Australian Government

Murray–Darling Water & Environment Research

Murray–Darling Water and Environment Research Program

Annual Progress Update 2022-23

November 2024

Contents

Cover photograph: Attendees discussing posters at the 2023 MD-WERP Annual Symposium.

Chair's Foreword

It has now been more than 10 years since the introduction of the Murray–Darling Basin Plan. Bringing everyone together to agree on a Plan aimed at ensuring a resilient and sustainable future for the Basin and its communities and industries was a remarkable achievement.

Much has changed in terms of the environment, climate change, water management, and the economic, social and cultural life of the Basin since the Plan's inception in 2012. Science and research are at the forefront of monitoring and assessing that change. More recently, the flooding across much of the Basin in 2022-23 has significantly changed ecosystems in many regions.

The projects funded by the Australian Government through the Murray–Darling Water and Environment Research Program (MD-WERP) are strengthening scientific knowledge of the Murray–Darling Basin by generating new knowledge, innovation, and tools to assist the Australian Government to address the objectives of the Basin Plan.

As projects are completed, we are publishing the findings and sharing the new science and knowledge. Our projects are underpinning the focus of the MD-WERP – that is, to deliver practical research on issues central to the future of the Basin and for project findings to be used to strengthen the evidence base for informed water and environmental management decisions.

With the roadmap to the 2026 Murray–Darling Basin Plan Review launched by the MDBA in June 2023, the new science, tools and techniques developed by projects funded through the MD-WERP and undertaken by research consortia led by our Program partners the Commonwealth Scientific and Industrial Research Organisation (CSIRO) and La Trobe University will inform the Review.

It is encouraging that everyone connected with the MD-WERP continues to work together with passion and commitment to ensure we can help to bring about real and lasting change for the Basin's environment, communities, First Nations peoples, and industries.

Thank you to everyone involved in delivering the Program's work during the past 12 months.

Professor Rob Vertessy

Independent Chair

MD-WERP Governing Panel

1. Introduction

The Murray–Darling Basin Water and Environment Research Program (MD-WERP; the Program) is a 5-year, up to $20 million Australian Government initiative aimed at strengthening scientific knowledge of the Murray–Darling Basin.

The MD-WERP is one of a range of measures announced by the then Australian Government on 10 April 2019 in response to the findings and recommendations of the Independent assessment of the 2018-19 fish deaths in the lower Darling.[1]

The Australian Government, through the Department of Climate Change, Energy, the Environment and Water (DCCEEW) has committed to providing up to $20 million for the implementation of MD-WERP from the Sustainable Rural Water Use and Infrastructure Program. DCCEEW and the Murray–Darling Basin Authority (MDBA) have agreed through a Memorandum of Understanding to implement the Program. The Commonwealth Environmental Water Holder (CEWH) participates in MD-WERP through its membership position on the MD-WERP Governing Panel (GP). The MD-WERP GP has been established to oversee the implementation of MD-WERP, which includes an Independent Chair, Professor Robert Vertessy.

The Program is delivering 3 components:

- **Strategic research** – collaboration between the Australian Government and Research consortia to co-design, co-invest and deliver practical, applied multi-year research.
- **Tactical investment** – delivery of short-term and responsive outputs to assist decisions and policy makers on water management, river operations, and Basin Plan implementation.
- **Synthesis activities** (referred to now as Communications, Adoption, Transparency and Engagement (CATE)) – synthesis and explainer products and activities which synthesise new and existing science for a variety of audiences.

The MD-WERP has 4 strategic research themes:

- Theme 1 Climate Adaptation
- Theme 2 Hydrology
- Theme 3 Environmental Outcomes
- Theme 4 Social, Economic and Cultural Outcomes.

These themes were developed by researchers in collaboration with Murray–Darling Basin (MDB) end users with the aim of encouraging engagement and cooperation to deliver the best possible

[1] Vertessy, R., Barma, D., Baumgartner, L., Mitrovic, S., Sheldon, F. and Bond, N (2019) *Independent assessment of the 2018-19 fish deaths in the lower Darling: Final Report*, prepared for the Australian Government.

outcomes for the Basin and to ensure the adoption of the Program's research. Strategic research projects funded through the Program are being undertaken by research consortia led by the Commonwealth Scientific and Industrial Research Organisation (CSIRO) and La Trobe University.

This Annual Progress Update provides a summary of the Program's progress in 2022-23.

Context

The MD-WERP is well established, 2 years into implementation. The Program is discovering new science and research which is already supporting water managers and decision makers to plan for the future. The Program's outcomes and findings are being shared with Basin communities and industries, which will continue as more projects are completed and reported.

In 2022-2023 the Program faced critical challenges for the MD-WERP and the Murray–Darling Basin more broadly – foremost among them the significant rainfall and flooding that impacted communities and industries across the Basin. The political landscape also shifted during 2022-23, with a new Australian Government elected, new governments in New South Wales and South Australia, and the Victorian government re-elected.

Even with external changes, projects funded through the MD-WERP are uncovering new information and generating new tools designed to improve water and environmental management and outcomes for Basin communities and industries. The projects are also encouraging and fostering strong cooperation and collaboration between Program partners, researchers, government agencies, communities, First Nations peoples and end users to ensure the new science and tools being developed will be adopted to deliver real and lasting impacts for the Basin and its people.

The MDBA launched the 2026 Murray–Darling Basin Plan Review Roadmap in June 2023. It is the first full review of the Basin Plan since its inception in 2012. The Roadmap outlines the work that needs to be undertaken and the engagement required during the next 3 years to successfully deliver the Basin Plan Review. The new science and tools being developed through MD-WERP projects will contribute to informing the Review and subsequent policy amendments to ensure the best possible outcomes for the Basin.

2. Key 2022-23 Achievements

The priority in 2022-23 was ongoing implementation of 26 strategic research projects and 5 tactical projects, and progressing remaining projects from design to implementation. Key achievements during the year included:

- completion of 11 key deliverables from strategic research projects, and another 4 key deliverables submitted for final approval (Table 1)
- publishing 10 strategic research deliverables on the MD-WERP website (Table 1)

- 3 journal articles published and 7 journal articles submitted across Themes 1 and 2 (Section 5 Progress in the Strategic Research Stream)
- completion of 3 tactical projects with 6 deliverables submitted (Table 1)
- publishing 3 tactical project reports on the MD-WERP website and software code shared on the MDBA's GitHub page (Table 1)
- initiation of 1 short-term tactical project that supports Basin Plan objectives and responds to emerging issues
- convening 10 end user advisory group (EUAG) meetings, providing a platform for ongoing co-design and impact pathways between end users and researchers
- preparation for the second annual symposium (held in July 2023)
- increasing transparency with regular research updates provided on the MD-WERP website, 2 editions of the MD-WERP e-newsletter (Section 7 Communication, Adoption, Transparency and Engagement Investment Stream) and publication of the MD-WERP Annual Progress Update 2021-22.

