assets more resilient and adaptive to changing circumstances. Community-level collaboration can help identify options and mobilise resources to build capacity and make decisions for preserving social values and assets.

Key insights

In a warmer-drier basin, the Lachlan and the Eastern Mount Lofty Ranges in the southern basin and the Namoi in the northern basin might observe higher runoff reductions for in-stream habitats than the other WRPA's in the Basin. Communities in the regions might face challenges in enjoying attractive natural places. Communities in the outer and remote regions of Intersecting Streams/Barwon-Darling and Queensland Border Rivers-Moonie have less access to affordable food/groceries at local shops and attractive natural places and are sensitive to flow change.

Cultural values

First Nations communities with sufficient and reliable access to water for cultural use

First Nations communities have strong spiritual and cultural connections to the water flows throughout the country's river systems. Figure 19 shows where First Nations residents live in the Basin. The waterways and wetlands in The Basin, including floodplains, hold immense cultural value for First Nations people. They are valued for their many uses, including transportation, trade, communication, ceremonies, rituals, food, and medicine. As a result, they hold significant economic, social, and cultural importance (Jackson 2021)(Clarke 2008). Many First Nations communities consider water a living being requiring respect and care. They use traditional knowledge and local wisdom to identify seasonal weather calendars, direct hunting, fishing, and planting and plan many seasonal dependant cultural events (Green *et al.* 2010).

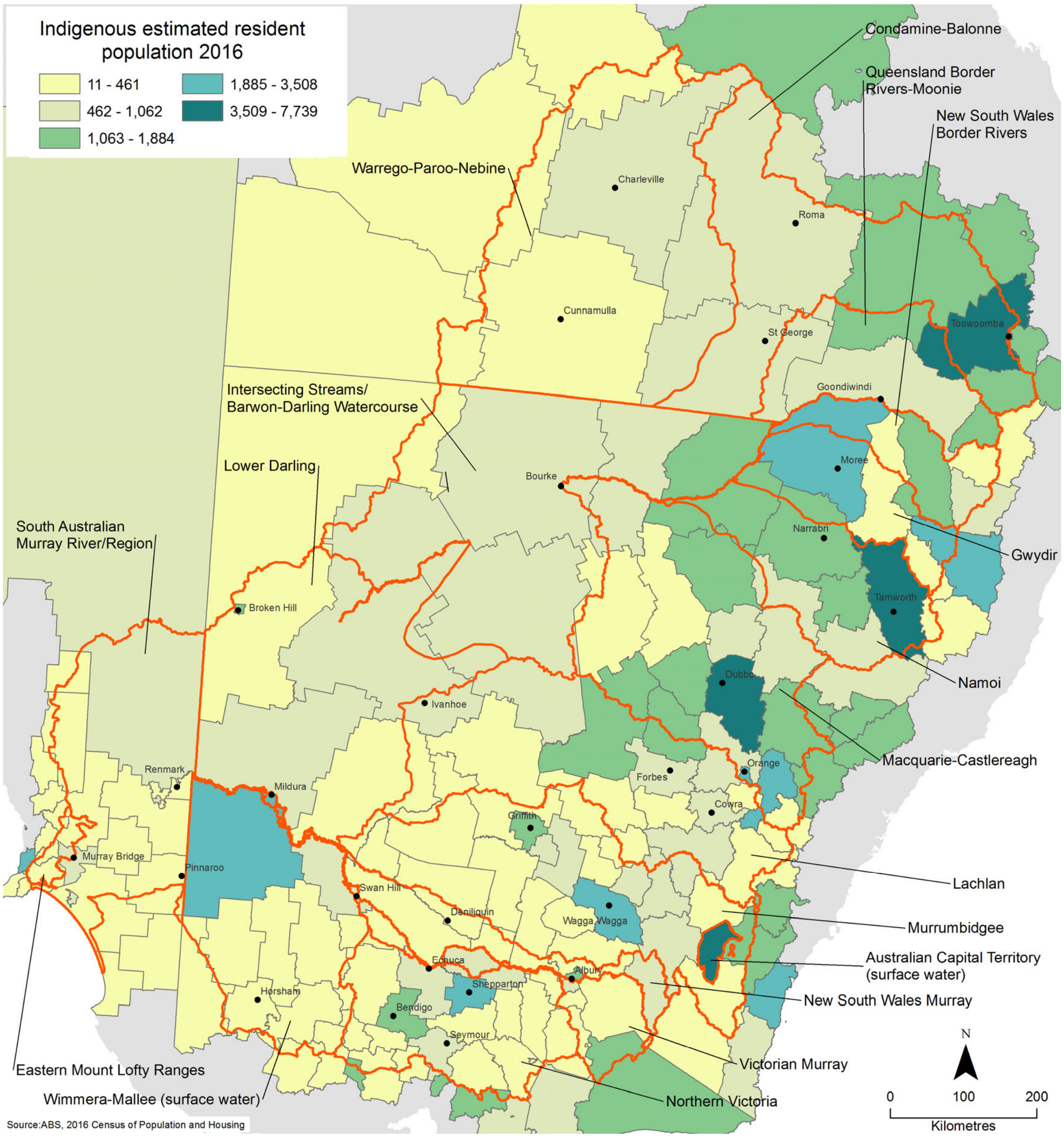

Figure 19 Map showing First Nations estimated population.

Ultimately, First Nations People should define the indicators that best represent sensitivity and adaptive capacity related to their values. The nature of their involvement in determining the indicators is important to the legitimacy of any values and vulnerability assessment. Here, for the rapid assessment, we use past studies to identify various indicators that capture the sensitivity and adaptive capacity of First Nations' selected cultural values (Table 10). Data related to these indicators, where available, are described after that.

Table 10 Indicators used to assess long-term sensitivity and adaptive capacity of First Nations Communities' cultural values with sufficient and reliable access to water for cultural use.

Asset	First Nations values	Indicators
Water-dependent sites, plants, and	Sustain customary practices or considered sacred or associated with protocols and lore	Sensitivity: Records of important and sacred places and site visits and access to

Asset	First Nations values	Indicators
animals of cultural and economic importance	Sustains Country including plants and animals and First Nations Peoples geographical obligations and responsibilities of water Use for gathering, camping, fishing, foraging or knowledge sharing Important for supplementing income	plants and animals of cultural and economic importance Water quality (Western science and First Nations identified indicators) records Adaptive capacity: First Nations traditional knowledge and wisdom and community-led monitoring programs
Employment of First Nation Peoples in water-dependent industries	Support the family to remain on or close to the Country or pay for services for the elders and youth Source of income to sustain wellbeing	Sensitivity: First Nations Peoples employed in water-dependent industries Number and demography of First Nations Peoples living in the Basin Number and types of reports from First Nations groups on access to Country and water place and types of activities practised that are sustaining connections to Country Adaptive capacity: Recognition of the importance of the participation of First Nations in water for the environment and support by the Australian government
Employment in land and water management programs (e.g., ranger programs, Indigenous-led community-based monitoring)	Acknowledgement of the importance of First Nations knowledge and practices in looking after the Country	Sensitivity: First Nations People jobs in land and water management programs Adaptive capacity: First Nation Peoples employed in decision-making positions
First Nations Peoples water holdings	Self-determination of First Nations Peoples	Sensitivity: Water entitlements are expensive, making it difficult for First Nations People to access water Adaptive capacity: First Nation Peoples water holding as a % of the Sustainable Diversion Limit (SDL)

Asset	First Nations values	Indicators
		Considerable improvement in consultation between governments and First Nations in the Basin towards recognising the importance of cultural water
First Nations seats on Basin plan policy committees	Acknowledgement and recognition of Indigenous Peoples' values, rights, interests, and goals in and through water First Nations representatives in Basin Plan policy committees who can contribute to and ensure the inclusion of First Nations values, interests, and rights in water policy Involvement in contemporary governance mechanisms to further 'Caring for Country.'	Sensitivity: Records of inclusion of Indigenous priorities in Basin Environmental Watering Priorities Adaptive capacity: First Nations participation in Basin Plan policy committees
Diverse Indigenous-led representative bodies for Indigenous groups in the Basin (e.g., confederated bodies of NBAN and MLDRN, other representative bodies) participating in water planning committees and boards across the Basin	Collective voice and representation of Traditional Owners' interests in water to defend and protect their water-related goals, rights, and interests.	Sensitivity: First Nations' participation in water for the environment First Nations involvement in Basin consultation Adaptive capacity: Joint literacy programs to improve understanding of Basin management

Sensitivity of cultural values

The cultural theory of risk suggests that perceptions about risk and sensitivity are formed within social and cultural processes, i.e., how individuals perceive risk, causes and sources of risk, and who and what is being affected by the risk, is greatly influenced by their social identification and setting, and the relationship between distinct cultural groups (Tansey and O'Riordan 1999). The risk perceptions and attributes will likely vary within larger groups with diverse cultural values and differences in value systems. The First Nations communities that are remote are likely to be more vulnerable to the impacts of climate change and suffer from socio-economic and cultural disadvantage than non-indigenous populations (Green *et al.* 2010; Nikolakis *et al.* 2016). However, there are not enough Basin-wide assessments and data available to assess the sensitivity of First Nations cultural values. The First Nations participation and engagement in land and water programmes has recently improved significantly. Yet, First Nations still have unmet water needs and contested claims for cultural water (Bischoff-Mattsona *et al.* 2018; Jackson 2021). We used the information on First Nations' jobs related to land and water management programs and First Nations Enterprises reliant on water as indicators to identify the sensitivity of their cultural values.

First Nations jobs in land and water management programs

First Nations and their representative organisations' participation in decision-making and collaboration in management is impacting the Basin management positively (Jackson 2021). Besides this, First Nations' participation in decision-making and policy and formal roles or jobs in land and water management have multiple benefits beyond individual income gains. For example, they provide purpose, self-worth, and value to many socially, economically, and culturally stressed First Nations people and help them build relationships with elders and Country. These relationships maintain the connection to the Country, underpin cultural inheritance and knowledge transfer, and lead to effective land and water management strategies and decisions (MDBA 2021a). The acquisition, application, and transfer of cultural knowledge help preserve valuable cultural assets, which are important for many First Nations people (Salmon *et al.* 2019).

Recently, the MDBA began reporting First Nations employment and capacity development programs. They identified new types of positions in the water sector: water project and engagement officers, policy officers and ranger programs that create jobs. Without consulting with these management programs and consistent annual reporting, a full understanding of First Nations people's jobs in land and water management programs' sensitivity to flow change is impossible. Here, we provide a summary of available information (Table 11).

Table 11 Examples of First Nation's jobs in land and water management programs.

WRPA Names	First Nation's jobs in land and water management programs
Wimmera–Mallee	An Indigenous River ranger group was established in the 2020–21 water year. The First People of the Millewa-Mallee Aboriginal Corporation (FPMMAC) are the Traditional Owners of Country in the northwest of Victoria that runs south of the Murray River to the Mallee Highway and west from the Calder Highway to the South Australian border, including the Murray-Sunset National Park (MDBA 2021b).
South Australian Murray Region	Riverland Indigenous Rangers developed a wetland tour emphasising water's benefit for the environment (MDBA 2021b). They also participated in an Indigenous Ecology in Action workshop. Through the Murraylands and Riverland Landscape Board in South Australia, the Mannum Aboriginal Community Association Inc. (MACAI) managed Sugar Shack Wetlands' environmental watering, maintaining the pump equipment and monitoring water levels. Working with the Board, the MACAI planned, coordinated and implemented the first water for the environment event. The Board also worked with Gerard Community Cultural Rangers in the watering at Katarapko, Regent Parrot Floodrunner and Kat Creek Floodrunner North (MDBA 2021b).
Eastern Mount Lofty Ranges	First Peoples Water Co-ordinator
New South Wales Murray and Lower Darling	There are two Indigenous River Rangers groups. In the latest grant round, the Barkandji Native Title Group Aboriginal Corporation secured more than $4.2m to continue the Barkandji river rangers' operations until 2028 (MDBA 2021b). The Barkandji river rangers actively preserve and support the Darling (Baaka) River. The work includes the Lower Darling–Baaka Recovery Reach program, a collaborative project led by the New South Wales Government and the MDBA. An additional Indigenous River ranger group was established in the 2020–21 water

WRPA Names	First Nation's jobs in land and water management programs
	year - Yarkuwa Indigenous Knowledge Centre Aboriginal Corporation. Gunbower Forest is a Living Murray Icon Site. The Living Murray program funds an Indigenous Facilitator to engage with Traditional Owners of the Gunbower Forest – the Barapa Barapa and Yorta Yorta people. North Central CMA was able to leverage funding from TLM and Barapa Water for Country to deliver the project (MDBA 2021b).
Murrumbidgee	An additional Indigenous River ranger group was established in the 2020–21 water year - Nari Nari Tribal Council (MDBA 2021b).
Macquarie–Castlereagh	An additional Indigenous River ranger group was established in the 2020–21 water year - Dharriwaa Elders Group (MDBA 2021b).

