State of knowledge about water variability effects on northern Murray–Darling Basin communities

Final report

Prepared for One Basin CRC by Mosaic Insights

March 2024

Mosaic Insights recognises and acknowledges the unique relationship and deep connection to Country shared by Aboriginal and Torres Strait Islander people, as First Peoples and Traditional Owners of Australia.
We pay our respects to their Cultures, Country and Elders past and present.

Artwork by Melissa Barton. This piece was commissioned by the Alluvium Group, and tells our story of caring for Country, through different forms of waterbodies, from creeklines to coastlines. The artwork depicts people linked by journey lines, sharing stories, understanding and learning to care for country and the waterways within.

This report has been prepared by Mosaic Insights Pty Ltd for One Basin CRC under the contract titled 'Equity and vulnerability in a drying basin: water sharing policy and quality of life in towns.'

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1 Introduction

Mosaic Insights was contracted by One Basin CRC to conduct this work under the original Quickstart project title: *Equity and Vulnerability in a drying basin: water sharing policy and quality of life in towns* (Project QS8). As the work progressed, it became evident that a more appropriate title was needed, hence the different title of this report.

This project entailed a comprehensive review of existing studies about the effects that different levels of water availability and access – from floods to droughts, and managed flows – have on rural communities in the northern Murray Darling Basin. The process has helped to highlight knowledge gaps, which can help One Basin CRC to identify areas for investment in future research with these communities, which will ultimately support communities in managing the effects of water variability.

1.1 Project purpose

The project aimed to identify:

(i) research conducted to date on the effects (positive and negative) of flow variability on communities in the Northern Murray Darling Basin (NMDB),
(ii) the effects communities experience, and
(iii) knowledge gaps.

A conceptual model was developed to show the evidence-based effects documented in empirical studies. The conceptual model was used in a stakeholder workshop to ground-truth the model and confirm further knowledge gaps or areas of interest to the community for future research.

1.2 Project tasks

There were two key tasks in this project: (1) a literature review, and (2) development of a conceptual model to explain community effects of water variability. First, a systematic literature review was conducted to identify studies that provide evidence of social effects linked to water variability within the Northern Basin catchments. In this project, we sought to identify studies that report social effects caused by both biophysical drivers (such as floods or droughts) and institutional drivers, including policies and programs that affect water flow (such as water allocation and water markets). Findings from the literature review have been used to develop the conceptual framework (included in Section 3).

In the second task, the conceptual framework was tested with local community members and relevant government stakeholders from NMDB with lots of on-ground knowledge of the communities. The participants were suggested by members of the Project Advisory Committee, and the workshop was conducted online due to budget and time constraints. Prior to the workshop, participants were sent information about the project, the findings, and the draft conceptual model. During the workshop, they were asked to review the conceptual framework to identify any other research or evidence they were aware of, and any other effects that were not covered by research so far. Further information about the workshop is included in Section 4. The detailed methodology is provided in Section 2 below.

1.3 Why water access and availability vary in the Northern Murray Darling Basin

The following information summarises events in the Northern Basin that drive variability in water levels, access, and availability, with a particular focus from 2000 onwards. It is provided to readers for background information and context for this project.

Overview of the Northern Basin

The Northern Murray-Darling Basin (Northern Basin) spans northern New South Wales and southern Queensland, covering about half of the total Murray-Darling area (Figure 1). Tributaries of the Northern Basin flow into the Darling River then joining Murray River in the southern Murray-Darling Basin.

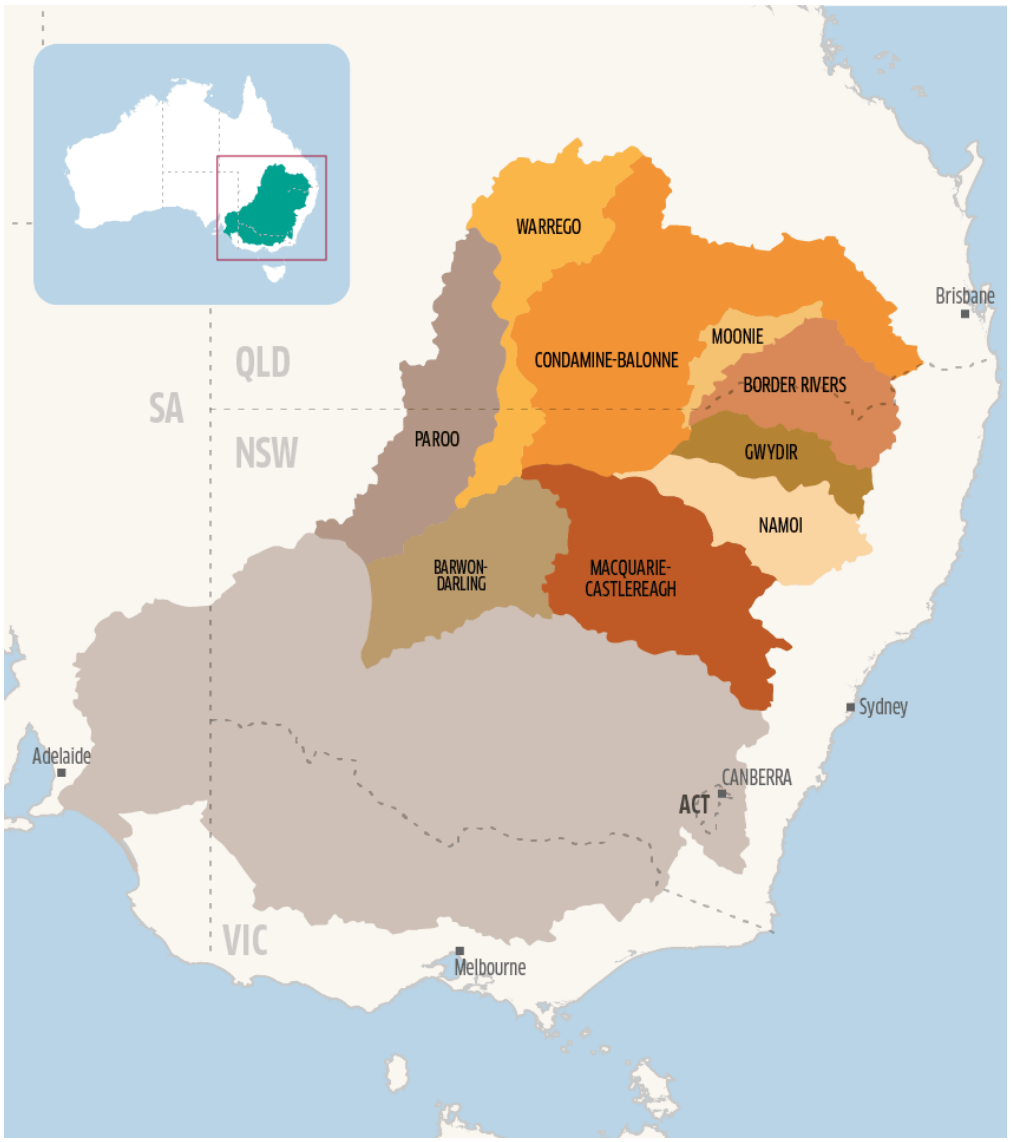

Figure 1. Murray Darling Basin with Northern Basin catchments (highlighted in colour). Source: MDBA (2024a).

The Northern Basin's climate is characterised as sub-tropical in the north and semi-arid in the west. Most of the Northern Basin's rainfall occurs in the east or over the mountain ranges and has lower rates of evapotranspiration. In the drier and flatter areas (e.g. floodplain wetlands), rainfall is very low, and evapotranspiration is naturally high (DCCEEW, 2022). Water availability in the system is driven by rainfall and evapotranspiration. The high variability in rainfall and evapotranspiration across the Northern Basin means that the water availability is also highly variable within the system. Of the available water only 5% flows into the rivers, causing river flows to be highly variable and unreliable throughout the year (DCCEEW, 2022). It should be noted that, as a whole, the Murray-Darling Basin also experiences high degree of water losses and around 86% of the Basin contributes to almost no

runoff to the river system, except during floods (MDBA, 2024b), making the entire Basin an inherently an inefficient hydrologic system (CSIRO, 2008).

Water availability in the Northern Basin also varies seasonally with rainfall and river flows occurring mainly in the summer half of the year (Figure 2). In winter, the upper catchments such as Condamine – Balonne and Warrego experience less rainfall and higher evapotranspiration resulting in lower water availability during this season.

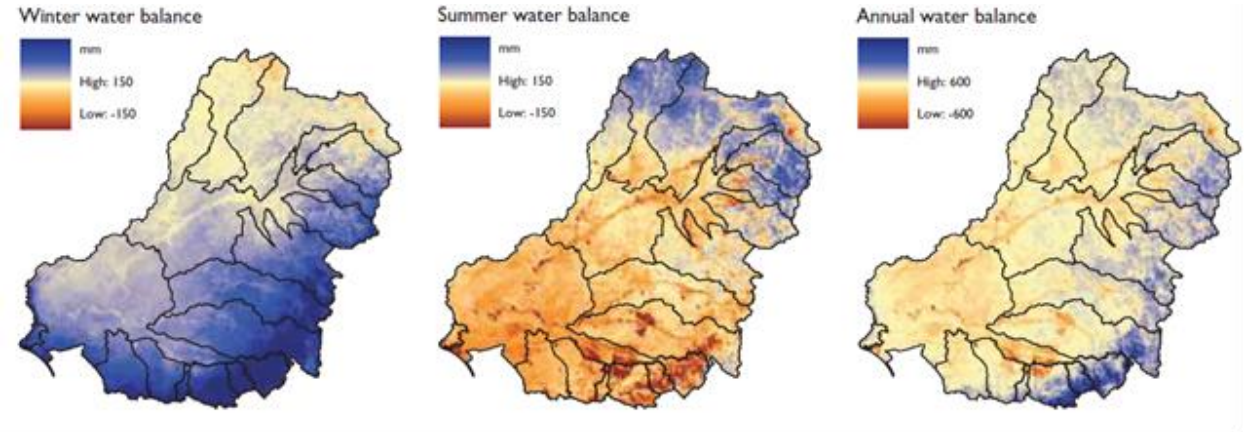

Figure 2. Annual, winter, and summer water balance spatial patterns across MDB. Red indicates when evapotranspiration exceeds rainfall and blue indicates when rainfall exceeds evapotranspiration (extracted from CSIRO, 2008).

The landscape and ecosystems have evolved to adjust to these natural, variable 'boom / bust' conditions. Through long dry spells and occasional flooding, the flow regime has evolved to support extensive floodplains and wetland ecosystems throughout the Murray Darling Basin, creating diverse habitats for a large range of species adapting to the extreme environment. These unique ecosystems also provide essential ecosystem services to the communities and First Nations people through food and resources, cultural connection, well-being, and recreation.

What is a flow regime?