Table 1. Key achievements of strategic research and tactical investment streams key deliverables in 2022-23. Submitted = final deliver submitted to the Project Delegate and pending approval; Complete = deliverable approved by Project Delegate; Published = deliverable published on the MD-WERP website.

Theme	Project	Deliverable(s)	Achievement in 2022-23
STRATEGIC RESEARCH			
1. Climate Adaptation	FS. Climate Adaptation Foundational Science	Report on the interactions between climate change and farm dams	Completed
		Synthesis of indirect impacts of climate change in the Murray–Darling Basin	Published
	SA. Showcasing Adaptability and Pilots	Technical paper describing the system for classification of adaptation options and adaptation investigations	Completed
	SI. Synthesis and Implementation	Report outlining framework for Basin-wide monitoring and management	Completed
	TK. Science Applications and Assessment Toolkit	Architecture design for the climate adaptation toolkit workflow	Published
		Demonstration of the climate adaptation toolkit workflow	Published
2. Hydrology	RQ6. Enhancing low flow prediction to support water resources planning	Progress towards enhancing low flow predictions	Submitted
		Summary of datasets for classification of river reaches in the Murray–Darling Basin and changes in the flow regime over the past few decades	Published
	RQ7. Enhancing floodplain inundation and volume prediction to support environmental watering and water resource planning	Description and metadata for two monthly maximum flood water extent and depth for the Murray–Darling Basin	Submitted
		Flood inundation modelling summary report – a review of existing methods and data and descriptions of proposed method March 2022	Published
		Description and metadata for composite datasets for developing and validation of a predicted flood inundation	Published
	RQ8a. Enhancing river operation outcomes using forecasts and optimisation	Opportunities for water forecasts to inform water management decision in the MDB November 2021	Published
		Water forecasts to quantify risks in the southern Murray–Darling Basin for informing water management	Published

Theme	Project	Deliverable(s)	Achievement in 2022-23
	RQ8b. Groundwater as an adaptation to current water resources management	Scripts and tools developed for trend and cluster analysis, GDE analysis, salinity mapping and time series analysis	Submitted
		Summary of main alluvial aquifers and groundwater use potential in the Murray–Darling Basin November 2021	Published
		Groundwater level trends and aquifer prioritisation in the Murray–Darling Basin	Published
	RQ-H. Impact of hydrological non-stationarity and changing catchment conditions on runoff in the northern Basin	Technical report and/or research paper on climate and development drivers on the hydrology of the Northern Basin	Completed
3. Environmental Outcomes	RQ11.1 Spatially explicit population models for fish in the Barwon–Darling river system	Annual progress report	Completed
	RQ11.4 Assessing future vulnerability of species and ecological communities	Annual progress report	Completed
4. Social, Economic and Cultural Outcomes	RQ12.1 The mental health benefits from improvements to riverine ecosystem health	Progress report on literature review, focus group, conceptual model	Submitted
	RQ12.2 The recreational and tourism value of healthy rivers	Progress report on visitation models, data collation and sampling strategy	Completed
		Interim report on results from count data regression to establish credible quantitative link(s) between location-specific Flickr-derived metrics of visitation rate and environmental/riverine condition	Completed
	RQ14.1 Basin-wide socio-economic, socio-demographic and biophysical data platform	Progress report on development of practice note suggesting appropriate geographical scales for the retrieval, processing and aggregation of socio-economic, socio-demographic and biophysical data to support socio-economic analyses across the WERP – and into the future	Completed
	RQ14.2 Pathways to community resilience	Completion Stage 2 – Completion Study Foundation	Completed

Theme	Project	Deliverable(s)	Achievement in 2022-23
	RQ14.3 Navigating change	Interim progress report	Completed
TACTICAL			
	TP3 Evaluation of Causes of Reduced Flow through the Northern Basin	Evaluation of causers of reduced flow in the northern Murray–Darling Basin	Completed Published
	TP7 Innovation Sweep, Scoping and Development of Drone-based Waterbird Monitoring	Nesting waterbird colony population size monitoring using automated counts on drone imagery	Completed Published
		Innovation sweep – technological insights for the Murray–Darling Basin	Completed Published
		Software code	Completed
	TP13 Summary and analysis of blue-green algal trends in the Basin	Synthesis of Blue Green Algae (Cyanobacteria) bloom knowledge & analysis of recent trends in the MDB	Completed
	TP12 Riverbank Stability and Erosion	Desktop synthesis of bank condition and the scientific knowledge of the influences on erosion	Completed

3. Progress Towards Program Objectives

Objective 1: Invest in applied research that delivers better informed environmental water management decisions by Commonwealth agencies and improved outcomes for communities.

To meet this objective we need to ensure our research is useful and used by end users by:

- developing benefit realisation maps to graphically represent the relationship between the research, outputs, outcomes and how they align to Australian Government objectives and vision (Section 4 Policy and Program Outcomes)
- mapping research outputs to the Basin Plan Review to outline how the program will realise benefits for the water reform objectives of the Australian Government (Section 4 Policy and Program Outcomes)
- completion of 3 tactical research projects and progressing another 3, designed to address Australian Government priorities or gaps while avoiding duplication with other programs (Section 6 Progress in the Tactical Investment Stream).

Objective 2: Maximise value to water reform and management from investment.

The program meets this objective by consulting with Australian Government partners, State collaborators and members of the research and knowledge community on research projects to address knowledge gaps (Section 7 Communication, Adoption, Transparency and Engagement Investment Stream). Activities included:

- engaging with end user advisory groups, one for each theme, consisting of Australian Government and state policy makers
- preparation for the second MD-WERP Annual Symposium
- providing regular updates on the MD-WERP website
- publishing 2 MD-WERP e-newsletters
- publishing the MD-WERP 2021–22 Annual Progress Update.

Objective 3: Leverage co-investment with research providers and key stakeholders.