Examples from the Wimmera-Mallee, South Australian Murray, New South Wales and Lower Darling WRPA regions indicate First Nations Peoples formal involvement in land and water management programs enables project activities aligned with First Nations water values, rights, and interests. Here, we provide several examples:

- A First Nations organisation recruited First Nations-identified positions in areas of fish and aquatic systems, land management and First Nations heritage or in water and aquatic systems and cultural ranger roles in the Wimmera-Mallee WRPA (FPMMAC n.d). The duration of these roles is unclear. This could be attributed to the nature of grant funding, where ongoing funding may not be guaranteed.
- An additional Indigenous River Ranger group to start in the NSW Murray and the Lower Darling WRPAs, and an existing Indigenous River Ranger operation will continue until 2028. This work includes the Lower Darling- Baaka Recovery Reach Program, a collaborative project led by the NSW government and the MDBA.
- First Nations ranger employment to undertake land management activities and training, including developing a wetland tour emphasising the benefit of water for the environment.

Other examples of First Nations in formal roles and jobs in these WRPA regions include:

- The Living Murray Program, which funds Indigenous facilitators for all The Living Murray iconic sites (e.g., Gunbower Forest, NSW Murray and the Lower Darling WRPA).
- The Victorian Government, through the Department of Environment, Land, Water and Planning, funds Aboriginal Water Officers (AWO) in First Nations organisations.
- Partnerships, e.g., Landscape South Australia - Murraylands and Riverlands Aboriginal Partnerships Program.

First Nations enterprises reliant on water

Several types of First Nations enterprises rely on water in the Murray-Darling Basin. For example, enterprises are involved in cultivating native food and medicinal plants, which depend on water as the most important business factor. Similarly, various Indigenous tourism enterprises and recreational activities such as fishing, swimming, and boating also rely on access to water. These activities allow First Nations to share and promote their culture and traditions with visitors and reap economic benefits. Many Indigenous communities in the Basin have also successfully developed agricultural and livestock enterprises by cultivating crops such as cotton and rice and raising animals such as cattle and sheep.

First Nations enterprises support community activity and help them access various services, including education and health. Employment of First Nations people in Indigenous enterprises generates income and well-being for individuals and their families. The decline in water availability can severely impact many enterprises.

The number of First Nations enterprises reliant on water is not reported in MDB-related literature. The University of Melbourne Indigenous Business Longitudinal Analysis Data Environment (I-BLADE) provides a methodology and basis for reporting First Nations enterprises within the Basin. We found various examples of partnerships between the First Nations community organisations and government agencies, non-governmental organisations, and other stakeholders. These collaborations present opportunities to access water, restore environments, and affirm and rebuild socio-ecological relationships and water-dependent livelihoods (Jackson and Nias 2019).

Adaptive capacity related to First Nations cultural values

We identified various adaptive capacity indicators earlier (Table 10). We could find examples on First Nations' participation in water for the environment, First Nations' involvement in Basin consultation, First Nation Peoples's water holding as a % of Sustainable Diversion Limit (SDL), decisions that show inclusion of Indigenous values, and Literacy programs to improve understanding of the Basin management. These examples are used to summarise the adaptive capacity of First Nations cultural values.

First Nation's participation in water for the environment

Over millennia, First Nations peoples have developed a profound understanding of the Basin's ecology, biodiversity, and water resources. Their water management approach involves careful observation, monitoring, and consideration of water for the environment. Recognising the importance of First Nations' participation in water for the environment, the Australian government has worked closely with First Nations communities to ensure their meaningful involvement in developing and implementing the Murray-Darling Basin Plan (MDBA n.d). The environmental water guidance project worked to include Indigenous objectives and priorities on an annual timescale.

An example of First Nations' participation in water for the environment in the Murray-Darling Basin is the Yorta Yorta Nation's involvement in the Barmah-Millewa Forest Environmental Watering Project. The project aims to restore the Barmah-Millewa forest's health, an important cultural site for the Yorta Yorta Nation and a vital habitat for various native species. From the outset, the Yorta Yorta Nation has been involved in the project, advising on environmental flows, monitoring the impact of watering events, and participating in the project's governance and decision-making processes (MDBA 2012). Similarly, the Ngarrindjeri Regional Authority managed the Lower Lakes and Coorong. The Ngarrindjeri people have a deep cultural and spiritual connection to these waterways and have been actively involved in advocating for the protection and restoration of the area. They have been developing water management plans, advising on environmental flows, and participating in monitoring and evaluation activities.

Here, we list examples of First Nations' participation in water for the environment (Table 12) and First Nation’s involvement in the Basin consultation (Table 13).

Table 12 Examples of First Nation’s participation in water for the environment

WRPA	First Nation's participation in water for the environment (examples)
Victorian Murray	Various case studies are available. For example, Yorta Yorta Nation Aboriginal Corporation is involved in water resource management in the Victorian Murray, including participation in water for the environment programs (Bischoff-Mattson *et al.* 2018).
Northern Victoria	Two of six self-determined water projects funded by the Victorian Government through its Water, Country and Community Program in 2020–21 are implemented by the Dja Dja Wurrung Clans Aboriginal Corporation and Taungurung Land and Waters Council and North Central CMA in partnership with Barapa Barapa Wamba Wamba.
Wimmera–Mallee	Two of six self-determined water projects funded by the Victorian Government through its Water, Country and Community Program in 2020–21 are implemented by First People of the Millewa–Mallee Aboriginal Corporation and First People of the Tati Tati Wadi Wadi.
South Australian Murray Region	The Ngarrindjeri people are recognised as Traditional Owners of the Lower Lakes and Coorong region and have been involved in delivering environmental water, monitoring water quality, and managing cultural sites and values (Ngarrindjeri Regional Authority 2021).
Eastern Mount Lofty Ranges	Living Murray Initiative. First Peoples Working Group and the First Peoples Water Coordinator support site management and environmental watering. (Participation through a working group and facilitation by Frist Peoples water co-ordinator)
New South Wales Murray and Lower Darling	Report cards, and waterway assessments, water projects. Diverse forms of participation feed into water for the environment.
Murrumbidgee	Involvement of First Nations through environmental advisory groups. Commonwealth environmental watering at Toogimbie Indigenous Protected Area and Nimmie–Caira in consultation with the Nari Nari Tribal Council.
Lachlan	First Nations peoples participate in environmental watering through partnerships with CEWO.
Macquarie–Castlereagh	First Nations peoples participate in environmental watering through partnerships with CEWO.
Barwon–Darling Watercourse	The Commonwealth Environmental Water Office (CEWO) has been working with Barkandji Native Title Group Aboriginal Corporation and other Traditional Owner groups to incorporate Indigenous knowledge and values into environmental watering decisions. This includes holding workshops to understand better Traditional Owners’ perspectives and priorities(Commonwealth of Australia 2021). Case studies provided by the environmental water holders demonstrate a range of engagement undertaken with First Nations people and some of the benefits and outcomes achieved through involvement in the planning and delivery of water for the environment- Northern Fish Flow case study.
Intersecting Streams	Two Indigenous Protected Areas (IPAs) (Figure 20) provide opportunities for Indigenous people to be involved in managing their traditional lands and waters.
Gwydir	1 Indigenous Protected Area
New South Wales Border Rivers	1 Indigenous Protected Area

WRPA	First Nation's participation in water for the environment (examples)
Condamine –Balonne	Balonne River Indigenous Advisory Group: The Balonne River Indigenous Advisory Group (BRIAG) was established in 2018 to provide input into the Balonne River catchment. The group includes representatives from the Barunggam, Kamilaroi, Kooma peoples and other First Nations groups. The Murrawarri Indigenous Rangers have been involved in environmental monitoring and management in the Condamine-Balonne region, including monitoring water quality and the health of river ecosystems.
Warrego–Paroo–Nebine	1 Indigenous Protected Area - Jamba Dhandan Duringala means place of happy frogs, and the IPA includes claypan lakes within a nationally listed wetland. There are over 100 individual lakes, swamps and gilgais, and the only permanent waterhole along Nebine Creek. Priority management issues for the Jamba Dhandan Duringala IPA include cultural heritage protection, Indigenous employment, caring for waterways, reducing the impact of livestock, and weed, pest and fire management. The IPA is managed under the International Union for Conservation of Nature (IUCN) Category VI as a protected area with sustainable use of natural resources.

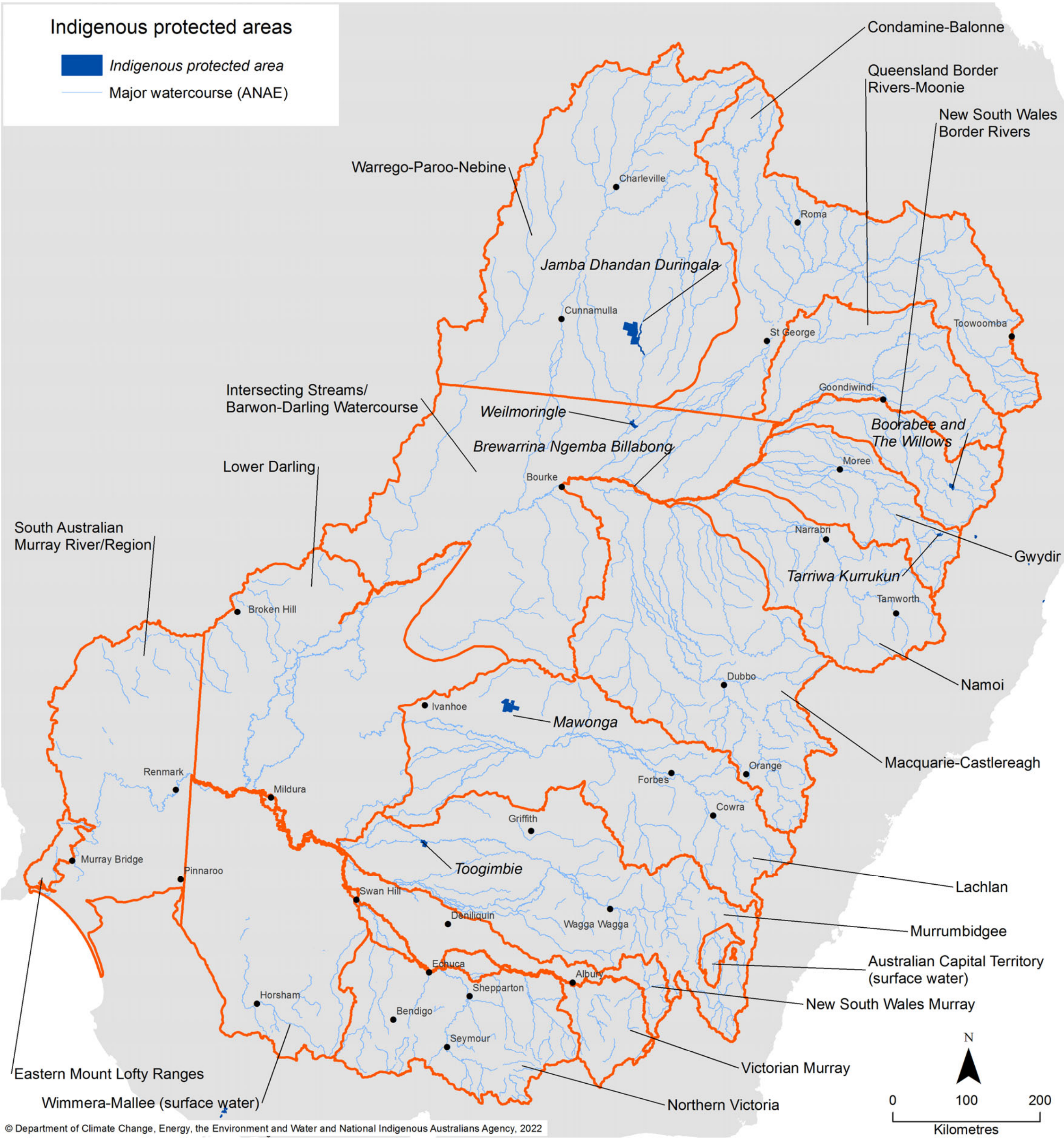

Figure 20 Map showing Indigenous protected areas.

Table 13 Examples of First Nation's involvement in the basin consultation.