A flow regime is the pattern of water flowing through a river and is fundamental to the ecological functioning of the riverine systems. There are several characteristics that makes up a flow regime (Kennard et al. 2009) by:

- the magnitude
- the timing of flows
- the frequency and duration
- daily, seasonal, and annual flow variability
- rates of change in discharge events

A flow regime can be natural or altered by water resource development such as regulating structures, urbanisation, channel modification. The key components of the flow regimes used in the Basin Plan and Basin-wide environmental watering strategy are described below and in Figure 3 (VEWH, 2019):

- Cease to flow: Cease to flows are events where there are no apparent flows in a river or partial drying of the river channel. It is a risk to environment and communities if cease to flow lasts too long in rivers or when these events are occurring more frequently than what is normally occurring in the system.

- Baseflows / low flow: Baseflows provides sustainable low-level flow in a river. It is important in connecting habitat within the channel, providing benefits to aquatic ecosystems and keeping the riverbed and lower banks wet to maintain riparian ecosystems.

- Freshes: Freshes are short duration flow events that submerge the lower section of the river channel and occurs several times a year. They are important for providing necessary nutrients to plants on riverbanks and facilitate movements for fish and other animals along the river.

- High flows / Bankfull flows: High flows or bankfull flows are larger flows than freshes that can fill up the river channel without any spilling onto the floodplain. They provide benefits to plants higher up along the river banks or on higher channel benches, facilitate larger fish species to move along the river, and encourage breeding for fish and other animals. They also move sediments and help shape river channel.

- Overbank / overland flows: Overbank / overland flows are flows that spills onto the floodplain. These flows fill wetlands and improve floodplain productivity, providing crucial ecological connectivity between rivers and floodplains, providing feeding and breeding opportunities for waterbirds, fish and other animals.

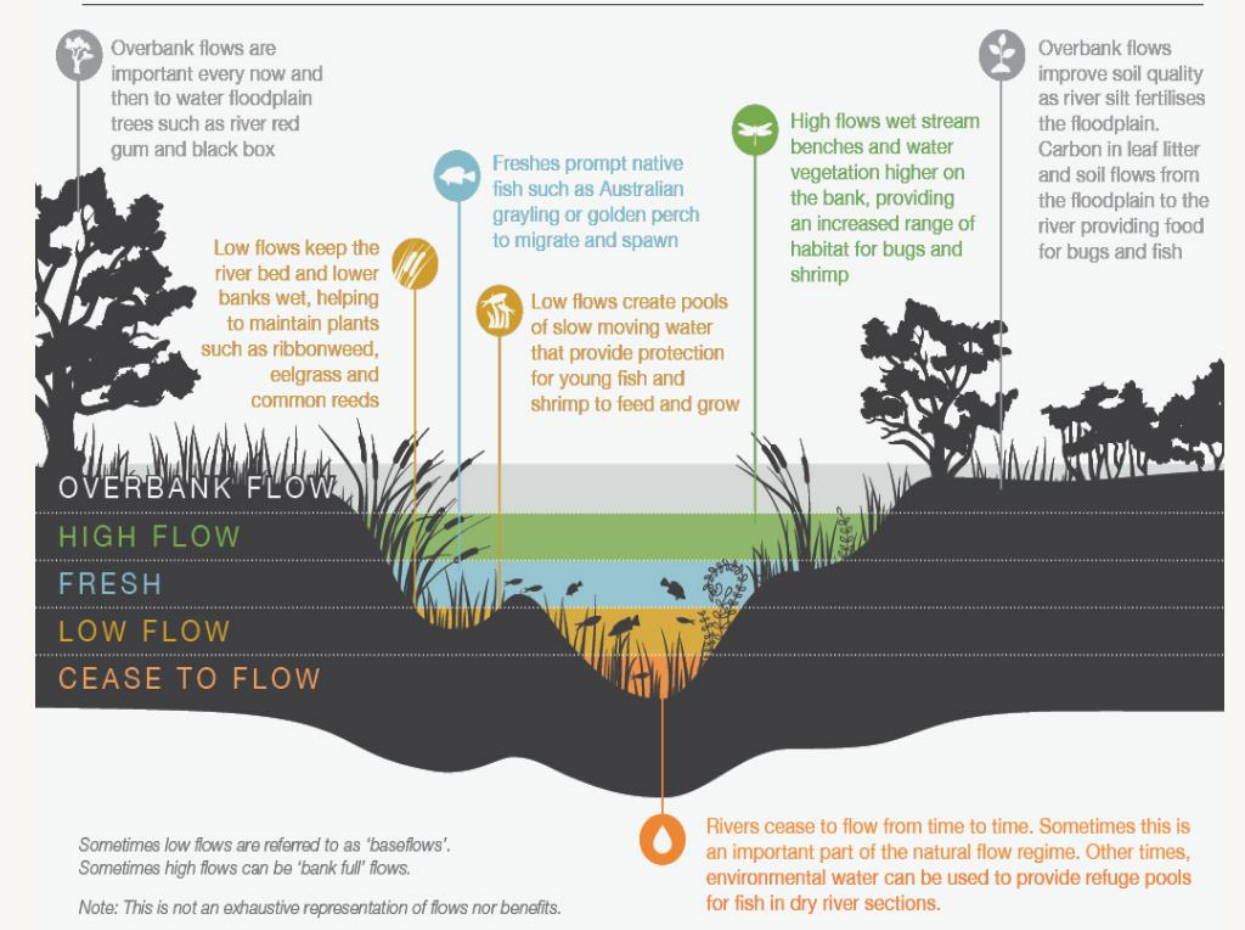

Figure 3. Components of a flow regime (extracted from VEWH, 2019).

Regulation in the Northern Basin

The natural flow regime in the Northern Basin is highly variable and since European settlement, the system has been used for agricultural, industry and drinking purposes. Regulating structures such as dams and storages, river diversions and water transfer pipelines were built to cope with the flow availability and variability in the system to allow for longer term storages and releasing water during drier years (CSIRO 2008). These regulating structures altered many hydrological systems including lakes, rivers, wetlands and groundwater resources, and the flow regime has been altered from what it was naturally.

These regulating structures alter the flow regime by:

- Less water flowing downstream overall and reducing downstream flooding
- Reducing flows in summer and extend low flow periods as water users pump water out of waterways for irrigation
- Reduce frequency of small freshes
- Releasing water from dam during summer for irrigation that reverse the natural flow regime downstream, with higher flows during summer and autumn rather than winter and spring
- Increasing events where rapid changes in water depth and speed when water is released from dam

The degree of regulation varies across the Northern Basin, but compared to the Southern Basin, there is less regulated flow available, which means the amount accessible to all water users is dependent on the high flow variability in the catchment.

Private storages and floodplain harvesting

Two of the main regulations in the Northern Basin are water storages and floodplain harvesting. There are a few public water storages in the Northern Basin which authorities are permitted to store and release water. These public storages are unevenly distributed across the Northern Basin, with larger water storage capacity in Namoi, no public water storage in Moonie and Paroo and very few in Warrego and Barwon-Darling. However, there are substantial numbers of private water storages (or on-farm storages) in the Northern Basin, with more than 90% of the total water storage capacity in Barwon-Darling, Paroo, Warrego, Condamine-Baloone and Moonie region are private water storages (CSIRO 2008). Private water storages provide greater flexibility for landholders to extract and store water during drier period, in response to the highly variable hydrological conditions in the Northern Basin.

Floodplain harvesting is also prevalent in the Northern Basin. When flooding occurs, water spills over onto the floodplain as overbank / overland flows. Water users can harvest overland flows and runoff (from rainfall) during flooding events, and these are not regulated or monitored. Arrangements to license floodplain harvesting have only been introduced recently (MDBA, 2023).

Private water storages and unconstrained floodplain harvesting reduce flows that are crucial in maintaining floodplains ecosystems and reduce connectivity across rivers, wetlands and terrestrial systems (MDBA, 2019 NSW, 2021; UNSW, 2019). Private water storages are often unregulated and unmonitored which means flows are vulnerable to over-extraction, water theft or poor compliance especially during drier periods. The lack of large water storage public dams also means that water managers have less control over providing environmental flows within seasons and between years. This can have adverse impact on floodplain and riverine ecosystem that rely on the natural flow variability to thrive.

While historically it has been difficult to estimate the volume of floodplain harvesting, regulating floodplain harvesting is necessary to ensure environmental and community outcomes are protected (MDBA, 2019). Accounting for floodplain harvesting by putting in place compliance measures and introducing licensing to ensure the use of floodplain harvested water is within legal limits in Northern Basin (MDBA, 2023).

There are proposed changes to licensing, monitoring and account arrangements in New South Wales and Queensland to understand how much water can be allowed to be harvested under the limits. In some areas of the NSW within the Northern Basin, there has been growth in floodplain harvesting causing an increase in water diversions above the legal limits. As such, the NSW government is proposing floodplain harvesting should not exceed the levels used in the year 2000, and the limits will change to account for more accurate floodplain harvesting use. A Floodplain Harvesting Action Plan has also been developed to address recommendations and improvements to floodplain harvesting management (e.g. incorporating into water resource plans) (MDBA, 2023). In Queensland, they have recently committed to ensuring full measurement and licensing of the Border Rivers and Moonie floodplains before the Basin Plan review in 2026. The Queensland Government will continue to work with floodplain harvesters to improve measurements and licensing and once floodplain harvesting is

fully measured and licensed, there is plans to revise water limits and update water resource plans (MDBA, 2023).

Millennium drought

During the Millennium Drought, the Northern Basin experienced the effects of drought between 2001 – 2009 (Figure 4). A significant decline in rainfall was observed during the autumn season between 2001 – 2009, roughly 35% less than normal (Leblanc et al. 2012).

Impacts of the Millennium drought were not as severe in other seasons particularly in Spring, however due to the high climatic variability in the Northern Basin, the effect of drought is felt across the Basin and is amplified with low soil moisture, low rainfall and high evapotranspiration, and human-induced factors such as increased uptake of private storages and floodplain harvesting.

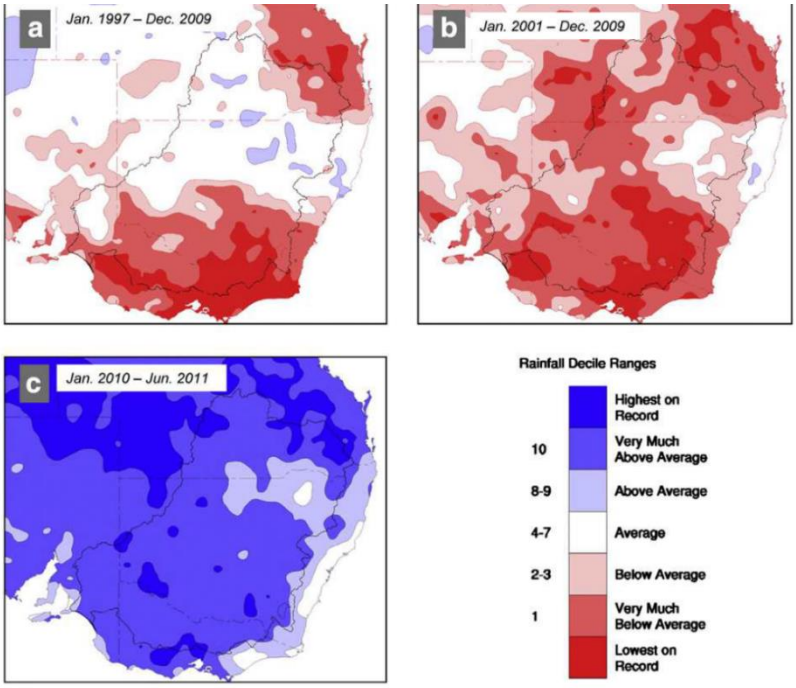

Fig. 10. Maps of rainfall deciles across the south eastern part of Australia including the MDB (catchment boundary is shown as a black line) for the rainfall from January 1997 to December 2009 (a); from January 2001 to December 2009 (b) and from January 2010 to June 2011 (c). Deciles are expressed from the long-term 1900 to 2011 climatology. Maps courtesy of the National Climate Centre using AWAP data (Jones et al., 2009), Australian Bureau of Meteorology, Melbourne, Australia.