The program supported this objective by building on, linking to and leveraging research that has occurred or is underway. Activities included:

- the Research Consortia co-investing a minimum of 31% for the strategic research activities (Section 10 Financial Summary)
- regular engagement and briefing with key stakeholders and committees to understand research linkages and connections

- providing $100,000 in top-up funds to the Australian Research Council (ARC) Special Initiative on Australian Society and Culture for the project 'Understanding the water cultures of the MDB' (Section 5 Progress in the Strategic Research Stream)
- RQ14.2 and RQ14.3 researchers engaged under the MD-WERP Deed with La Trobe University to deliver the MDBA's Basin Condition Monitoring Program Community Oral Histories project – recognising the opportunity to leverage greater value from all three projects through methodological and management synergies.

Objective 4: Facilitate adoption of research by advancing cooperation between users and researchers.

The program aims to meet this objective by engaging with end users in the design, development and delivery of the research through:

- maintaining a regular avenue of communication between researchers and end users to provide timely feedback on the development and delivery of the research via theme-based EUAGs (Section 7 Communication, Adoption, Transparency and Engagement Investment Stream)
- regular meetings of the Science Leadership Team (SLT), a multi-disciplinary group of end users and research leaders promoting thought leadership (Section 9 Governance and Structure)
- identifying new capabilities that will be created from each output, and potential barriers or business changes required for adoption of the new capability and benefits realisation (Section 4 Policy and Program Outcomes).

Objective 5: Be a platform from which to launch a more enduring research program that supports effective water management over the long term.

The program aims to deliver this objective by building foundations to show the importance of new knowledge generated by the program. Successful delivery of the program and achievement against the strategic objectives will contribute to the justification for ongoing investment in water research and highlight the critical value of science and knowledge toward achieving sustainable outcomes in the face of an uncertain future. Of critical importance is the ongoing effort to ensure the knowledge generated through this research program is applied for policy and planning purposes, such as for the 2026 Basin Plan Review — ensuring the knowledge is applied for impact will increase support for future research programs.

Activities in 2022-23 included:

- demonstrating program benefits, particularly in building collaboration between the research community and policy makers (Section 4 Policy and Program Outcomes)

- delivering research outputs that result in outcomes and impact within the program's duration and as a legacy, and ensuring that synthesis and tactical projects deliver useful outputs early (Section 4 Policy and Program Outcomes)
- preparing for the mid-term independent program evaluation to commence July 2023, followed by an end of program review.

4. Policy and Program Outcomes

The objective of the MD-WERP is to advance knowledge, understanding and response options for water and environmental management in the Murray–Darling Basin, and improve the investment in, and the coordination of, applied research and knowledge generation.

A focus of the program is applied research that serves the information needs associated with Basin Plan implementation.

The program aims to generate new knowledge to support adaptive management to improve water policy, reduce risk in management decisions and enhance outcomes of water management. The primary areas where the program is expected to deliver value are set out below.

Policy Outcomes

The Basin Plan is founded on complementary adaptive management activities which are informed by specific statutory reviews (for example the 2023 Productivity Commission inquiry, the 2025 Basin Plan Evaluation, and the 2026 Basin Plan Review). These adaptive management activities depend on an evolving body of knowledge such as that being generated by MD-WERP, both to evaluate the contribution of actions to achieving Basin Plan objectives and to identify appropriate policy responses.

Climate change is a major threat to river flows, groundwater systems, water supply, water demand, water prices and trade. There is no doubt that climatic conditions are changing, and water managers will want to understand the threats to water in the Basin. Climate change also threatens species and ecosystems, agricultural productivity and community well-being. The 5 research questions to be answered by the 4 projects under Theme 1: Climate Adaptation aim to provide better knowledge to understand these climate change impacts and how to adapt.

The Commonwealth Theme leads and Implementation Team commenced mapping of science outputs to the Basin Plan Review in June 2023, expanding on the benefits mapping undertaken in 2021-22. Benefits mapping will be updated further in 2023-24. At this stage, deliverables of the following projects have been identified as informing the Basin Plan Review or subsequent policy development:

- Theme 1 Climate adaptation – Foundational Science (FS); Science Applications and Assessment Toolkit (TK); Showcasing Adaptability and Pilots (SA); Synthesis and Implementation (SI).
- Theme 2 Hydrology – RQ6. How to represent low flows in river models; RQ7. Enhancing floodplain inundation and volume prediction to support environmental watering and water resource planning; RQ8b. Groundwater as an adaptation to current water resources management; RQ-H. Drivers of northern Basin hydrology.
- Theme 3 Environmental Outcomes – RQ9. Drivers of ecological resilience and persistence during low and cease-to-flow in the northern MDB; RQ10. A data atlas for conservation prioritisation; RQ11. Fish habitat, connectivity and floodplain habitat and species and communities – predictive modelling.
- Theme 4 Social, Economic and Cultural Outcomes – RQ12.1. The mental health benefits from improvements to riverine ecosystem health; RQ12.2. The recreational and tourism value of healthy rivers; RQ13.1. First Nations water-based outcomes in the southern Basin; RQ13.2. First Nations water-based outcomes in the northern Basin; RQ14.1. Basin-wide socio-economic-demographic and biophysical data platform; RQ14.2. Pathways to community resilience; RQ14.3. Navigating change.

Risk Management Outcomes

The Basin Plan requires the MDBA and the Basin states to identify and manage risks to the condition of or the continued availability of Basin water resources. It is expected that under current and future climates water availability in the Basin will, on average, be reduced and more variable. This will lead to increased uncertainty and risk in water management.

Improved knowledge of water requirements and of changes in river flow and groundwater recharge, and improved capacity to evaluate management strategies, through the MD-WERP, will improve the MDBA's overall capacity to manage risks. Relevant projects include:

- RQ6. Enhancing low flow prediction to support water resources planning
- RQ7. Enhancing floodplain inundation and volume prediction to support environmental watering and water resource planning
- RQ8a. Enhancing river operation outcomes using forecasts and optimisation
- RQ8b. Groundwater as an adaptation to current water resources management
- RQ-H. Impact of hydrological non-stationarity and changing catchment conditions on runoff in the northern Basin
- RQ9.1. Drivers of ecological resilience and persistence during low and cease-to-flow conditions in the northern Murray–Darling Basin
- RQ11.2. Predicting changes to the persistence and connectivity of in-channel aquatic habitat in the lower Darling River
- RQ11.3. Predicting change in floodplain aquatic habitat availability at the Basin scale

- RQ14. How can communities adapt to and be more resilient to a future with less water? What makes a community more resilient and adaptable to a future with less water?