WRPA Names	First Nations involvement in the Basin consultation (examples)
Victorian Murray	Three examples of community and Traditional Owners' involvement in Basin discussion in 2018-19- one across 5 Environmental Water Advisory Group (EWAG), a review of environmental flows study and Indigenous Facilitator organised a field visit to Guttrum Forest to discuss cultural objectives with the Traditional Owners and the staff.
Northern Victoria	A partnership between the Yorta Yorta Traditional Owners, Parks Victoria, and the Victorian Government has involved the Traditional Owners in managing Barmah National Park. It provides training and employment opportunities for Indigenous rangers. A partnership between the Taungurung Traditional Owners and the Northern Victoria Resource Manager involved the Traditional Owners in the planning and delivery of environmental water releases in the Goulburn River (DELWP 2019).
Wimmera–Mallee	Several initiatives have been aimed at increasing First Nations' involvement in the consultation processes. These initiatives have included consultations and engagement sessions with local First Nations groups, establishing formal partnerships and agreements between First Nations and government agencies, and incorporating Indigenous knowledge

WRPA Names	First Nations involvement in the Basin consultation (examples)
	and perspectives into water planning and management processes. However, much work must be done to ensure that First Nations' perspectives, knowledge, and rights are fully incorporated into water management and consultation processes in the Wimmera-Mallee region.
South Australian Murray Region	The Coorong, Lower Lakes, and Murray Mouth (CLLMM) Partnership between the Ngarrindjeri Regional Authority, the Murray-Darling Basin Authority, and other government agencies and stakeholders was established in 2009 to develop and implement a long-term plan. The Ngarrindjeri Regional Authority (NRA) is involved in developing and implementing the Murray Futures Program and the River Murray and Wetland Partnership Program. The NRA's involvement has included participation in program development and implementation and advocating for the Ngarrindjeri people's interests in these processes. (Source: https://ngarrindjeri.org.au/who-we-are/ngarrindjeri-regional-authority/) The Barkandji people shared their knowledge and perspectives on water management and environmental protection and played a central role in developing and implementing the Riverland Floodplain Integrated Management Plan (RFIMP). The RFIMP has been instrumental in promoting collaboration and cooperation between Traditional Owners, government agencies, and other stakeholders and has helped reconcile the interests and needs of all stakeholders (Victorian Murray Floodplain Restoration Project 2021).
Eastern Mount Lofty Ranges	First Nations including the Peramangk, Ngarrindjeri, and Ngadjuri people were consulted during the development of the Eastern Mount Lofty Ranges (EMLR) Water Management Plan. Improved open and transparent processes and dialogue for watering priorities. The South Australian Government established a First Nations Working Group to provide input and advice on the plan's development. The plan contains provisions for ongoing consultation with First Nations communities and establishing a Cultural Flows Assessment Framework. (Source: https://www.mdba.gov.au/sites/default/files/pubs/sa-eastern-mount-lofty-ranges-factsheet.pdf
New South Wales Murray and Lower Darling	The Murray Lower Darling Rivers Indigenous Nations (MLDRIN) and the Northern Basin Aboriginal Nations (NBAN) are involved in the development of the NSW Murray-Darling Basin Aboriginal Nations (MDBAN) Water Strategy. The Strategy recognises cultural water values and includes provisions for ongoing consultation with Traditional Owners and First Nations communities in water planning and management (MDBA n.d) (Source: https://www.mdba.gov.au/about-us/partnerships-engagement/working-first-nations)
Murrumbidgee	There are various efforts for consultations regarding the most appropriate methods of engagement, the development of engagement frameworks and the publication of detailed guidance manuals or implementation plans. Nearly all states involved First Nations water coordinators and Aboriginal Rangers. In some Basin states, steps are being taken towards having First Nations people manage lands and waterways of significance to them.
Barwon-Darling Watercourse	The Traditional Owners and First Nations representatives from the Barwon-Darling Watercourse region were consulted during the development of the Northern Basin Aboriginal Nations (NBAN) Water Management Plan (DPIE 2019).
Queensland Border River–Moonie Condamine – Balonne	The engagement process during the Condamine–Balonne and the Border Rivers–Moonie WRPs preparation included 38 Aboriginal Nation workshops, face-to-face consultation with over 500 people and 30 Country visits. These WRPs cover land belonging to 14 First Nations. The Queensland Government worked with First Nations members to improve the cultural context of water management in the WRP areas. They identified risks to First Nations' values and uses of water through engagement with Aboriginal people with a connection to the land and waters in the Condamine-Balonne.
Namoi	Consultations with First Nations peoples to secure the development of WRPs that would genuinely consider and respect the social, cultural, and social values, risks and uses of water

WRPA Names	First Nations involvement in the Basin consultation (examples)
	resources was undertaken in 2019 with positive responses from Aboriginal Peoples (DPIE 2020).

Decisions that show the inclusion of Indigenous values

The Murray Darling Basin Authority (MDBA) works through different Catchment Management Authorities (CMAs) for the planning and management at the local level. These CMAs work closely with local communities, including First Nations people, to develop proposals for environmental watering in rivers and wetlands. The MDBA combines Indigenous knowledge and cultural values with scientific knowledge in water planning and management decisions, particularly in the management of environmental watering. For example, the MDBA's Basin Plan includes water allocation for cultural purposes, such as maintaining spiritual needs and ceremonial sites and protecting biodiversity.

Table 14 Examples of the decisions that show the inclusion of Indigenous values

WRPA Names	Decisions that show the inclusion of Indigenous values
Victorian Murray	The waterway managers develop the environmental watering proposal in consultation with local communities, including First Nations people.
Northern Victoria	The waterway managers develop the environmental watering proposal in consultation with local communities, including First Nations people.
Wimmera–Mallee	The updated Environmental Water Management Plan (EWMP) for the Wimmera-Mallee region includes input from First Nations people (Barengi Gadjin Land Council, Northern Grampians Shire, and Jeparit Town Committee). It explicitly outlines how they are involved in the planning and delivery of environmental water. This includes the development of seasonal watering proposals and joint land management with Parks Victoria. The ongoing engagement process with First Nations people has resulted in benefits such as maintaining small-bodied native fish in all watered reaches of the Wimmera catchment (Watson *et al.* 2015).
South Australian Murray Region	The South Australian Government partnered with several key reference groups, including the Ngarrindjeri Aboriginal Corporation and the First Peoples of the River Murray and Mallee Region. Consultation informed annual watering priorities, ecological objectives and targets; for example, the recruitment and survival of threatened small-bodied fish in the Lower Lakes. South Australia also amended its River Murray Long-Term Environmental Watering Plan to include updated First Nations' values (DEW 2020).
Eastern Mount Lofty Ranges	The South Australian Department for Environment and Water has partnered with the Peramangk and Ngarrindjeri communities to incorporate their cultural values into water planning. A monitoring program was developed in partnership with the Ngarrindjeri Regional Authority. The Ngarrindjeri Yannan Agreement between the Ngarrindjeri Regional Authority and the South Australian Government recognises the Ngarrindjeri peoples' traditional ownership of the river Murray and its tributaries and their role in managing the environment.
New South Wales Murray and Lower Darling	Traditional Owners from Ngaywang, Maraura and Yorta Yorta Nations are involved in several water management initiatives, including developing the Yorta Yorta Nations Aboriginal Corporation Water Management Plan. This plan outlines the Yorta Yorta's vision for sustainable water management, incorporating traditional knowledge and values. The Ngayawang Nation has been involved in developing a joint management plan for Barmah National Park, which contains their cultural values and knowledge.
Murrumbidgee	Cultural flows embedded in water planning processes.

WRPA Names	Decisions that show the inclusion of Indigenous values
Lachlan	First Nations values are included in water-sharing plans and in decision-making through various mechanisms. For example, the Water Sharing Plan for the Lachlan Regulated River Water Source Order 2020 under the Water Management Act 2000 provides for “the spiritual, social, customary and economic benefits of surface water to Aboriginal communities.” First Nations People are one of the multiple stakeholders of the Environmental Water Advisory Group.
Macquarie-Castlereagh	First Nations are involved with the CEWO and NSW Government for the release of water for the Northern Fish flow.
Barwon-Darling Watercourse Intersecting Streams	The Barkandji Native Title Group Aboriginal Corporation (BNTGAC), Traditional Owners of a large land area in far western NSW, including the Darling River, released the Barkandji Healthy Country Plan in 2018. It sets out the Barkandji people's vision for caring for their Country, and values related to water, such as maintaining the river system's health, protecting cultural sites and values, and ensuring water availability for future generations. The NSW Government recognised the plan as an important resource for informing water management decisions in the region. In 2020, the NSW Government released its water for the Environment Strategy, which specifically mentioned the Barkandji Healthy Country Plan as a key resource to support the implementation of the government's strategy.
Condamine-Balonne	The Condamine-Balonne First Nations Cultural Waterway Strategy developed by the Balonne River Improvement Trust, the Condamine Alliance, and the Murray-Darling Basin Authority incorporates First Nations cultural values and knowledge into water planning in the region. The strategy seeks to increase water availability for cultural purposes and protect cultural sites and values. Various initiatives involving First Nations peoples and water managers have been launched to support the implementation of this strategy. For example, the Murray-Darling Basin Authority has established a First Nations Engagement Team to support the development of cultural water plans in the region, while the Condamine Alliance has worked with local Indigenous communities to develop a range of initiatives aimed at improving water management outcomes. The Queensland Department of Natural Resources, Mines and Energy has engaged with local First Nations groups to conduct cultural values assessments in the Condamine-Balonne region. These assessments help identify cultural significance areas and inform water management decisions.

Literacy programs to improve understanding

Table 15 Examples of the literacy programs to improve understanding.

WRPA Names	Literacy programs to improve understanding
Victorian Murray	The Living Murray Indigenous Partnerships Program (IPP), a partnership between the Murray-Darling Basin Authority (MDBA) and a range of First Nations groups in the Murray-Darling Basin region, aims to build capacity among Indigenous communities and provide opportunities for First Nations groups to become involved in water management and planning processes. The IPP supports training, workshops, and other capacity-building activities and the development of partnerships between Indigenous groups and water management authorities (MDBA n.d.). (Source: https://www.mdba.gov.au/basin-plan-roll-out/murray-darling-basin-plan-priorities/healthy-rivers-program/living-murray-3)
Northern Victoria	Living Murray Indigenous Partnerships Program (IPP)

WRPA Names	Literacy programs to improve understanding
Wimmera–Mallee	Living Murray Indigenous Partnerships Program (IPP)
South Australian Murray Region	South Australia is committed to the capacity building of the First Peoples. The Ngarrindjeri water program is a particularly notable example of South Australia's commitment to capacity building, as it employs water coordinators within Ngarrindjeri Nation organisations to lead engagement on water issues. Through workshops and other engagement opportunities, First Peoples can better understand the planning and management processes and provide input into these processes. A clear engagement process also helps build trust between water managers and First Peoples and can lead to more effective and sustainable water management outcomes.
South Australian River Murray	Living Murray Indigenous Partnerships Program (IPP)
Eastern Mount Lofty Ranges	Living Murray Indigenous Partnerships Program (IPP)
New South Wales Murray and Lower Darling	Water talks events with First Nations People in New South Wales Murray and Lower Darling have been ongoing for several years. These events have been well-received by local communities and have helped to build trust and understanding between First Nations people and government agencies. The New South Wales Office of Environment and Heritage, the Murray-Darling Basin Authority, and the Murray Lower Darling Rivers Indigenous Nations (MLDRIN) jointly developed the Aboriginal Water Planning tool to support Aboriginal communities in the Murray and Lower Darling regions to build capacity and knowledge around water planning and management. It is well-received by Aboriginal communities.
Murrumbidgee	Living Murray Indigenous Partnerships Program (IPP)
Lachlan	Living Murray Indigenous Partnerships Program (IPP)
Macquarie–Castlereagh	Living Murray Indigenous Partnerships Program (IPP)

First Nation Peoples' water holding as a % of the Sustainable Diversion Limit (SDL)

Uncontested water holdings could be crucial for First Nations and their values to adapt to the changing climate and flow characteristics. First Nation Peoples' water holding as a % of the Sustainable Diversion Limit (SDL) indicates their water use via state-issued or statutory water entitlements. It grants holders permission to take, extract and use water from surface water sources (such as rivers and creeks) and groundwater sources (aquifers). Water use may include temporary trade of water, which can generate income for First Nations People or be used for various social, community or economic outcomes, as determined by First Nations organisations and communities (Hartwig *et al.* 2020).

First Nation Peoples' water holdings in the Basin represent a small percentage of the SDL in the Basin (Hartwig and Jackson 2020) (Figure 21). In recent years, there have been calls to increase the percentage of water holdings by First Nation Peoples. The Murray Lower Darling Rivers Indigenous Nations (MLDRIN), a coalition of 25 First Nations Peoples from the Murray-Darling Basin, has called for a minimum of 10% of the Sustainable Diversion Limit to be allocated to First Nations Peoples to manage and use for cultural and economic purposes (MLDRIN n.d).

There are several challenges to increasing the percentage of water holdings by First Nation Peoples, including the high cost of water entitlements, the complexity of water markets, and the need for greater support for First Nation Peoples' water management practices. Water markets are highly regulated and involve various actors, including irrigators, environmental water holders, and government agencies. First Nation Peoples may not have the same understanding or experience in navigating water markets as other actors, which can put them at a disadvantage when accessing water. According to a report by the Productivity Commission, where the consumptive pool is fully allocated, water should be bought from entitlement holders on the market to recognise the needs of the First Nations Peoples (Productivity Commission 2021). The same report suggests that water could be reserved for the First Nations Peoples in relatively undeveloped and developing water systems where the consumptive pool has not been fully allocated.