Figure 4. Rainfall deciles across Murray Darling Basin for rainfall from January 1997 to December 2009 (Source: Leblanc, 2012).

Managed flows in the Northern Basin

Maintaining healthy ecosystem under the pressure of regulation and drying climate condition is challenging. With most parts of Northern Basin being an unregulated system, it is challenging for water managers to provide environmental flows into the systems. Environmental flows have been provided in regulated systems where possible and contribution of the Basin Plan to improve flow conditions in the Northern Basin have been limited to the Macquarie River and some part of Gwydir River (MDBA, 2020). Some examples of environmental flows are:

- Two large flows between 25 – 30 GL of water were delivered between April to July 2018 – 2019 as part of the two Large Northern Basin connectivity flows. These two events provided flows to connect in-channel pools and inundate river channels in the Gwydir, Mehi,

Dumaresq, Macintyre, and Barwon-Darling Rivers which reduced the duration of cease-to-flow periods (MDBA, 2020).
- Environmental flow delivery in the Macquarie River system to avoid long periods of low flows / baseflows.

Since implementation of the Basin Plan, hydrological conditions in the Northern Basin have largely declined (MDBA, 2020). The Basin Plan 2020 evaluation identified that there are more occurrences of cease-to-flow periods in many Northern Basin Rivers driven by the continued drier conditions. While some components of the flow regimes were maintained such as freshes in Border Rivers and Gwydir system, in most other hydrological conditions despite adding environmental water, there has been a reduction in flows.

Decreased flow availability since the Millennium Drought

The reduction in rainfall since the Millennium Drought has impacted the Northern Basin, with the largest reduction occurring in the Macquarie, Namoi-Peel and Border Rivers catchments (BoM, 2020). Soil moisture levels have also dropped significantly since Millennium Drought, driven by decreased rainfall and increased temperature and evapotranspiration.

Declining flow availability is observed in the Northern Basin, with average annual flows declining for the periods after 1996 compared to pre-1996 (BoM, 2020). Between 2012 – 2019, volumes of flows in the Northern Basin (average of 199 GL/year) were much less than in the Southern Basin (2,027 GL/year). Flows along the Barwon-Darling River over 2012/2013 – 2018/2019 were 66% and 72% of expected at Bourke and Wilcannia, respectively, with two of the 13 sites surveyed receiving less than half of the water expected (Wentworth Group of Concerned Scientists, 2020).

While some of these reductions were attributed to natural climate variability and climate change, Grafton et al. (2022) found that reduction in flow availability could be caused by anthropogenic influences, rather than climate change itself. Of note, these anthropogenic influences are mostly extractions that significantly impacted on baseflows particularly downstream of Bourke, and factors such as water theft, lack of compliance, water extraction rules and floodplain harvesting caused the declines of flows in the Northern Basin (Interim Inspector-General of Murray-Darling Basin Water Resources, 2020). In addition, the Australian Academy of Science also identified that upstream extractions was the primary cause of reduced flows in the Barka River during the drought in 2019 that led to the Menindee fish kills in the same year.

Improvements to compliance and licensing of floodplain harvesting is now underway across Northern Basin to ensure there is good understanding of how much water is needed to be remain in the river system to improve environmental health outcomes.

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2 Method

A systematic review of scientific and grey literature was conducted to identify studies that provide evidence of social effects linked to water variability within the Northern Murray-Darling Basin (NMDB) catchments. In this study we sought to identify studies that report social effects that are caused by both natural drivers (such as floods and droughts) and institutional drivers, including policies and programs that influence water variability (such as water allocation and water markets). It is important to note that, as agreed in the inception meeting with the CRC, this research did not seek to identify economic values impacted by water flow variability, noting that this research has been conducted by Wheeler et al., (2023). The PICO – Population, intervention, comparators, outcomes – framework was used to achieve the review objectives. Search terms were defined by the project team, with input from the Project Advisory Committee, who have knowledge of water variability in the Murray-Darling Basin (MDB) and associated social issues.

The review was conducted between October 2023 and November 2023. For the scientific review, four databases were used to conduct the search to ensure multi-disciplinary coverage of scientific literature. These databases included Web of Science, Scopus, ProQuest and APA PsychInfo (EBSCOhost). A total of 23 search strings were used to identify a broad range of social effects impacting individuals and communities located throughout MDB and NMDB specifically (see Appendix A – Searches and terms). Depending on the functionality of the database, the search was limited to the title, abstract, keyword and/or topic (with exception of APA PsychInfo where no search type was set). The date range of articles searched was set between 2000 (to capture studies from the Millennium Drought) through to November 2023.

A total of 2,311 scientific journal articles were identified in the search. The number of papers found within each database are listed in Table 1.

Table 1. Scientific databases searched, and number of papers found.

Database	# number of papers (before duplicates removed within each database)
Web of Science	1,041
Scopus	924
ProQuest	324
APA PsychInfo (EBSCOhost)	22
TOTAL	2,311

All papers were imported into an Endnote library and 461 duplicates from the pool of papers were removed. Abstracts of the remaining 1,850 journal articles were then screened to identify relevant literature for review. Inclusion and exclusion criteria are listed in Table 2.

Table 2. Inclusion and exclusion criteria.

Inclusion Criteria	Exclusion Criteria
Research conducted in the Murray-Darling Basin	Research conducted outside of the Murray-Darling Basin
Study is presented as a peer-reviewed journal article	The article is presented as a systematic review, discussion paper or book chapter
The research presents social effects relating to water flow variability	The research focuses on biophysical aspects of water flow variability, rather than social aspects

The research involves collection of primary data or uses existing data sets to describe social phenomena	The research uses models to make economic predications and/or forecasts

This process resulted in a total of 89 journal articles to be reviewed.

In addition, grey literature was identified using the search terms and websites listed in Appendix A – Searches and terms**.** Research reports presenting social effects of water flow variability in MDB were also suggested by the Project Advisory Committee. Four grey literature reports and a video were included in the pool of final sources for review (MDBA, 2020; MDBA, 2016; Ngarrindjeri Aboriginal Corporation, 2022; Schirmer & Mylek, 2020; Sefton et al., 2020), resulting in a total of 93 papers and 1 video.

Each source was interrogated to identify:

- The type or driver of flow variability discussed in the study (described below).
- The social effect associated with variability in water flow, including who is affected, where and how.

Three categories of water flow variability identified in the analysis of the literature were:

- Low water access/availability within river systems: which includes any mentions of effects on communities as a result of periods of low water flow availability e.g., drought, dry periods, etc.
- Flooding: which includes any mentions of effects on communities as a result of very high or above average water availability within the river system, including floods.
- Regulation-driven variation in water flow: which includes any mentions of effects on communities as a result of policies and programs which affect the flow of the river system.

This information was captured in an Excel spreadsheet together with information on the approach used to conduct the research in terms of whether it used a qualitative, quantitative, or mixed methods approach. Analysis of identified literature was also guided by the Values Assessment Typology developed by the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Service (IPBES, 2022). This typology accounts for the spectrum of ways in which people value, relate to, and derive benefit from nature, including waterway environments. It reflects diverse knowledge systems and worldviews to make visible those relationships people have with waterways that are often neglected in management decision-making (IPBES, 2022), and potentially research also.

The Values Assessment Typology provides four categorises which represent the diversity of human-environment relationships and values. In identifying the types of social effects that have been researched in relation to water flows in the MDB, this typology serves to highlight the types of human-environment connections that have attracted attention in dedicated studies, and those that have been overlooked. While all four categories may not require equal attention, they provide a structure for highlighting gaps and can thus support dialogue with the aim of identifying future research needs and priorities.

The categories are described in Table 3 as defined by IPBES (2022). Included in the table is the term that is used for each category in this particular study. These terms more accurately capture the social effects identified in relation to water flow variability in the MDB and thus reduces ambiguity.

Table 3. Categories adapted from Values Assessment Typology (IPBES)

Values Assessments Typology Category	Definition	Term Adopted in this Study
Living from	Refers to the importance of 'using' natural resources,	Waterway use

	including water, to sustain people's livelihoods and needs, including food.	
Living in	Refers to the values people attribute to using nature as social settings. This includes providing a place to live and carry out cultural practices and recreational activities	Waterways as social settings
Living with	Refers to valuing ecological processes that sustain all of life, including humanity. This includes learning how to live with and take care of environmental resources systems (i.e., stewardship).	Stewardship and ecological learning
Living as	Refers to the relationships people have with the environment when they see nature as part of themselves - physically, mentally and spiritually – and not separate.	Spiritual and cultural connections

Within each paper reviewed, the type of human-environment connection was recorded in the Excel spreadsheet.

The findings of the review were then used to create a conceptual framework that depicts social effects from variability in water flows in the MDB (separated into low water, flooding, and managed/ regulation-driven variation), noting effects observed specifically within research conducted in NMDB. The overall conceptual framework was then presented in a workshop to gain feedback from stakeholders located in the NMDB. This workshop sought to ground truth the conceptual framework and identify potential gaps. Further details about this workshop are provided in Section 4.

3 Results

Systematic literature review findings

The conceptual framework based on the systematic literature review is presented below in three tables according to type of water flow variability (low, flooding, and regulation-driven).

The social effects included represent those observed in research conducted in the MDB overall (including the Southern Murray Darling Basin (SMDB)), with those specifically observed in the NMDB highlighted with an asterisk (*). It is important to note that while the conceptual framework depicts the range of social effects identified in the literature, it does not give weight to the importance or salience of those social effects for different people or communities as this information varies spatially, temporally as well as within and across communities. Furthermore, the social effects in italics have been integrated into the conceptual framework based on a gap identified within the stakeholder workshop.

Table 4. Conceptual model of water variability effects on communities (based on literature review and stakeholder workshop)

Low water access/availability within river systems has an effect on:			
Waterway Use	Waterways as Social Settings	Stewardship and ecological learning	Spiritual and Cultural Connections
Livelihoods* Physical and mental well-being* Participation in water use decision-making* Use of waterway resources to sustain people (e.g., food and drinking water)	Individual identity* Community identity and well-being Waterways as social settings (i.e., a place for social gatherings and interactions)* Waterways for recreation* Property values	Places of learning and knowledge exchange* On-farm innovation (i.e. management water scarcity) Stewardship participation, roles and responsibilities	Spiritual and cultural connection* Kinship with rivers and other species Physical and mental well-being derived from connecting to waterways*
Flooding has an effect on:			
Waterway Use	Waterways as Social Settings	Stewardship and Ecological Learning	Spiritual and Cultural Connections
Livelihoods	Waterways for recreation Human health *Community identity and well-being* Property prices (*and insurance costs*)	Places of learning and knowledge exchange On-farm innovation (i.e., management of pests)	
Regulation-driven variation in water flow and access has an effect on:			
Waterway Use	Waterways as Social Settings	Stewardship and Ecological Learning	Spiritual and Cultural Connections

Livelihoods* Physical and mental well-being Participation in water use decision making* Use of waterway resources to sustain people (e.g., food and drinking water)	Individual identity Community identity and well-being Waterways as social settings (i.e. a place for social gatherings and interactions)* Waterways for recreation*	Places of learning and knowledge exchange* Stewardship participation, roles and responsibilities*	Spiritual and cultural connection*

*Includes studies from the northern Basin. Effects in italics refer to knowledge gaps identified by stakeholders.