River Operations and Water Management Outcomes

Operational decisions will also benefit from the knowledge generated by the program. There is a sophisticated set of operational decisions that are made to deliver water effectively to users and to deal with operational constraints in the system. Better information on water needs, flow regimes, water forecasting, ground-surface water connectivity, constraints and changing circumstances can lead to better operational planning and real-time decision making. Relevant projects include

- T1.SI1. Report outlining framework for Basin-wide monitoring and management
- RQ6. Enhancing low flow prediction to support water resources planning
- RQ7. Enhancing floodplain inundation and volume prediction to support environmental watering and water resource planning
- RQ8a. Enhancing river operation outcomes using forecasts and optimisation
- RQ8b. Groundwater as an adaptation to current water resources management.
- RQ11. How can adaptation through enhanced river operations and water resources management improve water outcomes?
- TP12. Riverbank Stability and Erosion

Program Benefits and Barriers for Adoption

The MD-WERP was designed for end-users, to deliver outcomes and benefits for the Australian Government. An important aspect of the engagement and adoption of the program's outputs is the benefits mapping and realisation component. Benefit logic maps (see the MD-WERP Annual Progress Update 2021-22) are being used as a foundation to define new capabilities that will be created from each output, and identify potential barriers/business changes required to for adoption of new capabilities and benefits realisation.

5. Progress in the Strategic Research Stream

The Strategic Research Stream consists of applied research investments delivered by a collaboration between the Australian Government and the MD-WERP Research Consortium to co-design, co-invest and deliver applied research by mid-2025. The bulk of the MD-WERP investment is in this stream.

Theme 1: Climate Adaptation

The Murray–Darling Basin is one of the world's most variable hydroclimate regions. Catchment inflow can be more than 20 times greater in a wet year than in a dry year. The system also faces profound future challenges to adapt to a hotter, drier climate. The Climate Adaptation Theme will address 5 research questions (Table 2) with the aims to:

- better understand how climate change will impact the Murray–Darling Basin
- identify and evaluate options to adapt to change
- evaluate potential outcomes for Basin values.

The research outputs will be a line of evidence used by the MDB Sustainable Yields project and the 2026 Basin Plan Review.

Table 2. Summary of key research questions (RQ), outputs and outcomes for the climate adaptation theme.

Key questions	Key outputs and outcomes
RQ1. Which of the Basin's economic, social, environmental, and cultural values are most vulnerable to the flow-related impacts of climate change? RQ2. How do other threats interact with climate change to affect vulnerabilities? RQ3. What is the best way to evaluate the effectiveness of water management arrangements to manage risks, including climate change? RQ4. What adaptation options can provide better protection to vulnerable values in the Basin? RQ5. How do we undertake climate adaptation at regional scales that are most relevant to communities and environmental assets?	An improved understanding of the water-related impacts of the future climate, both through direct (that is, hydrological) and indirect (for example bushfires) changes. An enhanced ability to assess and compare the outcomes of adaptation options for catchment and Basin-scale water planning under climate change. Strategically selected case studies to identify and explore adaptation pathways at multiple scales and across values, including through community participation. Develop tools to enable the Australian Government to evaluate potential water management arrangements.

Progress and Achievements

All 4 projects (mentioned below) in the climate adaptation theme continued to progress well during 2022-23.

The Climate Adaptation Foundational Science (FS) project is developing modelling methods to provide insights into the indirect impacts of climate change on water supply, demand and management.

- Completed modelling and analysis of the impacts of bushfires on water availability under climate change, making use of remote-sensing data on fire extents and impacts.
- Completed sensitivity testing assessments of the impacts of farm dams on inflows under climate change in response to jurisdictional reviews facilitated by the Climate Theme EUAG.
- Published Synthesis of indirect impacts of climate change in the Murray–Darling Basin on the MD-WERP website.
- Published 1 journal article and another 3 articles submitted.[2]

The Showcasing Adaptability and Pilots (SA) project is investigating adaptation to climate change in the including identifying adaptation options and assessing their potential impacts on Basin values through a series of case-studies.

- Significant technical progress with the Hydroclimate Analysis Adaptability Investigation in the Macquarie River catchment, including formalising of model and data sharing arrangements with New South Wales Department of Planning and Environment (DPE).[3]
- Generated preliminary projections of river system outcomes, including irrigation water allocations and use, and satisfaction of environmental water requirements, using historical, stochastic and projected climate forcing.
- Commenced conceptualising how adaptation options proposed by the contributing partners (CEWH, NSW, MDBA) can be introduced into the Integrated Quantity and Quality Model (IQQM).
- Developed a framework for an economic assessment tool for the Macquarie River catchment.

The Synthesis and Implementation (SI) project is synthesising outputs and learnings from the main research activities to ensure understanding of processes and constraints and develop acceptance of tools and address potential mismatch of scale of research and decision making.

- Developed a framework for Basin-wide monitoring and management, with the report (T1.SI1 Issues in managing a large river at a Basin scale) being revised into a draft journal manuscript.
- CSIRO engaged with the Murray Lower Darling Rivers Indigenous Network (MLDRIN) to discuss possible opportunities for co-designing a project.

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[2] Robertson DE, Chiew FHS and Potter NJ (2023) Adapting rainfall bias-corrections to improve hydrological simulations generated from climate model forcings. Journal of Hydrology, 619, 129322, http://dx.doi.org/10.1016/j.jhydrol.2023.129322

[3] As of 1 January 2024 NSW DPE is NSW Department of Climate Change, Energy, the Environment and Water (DCCEEW).

- CSIRO engaged with other Traditional Owners to discuss opportunities for co-designing First Nations focussed projects. The current project being explored is to understand cultural values in the Macquarie Marshes region and possible impacts of climate change and adaptation.

The Science Applications and Assessment Toolkit (TK) project is enhancing the ability of the Australian Government, and other stakeholders, to identify and assess the likely future impacts of climate change across social, environmental, cultural and economic values in the Basin.

- Completed the vulnerabilities and values assessment using a novel flow-assets-values framework.
- Continued to implement the toolkit architecture with work focusing on transitioning a proof-of-concept workflow used for an initial single-catchment demonstration into a modular codebase.
- Produced a companion documentation website.
- Ongoing development for application to the Macquarie case study and additional response modules.
- Presented 'Developing tools to incorporate the impacts of climate change and adaptation on water supplies and Basin assets in water planning' at the 2023 Freshwater Sciences Conference in June 2023.
- Published 'Architecture design for the climate adaptation toolkit workflow' and 'Demonstration of the climate adaptation toolkit workflow' on the MD-WERP website.