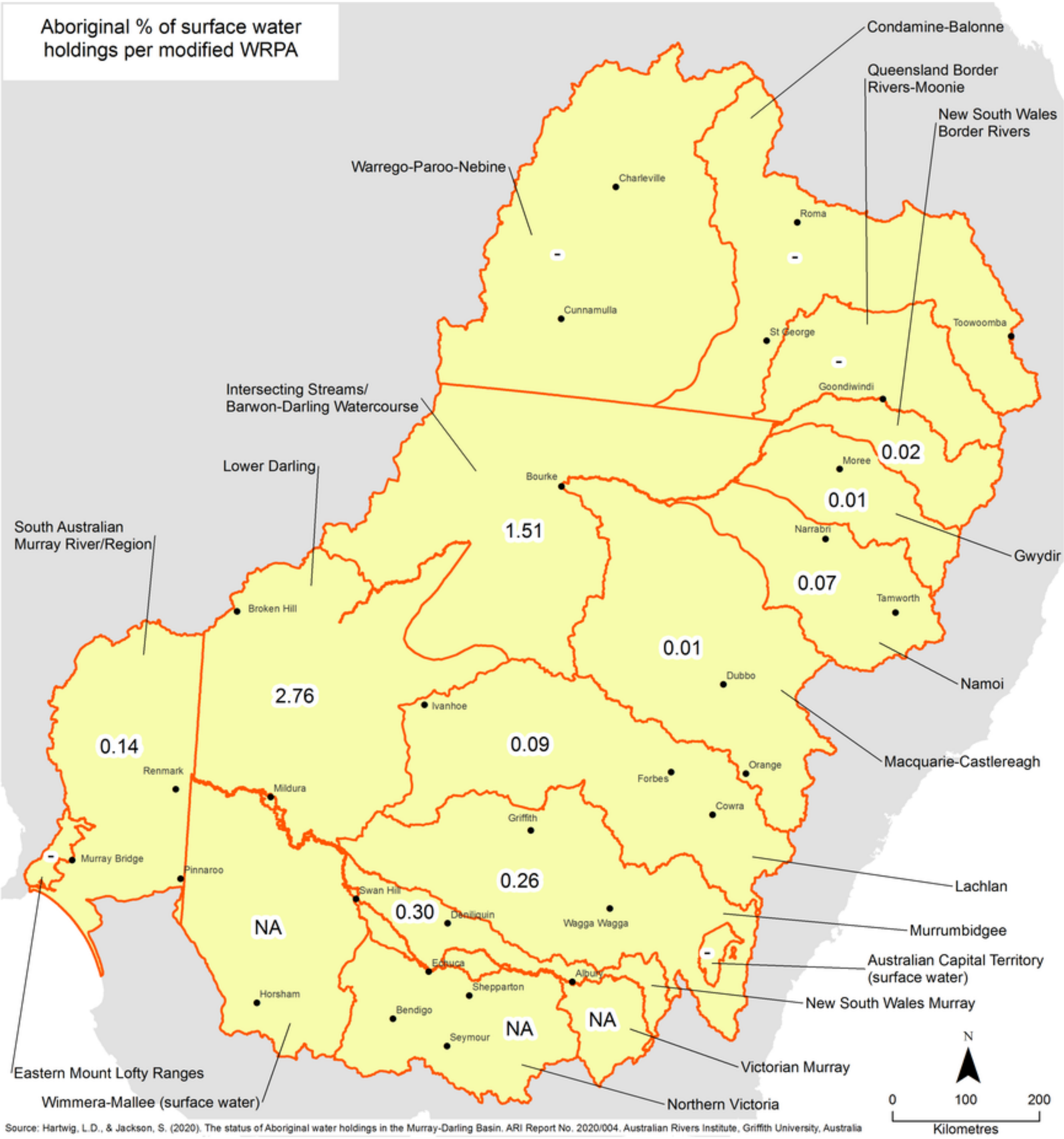

Figure 21 Map showing Aboriginal % of surface water holding per modified WRPA in the Murray-Darling River Basin.

Key insights

First Nation Peoples' deep cultural and spiritual connection to water is highly sensitive to the timing, quantity, and quality of water flows and availability. Water is central to many aspects of First Nation Peoples' cultural and economic factors, including food and fibre production, ceremonial practices, and the maintenance of biodiversity. Changes in river flow patterns can affect the availability of fish and other aquatic resources. Changes in salinity or pollution levels can affect the suitability of water for cultural and economic activities.

The sensitivity of First Nations assets (e.g., important and sacred places and sites) and cultural values (e.g., hold or assigned protocols or associated with the law) are hard to measure quantitatively or qualitatively due to a lack of basin-wide consistent data or information. We relied on case studies or examples of *First Nations' formal roles in decision-making positions and* *processes* to and *First Nations enterprises reliant on water* to identify the sensitivity of their cultural values to flow changes.

We found that efforts are being made to increase First Nation Peoples's formal roles in decision-making and recognise the importance of their authority, connections, wisdom and expertise in water management. The MDBA has established a First Nations Advisory Group to advise implementing the Murray-Darling Basin Plan from a First Nations perspective. Several regions like Wimmera–Mallee, South Australian Murray Region, Eastern Mount Lofty Ranges, New South Wales Murray and Lower Darling, Murrumbidgee and Macquarie-Castlereagh have successful Indigenous River Rangers programs (NIAA n.d.), which provide funding for First Nations communities to establish and operate their river ranger programs and supports the development of training and accreditation frameworks for IRRs.

The MDBA is working with the First Nations and environmental water holders to incorporate First Nations' objectives into environmental watering and sharing the outcomes of environmental flow with First Nations, which will evolve into a two-way exchange of knowledge (MDBA 2022).

We could not gather consistent information on *First Nations enterprises reliant on water* and their sensitivity to a flow change. Case study information indicates that these enterprises face declining water availability and management challenges. The complexity of water management regimes, including water trading and environmental water allocations, pose challenges for these enterprises to access the necessary water. However, we found examples of First Nations enterprises' strategies to adapt to changing water conditions.

Assessing or establishing the First Nations' adaptive capacity to adjust to a warmer and drier or wetter basin is hard. Much will depend on First Nations Peoples' understanding of the Basin planning and meaningful participation in water policy, regulatory mechanisms, and programs to secure outcomes that align with their different sets of values and rights. Case studies on *First Nations' participation in water for the environment and involvement in basin consultation* show that significant progress has been made in most regions. The middle to the southern areas of the MDB seems to have greater adaptive capacities in terms of involvement in environmental water programs.

A careful interpretation of the findings of the rapid assessment of First Nations cultural values is needed because the evaluation relies on case studies and examples that may report the extraordinarily highlighted events rather than a selection from the regularly planned events with First Nations Peoples. For example, an Indigenous Protected Area (IPA) is showcased in the Warrego-Paroo Region. Still, it is unclear if the waterway program is a part of the MDBA and QLD government water programs or an independent program established through independent IPA-funded programs. Again, we could not find definitive examples of First Nations Peoples' participation in decision-making or formal basin planning processes in the Warrego-Paroo WRPA. Therefore, we recommend a planned and structured data-gathering and reporting process to improve understanding First Nations cultural values, vulnerability, and adaptive capacity.

Environmental values

Healthy and resilient ecosystems

Waterbird sites

The Basin contains more than half the wetlands in Australia where waterbirds that breed and nest in colonies can be found, which support more than 120 species of waterbirds, providing habitat for 25 internationally and 16 nationally listed waterbirds. These waterbirds depend on healthy wetland ecosystems to breed, forage for food and roost (MDBA n.d). Waterbirds and significant waterbird sites (Figure 22) play a vital role in the Basin's environmental and residents' social values, cultural aspirations, food, recreation, amenity, tourism, non-agricultural enterprises etc. Four main functional groups of waterbirds exist in the MDBA – colonial nesting waders, shorebirds, cryptic waders, swimmers/grazers, and migratory birds. These waterbirds live in a range of wetlands – lakes, floodplains, swamps, and estuaries – with different species breeding and feeding in different wetland environments.

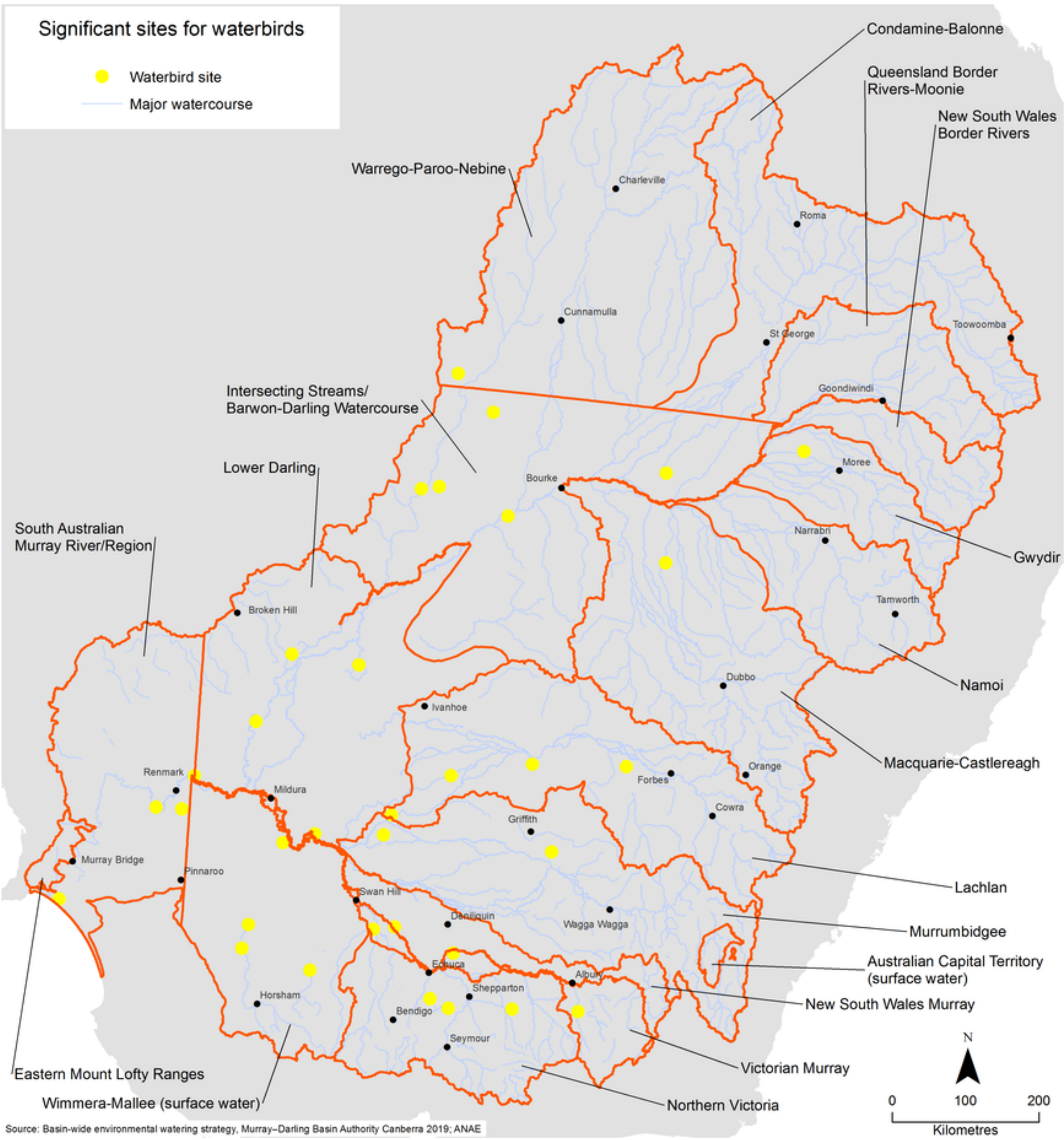

Figure 22 Map showing significant sites for waterbirds in different WRPAs in the Murray-Darling River Basin.

For most waterbird species, significant flooding events resulting from lateral connectivity (Q95) are needed to maintain nesting sites, foraging habitats and shelter sites, to induce breeding and support recruitment. These events also strengthen the network of wetlands on which waterbirds rely. Runoff for in-stream habitats (Q75) maintains riparian vegetation and nutrients for in-stream habitats. Runoff for river pools and water holes (Q25) maintain downstream storages and refill pools and water holes in river systems.

The Victorian Murray, Wimmera-Mallee (surface water), and South Australian Murray regions have multiple bird sites. The Victoria Murray WRPA is home to three Ramsar sites (Barmah Forest, Gunbower Forest and Hattah-Kulkyne Lakes) and The Living Murray (TLM) icon site (Lindsay, Wallpolla, and Mulcra Islands Icon Site).

Table 16 Changes of flow characteristics in a warmer and drier Basin from historical baseline and number of Bird sites in the regions.