The total number of papers reporting social effects associated with each of the categories of water flow variability are shown in Figure 5, Figure 6, and Figure 7. Detailed descriptions of each social effect are elaborated in the following section. Additionally, these descriptions have been separated into studies that focus on First Nations (Indigenous) and non-Indigenous peoples[1]. This is due to the way in which studies focus on Indigenous relationships to waterways specifically, typically expressing the social effects in a way that span each of the four categories (that is, a holistic experience of the water variability effects). Thus, it is more appropriate to reflect these impacts in a non-compartmentalised way. Studies reporting on social effects for non-Indigenous people, on the other hand, report on social effects that typically span only one or two human-environment relationship categories.

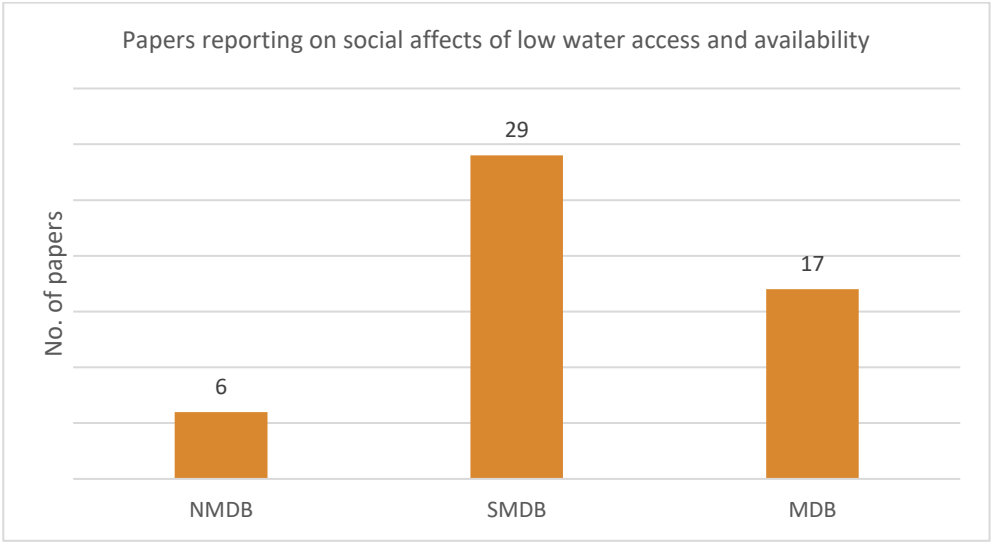

Figure 5. Papers reporting on social effects of low water access and availability

[1] It was agreed between the project team and the Advisory Committee not to search specifically for effects on First Nations peoples, as this is the focus of other CRC work. However, the literature review revealed a number of First Nations-focussed studies, which have been retained in this review as they provide a valuable resource for future work with First Nations communities.

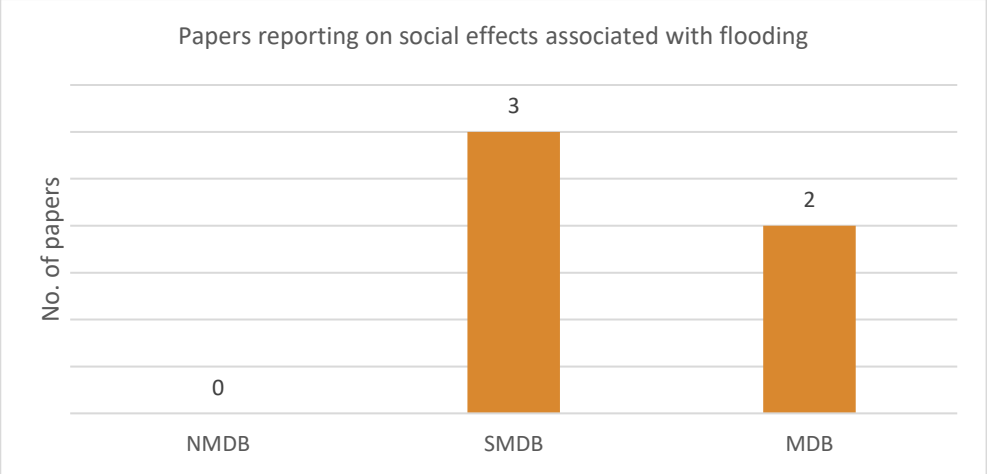

Figure 6. Papers reporting on social effects associated with flooding

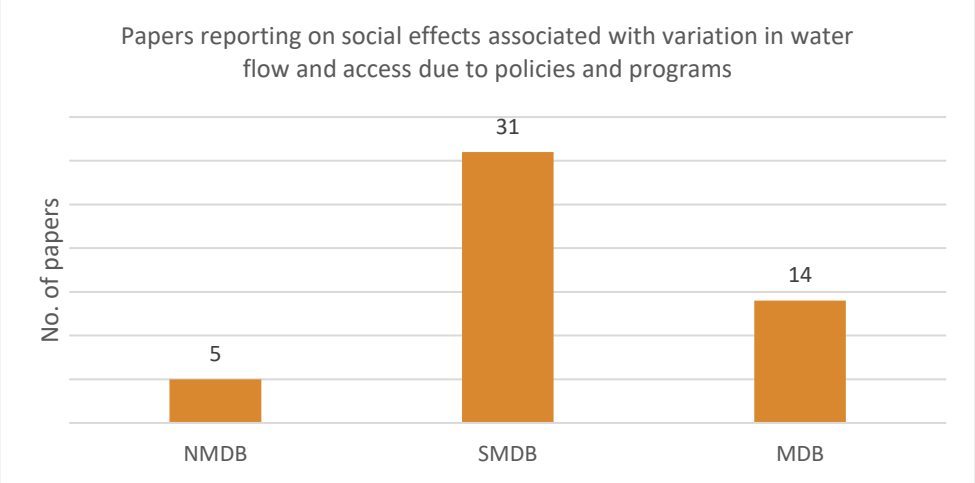

Figure 7. Papers reporting on social effects associated with variation in water flow and access due to policies and programs

Figure 8 shows the number of papers discussing social effects in relation to the different human-environment relationship categories adapted from the Values Assessment Framework.

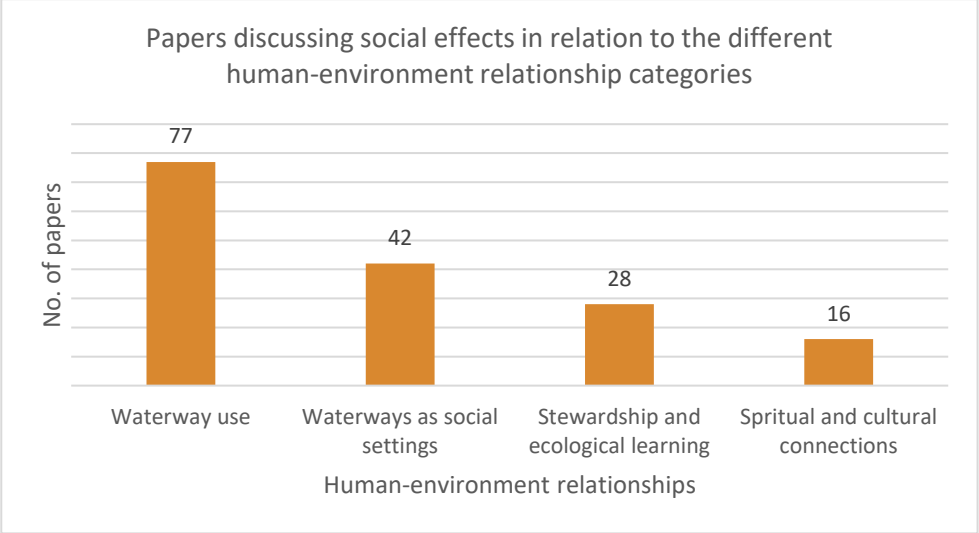

Figure 8. Papers discussing social effects in relation to the different human-environment relationship categories

3.1 Non-Indigenous social effects

3.1.1 Low water access and availability

Overall, the greatest number of papers reviewed reported on social effects associated with low water access and availability compared to variation caused by floods or variation caused by regulated flows.

Most papers reported on social effects associated with low water access and availability in SMDB (29 studies), followed by MDB at large (17 studies) with only 6 studies reporting on social effects within NMDB.

Low water access and availability was mostly discussed in relation to drought, though it was also expressed in relation to over-extraction, which reduces the amount of water available to certain users within the Basin. Some papers discussed effects of low water access and availability due to water allocation specifically[2].

Waterway Use

The majority of papers discussing low water access and availability were concerned with SMDB (21), followed by MDB (14) broadly and NMDB (6).

Livelihoods: Most studies reporting on the social effects of low water access and availability discussed effects relating to people's 'use' of water resources. Most notably was the effect of drought, over-extraction, and reduced allocation on people's livelihoods, specifically on farmers' income and practices (Connor et al., 2014; Dinh et al., 2017; Freak et al., 2022; Kuehne & Bjornlund, 2010; Martin et al., 2004; MDBA, 2016; Mooney & Tan, 2012; Pearson & Dare, 2021; Sefton et al., 2020; Smith & Maheshwari, 2002; Ticehurst & Curtis, 2015, 2018; S. A. Wheeler et al., 2020; S. A. Wheeler & Zuo,

[2] In papers reporting on the effects of water allocation in terms of *reduced* water access or availability specifically, these social outcomes are discussed in this section. In papers reporting on the *variability* of water access and availability due to programs and policies (including water allocation) whereby some people, for example, may increase access and some people have reduced access, these social effects are reported in the section below.

2017; Zuo et al., 2011), with variation in scale of impact observed in relation to farm size and crop type in some studies. A small number of papers mentioned livelihood impacts in NMDB specifically due to reduced availability or access to water, including drought (Aitkenhead et al., 2021; Asghari et al., 2021; MDBA, 2016).

Several articles discussed how water scarcity and drought has an effect on water trading within the Basin (Haensch et al., 2019), highlighting a direct interaction with the regulated flow regime. A number of studies highlighted how drought increases water prices. While water markets benefit some landholders by selling their allocations, others are negatively impacted by the high prices they have to pay (Lesslie et al., 2023; Loch et al., 2012; Mai et al., 2019). Those farmers who are negatively impacted by high water prices - a consequence of water scarcity - may suffer financial hardship and reluctantly exit the industry and sell their property.