Case Studies

TK. Climate Adaptation Science Applications and Assessment Toolkit Project

The 'toolkit' being developed by Theme 1 seeks to provide the ability to model environmental, social and economic responses to hydrology and synthesise those responses to provide actionable information for the MDBA. Flows in the river influence a wide range of values. The toolkit takes these flows, whether historical or modelled, as inputs to response models for those values. The outputs of those response models are, in turn, aggregated, analysed, and presented with consistent methods to produce graphics and other outputs useful for decision-making. Key features of the toolkit are modularity, allowing different components to be run separately; reproducibility, including self-documentation; and consistency, providing a unifying approach to analysing a variety of responses to hydrology.

As an example, consider a set of hydrographs representing baseline flows, as well as increases or decreases, and an interest in how environmental values might respond. The toolkit sends each of these flow scenarios to the MDBA Environmental Water Requirement (EWR) tool, which returns a large table of whether thousands of hydrologic indicators such as bankfull flows or low flow events are met. The toolkit then takes these hydrologic indicators and maps them to relevant environmental values such as waterbird breeding or native fish diversity using causal networks defined in Long Term Watering Plans. These outcomes may also be scaled up in time to

Sustainable Diversion Limit (SDL) units or the basin. The toolkit then compares across the scenarios; in this example, we could create maps of how waterbird breeding or native fish diversity change between the baseline scenario and increased or decreased flow.

The toolkit has been developed into an R package (collection of functions and data sets) available internally through the MDBA GitHub. This R package provides a comprehensive set of functions to ingest hydrographs, call response models, and process the outputs of those response models into graphics and other analyses. Along with the toolkit, a documentation and example website has been developed. This website provides example uses of the toolkit, as well as in-depth exploration of its capabilities. While the toolkit provides a unified and consistent approach to modelling response to hydrology, it embeds significant opportunity for users to determine how that processing occurs and how results are presented. The capability demonstrations on the website provide valuable guidance for making these choices.

Key next steps for the toolkit are underway, including writing a paper introducing the toolkit and its capabilities, using the toolkit to assess environmental outcomes across a range of hydrographs scaled by future rainfall projections, and applying the toolkit to the Macquarie case study. Further technical development is proceeding to enable use for a range of hydrograph data formats, incorporation of additional response modules, and refinement of synthesis outputs such as graphics and summary tables.

SA. Hydroclimate analysis for the Macquarie River catchment

The Showcasing Adaptability and Pilots project of the Climate Adaptation theme seeks to investigate a range of adaptation options and their potential impact on Basin values. In Year 2, a hydroclimate analysis case study focussing on the Macquarie River catchment was established. The case study aims to demonstrate how existing science can be applied to understand the vulnerability of the Macquarie River catchment to climate change and identify and assess the effectiveness of adaptation options to mitigate climate change impacts on management outcomes. The work is designed to support decision-making on methods that can be used to support Basin planning and provide an initial assessment of adaption options.

The case study has established a system that enables large number of climate change scenarios to be simulated through a chain of models including rainfall-runoff models to generate catchment inflows from rainfall and other climate data, river system models to simulate water management within the catchment, and management outcome models to translate simulated river flows to outcome indicators. The system has been used to simulate water management outcomes in the Macquarie River catchment for many scenarios representing plausible historical climate variability, informed by paleoclimate records, and future climate change, informed by global climate model projections.

Key findings are that all components of the water balance, including water use by general and high security licence holders and end-of-system flows are sensitive to variability and change in rainfall and potential evaporation patterns. End-of-system flows and general security water licence holders

are expected to be most vulnerable to climate change, suggesting that regional economic and environmental outcomes are likely to be impacted. Investigation into adaptation options, and their efficacy has commenced in 2023-24 and the use of modelling tools that facilitate a wider assessment of economic and environmental outcome indicators.

Theme 2: Hydrology

Robust knowledge and modelling of hydrological and water resources characteristics under current and future climates is essential to inform water resources management and planning. The hydrology theme is addressing the research questions in Table 3.

The first 2 research questions aim to enhance prediction at the ends of the flow spectrum: low flow and floodplain flow. The third research question is exploring and demonstrating adaptation to enhance hydrological outcomes from the same amount of available water. The fourth research question links to Tactical Project TP03. Evaluation of Causes of Reduced Flow through the northern Basin.

Table 3. Summary of key research questions (RQ), outputs and outcomes for the hydrology theme.

Key questions	Key outputs and outcomes
RQ6. How can low flow prediction be improved to support water resources management planning?	Enhanced low flow prediction and modelling to inform water resources management.
RQ7. How can floodplain flow volumes, components, and inundation prediction be improved to support environmental watering and water resources planning?	Enhanced floodplain flow prediction to inform environmental watering and water resources management.
RQ8. How can adaptation through enhanced river operations and water resources management improve water outcomes?	Knowledge of water forecasting application and groundwater use to enhance water resources management.
RQ-H. How can we better disentangle and model the impacts of climate and development drivers on the hydrology of the Basin?	Improved understanding, quantification and communication of drivers of northern Basin hydrology.

Progress and Achievements

Research outputs from the Hydrology theme are providing insight for river management and environmental water decision makers. Several future research outputs have been identified as providers of input towards key MDBA milestones including the Sustainable Yields 2 program, the 2025 Basin Plan Evaluation, and the 2026 Basin Plan Review.

There has been sustained and effective engagements in all 5 Hydrology projects, with the efforts of CSIRO's Hydrology theme researchers boosted to include input and expertise from MDBA

technical experts, CEWH environmental water managers, and other MD-WERP Consortium Researchers (particularly in the Climate Adaptation theme). The result over Years 1 and 2 of implementation is publication of 15 technical reports, 7 peer-reviewed journal papers and 18 conference abstracts.

The MD-WERP Hydrology theme workshop in March 2023 was a highlight of the year, providing good insight into the progress made in each of the Hydrology projects and provided an opportunity for discussion on pathways to adoption. In addition to this workshop, the interest, input and contributions of the Basin Officials Committee and the Basin States Modelling Advisory Group is helping to inform how the research outputs will be adopted to inform future decision making.

The **Enhancing low flow prediction to support water resources planning (RQ6)** project is focussing on improving the simulation of low flows that are important to maintain environmental and refugia conditions, avoid poor water quality risk and support downstream water uses.