Murray-Darling Basin Water Resource Plan Areas (WRPAs)	Changes from historical baseline (1898-2018)				
	Runoff for floodplain inundation (Q95)	Runoff for in-stream habitats (Q75)	Runoff for pools and water holes in rivers (Q25)	Low flow days (Q1)	Bird sites BW-EWS (No.)
Victorian Murray	-18%	-22%	-21%	80%	5
Northern Victoria	-19%	-21%	-18%	85%	3
Wimmera-Mallee (surface water)	-20%	-22%	-19%	87%	5
South Australian Murray Region	-23%	-22%	-19%	86%	4
Eastern Mount Lofty Ranges	-24%	-26%	-15%	93%	0
Lower Darling	-25%	-23%	-16%	70%	4
New South Wales Murray	-22%	-23%	-16%	71%	2
Murrumbidgee	-22%	-23%	-19%	66%	2
Lachlan	-25%	-26%	-20%	70%	4
Macquarie-Castlereagh	-25%	-25%	-23%	71%	1
Intersecting Streams	-25%	-23%	-16%	67%	5
Namoi	-27%	-26%	-17%	90%	0
Gwydir	-24%	-20%	-12%	66%	1
New South Wales Border Rivers	-25%	-22%	-16%	64%	0
Queensland Border Rivers-Moonie	-28%	-24%	-14%	59%	0
Condamine-Balonne	-25%	-22%	-15%	66%	0
Warrego-Paroo-Nebine	-22%	-25%	0%	42%	1

The Lower Darling and the Lachlan regions in the Southern Basin could have 25% less runoff for flood plain inundation under a warmer-drier scenario. This reduction might reduce the frequency, extent, and duration of flooding critical to maintaining waterbird habitat and ensuring successful breeding and recruitment in these regions. It may also increase reliance on refuge sites. At the same time, an expected decrease of 23% reduction in runoff for in-stream habitats (which maintain riparian vegetation and nutrients for in-stream habitats) may also put pressure on refuge habitats.

Under a warmer-wetter scenario, *runoff for floodplain inundation* might increase by 17-18% and *low flow days* might reduce by 21-26% in the Victorian Murray, Wimmera-Mallee (surface water), and the Intersecting Streams /Barwon Darling regions. Such changes are likely to benefit waterbirds in these regions. However, larger magnitude flooding from extreme events might impact waterbirds negatively by washing away nesting sites or altering inundation patterns required for healthy vegetation relied on by waterbirds. We note that water bird abundances are highly dynamic and depend on wetland conditions across the Basin and continent. For example, abundance and diversity can decrease at key sites when multiple smaller sites are in good condition, offering habitat over a more distributed area.

Area of native vegetation

Native vegetation assets (measured as percentage cover of Red Gum, Black Box and Coolabah) have significant environmental values. Figure 23 shows the area under Red Gum, Black Box, and

Coolabah in different WRPAs in the Murray-Darling River Basin (Cunningham *et al.* 2013) . Red Gum, Black Box and Coolabah forests and woodlands occur on floodplains and riparian habitats and use water available from rainfall, river flows, and periodic flooding events (MDBA 2017a). Regular inundation maintains the health of these communities and supports recruitment to ensure a diverse age structure. Black box and Coolabah communities require less frequent inundation (3-7 and 10-20 years, respectively), while an optimal inundation regime for Red Gum forest that maintains a healthy multi-age structured community is every 1-3 years (Jane and Frances 2000; MDBA 2017a). Flows that inundate floodplains (Q95) are necessary to maintain these forests, and large flooding events are essential for Coolabah and Black Box, which occur higher on the floodplain.

Lower flow (Q75) maintain riparian forest stands and trees around in-stream waterholes. This analysis does not consider other important flow-dependent vegetation communities including Lignum shrublands and non-woody sedgeland, grassland, herbland, rushland, riparian and instream vegetation.

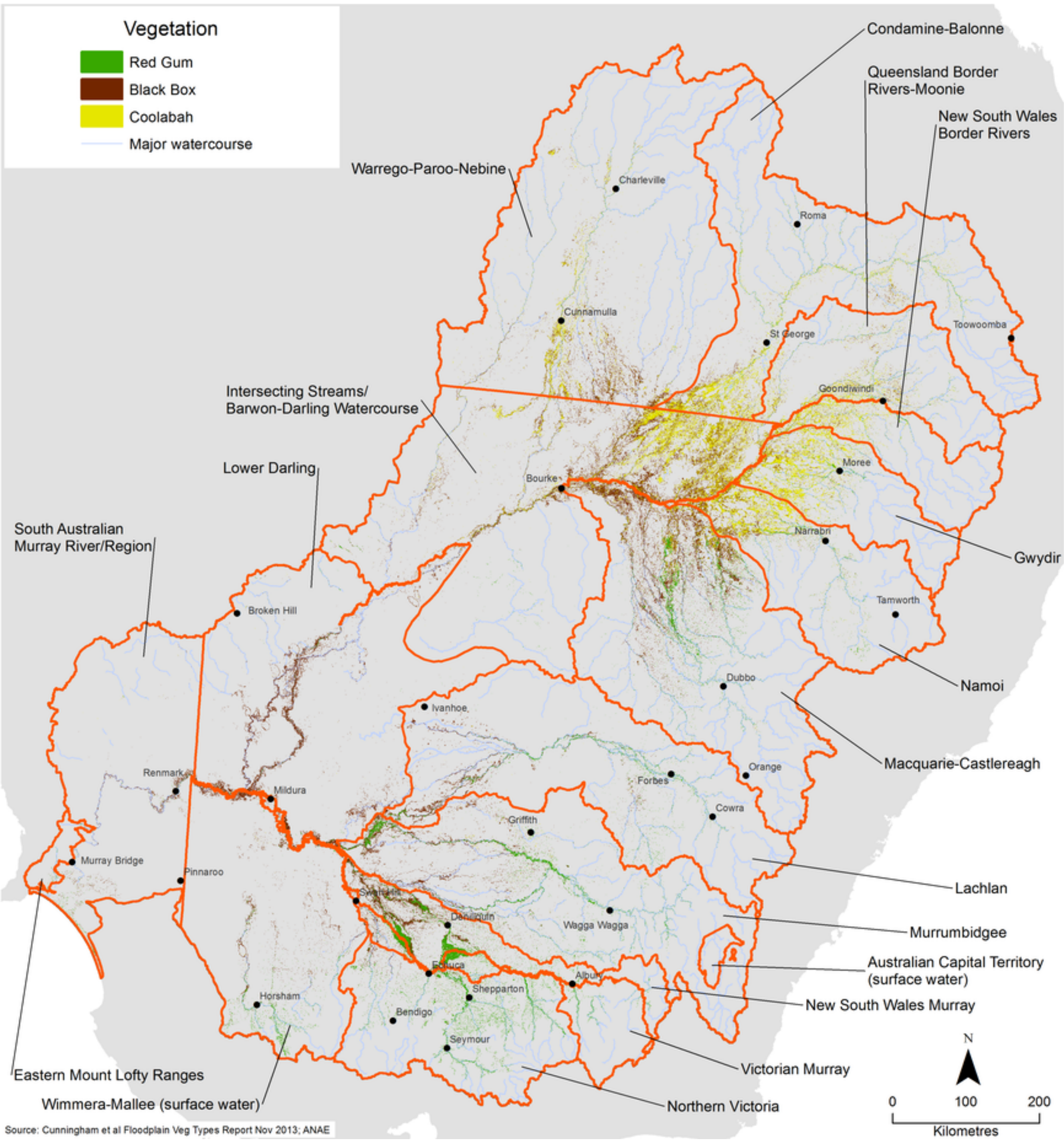

Figure 23 Map showing area under vegetation by Red Gum, Black Box, and Coolabah in different WRPAs in the Murray-Darling River Basin.

The New South Wales Murray and the Gwydir regions have significant areas under native vegetation. The New South Wales Murray region is characterised by extensive river Red Gum forests listed under the Ramsar Convention and the Directory of Important Wetlands in Australia, including the largest and the second largest Red Gum forests in Australia, Barmah-Millewa and Gunbower Forests (DPI Water 2018). It also contains extensive areas of Black Box woodland. The Gwydir region has a dense cover of Coolabah. In these regions runoff for flood plain inundation is expected to decline under a warmer-drier scenario by 22% and 24%, respectively, and some flood plain woodlands and forests may transition to other community types over time as lower rates of inundation affect their survival, germination, and seed stock. Runoff for instream habitats may decline by 23%and 20%, respectively, resulting in a decrease in longitudinal connectivity with potential repercussions for the riparian forest (Table 17) and a potentially negative impact on the extent and condition of these important forests. This comes in addition to a significant reduction in the frequency of inundation events and flood volumes as a result of water resource development affecting these flood plain forests (DPI Water 2018).

Table 17 Changes of flow characteristics in a warmer and drier Basin from historical baseline and per cent area of native woody vegetation in the regions.

Murray-Darling Basin Water Resource Plan Areas (WRPAs)	Changes from historical baseline (1898-2018)		
	Runoff for floodplain inundation (Q95)	Runoff for in-stream habitats (Q75)	Percent area of native woody vegetation (%)
Victorian Murray	-18%	-22%	9
Northern Victoria	-19%	-21%	5
Wimmera-Mallee (surface water)	-20%	-22%	2
South Australian Murray Region	-23%	-22%	1
Eastern Mount Lofty Ranges	-24%	-26%	1
Lower Darling	-25%	-23%	3
New South Wales Murray	-22%	-23%	16
Murrumbidgee	-22%	-23%	4
Lachlan	-25%	-26%	2
Macquarie-Castlereagh	-25%	-25%	8
Intersecting Streams	-25%	-23%	8
Namoi	-27%	-26%	8
Gwydir	-24%	-20%	12
New South Wales Border Rivers	-25%	-22%	7
Queensland Border Rivers-Moonie	-28%	-24%	4
Condamine-Balonne	-25%	-22%	4
Warrego-Paroo-Nebine	-22%	-25%	3

Nevertheless, the warmer-wetter Basin scenario indicates potential 21% and 19% increases in floodplain inundation flows in both WRPAs, which could benefit the health of some Red Gum, Black Box and Coolabah forests and woodlands. However, the longer duration or frequent inundation may result in the transition of communities to other vegetation types. The impact of more frequent and extreme events is yet unknown but has the potential to impact the riparian forests in the region.

Percent of wetlands fish species

The continuity of flow regimes is crucial for life functions, movements, migration, spawning and recruitment, as well as habitat and processes essential for the survival of native fish. Most native fish species in the Murray-Darling Basin use wetlands at some life cycle stage, and many depend on wetlands for nursery areas, spawning grounds or food resources. Connectivity with wetland habitat is critical for many short-lived species. The responses of species such as Murray Hardyhead and Olive Perchlet show the importance of wetland inundation (MDBA 2017b). Figure 24 shows important fish assets in different WRPAs in the Murray-Darling River Basin.

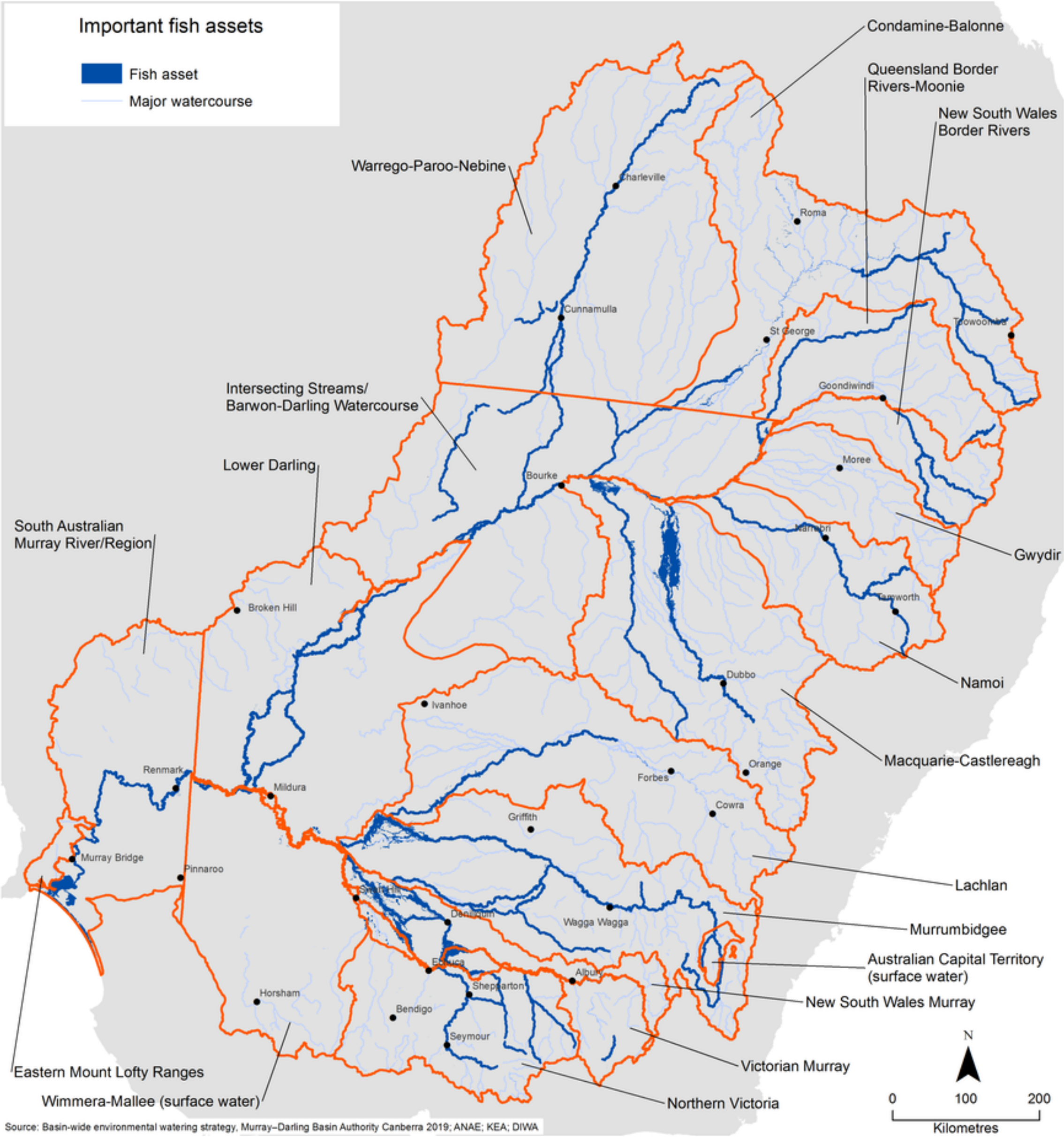

Figure 24 Map showing important fish assets in different WRPAs in the Murray-Darling River Basin.