Mental health: Several authors tied livelihood impacts of low water flow to mental health issues (Xu et al., 2023; Yazd et al., 2019, 2020). Alston et al. (2017; 2018; 2011, 2013) applied a gender lens to explore how men and women experience the effects of drought differently in terms of their work roles, as well as their mental and physical well-being. Casey et al. (2022) conducted research on women's livelihood impacts in NMDB specifically and how mental health issues are managed by staying connected within community and social networks.

Water resource decision-making: A few articles discussed the relationships between low water flow and water management decision-making. In most studies, water users felt left out of government decision-making, which led to feelings of uncertainty (Sobels, 2009). Bryant et al. (2016) however, found that in times of limited water access irrigators were more likely to work collectively to meet their water needs compared to times of water abundance.

Waterways as Social Settings

The majority of papers discussing impacts of low water access and availability on use of waterways as social settings focused on MDB and SMDB, with only three papers reporting social effects in NMDB. The key effects identified related to identity and the use of waterways as social settings, and enjoyment of places including the aesthetic characteristics.

Individual identity: Direct connections were made in the literature between the impact scarce water resources can have on people's livelihoods (as explained earlier) and the effect this has on identity at both an individual and community level[3]. Casey et al. (2022), in studying how rural women in NMDB responded to impacts of drought, identified livelihood adaptation strategies whereby women engage in new entrepreneurial activities and thus create new identities as they participate to a greater extent in off-farm activities. The study illuminates creative responses to water scarcity and economic hardship through individual innovation.

Several studies highlighted how water scarcity has prompted many to exit the agricultural industry by selling their land and associated water allocation (Alston & Whittenbury, 2013; Mooney & Tan, 2012; Wheeler et al., 2020; Wheeler & Zuo, 2017). As such, an individual or family who have relied on the use of water to sustain their livelihood is likely to re-orientate their relationship to a given waterway environment; an environment which has long been integral to their identity as a farmer and thus the way land is used and managed within a catchment. Individual identity may also be changed through engaging in off-farm work (Alston et al., 2018b) as mentioned above.

Community identity and well-being: The literatures shows that low water access or availability - often combined with water trading (discussed below) - drives changes within social landscapes throughout the Murray-Darling Basin (Sefton et al., 2020). As large numbers of farmers exit the industry, this affects the sustainability and cohesion of communities, as well as people's sense of belonging (Sefton et al., 2020; Alston, 2011; Alston et al., 2017; Head et al., 2018; G. M. Robinson & Song, 2023). Research conducted in NMDB in particular described communities experiencing job losses, declining health due

[3] Research shows that occupational identity, particularly in relation to agriculture, influences land use and management and is therefore important for consideration in a catchment management and water flow variability context within the Murray-Darling Basin (Groth T.M & Curtis, 2017).

to reduced services and threats to domestic water supply, with variation in the type and scale of impact experienced both within and across communities (Sefton et al., 2020). Vidyattama et al. (2016) similarly concluded that drought in MDB is correlated with the migration of young people out of certain Basin communities, identifying employment and educational opportunities as the main pull factors.

Social settings, recreation, and property values: Recognition of the contribution water flow makes to people's enjoyment of places, particularly in terms of their aesthetic qualities and in providing recreational opportunities, were explored in the literature. Low water flow was found to reduce people's enjoyment and use of waterways as places for recreation and social gatherings in NMDB (MDBA, 2016), including for recreational fishing (Crase & Gillespie, 2008; Ochwada-Doyle et al., 2023). Tapsuwan et al. (2015) similarly found a relationship between water flow and people's appreciation of the aesthetic and recreational attributes of waterways, which are reflected in property values, with landowners showing a preference for neither times of water scarcity nor flooding. This suggests low and high flows may decrease property value.

Learning and Stewardship in Waterway Environments

Papers within this category explored the importance people place on fulfilling their roles and responsibilities in taking care of waterways environments, emphasising a sense of stewardship in protecting ecological function. It also captures the importance of waterways environments as places of learning; both in creating new knowledge and as sites for communicating knowledge to others. The majority of papers discussing impacts of low water access in relation to learning and stewardship in waterway environments was within SMDB, followed by MDB broadly and NMDB (with only two papers). Two key themes emerged in the literature: (i) learning and innovation in farming systems, and (ii) education and environmental degradation.

Learning and innovation in farming systems: A number of studies link generating new knowledge and learning about river flow with resource use. A study by Head et al. (2018) described how times of drought prompt landholders to pay more attention to data generated to measure biophysical processes associated with water flow to improve their overall understanding of the river system. Similarly, Robinson and Song (2023) reported that in times of drought farmers learn to live with water scarcity by engaging in innovation and practice change. Innovations for dealing with drought can sometimes prompt farmers to engage in new stewardship activities. Smith and Maheshwari (2002), for example, found that irrigators installation of on-farm water storage as a means to deal with drought was also used to keep nutrient-rich water out of the river system. A study by Herring et al. (2022) however, found that periods of low scarcity, compared to high flows, reduces the willingness of farmers (in this study rice farmers) to participate in a stewardship program aimed at conserving the habitat of an endangered water bird.

Education and environmental degradation: Environmental degradation caused by low flows has also inspired public education campaigns to promote responsibility in caring for the environment (Vanclay et al., 2004). Stewart (2004) explored how canoeing the Murray River provides people with an experiential learning experience to directly observe the impacts of low flows that are caused by damming the river for irrigation. Prolonged drought has also promoted the implementation of educational campaigns, particularly for irrigator communities, to assist them in living with water scarcity (Golding et al., 2009; Golding & Angwin, 2009). Similarly, Thomas et al. (2016) describe a citizen science project that engaged the community in learning how to better respond to the environmental impacts of drought which resulted in stronger social networks being formed.

Spiritual and cultural connections

The review did not identify any research on social effects from low water access and availability on non-Indigenous people's spiritual and cultural connections to waterways in MDB.

All papers discussing social effects of low water flows in relation to spiritual and cultural relationships with waterways were associated with Indigenous perspectives and experiences. These will be discussed in the 'Indigenous social effects' section further below.

3.1.2 Floods

Minimal research on social effects of high flows has been conducted, with only 5 studies identified in total that relate to floods. Three of these were conducted in SMDB and two in MDB.

Waterway use

A total of two papers discussed impacts of floods on waterway use, both within SMDB.

Livelihoods: A study by Skinner (2023) discussed the effect of flooding on farming livelihoods, specifically viticulturalists in South Australia. For these farmers, floods provide environmental benefits which improve production. The study also reported how floods provide an important social benefit as farmers work together in learning how to manage the impact of flood waters, thereby building and maintaining social relations within the community. Research by Head et al. (2018) described livelihoods impacts associated with excessive rainfall which increase the incidence of pests on farms.

Waterways as Social Settings

Three papers also discussed impacts of floods on waterways as social settings, with no studies conducted in NMDB.

Social settings: A study conducted by Ochwada-Doyle et al. (2023) used survey data collected from recreational fishers to examine how environmental changes affecting ecological processes can influence human behaviour, i.e., recreational fishing. The study concluded that ecological fluctuations, such as flooding, can indeed have an impact on recreational fishing behaviour which may affect the availability of catch and/or access to sites.

As mentioned earlier, high flows (such as floods) and low flows influence the desirability of properties within MDB, which affects property prices within riverine landscapes (Tapsuwan et al., 2015) and thus can have a bearing on the social demographics of an area.

Health: A study by Tall et al. (2020) found that flooding events within MDB are linked to a higher incidence of Ross River Virus. Findings show that late spring to mid-summer flooding increases the odds of late summer outbreaks.

Learning and Stewardship in Waterway Environments

Two papers identified social affects linked to floods in relation to waterways as places for exchanging ecological knowledge and learning (Skinner et al., 2023; Tall et al., 2020).

Places of learning and knowledge exchange: As mentioned earlier, Skinner et al., (2023) describes how flooding events drive collaboration among farmers to manage impacts of flood waters in grape growing regions, thereby providing an important social function.

Learning and innovation in farming systems: As identified by Head et al. (2018) increased incidence of pests, which result from flood conditions (including humidity), can increase on-farm innovation among irrigators to manage and monitor pests, including fungus.

Spiritual and Cultural Connections

The review did not identify any studies on the social effects from floods on non-Indigenous people's spiritual and cultural connections to waterways in MDB.

All papers discussing social effects of variability in water flows in relation to spiritual and cultural relationships with waterways were associated with Indigenous perspectives and experiences. These are discussed in the 'Indigenous social effects' section below.

3.1.3 Variation in water flow and access through policies and programs

This section reports on the social effects resulting from people's experiences of variation in water flow and access that are due to policies and programs. These policies and programs can increase water access and availability for some people and not for others, for example via water markets/trading, water

allocation (licences), environmental flows, and cultural flows. These tools and strategies are controlled by management authorities and are typically in response to environmental and/or social needs. For example, in times of drought, water allocation of water licences may be restricted and water markets may see an increase in water price. Studies reported in this section discussed these management tools and mechanisms in a general way, or the impacts they have in terms of providing more water access or availability to some and less to others. The majority of papers were conducted in SMDB, followed by MDB and NMDB (five papers).

Waterways use

Most papers discussed the impact of water variability due to policies and programs on livelihoods, particularly in SMDB. Social effects in terms of domestic water use, mental health impacts, and participation in decision-making were also reported in the literature.

Livelihoods: The impact of managed water flow on livelihoods was discussed in relation to: (i) the buyback of water entitlements through water markets, and (ii) water allocation more generally. Water recovery through buybacks and water markets were found to affect farmer livelihoods and decision-making, including managing risks (Alston & Whittenbury, 2011; Douglas et al., 2016; Edwards et al., 2008; Gross & Dumaresq, 2014; Hasselman & Stoker, 2017; Lesslie et al., 2023; Loch & Bjornlund, 2010; Sefton et al., 2020; Turral et al., 2005; S. Wheeler, Bjornlund, et al., 2012; S. Wheeler, Zuo, et al., 2012; S. A. Wheeler, Zuo, & Bjornlund, 2014; S. A. Wheeler, Zuo, & Hughes, 2014; S. A. Wheeler & Cheesman, 2013; Zuo et al., 2011, 2014; Zuo, Nauges, et al., 2015). Water investors were also found to derive financial benefit (Seidl et al., 2020). Many studies reported how these water management mechanisms create both winners and losers (Head et al., 2018; Kiem, 2013; Lukasiewicz & Baldwin, 2017; Patrick et al., 2014; G. M. Robinson & Song, 2023; Zuo et al., 2012), depending on farm scale and type. Alston et al. (2017) explored the differential impact the buyback of water licences have on gender roles within the dairy industry. Times of drought, for example, can increase water prices, benefiting those choosing to sell water, while negatively impacting those needing to buy water to maintain production (Loch et al., 2012; Mai et al., 2019). Water trading can provide a form of income for landholders which can flow through to create employment opportunities within the wider community (Mai et al., 2019). In NMDB, "higher recovery volumes are linked to improvement in floodplain grazing" (MDBA, 2016, p.14), with buybacks also associated with employment losses throughout the wider community (MDBA, 2016).