- Developed and tested enhanced process conceptualisations to improve low flow simulations without degrading overall flow simulations. The project focussed on developing a river reach scale water exchange function that incorporates bed and bank storage processes and losses to groundwater dependent upon groundwater levels. These were identified as key physical processes missing from river system models that are important in the simulation of low flows.
- Developed a new algorithm to incorporate the processes of bed storage and feedback from groundwater levels on river losses, and coded into the Australian Water Resources Assessment river model (AWRA-R) to calibrate the flow in the Border Rivers and Gwydir catchments as the test case.
- Published 'Summary of datasets for classification of river reaches in the Murray–Darling Basin and changes in the flow regime over the past few decades' on the MD-WERP website.
- One peer-reviewed journal paper submitted and under review.

The **Enhancing floodplain inundation and volume prediction to support environmental watering and water resource planning (RQ7)** project is addressing knowledge gaps in (i) predicting flood inundation extent, depth and duration and (ii) predicting floodplain volumes.

- Good progress developing the remote sensing-based flood inundation model, building on research in Year 1 to improve water extent detection from remotely sensed images and develop the best method for water depth estimation.
- Published two basin-wide datasets (1988–2022) on the CSIRO Data Access Portal (DAP) – each provide a comprehensive view of the changing water extent, depth and volume across the entire Murray–Darling Basin. The latest 2-monthly water depth dataset is now accessible on Terria.

- Published 'Flood inundation modelling summary report – a review of existing methods and data and descriptions of proposed method March 2022' and 'Description and metadata for composite datasets for developing and validation of a predicted flood inundation' on the MD-WERP website.
- Published 1 peer-reviewed journal article and another 1 submitted for review.[4]
- Published a technical note which includes description and metadata for two datasets (i) Maximum two-monthly surface water extent for MDB from MIM and WOFS - Version 2, and (ii) Two-monthly maximum flood water depth spatial timeseries for the MDB.[5,6,7]
- Contributed to improvement of the Earth Analytics Science Innovation (EASI) platform, which can be used to publish other MD-WERP related datasets.[8]

The **Enhancing river operation outcomes using water forecasts and optimisation (RQ8a)** project is evaluating the value of combining ensemble water forecasts and optimisation methods for river operations in the Murray–Darling Basin. It aims to demonstrate how water forecasts can inform river operation decision-making in the Basin, for example, decisions on dam releases and environmental water delivery.

- Commenced first case study on better characterising the risks related to river regulation decisions in the upper Murray, in collaboration with the MDBA river operators.
- Used, adapted and customised models to demonstrate the value of forecasting to quantify risks related to river regulation decisions in the upper Murray.
- Developed hydrological forecasting model to support environmental water delivery to the Narran Lakes.
- One journal paper submitted and under review.
- Presented 'Forecasting irrigation water demands from orders' at the 2022 Hydrology and Water Resources Symposium.
- Published 'Opportunities for water forecasts to inform water management decision in the DB November 2021' and 'Water forecasts of risks in the southern Murray–Darling Basin for water management'.

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[4] Teng J, Penton D, Ticehurst C, Sengupta A, Freebairn A, Marvanek S, Vaze J, Gibbs M, Streeton N, Karim F, Morton S (2022) A comprehensive assessment of floodwater depth estimation models in semiarid regions. Water Resources Research, 58, e2022WR032031. https://doi.org/10.1029/2022WR032031.

[5] Teng, J, Ticehurst, C, Penton, D, Yang, A, Marvanek, S, Khanam, F, Vaze, J & Mateo, C (2023) 'Description and metadata for two-monthly maximum flood water extent and depth for the Murray–Darling Basin', CSIRO Data Access Portal.

[6] Teng, J, Penton, D, Ticehurst, C, Sengupta, A, Freebairn, A; Marvanek, S, King, D, & Pollino, C (2023) 'Two-monthly maximum flood water depth spatial timeseries for the MDB'. v20. CSIRO. Data Collection. https://doi.org/10.25919/c5ab-h019

[7] Ticehurst, C, Penton, D, Teng, J, & Sengupta, A (2022) 'Maximum two-monthly surface water extent for MDB from MIM and WOFS - Version 2'. CSIRO. Data Collection. https://doi.org/10.25919/s7c2-hc39.

[8] Woodcock, R, Paget, M, Squire, G, Taib, R, Penton, D, & Teng, J (2022) 'EASI OWS web service. v1'. CSIRO. Service Collection. http://hdl.handle.net/102.100.100/482271?index=1

The Groundwater as an adaptation to current water resources management (RQ8b) project is evaluating where, when and how enhanced groundwater use, particularly when managed conjunctively with surface water, can benefit economic, social and environmental outcomes in the Basin.

- Improved understanding of spatial and temporal patterns of trends in groundwater level and commenced implementation of a long short-term memory (LTSM) model to explore the causal attribution of the groundwater level trends.
- Commenced assessing opportunities for water banking, in particular managed aquifer recharge (MAR), which includes quantifying resilience, stress and sustainability of alluvial aquifers, and characterising opportunities for managed aquifer recharge.
- Published 1 peer-reviewed journal paper and 1 paper submitted and under review.[9]
- Published 'Summary of main alluvial aquifers and groundwater use potential in the Murray–Darling Basin November 2021' and 'Groundwater level trends and aquifer prioritisation in the Murray–Darling Basin' on the MD-WERP website.

The Drivers of northern Basin hydrology (RQ-H) project aims to disentangle, model and quantify impacts of climate/natural and policy/development drivers on the hydrology of the northern Basin.

- Synthesised, collated and curated observed hydroclimate data (rainfall, streamflow and groundwater) and remotely sensed data to characterise impact of hydrological non-stationarity and changing catchment conditions on runoff in the northern Basin.
- Published the report 'Evaluation of causes of reduced flow in the northern Basin' (as part of TP03) on the MD-WERP website following significant interest and contribution from the EUAG and the Basin Officials Committee the project.

Case Studies

RQ6 Enhancing low flow prediction to support water resources planning

In Year 1, project RQ6 achieved its goals in gathering a collective understanding – of ecologists and hydrologists – to conclude that there are a vast number of metrics for low flows and that there was a collective need for improved simulation of low flows.

The research of Year 1 identified 2 key issues in the simulation of low flows. These were that changes in groundwater and surface water interactions from gaining to losing conditions could not be represented in the current generation of models, and that antecedent conditions were not accounted for in intermittent streams. These findings have implications for the representation of a number of reaches across the Murray–Darling Basin over recent decades.