Inundation of wetlands supports ecological processes and in-channel primary productivity benefiting other native fish species. A reduction in wetland inundation has been identified as a potential risk to availability of recreational fish in some populations (MDBA 2017b). These responses indicate an important role for flooding events (Q95) that replenish wetlands in maintaining values associated with native fish. The longitudinal connectivity provided by lower-level flows (Q75 and Q25) is also important to provide for movements, habitat, refugia and to trigger migration or spawning.

The Queensland Border Rivers-Moonie with the highest percentage of wetland fish species, and the Condamine-Balonne and the South Australian Murray Region WRPAs with the second highest percentage of wetland species that may witness a reduction in runoff for floodplain inundation (Q95). The values associated with wetland species significantly contribute to overall environmental values in these areas.

Table 18 Changes of flow characteristics in a warmer and drier Basin from historical baseline and percent of wetland fish species in the regions.

Murray-Darling Basin Water Resource Plan Areas (WRPAs)	Changes from historical baseline (1898-2018)		
	Runoff for floodplain inundation (Q95)	Runoff for in-stream habitats (Q75)	Ratio of wetland species to total species count (%)
Victorian Murray	-18%	-22%	40
Northern Victoria	-19%	-21%	35
Wimmera-Mallee (surface water)	-20%	-22%	57
South Australian Murray Region	-23%	-22%	71
Eastern Mount Lofty Ranges	-24%	-26%	42
Lower Darling	-25%	-23%	62
New South Wales Murray	-22%	-23%	45
Murrumbidgee	-22%	-23%	50
Lachlan	-25%	-26%	47
Macquarie-Castlereagh	-25%	-25%	56
Intersecting Streams	-25%	-23%	67
Namoi	-27%	-26%	56
Gwydir	-24%	-20%	53
New South Wales Border Rivers	-25%	-22%	58
Queensland Border Rivers-Moonie	-28%	-24%	73
Condamine-Balonne	-25%	-22%	71
Warrego-Paroo-Nebine	-22%	-25%	62

Under a warmer and drier scenario, a runoff reduction for floodplain inundation of 23-28% in these WRPAs is expected. This may reduce the inundation of wetlands, negatively affecting the spawning, recruitment, survival, and distribution of wetland-dependent native fish and impacting associated environmental values. Conversely, under a warmer and wetter scenario, expected increases in runoff for floodplain inundation in the order of 21-24% in these WRPAs could help improve conditions for wetland fish species and the associated environmental values.

Key insights

Waterbird sites: The Basin contains more than half the wetlands in Australia where waterbirds that breed and nest in colonies can be found, home to over 120 species of waterbirds, including internationally and nationally listed species. These waterbirds are important for the environment and the residents' social, cultural, and economic well-being. The Victorian Murray, Wimmera-Mallee (surface water), and South Australian Murray regions are significant bird sites in the Murray-Darling Basin. Flooding events resulting from lateral connectivity (Q95) and runoff for in-stream habitats (Q75) and pools and water holes in rivers (Q25) are crucial for the maintenance of nesting sites, foraging habitats, and shelter sites, triggering breeding events, and supporting recruitment. However, these regions will likely witness larger decreases in flow characteristics in a warmer and drier world. Under a warmer-wetter scenario, these regions are likely to experience increases in inundation flows and a reduction in low-flow days, benefiting waterbirds, but larger magnitude flooding from extreme events might impact waterbirds negatively by inundating nesting sites or altering inundation patterns required for healthy vegetation relied on by waterbirds.

Native vegetation: The native vegetation assets of Red Gum, Black Box, and Coolabah have significant environmental values in the Murray-Darling River Basin, and regular inundation is necessary to maintain their health and diversity. The New South Wales Murray and the Gwydir regions have significant areas under native vegetation, including extensive river red gum forests and black box woodland. Runoff for floodplain inundation and instream habitats is expected to decline under a warmer and drier scenario, potentially affecting the survival and condition of these important forests. However, under a warmer, wetter scenario, increases in floodplain inundation flows could benefit the health of some vegetation communities, although longer or more frequent inundation may also result in the transition of communities to other vegetation types.

Native wetland fish: Flow regimes are crucial for wetland fish species in the Murray-Darling Basin, as they depend on wetlands for nursery areas, spawning grounds or food resources. The inundation of wetlands supports ecological processes and in-channel primary productivity, and a reduction in wetland inundation has been identified as a potential risk to the availability of recreational fish. The Queensland Border Rivers-Moonie and the Condamine-Balonne and South Australian Murray Region WRPAs have the highest percentage of wetland fish species, which may witness a reduction in runoff for floodplain inundation. Under a warmer and drier scenario, a runoff reduction for flood plain inundation of 23-28% in these WRPAs is expected, which may negatively affect the spawning, recruitment, survival and distribution of wetland-dependent native fish and impact associated environmental values. Conversely, under a warmer and wetter scenario, expected increases in runoff for plain inundation in the order of 21-24% in these WRPAs could be helpful for wetland fish species and the associated environmental values.

5. Conclusion

The Murray-Darling Basin (MDB) is a mosaic of life and livelihoods. Water is crucial for the viability of the communities. How people value water varies between regions, communities, and individuals and can change drastically between times of plenty and times of scarcity. The impacts of climate change on flow, assets and values are inextricably woven into the regional environmental and economic fabric. Assessing the values and vulnerability to climate change within the broader everyday socioeconomic stressors is challenging.

We used a Flow-Asset-Value (FAV) to track how changes in water flow could impact physical assets and the values attached to them by the communities. We used indicators to describe the FAV relationships and assess the economic, social, cultural and environmental values. This report provided a rapid assessment of the nature of vulnerability in the regions of the Basin and contains data on how many sensitive assets are in each region. For example, the economic vulnerability may be greater in areas with higher employment in agriculture. However, our study lacks detailed data on how susceptible these assets are to changes in water flow characteristics. How, for instance, a 20% decline in surface water availability at a particular location by 2050 would affect agricultural job numbers is not presented in the rapid assessment and represents a critical knowledge gap.

Overall, there is a variation of values and vulnerability across the Basin, and we have tentatively highlighted regions where the available data indicate a possible tendency to higher vulnerability. However, it should also be noted that as far as can be elicited with the data available for this rapid assessment, (a) flow changes will likely affect economic and social values in different ways across the Basin, (b) under climate change there will likely be changes in long-term average flow conditions, (c) flow-dependent assets in all regions are sensitive to those changes, and (d) all regions have some degree of adaptive capacity, although it is unclear how effective these capacities may be in the face of the magnitude and sustained nature of climate change in future decades. We recommend case studies in multiple locations. These studies would offer a granular view of the complex relationships between flow changes and values indicators. They would also shed light on critical immediate coping decisions that have a long lifetime to account for the effects of climate change.

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Annex A. Methods for estimating runoff

The approach to generating estimates of future runoff change follows that used to produce plausible hydroclimate futures for the MDB as a part of an earlier project (Zhang *et al.* 2020b) with some modifications to support assessment of spatial differences between Water Resource Plan Areas.

Data

Gridded rainfall and weather data from SILO are used for this analysis. Morton's Wet Area Potential Evaporation is calculated from daily radiation, humidity and temperature data.

Gauged streamflow observations for more than 700 unregulated catchments across Australia are used for hydrological model parameterisation. Streamflow observations for these gauges were obtained from state agencies and the dataset curated using the methods described by (Zhang *et al.* 2013).

Hydrological modelling

The GR4J rainfall-runoff model (Perrin *et al.* 2003) is used to simulate catchment runoff from rainfall and potential evapotranspiration forcing data. The GR4J model has four parameters that require calibration.

These parameters are calibrated for more than 700 natural catchments across Australia (Chiew *et al.* 2017; Zheng *et al.* 2018). Catchment average rainfall and potential evaporation are computed from the gridded SILO data. The calibration process involves finding the set of parameters that yields the optimal objective function. For this analysis the adopted objective function (OF) combines the Nash-Sutcliffe Efficiency (NSE) and a measure of Bias (Viney *et al.* 2009).

$$OF = (1 - NSE) + 5(log(1 + bias))^{2.5}$$

$$NSE = 1 - \frac{\sum_{t=1}^{T} \left(Q_{s,t} - Q_{o,t}\right)^2}{\sum_{t=1}^{T} \left(Q_{o,t} - \overline{Q_o}\right)^2}$$

$$bias = \frac{(\overline{Q_s} - \overline{Q_0})}{\overline{Q_0}}$$

where *NSE* is the Nash-Sutcliffe efficiency (Nash and Sutcliffe, 1970), Q_s is the simulated streamflow for time step t ,Q_o is the observed streamflow, $\overline{Q}_S$ is the mean simulated streamflow, $\overline{Q}_O$ is the mean observes streamflow and T the total number of time steps.

Generation of runoff scenarios

Hydrological model parameters are interpolated to the SILO gridcells from the nearest stream gauge. Daily gridded runoff simulations are generated by forcing the hydrological model with gridded forcing data (rainfall and potential evaporation).

The daily gridded runoff simulations are then spatially averaged across the Water Resource Plan Areas (WRPAs) to produce runoff time series. Each WRPA runoff time series is then used to compute a range of runoff statistics (Annex B).

Three runoff scenarios are generated for each WRPA. The first uses the observed forcing data for the period 1890 - 2019 and represents historical observations. The second scenario corresponds to a warmer and drier climate where rainfall is reduced by 5%, by multiplying the historical observations by 0.95, and potential evaporation increases by 7%, by multiplying historical observations by 1.07. This second scenario represents a future climate that is 2°C warmer and rainfall reductions equivalent to the median of the CMIP5 global climate model projections for the MDB (Chiew *et al.* 2017).

Scenario	Rainfall changes from the historical baseline	Potential evapotranspiration changes from the historical baseline	Temperature change from historical baseline
Warmer-drier (WD)	-5%	+7%	+2°
Warmer-wetter (WW)	+10%	+7%	+2°

The third scenario corresponds to a warmer and wetter climate where rainfall is increased by 10%, by multiplying historical observations by 1.1, and potential evaporation increases by 7%, by multiplying historical observations by 1.07. This second scenario represents a future climate that is 2°C warmer with an increase in rainfall that is exceeded by approximately 10% of the CMIP5 global climate model projections for the MDB (Chiew *et al.* 2017). Future changes in the flow statistics are expressed as the difference between the future scenarios (i.e., the second or third scenario) and the historical scenario, expressed as a percentage of the historical scenario.

Annex B. Flow change assessment

Climate record shows that the duration, seasonality, interannual variability and magnitude of temperatures, rainfall, evaporation, and wind are changing in the MDB. Changes in temperature, rainfall and evaporation have the most direct impact on the water system and are studied extensively (Timbal *et al.* 2015; CSIRO & Bureau of Meteorology 2020; Zhang *et al.* 2020a). These climate changes influence the frequency and magnitude of runoff and hence river flow.

Flow changes are assessed using simplified measures that are appropriate for assessing climate change exposure of vulnerable assets and values and support easier communication of the extent and magnitude of change.