Water allocations were also found to affect farmers livelihoods, particularly in relation to income and cropping decision-making (Grafton & Jiang, 2011; G. M. Robinson & Song, 2023; Wheeler et al., 2021; Wheeler & Marning, 2019). Keogh (2004) conducted a study in NMDB to explore how accessing information relating to water availability, including via allocations, has an influence on livelihood strategies in relation to crop type and area. Tan et al. (2012) explored stakeholder perceptions of over-allocation within NMDB, and the negative impact this can have on farming livelihoods. Over allocation can have a significant impact on downstream communities particularly (Sefton et al., 2020). Another study carried out within NMDB explored different climate change and water allocation scenarios to identify effective adaption strategies for cotton growers to remain viable with reduced water access (Williams et al., 2018).

Domestic use: A report by MDBA (2016) on economic, social, and environmental outcomes from water recovery highlighted the importance of ensuring sufficient flows with river systems for domestic water use.

Mental health: As identified with low water flows, the management of these flows also affects people's mental health. Farmers can be positively or negatively impacted by water allocation and trading which can either have a positive or negative impact on mental health (Alston & Whittenbury, 2011; Mai et al., 2019; Wheeler et al., 2018). Negative impacts include the distress that can be caused by uncertainty and lack of security relating to water access and volume of availability (Kiem, 2013; Wheeler et al., 2018), as well as the uncertainty and confusion among people in response to Government decision-making surrounding policies and reform (Alston et al., 2016).

Decision-making: Social effects were identified in relation to decision-making processes and governance structures underpinning management of water flows (Lukasiewicz & Baldwin, 2017), particularly for irrigation communities (Alston et al., 2018b; Alston & Whittenbury, 2011). Wheeler et al. (2017) identified concerns among communities who felt local voices were overlooked in Government decision-making processes, which will potentially lead to negative impacts for some segments of society.

Waterways as Social Settings

Individual identity: Management of water flows was largely discussed in terms of the effect water allocation has on identity at an individual level, as well as community level. For individuals, mechanisms allowing farmers to sell their water allocation provides a pathway for them to leave the industry to either retire or take up employment elsewhere (Sefton et al., 2020; Alston et al., 2018a; Alston & Whittenbury, 2013; Edwards et al., 2008; Gross & Dumaresq, 2014; Loch & Bjornlund, 2010; Wheeler et al., 2018; Zuo, Wheeler, et al., 2015). Conversely, enabling farmers to purchase water when needed provides them with a greater sense of security allowing them to stay on the land and potentially hand their farm down to the next generation (Wheeler et al., 2012).

Community identity and well-being: At a community level, water buybacks and trading have an effect on the social landscape as individuals leave the agricultural industry, generating flow-on impacts (positive and negative), such as the employment of others (on- and off-farm), which can affect the overall sustainability of a given community (Head et al., 2018; Mai et al., 2019; Roobavannan et al., 2017), as reported by MDBA (2016) in NMDB specifically. As water trading can create both winners and losers (as noted earlier), the 'sense of community' may be negatively impacted by water markets (Alston & Whittenbury, 2011; Robinson & Song, 2023), particularly as a result of changing land use patterns within a given region, as observed in irrigation areas (Alston & Whittenbury, 2011).

In terms of management of 'environmental flows' specifically, Jackson (2022) explained how release of these flows can build a sense of community spirit as people come together to experience this event.

Social settings: Management of flows that ensures a certain level of water flow within a river system was identified as being important for recreational activities, with research conducted with communities in NMDB highlighting the importance of flows for recreational fishing (MDBA, 2016). Conversely, Lukasiewicz et al. (2013) found in the SMDB that release of environmental flows constrained people's recreational enjoyment of waterways whereby limits were placed on engaging in activities such as duck hunting. They noted that management decisions often overlook community and recreational needs when working to meet environmental objectives.

Learning and Stewardship in Waterway Environments

Only three papers were identified in the literature which explored impacts of regulated water flows on learning and stewardship in waterways.

Places of learning and knowledge exchange: Not only was the release of environmental flows important for building community spirit, they also provided a learning opportunity as the community observed first hand environmental changes taking place as the water was released and moved through the system (Jackson, 2022).

Learning and innovation in farming systems: Water markets have prompted irrigators to pay more attention to accessing and using data on rainfall and water prices (Head et al., 2018). Water markets have also been found to prompt farmers to learn new ways to reduce their water use on-farm to maintain profitability (G. M. Robinson & Song, 2023).

Spiritual and cultural connections

The literature review did not identify any studies on non-Indigenous social effects from floods on spiritual and cultural connection as a result of regulated water flows.

All papers discussing social effects of water variability in relation to spiritual and cultural relationships with waterways were associated with Indigenous perspectives and experiences. These will be discussed in the following section.

3.2 Indigenous social effects

Research discussing the social effects of water flow variability for First Nations peoples provided a more holistic view compared to research discussing non-Indigenous effects. In most studies, social effects spanned all four categories reflecting the intertwined connections First Nations peoples have with waterway environments. Rather than discussing these social affects according to the different frames representing how people relate and connect to waterway environments, these will be discussed in an integrated way.

3.2.1 Low water access and availability

Recognising the impacts of limited water access and availability in river systems on First Nations peoples located in NMDB, Bark et al. (2015) and Robinson et al. (2015) highlight the importance of allocating water for cultural flows to sustain cultural and spiritual connection to river systems. Jackson & Nias (2019) similarly discussed how Indigenous participation in 'Watering Country' programs can provide a food source for their communities, bring Indigenous families back to Country to camp and share cultural knowledge. To ensure cultural flows provide benefit in a socially equitable way however, Robinson et al. (2015) highlights the importance of ensuring local Indigenous participation in decision-making processes.

A number of studies describe how low flows that result from over-extraction upstream and drought has a significant impact on the ecological health of river systems and thus all aspects of Indigenous people's lives, including their health, well-being, culture, and knowledge, (Davies et al., 2021; Ellis et al., 2022; Jackson et al., 2015; Mooney & Tan, 2012; Ngarrindjeri Aboriginal Corporation, 2022). Bates et al. (2023) describes the impact of low flows on the Barkindji people located in both NMDB and SMDB. Davies et al. (2021) highlight the importance of cultural flows to sustain the health of the river system and thus people's connection with the river. It is explained, however, that many Indigenous communities through MDB have little power in influencing Government water management decisions (Hartwig et al., 2018, 2022). A study conducted by MDBA (2020) reported similar social effects associated with drought, identifying livelihood impacts, decreased water for domestic use, as well as reduced access to bush tucker and other natural resources with cultural significance. This has flow-on effects on the health and well-being of individuals and their wider communities. The study also reports that people are less likely to use waterway environments as places of learning and knowledge exchange (particularly cultural learning) and people are less likely to spend time at these places for social gathering or recreation. Similar findings were reported by Hartwig et al. (2022), who described how low flows have impacted Indigenous traditions, practices, customary obligations, ceremonies, and the daily habits that connect people to the river, including catching and eating fish, as well as swimming.

Drought, however, has also brought Indigenous peoples together as they identify ways of working collectively to care for their environment which is in poor health (MDBA, 2020).

3.2.2 Flooding

The literature review did not identify any studies on the social effects First Nations peoples experience from high water flows or floods.

3.2.3 Variation in water flow and access through policies and programs

A number of studies describe how regulated flows also impacts Indigenous peoples in the MDB, both positively and negatively. Woods et al. (2022) and Wyborn et al. (2023) call for water justice for First Nations peoples, particularly in terms of recognising and facilitating Indigenous ownership of water.

Hartwig et al. (2023)Hartwig et al. (2023) conducted a study on Indigenous participation in water trading, explaining the income benefits derived for Indigenous organisations which can be used to invest in infrastructure, further income generating opportunities, and environmental management.

Weir (2010)Weir (2010) in working with Indigenous communities in Murray River Country offers a critique of 'environmental flows' which are considered by Traditional Owners as another form of mismanagement of the river system. Traditional Owners explain that the impacts of environmental flows are narrowly concerned with measuring fish and bird breeding rather than taking a broader, more holistic look at the impact these flows have on all of life within the country.

4 Workshop to identify knowledge gaps

In February 2024, the conceptual framework was presented in an online workshop to stakeholders located in NMDB. The Project Advisory Committee provided a list of relevant stakeholders to invite. Nine participants took part in the 2-hour workshop, consisting of a range of relevant representatives from government, organisations, and the community. Following acceptance of the invitation, participants were provided with a copy of the conceptual framework and information about the overall study. It was explained via email that the focus of the workshop was to ground-truth the conceptual framework according to lived experience within NMDB, and to identify gaps whereby social effects from water variability within NMDB specifically had not been captured in the framework.

The ground-truthing exercise received valuable feedback from participants to refine the conceptual framework, particularly in terminology used to categorise water flow variability, recognising that this is a complex phenomenon that is both human-induced and natural, and potentially cannot be captured in a simple diagram. The importance of water infrastructure for NMDB particularly was discussed at length, which received minimal attention in the literature. Participants mentioned that (from their perspective) flow variability is a greater issue in SMDB compared to NMDB. Differentiation of regulated systems and non-regulated systems was also raised, as was the importance of considering groundwater.

Social complexity of the information captured in the framework was also discussed. Points of discussion included the politicised nature of certain terms used, such as 'over-extraction'. The purpose of the study was not clear for some participants, particularly as it was largely an academic exercise involving a scientific literature review. It was difficult to communicate the process of developing the conceptual framework and how it would be used by the One Basin CRC. There was a sense amongst the participants that a lot of research had already been done and this was seen by some as just another academic exercise that had little relevance to them.

In terms of constructive feedback that assisted refining the conceptual framework, while the literature review revealed negative effects on farmer livelihoods, workshop participants also noted the positive impact that floods in NMDB have on livelihoods and people's water use in general, particularly the positive effect they have on river health, groundwater and floodplains, and thus agricultural production. While positive social impacts of floods may be experienced in the long term, the damaging impact floods have on people in NMDB - at least in the short term - were also acknowledged, particularly the number of floods that have occurred within the last few years. The point was made that greater impacts are faced in towns that have had less experience with floods, such as Roma. A gap was identified in relation to the effect flooding has on insurance premiums for property owners and has thus been included in the conceptual framework (Table 4).

There was a strong sense among some participants that while livelihood impacts were of high importance, other human-environment relationships included in the framework were significantly less important. It was difficult to communicate to participants that the conceptual framework sought to capture the full spectrum of social impacts of water flow variability and did not assign weight or importance to those impacts. At least one participant was not able to see why 'livelihood' effects were listed alongside the impact of water flow variability on the use of waterways as 'social settings', for example, with the latter seen to have little significance.

In terms of spiritual and cultural connections, it was raised that these relationships do not only exist among Indigenous people, but they are also important for non-Indigenous. As this comment highlighted a gap, further research on these spiritual connections to waterways could be conducted from a whole of community perspective.

Overall, while not identified as a social effect *per se*, the participants highlighted that in going forward there needs to be greater community consultation and input into future planning within the NMBD –

"embedding community within the process" - which has been lacking to date. They would also like to see more monitoring of biophysical research within MDB system, including monitoring of river health.