[9] Fu G, Rojas, R and Gonzalez D (2022) Trends of groundwater levels in alluvial aquifers of the Murray-Darling Basin and their attributions. Water, 14, 1808. https://doi.org/10.3390/w14111808.

In Year 2, the project identified key physical processes missing from river system models that were thought to be important in the simulation of low flows. Research focused on developing a river reach scale water exchange function that incorporates bed and bank storage processes and losses to groundwater dependent upon groundwater levels.

Throughout Year 2, a new algorithm has been developed and coded into the AWRA-R river systems model. This new algorithm has been used in the modified AWRA-R model to calibrate the flow in the Border Rivers and Gwydir catchments as the test case. These catchments were used as the 2018 and 2019 environmental flow releases provide a controlled test case under low flow conditions arising from different antecedent conditions that the project is aiming to improve the simulations of low flows.

Preliminary results from these test cases show minimal changes to the overall calibration based on bias and NSE (these are both positive findings) with substantially different behaviour at low flows (apparent improvement in low flow simulation).

The coming 12 months are expected to see further testing of the new algorithm in the modified AWRA-R model to better understand how it is performing, whether it improves low flow simulations without degrading overall flow simulations and whether it will require further modifications.

This project has so far produced 3 summary reports published by MD-WERP, 3 datasets published on the CSIRO Data Access Portal and 1 journal paper.[10]

RQ8a Demonstrating application of water forecasts for river operations

Project RQ8a aims to demonstrate how water forecasts can aid river operation decision-making for 3 case studies in the Murray–Darling Basin. The case studies are exploring:

- The use of tributary inflow forecasts to inform the Hume Dam release for water supply delivery to Lake Mulwala.
- The development of a suitable flow forecasting tool for the Balonne River at St. George to support environmental watering decision-making for the Narran Lakes.

[10] Crosbie, R, Vaze J, Kim S, Mateo C and Wang B (2021) Short summary document of discussions to define salient flow metrics for WERP research and applications. MD-WERP Deliverable T2.6.1, CSIRO, Australia.
Crosbie R, Vaze J, Kim S, Mateo C and Wang B (2022) Summary of datasets for classification of river reaches in the Murray-Darling Basin and changes in the flow regime over the past few decades. MD-WERP Deliverable T2.6.2, CSIRO, Australia.
Crosbie R, Kim S, Dawes W, Wang B, Mateo C, Vaze J, Chiew F and Alam J (2023) RQ6 – Progress towards enhancing low flow predictions. Report T2.6.4. CSIRO, Australia.
Crosbie R, Wang B, Kim S, Mateo C and Vaze J (2023) Changes in the surface water – Groundwater interactions of the Murray-Darling Basin (Australia) over the past half a century. Journal of Hydrology, Volume 622, Part B. https://doi.org/10.1016/j.jhydrol.2023.129683.

- The use of long-range inflow forecasts to establish and vary seasonal filling targets in Hume and Dartmouth Reservoirs for airspace management, which can be critical in high flow months when flood operations of the reservoirs are possible.

As of the end of Year 2, the project has completed the first case study and significant progress was also made in the second case study.

The project developed a hydrologic-forecasting model of the Lake Mulwala system. To support the hydrologic-forecasting model, the project also developed decision rules embedded in the model to govern the Hume Dam flow release. Results from simulating the system using the decision rules have yielded new insights into key operational questions that are useful to river operators seeking guidance on how best to apply water forecasts in their decision-making.

The project assessed flow forecasting products for the Balonne River at St. George but found no existing product that possesses the required characteristics. The forecasting of the Balonne River is challenging as the climate in the northern Murray–Darling Basin is highly variable, and forecasts are unlikely to be skilful beyond 7 days. Given this, the project has developed a new customised forecasting product and conducted preliminary testing to evaluate its effectiveness. In Year 3, the project is will continue testing and refining the new forecasting product.

Work to support the third case study is commencing and research will be undertaken throughout Year 3 and 4.

Theme 3: Environmental Outcomes

A healthy Basin relies on healthy ecosystems. However, parts of the Basin face a challenging future – severe droughts and extreme ecological events (e.g. algal blooms, fish kills) highlight the significant challenges in managing Basin ecosystems. Drought conditions associated with fish kills are likely to become more common in some parts of the Basin, and increasing water scarcity will require careful prioritisation of which environmental assets to protect. Climate change and land use in managing Basin ecosystems are central to this research.

This research theme seeks to improve our understanding of how rivers, wetlands and water-dependent species will respond to future environmental conditions (Table 4). It will:

- provide a better understanding of how reduced water availability affects the abundance of aquatic life and examine how fish populations may respond to the changing climate
- help identify areas of high priority conservation value and inform management and conservation of the Basin rivers and ecological assets
- map surface water and waterhole connections to determine flow-related changes in fish habitat along the Lower Darling channel
- collate a data atlas of environmental and socio-economic values.

Table 4. Summary of key research questions (RQ), outputs and outcomes for Theme 3: Environmental Outcomes.

Key questions	Key outputs and outcomes
RQ9. What are the low flow needs of the environment? RQ10. How can floodplain flow volumes, components, and inundation prediction be improved to support environmental watering and water resources planning? RQ11. How can adaptation through enhanced river operations and water resources management improve water outcomes?	Improved understanding of low flow requirements of the Basin's environmental assets and values to inform water planning and management, particularly under a changing climate. Prioritisation of environmental assets, values and functions for targeted water management and complementary measures to sustain and restore their conservation values. Development of predictive models to better understand the spatial distribution of environmental assets and values, how they respond over time to water management, and the risks to future population and ecosystem sustainability from ecosystem stress.

Progress and Achievements

Eight projects are underway and although there are some delays due to the persistent high flows in the Barwon-Darling into early 2023, Theme 3 is on track to deliver all outcomes. The researchers have been working effectively with the EUAG to identify management objectives for RQ10 and ensure the project outputs are targeted to meet end-user needs. A presentation on Theme 3 projects was given to at a Theme 1 Climate Adaptation Workshop in May 2023, reinforcing the integration between Themes 1 and 3.

The Drivers of ecological resilience and persistence during low and cease-to-flow conditions in the northern Murray–Darling Basin (RQ9.1) project is investigating the resilience and recovery of refuge waterholes after hydrological connection.