Flow change measurement

Flow change	Measurement	Why important
Mean annual runoff	Mean annual runoff	Integrates impacts of changes in rainfall (amount and variability), temperature and potential evaporation. Changes affect water availability, inflows to dams and allocation
Low flow days	Days	Flow thresholds are important factors for maintaining environmental assets for their role in, e.g., provisioning habitat; triggering breeding, spawning and movement; maintaining ecosystem productivity, diversity, processes and function; providing and cycling nutrients; connecting habitat; reducing black water events etc.
Runoff seasonal change	Runoff (Jun-Nov)/ Runoff (Dec-May)	Describes the impact of rainfall change in seasonality
Runoff for floodplain inundation	Daily runoff not exceeding 95% of the time	Describes when floodplains are inundated
Runoff for in-stream habitats	Daily runoff not exceeding 75% of the time	Describes water for riparian vegetation and nutrients for in-stream habitats
Runoff for pools and water holes in rivers	Daily runoff not exceeding 25% of the time	Affected by groundwater storage and dam operation but not directly by rainfall. Important for aquatic habitat.

Annex C. Data remapping

	Indicators	Data source	Reported spatial unit	Transformation method
Sensitivity				
1	Ratio dryland crop to total agricultural area	ABS, 4618.0 - Water Use on Australian Farms, 2015-16	SA2	NLUM 2015-16 (ABARES) area-based correspondence
2	Ratio irrigated crop to total agricultural area	ABS, 4618.0 - Water Use on Australian Farms, 2015-16	SA2	NLUM 2015-16 (ABARES) area-based correspondence
3	Ratio agribusiness irrigating to total agribusinesses	ABS, 4618.0 - Water Use on Australian Farms, 2015-16	SA2	NLUM 2015-16 (ABARES) area-based correspondence
4	Total water applied (ML)	ABS, 4618.0 - Water Use on Australian Farms, 2015-16	SA2	NLUM 2015-16 (ABARES) area-based correspondence
5	Area of floodplain (ANAE) grazing (ha)	ANAE (v3), NLUM 2015-16 (ABARES)	Polygon, 250m raster	Tabulate intersection
6	GVAP (million AUD)	ABS, 7503.0 - Value of Agricultural Commodities Produced, Australia, 2015-16	SA2	NLUM 2015-16 (ABARES) area-based correspondence
7	Average irrigation expenditure per irrigating business (AUD)	ABS, 4618.0 - Water Use on Australian Farms, 2015-16	SA2	NLUM 2015-16 (ABARES) area-based correspondence
8	Employment in agriculture related jobs (no.)	ABS, Census Working Population profile, 2015-16	SA2	NLUM 2015-16 (ABARES) area-based correspondence
9	Ratio agricultural related employment to	ABS, Census Working Population profile, 2015-16	SA2	NLUM 2015-16 (ABARES) area-

	Indicators	Data source	Reported spatial unit	Transformation method
	total employment			based correspondence
10	Percent area of native vegetation	Cunningham et al Floodplain Veg Types Report, Nov 2013	25m raster	Tabulate intersection
11	Percent wetland species - fish	https://data.gov.au/data/dataset/murray-darling-Basin-fish-and-macroinvertebrate-survey	point location	Spatial join
12	Bird sites BW-EWS (no.)	Basin-wide environmental watering strategy, MDBA, 2019	point location	Count
13	Ramsar sites (no.)	Ramsar wetlands of Australia, Commonwealth of Australia, 2018	Polygon	Count
14	Agriculture business number	ABS, 4618.0 - Water Use on Australian Farms, 2015-16	SA2	Area-based correspondence
15	Business doing well (reversed)	2020 Regional Wellbeing Survey data tables, Version 1.0, Sept 2021	LGA-based	Visual assessment
16	Tourism (Domestic overnight spend per trip)	Tourism Research Australia, 2020, Summation options by stopover Local Government Area	LGA	Visual assessment
17	Tourism business number	ABS, 2020, customised extraction for TRA	LGA	Visual assessment
18	Percent area of native vegetation	Cunningham et al Floodplain Veg Types Report, Nov 2013	25m raster	tabulate intersection
19	Percent wetland species - fish	https://data.gov.au/data/dataset/murray-darling-Basin-fish-and-macroinvertebrate-survey	point location	spatial join
20	Bird sites BW-EWS (no.)	Basin-wide environmental watering strategy, MDBA, 2019	point location	count
21	Access to affordable food/groceries at local shops	2020 Regional Wellbeing Survey data tables, Version 1.0, Sept 2021	LGA-based	visual assessment
22	Percent area of native vegetation	Cunningham et al Floodplain Veg Types Report, Nov 2013	25m raster	tabulate intersection
23	Percent wetland species - fish	https://data.gov.au/data/dataset/murray-darling-Basin-fish-and-macroinvertebrate-survey	point location	spatial join

	Indicators	Data source	Reported spatial unit	Transformation method
24	Bird sites BW-EWS (no.)	Basin-wide environmental watering strategy, MDBA, 2019	point location	count
25	Ramsar sites (no.)	Ramsar wetlands of Australia, Commonwealth of Australia, 2018	polygon	count
26	Attractive natural places	2020 Regional Wellbeing Survey data tables, Version 1.0, Sept 2021	LGA-based	visual assessment
27	Indigenous enterprises reliant on water allocations	Indigenous Business Sector Snapshot 1.1/Indigenous-Business Longitudinal Analysis Data Environment (I-BLADE), University of Melbourne https://fbe.unimelb.edu.au/cibl/assets/snapshot/RFQ03898-M-and-M-Snapshot-Study.pdf	-	Expert opinion
28	FIRST NATIONS in formal roles and jobs in Water & Land management programs	National Indigenous Australians Agency (NIAA) List of Murray-Darling Basin Indigenous River rangers Organisations document https://www.niaa.gov.au/indigenous-affairs/environment/indigenous-ranger-programs First Nations participation in water for the environment reports, MDBA (2018-19, 2019-20, 2020-21)	-	Expert opinion
Adaptive capacity				
29	Volunteer proportion	ABS, 2016 Census of Population and housing	SA2	Population based correspondence
30	Percentage off-farm income	ABS, 7121.0 - Agricultural Commodities, Australia, 2015-16	SA2	Population based correspondence - weighted mean
31	Economic diversity	ABS, 2016 Census of Population and housing	SA1	Population based correspondence - weighted mean
32	% of high security water entitlement	http://www.bom.gov.au/water/dashboards/#/water-markets/mdb/eoi	SWWRPA	Count
33	Access to Financial and	2020 Regional Wellbeing Survey data tables, Version 1.0, Sept 2021	LGA-based	visual assessment

	Indicators	Data source	Reported spatial unit	Transformation method
	Professional Services index			
34	Remoteness (reversed rating)	ABS, 1270.0.55.005 - Australian Statistical Geography Standard (ASGS): Volume 5 - Remoteness Structure, July 2016	-	majority area
35	Access to local government services	2020 Regional Wellbeing Survey data tables, Version 1.0, Sept 2021	LGA-based	visual assessment
36	Household weekly income	ABS, 7121.0 - Agricultural Commodities, Australia, 2015-16	SA2	Population based correspondence - weighted mean
37	Getting Involved in the Community index	2020 Regional Wellbeing Survey data tables, Version 1.0, Sept 2021	LGA-based	visual assessment
38	Community Leadership and Collaboration index	2020 Regional Wellbeing Survey data tables, Version 1.0, Sept 2021	LGA-based	visual assessment
39	Personal weekly income	ABS, 7121.0 - Agricultural Commodities, Australia, 2015-16	SA2	Population based correspondence - weighted mean
40	Sense of Belonging index	2020 Regional Wellbeing Survey data tables, Version 1.0, Sept 2021	LGA-based	visual assessment
41	First Nations participation in water for the environment	National Indigenous Australians Agency (NIAA) List of Murray-Darling Basin Indigenous River rangers Organisation’s document https://www.niaa.gov.au/indigenous-affairs/environment/indigenous-ranger-programs First Nations participation in water for the environment reports, MDBA (2018-19, 2019-20, 2020-21)	-	Expert opinion
42	Number and type of decisions that show inclusion of	First Nations participation in water for the environment reports, MDBA (2018-19, 2019-20, 2020-21)	-	Expert opinion

	Indicators	Data source	Reported spatial unit	Transformation method
	Indigenous values			
43	Aboriginal involvement in Basin consultation	First Nations participation in water for the environment reports, MDBA (2018-19, 2019-20, 2020-21)	-	Expert opinion

Annex D. Scoping the rapid assessment

We developed an initial understanding of current climate conditions, climate extremes and climate change, potentially vulnerable assets, underlying factors (biophysical, technical, and socio-economic factors) that can influence climate impact based on information and outputs of several published reports and consultation with MDBA.

CSIRO 2020 MDB plausible hydroclimate futures

Hydroclimate futures are challenging to construct in the MDB. Available instrumental rainfall records are short and do not represent long-term variability (e.g., over time scales of more than ten years). Paleoclimate records are also not useful as they do not represent conditions under enhanced CO_2. To account for multiple uncertainties arising out of these issues, CSIRO Plausible Hydroclimate Futures for the Murray-Darling Basin study used the storyline approach. The storyline approach is easier for decision-makers to imagine and prepare for action. The focus is not predicting the future but working with plausible what-if scenarios to identify risks and opportunities.

The study identified seven hydroclimate scenarios. For each of the climate scenarios, several hydrologic matrices, as used by the MDBA ecohydrology community of practice project, were examined: soil moisture index, mean annual flow, overbank flow (daily flows not exceeded 95% of the time Q95), freshes (daily flows not exceeded 75% of the time Q75), replenishment flow (daily flows not exceeded 25% of the time Q25), baseflow (daily flows not exceeded 5% of the time Q5), cease-to-flow (daily flows not exceeded 1% of the time Q1), dry-spells (longest consecutive days with flow below the baseflow Q5) and flow sequencing.

NSW Government – Integrated Regional Vulnerability Assessments: Riverina Murray (State of NSW and Heritage, 2014)

Vulnerability is defined as how people are vulnerable to climate change within the context of socio-economic institutions and activities and regional biophysical resources in different scales. The report assessed vulnerability to climate change of the capitals (asset) associated with five sectors:

I. Landscapes and ecosystems - Natural resource management, biodiversity conservation, natural and cultural heritage, (water).

II. Industries - Primary industries, processing and manufacturing industries, tourism, (water).

III. Settlements and infrastructure - Transport, energy, communications, buildings and settlements, retail, water infrastructure.

IV. Human services - Employment, health, aged care, disability services, community services, education.

V. Emergency management - Preparation, response and recovery to fire, flood, storm, drought and other emergencies.

The assessment is undertaken in two steps: (1) sectoral workshops and (2) integration workshop to integrate sectoral workshop outcomes, to enable identification of regional vulnerability. The outcome of the assessment is subjective in nature.

Revised indicators of community vulnerability and adaptive capacity across the Murray-Darling Basin (Stenekes *et al.* 2012)

This report focused on irrigated agriculture and looked at indicators of community vulnerability and adaptive capacity across the MDB. The project reports on community vulnerability before exposure (using 2000-01 as a baseline) to any water policy intervention and then exposure to a 2800GL SDL scenario based on 2005-6 commodity prices. The report acknowledges large uncertainties, geographical variability and other limiting factors.

The report found existing vulnerabilities in the northern Basin – Gwydir, Moonie, Condamine-Balonne and south Warrego; and southern Basin – Murrumbidgee, Lower Darling, Murray and Lachlan. Key issues are high sensitivity to changes in water availability (high agroindustry employment) and limited levels of adaptive capacity (low levels of human capital, social capital and economic diversity) in comparison to other regions. 2800GL SDL scenario amplifies vulnerability in the Murrumbidgee and upper Murray Basin. Economic Diversity Index, socioeconomic advantage and age advantage were found to be most influential indicators. Methodologically,

I. Exposure was measured as the proportion of reduced irrigation water available compared to the long-term average water availability needed to implement and overall Sustainable Diversion Limit.
II. Sensitivity was measured as Statistical Local Area water dependence (SLA), irrigation intensity, SLA irrigation incidence, SLA local economy agricultural dependence (farm/agroindustry employment, proportion of households with agricultural and/or Agri-industry employment, proportion of total employment in agriculture, proportion of total employment in agriculture and Agri-industry)
III. Adaptive capacity was measured as Local economic diversity (Economic Diversity (Hachmann Index) Index), Human Capital (socio-economic advantage, age advantage, education advantage, mobility), Social capital (proportion of women in non-routine occupations, Participation in the voluntary group).

The standardised sub-indexes of exposure and sensitivity were multiplied together to produce a sub-index of potential impact. This approach allowed for the adjustment of exposure, and hence impact, according to several water recovery scenarios. The community vulnerability index was then calculated by subtracting the standardised value of the adaptive capacity subindex from the standardised value of the potential impact subindex.