In reflecting on the ground-truthing exercise, the workshop would have been more effective if run as a face-to-face meeting over a longer time period. This would allow greater time for discussion. It is difficult to communicate the purpose of creating a conceptual framework that involves synthesising 94 academic research papers and grey literature, and reports into a simplified figure. On the one hand, the conceptual framework was difficult and complex for the online workshop participants to understand, while on the other it was too simplistic to be meaningful to them. One participant noted, for example, that the social effects on community well-being is deeply complex which is not adequately captured within the framework presented.

The highly political and immensely complex nature of the topic discussed - both socially and biophysically – makes an online ground-truthing exercise with local stakeholders difficult, particularly as trust and rapport had not been established. This was further complicated by some participants' lack of familiarity with (i) research based on a systematic literature review process, and (ii) using a conceptual framework as a simplified representation of concepts and ideas. Instead of a ground-truthing exercise, the findings could have been used to design a participatory workshop with local stakeholders to identify research priorities, for example, and other activities that align with local needs in NMDB.

5 Final comments and future directions

This project identified empirical evidence published between 2000 (immediately prior to the start of the Millennium Drought) and November 2023 on the effects of variability in water access and availability to communities in the Northern Murray Darling Basin. *Variability* included low water access or availability in river systems (including drought), flooding, and regulation-driven or managed variation in water flow and access.

The review of the scientific and grey literature extended to the entire Murray Darling Basin, which enabled a comparison of the volume of research conducted in the Northern Basin with the Southern Basin, and Basin-wide. It is clear that Northern Basin communities have been underserved by research efforts in many areas, which suggests there is great potential for the CRC One Basin to make a valuable contribution to communities and knowledge through focussing future research efforts on relevant themes or specific topics. This report provides suggested areas for future research.

5.1 Future directions for research in the Northern Basin

The themes in the analysis of the literature were developed using the IPBES (2022) Values Framework, which highlighted differences in the empirical evidence according to how people value nature and natural assets such as waterways. The literature included in the review fell into four broad value types, which in plain language terms are:

1. Waterway use
2. Waterways as social settings
3. Stewardship and ecological learning
4. Spiritual and cultural connections

Knowledge gaps

While there was some Northern Basin literature present across all four themes in two levels of water variability (low and managed water), there was no Northern Basin research about ***flooding effects*** on communities. During the workshop, and subsequent informal discussions with landholders in the Northern Basin, it is clear that flooding can bring positive outcomes for agriculture. There may be other positive effects for others in the Northern Basin communities (for example, for First Nations peoples), as well as negative impacts such as damage to property. As these effects have not been documented in the literature published since 2000, this area of investigation warrants prioritisation by the research community.

This study also identified gaps in Northern Basin research on specific types of effects from low water and managed flows. These included:

Low water

- Use of waterway resources to sustain people (e.g., food and drinking water)
- Community identity and well-being
- Water resource decision-making
- Property values
- On-farm-innovation
- Stewardship
- Kinship with rivers and other species

Managed flows

- Physical and mental wellbeing
- Use of waterway resources to sustain people (e.g., food and drinking water)
- Individual identity
- Community identity and wellbeing

It is important to note that while some research has been conducted in the Northern Basin on other social effects of water variability, it is far from being comprehensively studied. There remains a need for further research on all aspects of social effects across the region.

5.2 Limitations

It is important to note that there are likely to be more sub-themes that have not been identified in this work due to the constraints on the search terms, extent of the literature search, and the limited time for input from the workshop process. For similar work in the future, we recommend researchers request budgets that enable in-person workshops, allow more to build rapport, and time to fully explain the research process so that participants are able to understand their role and take time to consider their responses. It is also important to make sure the right people are in the room, meaning that a broader representation of the community may provide more rich information about the community's experience of water variability.

The conceptual model developed in this project is a solid starting point for gaining a more comprehensive understanding of the effects of water variability on communities across the entire Murray Darling Basin. A co-design approach, guided by further conversations with the relevant communities, would benefit decisions about which areas of research to focus on in the future. This will help to ensure research efforts address the community's needs, provides relevant and valuable information, and helps to prepare and support communities who continue to experience the effects of variable water access and availability throughout the Basin.

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A

Appendix A: Searches and terms

Scientific database searches

Search Number	Terms included[4]
Search 1	("Murray Darling" OR "Murray Darling Basin" OR "Northern Connected Basin" OR "Murray Darling Northern Basin" OR "Murray River" OR "Darling River") AND ("social impacts" OR "social outcomes" OR "social effects")
Search 2	("Murray Darling" OR "Murray Darling Basin" OR "Northern Connected Basin" OR "Murray Darling Northern Basin" OR "Murray River" OR "Darling River") AND ("river flow" OR "variability in water flows" OR "flow rates" OR "variation in flow" OR "water level variability" OR "flow volume" OR "baseflow*" OR "high flow" OR "streamflow" OR "flow regime" OR "inflow" OR "cease to flow" OR "flood" OR "inundation" OR " high water flows" OR "drought" OR "Millennium drought" OR "water level variability" OR "floodplain inundation" OR "water depth") AND ("human" OR "social" OR "people" OR "users")
Search 3	("Murray Darling" OR "Murray Darling Basin" OR "Northern Connected Basin" OR "Murray Darling Northern Basin" OR "Murray River" OR "Darling River") AND ("mental health" OR "psychological" OR "anxiety" OR "depression" OR "wellbeing" OR "suicide" OR "physical health" OR "exclusion" OR "inclusion")
Search 4	("Murray Darling" OR "Murray Darling Basin" OR "Northern Connected Basin" OR "Murray Darling Northern Basin" OR "Murray River" OR "Darling River") AND ("employment" OR "income" OR "unemployment" OR "debt" OR "savings" OR "welfare" OR "vulnerability" OR "financial stress" OR "financial pressure")
Search 5	("Murray Darling" OR "Murray Darling Basin" OR "Northern Connected Basin" OR "Murray Darling Northern Basin" OR "Murray River" OR "Darling River") AND ("recreation*" OR "boating" OR "fishing" OR "swimming" OR "leisure")
Search 6	("Murray Darling" OR "Murray Darling Basin" OR "Northern Connected Basin" OR "Murray Darling Northern Basin" OR "Murray River" OR "Darling River") AND ("quality of life" OR "housing" OR "community services" OR "social services" OR "social infrastructure")
Search 7	("Murray Darling" OR "Murray Darling Basin" OR "Northern Connected Basin" OR "Murray Darling Northern Basin" OR "Murray River" OR "Darling River") AND ("cultural flows" OR "First Nations" OR "Aboriginal" OR "Indigenous" OR "culture" OR "Country" OR "customs" OR "practices")
Search 8	("Murray Darling" OR "Murray Darling Basin" OR "Northern Connected Basin" OR "Murray Darling Northern Basin" OR "Murray River" OR "Darling River") AND ("social cohesion" OR "cohesion" OR "belonging" OR "attachment" OR "community identity" OR "family structure" OR "family" OR "social networks" OR "social equity" OR "gender" OR "women" OR "marginalised" OR "social capital" OR "capacity" OR "human capital" OR "perception" OR "education")
Search 9	("Murray Darling" OR "Murray Darling Basin" OR "Northern Connected Basin" OR "Murray Darling Northern Basin" OR "Murray River" OR "Darling River") AND ("crime" OR "tension" OR "violence" OR "truancy" OR "theft" OR "domestic violence")
Search 10	("Murray Darling" OR "Murray Darling Basin" OR "Northern Connected Basin" OR "Murray Darling Northern Basin" OR "Murray River" OR "Darling River")

[4] Please note that search strings vary according to the conventions of each database used, including sensitivity to capitalisation and use of dashes.

	AND (“migration” OR “immigration” OR “emigration” OR “outward migration” OR “aging”)
Search 11	("Murray Darling" OR “Murray Darling Basin” OR "Northern Connected Basin" OR "Murray Darling Northern Basin" OR “Murray River” OR “Darling River”) AND (“food security” OR “nutrition” OR “food supply”)
Search 12	("Paroo" OR “Warrego” OR "Condamine-Balonne" OR "Moonie" OR “Border Rivers” OR “Gwydir” OR “Namoi” OR “Macquarie-Castlereagh” OR “Barwon-Darling” OR “Ward River” OR “Langlo River” OR “Nive River” OR “Maranoa River” OR “Macintyre River” OR “Dumaresq River” OR “Severn Rover” OR “Weir River” OR “Horton River” OR “Macdonald River” OR “Manilla River” OR “Peel River” OR “Mooki River” OR “Cockburn River” OR “Fish River” OR “Campbell River” OR “Cudgegong River” OR “Turon River” OR “Bell River” OR “Little River” OR “Talbragar River” OR “Culgoa River” OR “Bokhara River” OR “Gwydir River” OR “Namoi River” OR “Castlereagh River” OR “Macquarie River” OR “Bogan River”) AND (“social impacts” OR “social outcomes” OR “social effects”)
Search 13	("Paroo" OR “Warrego” OR "Condamine-Balonne" OR "Moonie" OR “Border Rivers” OR “Gwydir” OR “Namoi” OR “Macquarie-Castlereagh” OR “Barwon-Darling” OR “Ward River” OR “Langlo River” OR “Nive River” OR “Maranoa River” OR “Macintyre River” OR “Dumaresq River” OR “Severn Rover” OR “Weir River” OR “Horton River” OR “Macdonald River” OR “Manilla River” OR “Peel River” OR “Mooki River” OR “Cockburn River” OR “Fish River” OR “Campbell River” OR “Cudgegong River” OR “Turon River” OR “Bell River” OR “Little River” OR “Talbragar River” OR “Culgoa River” OR “Bokhara River” OR “Gwydir River” OR “Namoi River” OR “Castlereagh River” OR “Macquarie River” OR “Bogan River”) AND ("river flow" OR "variability in water flows" OR "flow rates" OR "variation in flow" OR "water level variability" OR "flow volume" OR "baseflow*" OR "high flow" OR "streamflow" OR "flow regime" OR "inflow" OR "cease to flow" OR "flood" OR "inundation" OR " high water flows" OR "drought" OR "Millennium drought" OR "water level variability" OR "floodplain inundation" OR "water depth") AND ("human" OR "social" OR "people" OR "users")
Search 14	("Paroo" OR “Warrego” OR "Condamine-Balonne" OR "Moonie" OR “Border Rivers” OR “Gwydir” OR “Namoi” OR “Macquarie-Castlereagh” OR “Barwon-Darling” OR “Ward River” OR “Langlo River” OR “Nive River” OR “Maranoa River” OR “Macintyre River” OR “Dumaresq River” OR “Severn Rover” OR “Weir River” OR “Horton River” OR “Macdonald River” OR “Manilla River” OR “Peel River” OR “Mooki River” OR “Cockburn River” OR “Fish River” OR “Campbell River” OR “Cudgegong River” OR “Turon River” OR “Bell River” OR “Little River” OR “Talbragar River” OR “Culgoa River” OR “Bokhara River” OR “Gwydir River” OR “Namoi River” OR “Castlereagh River” OR “Macquarie River” OR “Bogan River”) AND ("mental health" OR "psychological" OR "anxiety" OR "depression" OR "wellbeing" OR "suicide" OR "physical health" OR "exclusion" OR "inclusion")
Search 15	("Paroo" OR “Warrego” OR "Condamine-Balonne" OR "Moonie" OR “Border Rivers” OR “Gwydir” OR “Namoi” OR “Macquarie-Castlereagh” OR “Barwon-Darling” OR “Ward River” OR “Langlo River” OR “Nive River” OR “Maranoa River” OR “Macintyre River” OR “Dumaresq River” OR “Severn Rover” OR “Weir River” OR “Horton River” OR “Macdonald River” OR “Manilla River” OR “Peel River” OR “Mooki River” OR “Cockburn River” OR “Fish River” OR “Campbell River” OR “Cudgegong River” OR “Turon River” OR “Bell River” OR “Little River” OR “Talbragar River” OR “Culgoa River” OR “Bokhara River” OR “Gwydir River” OR “Namoi River” OR “Castlereagh River” OR “Macquarie River” OR “Bogan River”) AND (“employment” OR “income” OR “unemployment” OR “debt” OR “savings” OR “welfare” OR “vulnerability” OR “financial stress” OR “financial pressure”)

Search 16	("Paroo" OR "Warrego" OR "Condamine-Balonne" OR "Moonie" OR "Border Rivers" OR "Gwydir" OR "Namoi" OR "Macquarie-Castlereagh" OR "Barwon-Darling" OR "Ward River" OR "Langlo River" OR "Nive River" OR "Maranoa River" OR "Macintyre River" OR "Dumaresq River" OR "Severn Rover" OR "Weir River" OR "Horton River" OR "Macdonald River" OR "Manilla River" OR "Peel River" OR "Mooki River" OR "Cockburn River" OR "Fish River" OR "Campbell River" OR "Cudgegong River" OR "Turon River" OR "Bell River" OR "Little River" OR "Talbragar River" OR "Culgoa River" OR "Bokhara River" OR "Gwydir River" OR "Namoi River" OR "Castlereagh River" OR "Macquarie River" OR "Bogan River") AND ("recreation*" OR "boating" OR "fishing" OR "swimming" OR "leisure")
Search 17	("Paroo" OR "Warrego" OR "Condamine-Balonne" OR "Moonie" OR "Border Rivers" OR "Gwydir" OR "Namoi" OR "Macquarie-Castlereagh" OR "Barwon-Darling" OR "Ward River" OR "Langlo River" OR "Nive River" OR "Maranoa River" OR "Macintyre River" OR "Dumaresq River" OR "Severn Rover" OR "Weir River" OR "Horton River" OR "Macdonald River" OR "Manilla River" OR "Peel River" OR "Mooki River" OR "Cockburn River" OR "Fish River" OR "Campbell River" OR "Cudgegong River" OR "Turon River" OR "Bell River" OR "Little River" OR "Talbragar River" OR "Culgoa River" OR "Bokhara River" OR "Gwydir River" OR "Namoi River" OR "Castlereagh River" OR "Macquarie River" OR "Bogan River") AND ("quality of life" OR "housing" OR "community services" OR "social services" OR "social infrastructure")
Search 18	("Paroo" OR "Warrego" OR "Condamine-Balonne" OR "Moonie" OR "Border Rivers" OR "Gwydir" OR "Namoi" OR "Macquarie-Castlereagh" OR "Barwon-Darling" OR "Ward River" OR "Langlo River" OR "Nive River" OR "Maranoa River" OR "Macintyre River" OR "Dumaresq River" OR "Severn Rover" OR "Weir River" OR "Horton River" OR "Macdonald River" OR "Manilla River" OR "Peel River" OR "Mooki River" OR "Cockburn River" OR "Fish River" OR "Campbell River" OR "Cudgegong River" OR "Turon River" OR "Bell River" OR "Little River" OR "Talbragar River" OR "Culgoa River" OR "Bokhara River" OR "Gwydir River" OR "Namoi River" OR "Castlereagh River" OR "Macquarie River" OR "Bogan River") AND ("cultural flows" OR "First Nations" OR "Aboriginal" OR "Indigenous" OR "culture" OR "Country" OR "customs" OR "practices")
Search 19	("Paroo" OR "Warrego" OR "Condamine-Balonne" OR "Moonie" OR "Border Rivers" OR "Gwydir" OR "Namoi" OR "Macquarie-Castlereagh" OR "Barwon-Darling" OR "Ward River" OR "Langlo River" OR "Nive River" OR "Maranoa River" OR "Macintyre River" OR "Dumaresq River" OR "Severn Rover" OR "Weir River" OR "Horton River" OR "Macdonald River" OR "Manilla River" OR "Peel River" OR "Mooki River" OR "Cockburn River" OR "Fish River" OR "Campbell River" OR "Cudgegong River" OR "Turon River" OR "Bell River" OR "Little River" OR "Talbragar River" OR "Culgoa River" OR "Bokhara River" OR "Gwydir River" OR "Namoi River" OR "Castlereagh River" OR "Macquarie River" OR "Bogan River") AND ("social cohesion" OR "cohesion" OR "belonging" OR "attachment" OR "community identity" OR "family structure" OR "family" OR "social networks" OR "social equity" OR "gender" OR "women" OR "marginalised" OR "social capital" OR "capacity" OR "human capital" OR "perception" OR "education")
Search 20	("Paroo" OR "Warrego" OR "Condamine-Balonne" OR "Moonie" OR "Border Rivers" OR "Gwydir" OR "Namoi" OR "Macquarie-Castlereagh" OR "Barwon-Darling" OR "Ward River" OR "Langlo River" OR "Nive River" OR "Maranoa River" OR "Macintyre River" OR "Dumaresq River" OR "Severn Rover" OR "Weir River" OR "Horton River" OR "Macdonald River" OR "Manilla River" OR "Peel River" OR "Mooki River" OR "Cockburn River" OR "Fish River" OR "Campbell River" OR "Cudgegong River" OR "Turon River" OR "Bell River" OR "Little River" OR "Talbragar River" OR "Culgoa River"

	OR “Bokhara River” OR “Gwydir River” OR “Namoi River” OR “Castlereagh River” OR “Macquarie River” OR “Bogan River”) AND (“crime” OR “tension” OR “violence” OR “truancy” OR “theft” OR “domestic violence”)
Search 21	("Paroo" OR “Warrego” OR "Condamine-Balonne" OR "Moonie" OR “Border Rivers” OR “Gwydir” OR “Namoi” OR “Macquarie-Castlereagh” OR “Barwon-Darling” OR “Ward River” OR “Langlo River” OR “Nive River” OR “Maranoa River” OR “Macintyre River” OR “Dumaresq River” OR “Severn Rover” OR “Weir River” OR “Horton River” OR “Macdonald River” OR “Manilla River” OR “Peel River” OR “Mooki River” OR “Cockburn River” OR “Fish River” OR “Campbell River” OR “Cudgegong River” OR “Turon River” OR “Bell River” OR “Little River” OR “Talbragar River” OR “Culgoa River” OR “Bokhara River” OR “Gwydir River” OR “Namoi River” OR “Castlereagh River” OR “Macquarie River” OR “Bogan River”) AND (“migration” OR “immigration” OR “emigration” OR “outward migration” OR “aging”)
Search 22	("Paroo" OR “Warrego” OR "Condamine-Balonne" OR "Moonie" OR “Border Rivers” OR “Gwydir” OR “Namoi” OR “Macquarie-Castlereagh” OR “Barwon-Darling” OR “Ward River” OR “Langlo River” OR “Nive River” OR “Maranoa River” OR “Macintyre River” OR “Dumaresq River” OR “Severn Rover” OR “Weir River” OR “Horton River” OR “Macdonald River” OR “Manilla River” OR “Peel River” OR “Mooki River” OR “Cockburn River” OR “Fish River” OR “Campbell River” OR “Cudgegong River” OR “Turon River” OR “Bell River” OR “Little River” OR “Talbragar River” OR “Culgoa River” OR “Bokhara River” OR “Gwydir River” OR “Namoi River” OR “Castlereagh River” OR “Macquarie River” OR “Bogan River”) AND (“food security” OR “nutrition” OR “food supply”)
Search 23	("Murray Darling" OR “Murray Darling Basin” OR "Northern Connected Basin" OR "Murray Darling Northern Basin" OR “Murray River” OR “Darling River” OR "Paroo" OR “Warrego” OR "Condamine-Balonne" OR "Moonie" OR “Border Rivers” OR “Gwydir” OR “Namoi” OR “Macquarie-Castlereagh” OR “Barwon-Darling” OR “Ward River” OR “Langlo River” OR “Nive River” OR “Maranoa River” OR “Macintyre River” OR “Dumaresq River” OR “Severn Rover” OR “Weir River” OR “Horton River” OR “Macdonald River” OR “Manilla River” OR “Peel River” OR “Mooki River” OR “Cockburn River” OR “Fish River” OR “Campbell River” OR “Cudgegong River” OR “Turon River” OR “Bell River” OR “Little River” OR “Talbragar River” OR “Culgoa River” OR “Bokhara River” OR “Gwydir River” OR “Namoi River” OR “Castlereagh River” OR “Macquarie River” OR “Bogan River”) AND (“water recovery” OR “Water Act” OR “Basin Plan” OR “water for the environment” OR “environmental flow” OR “allocation price” OR “water license” OR “water entitlement” OR “inter-valley trade” OR “cap and trade” OR “water buyback” OR “water reform” OR “water market” OR “water allocation” OR “Water Reform Framework” OR “National Water Policy” OR “natural verses actual” OR “natural baseline modelled flow” OR “flood plain harvesting” OR “water accounting”)

Grey literature searches

Website searched	Terms included
Toowoomba Regional Council	"Murray darling basin" AND "river" AND "community"
Dubbo Regional Council	"Murray darling basin" AND "river" AND "community"
Tamworth Regional Council	"Murray darling basin" AND "river" AND "community"
NSW DPIE	"Murray darling basin" AND "river" AND "community"
Murray-Darling Basin Authority - Publications	"community"
Murray-Darling Basin Authority - Publications	"Social and economic"
Murray-Darling Basin Authority - Publications	"First Nations"
Murray-Darling Basin Authority - Publications	"drought"
NSW Bureau of Crime and Statistics Research	"Murray darling basin" AND "river" AND "community"
Qld Government DES	"Murray darling basin" "river" "community"
Qld Government - Library Services - https://qldgov.softlinkhosting.com.au/liberty/libraryHome.do	"Murray darling basin" AND "river" AND "community"
Qld Government - Library Services - https://qldgov.softlinkhosting.com.au/liberty/libraryHome.do	"Murray darling basin" AND "community"
Qld Government - Library Services - https://qldgov.softlinkhosting.com.au/liberty/libraryHome.do	"Murray darling basin" AND "community"
Qld Police	"Murray darling basin" "river" "community"
Office of the Qld Chief Scientist	"Murray darling basin" "river" "community"
Murray River Group of Councils	"Murray darling basin" AND "river" AND "community"
Vic Government DEECA	"Murray darling basin" "river" "community" - filter water and catchment
SA Government WaterConnect	"Murray darling basin" "river" "community" - advanced search including all the words
DCCEEW - https://www.dcceew.gov.au/water/policy/mdb/policy/independent-assessment-social-economic-conditions-basin	reviewed the list of reports on the webpage