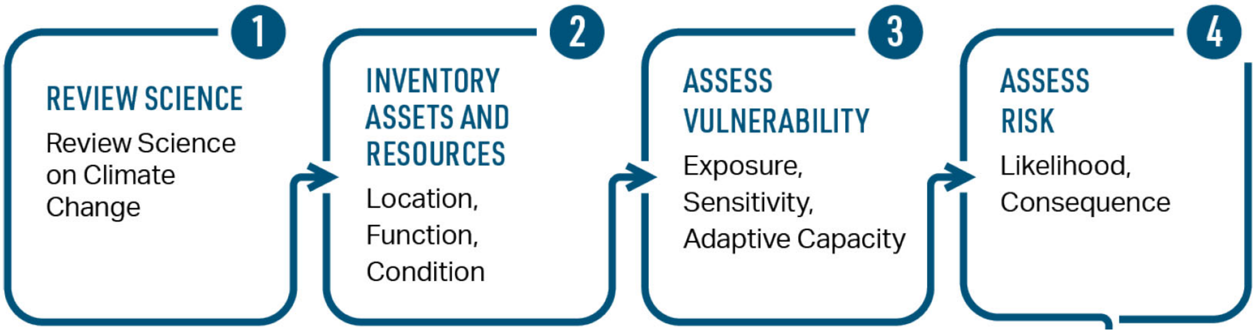
The disadvantage of this approach, as stated by (Stenekes *et al.* 2012), is that the complexity is reduced to a single index which could mask local contextual differences. However, the advantage is in being able to synthesise substantial amounts of socio-economic data into a single index.

The ABARES Water Trade Model (WTM) was used to develop the subindex of exposure. Alternatively, regional exposure could be estimated as part of a scenario-building exercise. Clear and quantifiable flow-related metrics would need to be identified and projections of how these changes in the future related to climate change determined.

Delta Stewardship Council 2021 – Delta Climate Change Vulnerability Assessment (Council, 2021)

This climate change vulnerability assessment is the first phase of the *Delta Adapts: Creating a Climate Resilient Future* study for the Sacramento-San Joaquin Delta of California in the US (Council, 2021). The study aims to understand regionally specific climate change vulnerabilities and risks and address how the delta communities, infrastructure, and ecosystems can adapt to future conditions.

The framework for the study of the first phase, i.e. the climate change vulnerability assessment, is below.



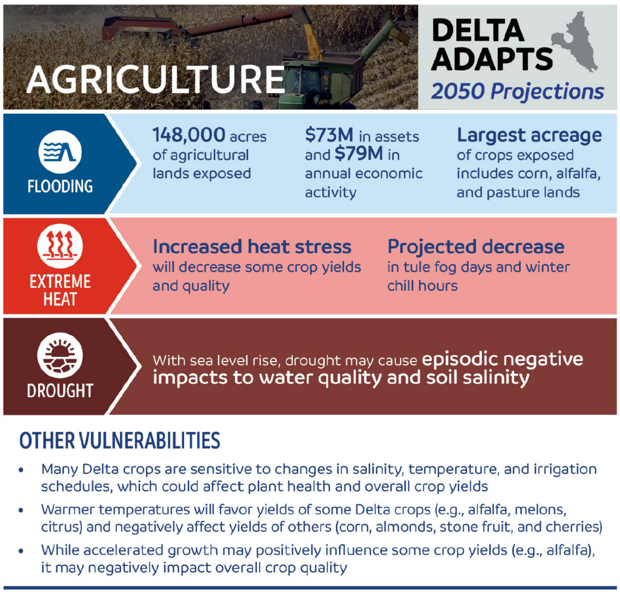
Guidance from the Intergovernmental Panel on Climate Change (IPCC 2012) was applied to evaluate exposure and vulnerability to climate hazards and the potential impacts, ie. by considering Exposure, Sensitivity and Adaptive Capacity of the assets or systems.

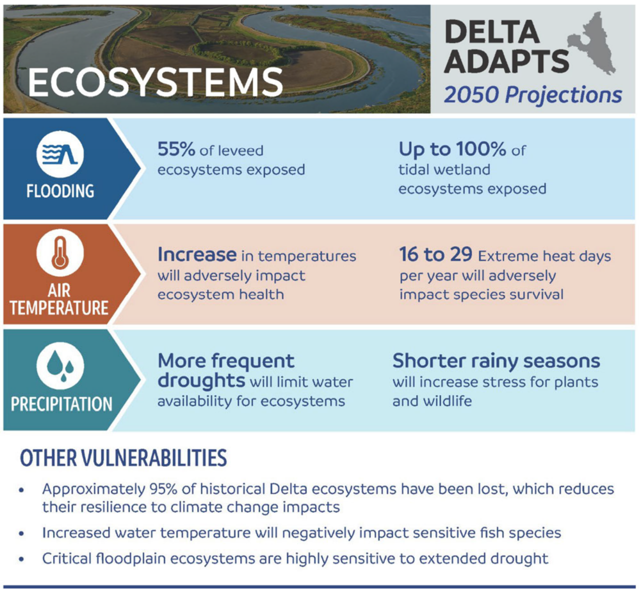
Flooding and Extreme Heat were identified as the primary exposure within the Delta. The study considers vulnerability to climate change across a broad range of assets and systems, including:

- 'Delta as an Evolving Place' assets, sectors or systems, including people, places, agriculture, recreation, and infrastructure
- Ecosystem
- Water Supply Reliability
- Economics

The vulnerability assessment was mainly subjective based on literature reviews and expert knowledge, with some objective estimates of climate change impacts where applicable, such as those due to flooding. As examples, the summaries of key results are shown below for agriculture and ecosystems.

The vulnerability assessment helps the Council and Delta communities better understand regionally significant climate vulnerabilities and risks and lays the foundation for future adaptation planning efforts.





MDBA 2020 Basin Plan Evaluation. Vulnerabilities to climate change in the Murray-Darling Basin

The *MDBA 2020 Basin Evaluation* was the first review of the Murray Darling Basin Plan. The review explored how the Basin Plan was implemented since its launch in 2021 to determine what's working, what's not, and where improvement is needed. Major findings were reported on the impacts of the Basin Plan in terms of the environment, hydrology, social, cultural, and economic aspects, with a due note on a changing climate across the Basin. As a result, six priority areas for the future were identified for all Basin's governments, communities, and change agents to work together to improve the health and productivity of the MDB.

Among the priority areas was 'Adapting to climate challenges and increasing resilience', a key cross-cutting theme for all water managers and users to plan and adapt to the changing climate. As part of the Basin Evaluation, the '*Vulnerabilities to climate change in the Murray-Darling Basin*' report presented an initial step to describe the Basin's social, environmental, cultural, and economic vulnerabilities to the future climate.

Guided by the CSIRO Climate Compass framework, the vulnerability assessment was a high-level subjective scan for the following: Socio-economic, First Nations, and Ecological vulnerabilities. It used different methods to appropriately scan for the vulnerabilities at the Basin-scale using the available evidence and in consultation with relevant experts.

The assessments outlined how Basin communities, water-dependent industries, water markets, ecological outcomes and First Nations people may be vulnerable to climate change. With higher temperatures and less streamflow projected for the Basin, exacerbated in various ways such as increased climate variability, higher evaporation rate and water quality issues, the impacts of climate change across the Basin are expected to be wide-ranging. When considering the factors underlying vulnerabilities, some research, water management and policy development needs have been identified and would be further considered in conjunction with other work being undertaken to inform the design of the MDBA's climate change work moving forward.

As a high-level scan, the assessment had some limitations, including (1) the assessment was at a macro level with readily available information, (2) it did not capture the significant spatial differences of vulnerabilities across the Basin, (3) cultural vulnerabilities and those socio-economic vulnerabilities experienced by First Nations of the Basin were assessed at a very high level, and (4) the vulnerability of the MDBA's River Murray operation was excluded from this assessment.

CSIRO 2019 Australian National Outlook

The Australian National Outlook 2019 report explores a range of nationally significant issues, risks and opportunities to identify how Australia's long-term prosperity can be secured. It was developed over more than two years using a highly collaborative approach that combined the CSIRO's integrated quantitative modelling and subjective analysis with input from the National Outlook participants, a group comprised of over 50 leaders across 22 well-known Australian organisations from industry, the not-for-profit and education sectors.

ANO 2019 focuses on two contrasting scenarios: Outlook Vision, which represents what could be possible if Australia can achieve its full potential, and Slow Decline, in which Australia fails to adequately address the challenges identified, leading to poorer outcomes in multiple dimensions. Each of these scenarios was modelled to 2060, considering the following domains: the global context, productivity and services, cities and infrastructure, and resources and energy.

The National Outlook participants identified the following six challenges to Australia's future success: the Rise of Asia, Technological change, Climate change and environment, Demographics, Trust, and Social cohesion. These challenges were considered carefully, as they also present an opportunity for Australia to develop sustainably, allowing future generations of Australians to enjoy a higher standard of living.

The ANO showed the need for five key shifts to deliver a more prosperous Australia, including (1) An industry shift for a revitalised and resilient economy, (2) an Urban shift towards world-class cities, (3) an Energy shift for affordable, reliable and low emission resources, (4) a Landuse shift for healthy and productive landscapes, and (5) a Culture shift for more inclusion and resilience.

Annex E. State vulnerability assessment reports

NSW

Dept. Primary industries

Project 6: Vulnerability assessment

https://www.dpi.nsw.gov.au/climate/climate/about-dpi-climate/climate-change-research-strategy/project-6-vulnerability-assessment

Adapt NSW

Assessing regional vulnerability to climate change

https://climatechange.environment.nsw.gov.au/Adapting-to-climate-change/Regional-vulnerability-and-assessment

e.g., Riverina Murray Integrated Regional Vulnerability Analysis and Enabling Regional Adaptation

https://climatechange.environment.nsw.gov.au/Adapting-to-climate-change/Regional-vulnerability-and-assessment/Riverina-Murray

Water in NSW

regional water strategies - The final strategies developed over 2020, 2021 and 2022

https://www.industry.nsw.gov.au/water/plans-programs/regional-water-strategies/about

Water resource plans – include risk assessment

https://www.industry.nsw.gov.au/water/plans-programs/water-resource-plans

https://www.industry.nsw.gov.au/__data/assets/pdf_file/0010/164647/5.-Risk-Assessment.pdf

VIC

CMA

Climate change strategies and plans - for natural resource management

Climate Change Adaptation Plan - Catchment Management Authorities (CMAs), funded through the Australian Government, have undertaken regional climate change adaptation planning.

https://www.gbcma.vic.gov.au/weconnect/climate-change-strategies-and-plans

Vulnerability assessment

https://www.nrmclimate.vic.gov.au/regional-cma-information/410/

DELWP

Water resource plans

https://www.water.vic.gov.au/mdb/mdbp/water-resource-plans

https://www.water.vic.gov.au/__data/assets/pdf_file/0023/484232/Victoria-North-and-Murray-WRP-Comprehensive_Report-AppendixB-ACCREDITED.pdf - risk assessment

Adaptation Action plans across ‘system’ in development

- Primary Production
- Built Environment
- Education and Training

- Health and Human Services
- Transport
- Natural Environment
- Water Cycle.

Draft water cycle plan:

https://s3.ap-southeast-2.amazonaws.com/hdp.au.prod.app.vic-engage.files/9516/2493/3338/Draft_Water_Cycle_Adaptation_Action_Plan_2022-26.pdf

QLD

Department of Environment

Sector Adaptation Plans

https://www.qld.gov.au/environment/climate/climate-change/adapting/sectors-systems

- Small and Medium Enterprise Sector Adaptation Plan
- Biodiversity and Ecosystems Climate Adaptation Plan
- Human Health and Wellbeing Climate Change Adaptation Plan
- Emergency Management Sector Adaptation Plan
- Agriculture Sector Adaptation Plan
- Built Environment and Infrastructure Sector Adaptation Plan
- Building a resilient tourism industry: Queensland tourism climate change response plan

Department of Business

Water resource plans – include risk assessment

https://www.business.qld.gov.au/industries/mining-energy-water/water/catchments-planning/qld-murray-darling-Basin

https://www.mdba.gov.au/sites/default/files/pubs/qld-moonie-ecological-risk-assessment-report-2019.pdf

SA

DEW – LSA - MDB

https://www.mdba.gov.au/publications/mdba-reports/south-australian-river-murray-water-resource-plan

https://www.mdba.gov.au/sites/default/files/pubs/sa-river-murray-wrp-risk-assessment-2019.PDF

Climate change was not considered independently as a source of risk. Climate change potentially influences all risk pathways, particularly with respect to the potential for a change in the frequency of climate extremes relative to past climate. Therefore, it was agreed that it was more efficient to consider climate change as a factor affecting multiple risk pathways during the analysis process.

VA – adaptation

https://www.environment.sa.gov.au/topics/climate-change/programs-and-initiatives/adapting-to-climate-change/regional-adaptation-plans

https://www.landscape.sa.gov.au/mr/about-us/our-regions-plan/climate-change/climate-change-adaptation-plan

ACT

Water resource plan

https://www.mdba.gov.au/publications/independent-reports/australian-capital-territory-surface-water-water-resource-plan

climate change strategy – no MDB references

https://www.environment.act.gov.au/cc/adapting-to-climate-change

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