- Progressed review and synthesis reports of low flow knowledge.
- Completed a draft manuscript looking conceptually at the impact of low flows on riverine systems.
- Commenced drafting manuscripts – (i) 'Conceptualisation of low flow impacts'; and (ii) 'Review of low flow impacts on the ecology of rivers of the northern MDB'.
- Researchers presented 'Predicting the resilience of riverine biota to low flows' at the Australian Freshwater Sciences Society Conference in December 2022.

The Forecasting risks to fish and their available habitat from low flows and hypoxia (RQ9.2) project is focussed on determining the drivers of ecological resilience during low flow periods and developing a model to forecast risk to fish populations during low flow periods.

- Explored ways in which to complement three-dimensional modelling with riparian shading to support detailed assessments of two river reaches – (i) Culgoa River region and (ii) the lower river region, likely Menindee Lakes region.

A data atlas for conservation prioritisation (RQ10.1) project will develop an integrated repository of baseline spatially-explicit data for ecological and socio-economic research.

- Developed version 1 of the Geodatabase.
- Completed user guide to accompany the spatial geodatabase.

The Evaluating protection gaps and conservation prioritisation (RQ10.2) project aims to help the MDBA to identify places of high conservation value and prioritise management actions to conserve the critical assets, values and functions of these areas.

- Hosted a workshop for the EUAG in November 2022, gathering valuable insights.
- Held a stakeholder objective setting workshop in 8 March 2023, establishing three key objectives for the prioritisation analysis.
- Completed a comprehensive gap analysis.
- Made substantial progress in the vulnerability analysis, including the acquisition of important climate velocity data.
- Commenced the initial conservation prioritisation analysis to guide decision-making.
- Gave a deep dive presentation to the Theme 3 EUAG in November 2022.
- Held a workshop with staff from the MDBA and CEWH to define a set of SMART objectives to guide prioritisation analysis (March 2023).

The Developing a First Nations perspective on conservation planning (RQ10.3) project aimed to evaluate how First Nations perspective on conservation planning aligns with existing scientific and management approaches. A workshop was held with MLDRIN and MD-WERP Theme 3 and 4 researchers in September 2022 to progress project design and planning. The project was then placed on hold pending further workshops with a wider participation, especially among First Nations, to test and develop the original workshop ideas.[11]

The Spatially explicit population models for fish in the Barwon-Darling river system (RQ11.1) project will build upon existing population models to predict the responses of fish in the Barwon-Darling to forecasted changes to climate and hydrology. It will focus on the reach between Louth and Menindee, and adapt the spatially explicit model structure used by Bond et al. (2015) to examine Golden perch population dynamics in the Moonie River, Queensland.[12] Analysis for RQ11 has

[11] In early 2023-24 it was agreed that RQ10.3 would not progress any further.
[12] Bond, N.R., Balcombe, S.R., Crook, D.A., Marshall, J.C., Menke, N. and Lobegeiger, J.S., (2015). Fish population persistence in hydrologically variable landscapes. Ecological Applications, 25(4), pp.901-913. https://doi.org/10.1890/14-1618.1.

advanced and the preliminary outputs appear very promising for informing Basin water management.

- Generated a reduced area model that is functional based on the work completed, characterising waterhole persistence and characteristics.
- Developed an alternate method to incorporate field data due to delays in RQ9.1 field collection as a result of persistent high flows. Species demographic analysis and the modelling of dispersal patterns of meta-populations will be determined based on available datasets from NSW Department of Primary Industries Fisheries.
- Researchers presented 'Spatial Metapopulation modelling of the long-term persistence of an Australian freshwater fish (*Macquaria ambigua*) in the intermittent holes of an arid floodplain river' at Freshwater Sciences in June 2023 (RQ11.1).

The Predicting changes to the persistence and connectivity of in-channel aquatic habitat in the lower Darling River (RQ11.2) project will map persistent in-channel aquatic habitat and its connectivity, focussing on the Darling River between Louth and Menindee. Linking time series and historical river flow will provide an avenue for scenario evaluations of future aquatic habitat availability under climate change and water use.

- Developed preliminary reach level metrics that describe the connectivity of the entire reach for every month in the Landsat record, and connectivity metrics for the Landsat record for each persistent waterhole within the reach.
- Progressed development of predictive models to relate connectivity to hydrology and obtaining modelled flow data and historical rainfall data.

The Predicting change in floodplain habitat availability at the Basin scale (RQ11.3) project This project will develop a Basin-scale spatial time series of inundation and use statistical models to relate the time series to flow and discharge in the Basin to identify floodplain aquatic habitats that become inundated under different antecedent flow and rainfall conditions. The statistical models will then be used to generate scenario evaluations of future floodplain aquatic habitat extent under climate change and water use scenarios.

- Developed R workflow to quantify the relationships between inundation and hydrology (flow and rainfall) across the Basin.
- Significant improvements made, including:
    - use of different flow data to train the models
    - modelling the data at an annual rather than monthly timestep
    - inclusion of more relevant and increased predictor variables
    - modifying statistical code to determine any interactive effects in the models.
- Commenced investigating the use of rainfall and runoff data only in a Basin-wide model to provide a Basin-wide descriptive relationship of rainfall-inundation patterns for key Australian National Aquatic Ecosystem (ANAE) wetland types.

The Assessing future vulnerability of species and ecological communities (RQ11.4) project will develop habitat suitability models for key fish and floodplain vegetation species and communities in the Basin, and improve our ability to identify species and communities vulnerable to future hydrological and climate changes.

- Built preliminary model of fish habitat suitability using historic fish records with the ability to be updated to include more recent records.
- Sourced future climate (temperature) data from CSIRO, fish data from Queensland Department of Environment and Science, and progressed sourcing fish data from NSW DPI Fisheries and vegetation data from the CEWH Flow-MER program and Atlas of Living Australia.
- Developed Shiny App template with the preliminary fish models.
- Built preliminary models of macroinvertebrate families from NSW and Victorian Environmental Protection Agency (EPA) data and commenced validation and selection of suitable models.

Case Studies

RQ10.1 Data Atlas for conservation prioritisation and RQ10.2 Basin Wide Conservation Prioritisation

Project RQ10.1 has successfully developed and delivered a series of comprehensive spatial geodatabases, serving as the central repository for essential data required by RQ10.2 Basin Wide Conservation Prioritisation. These geodatabases have been designed to ensure transparency, repeatability, and reproducibility in future research endeavours. An extensive user guide and metadata accompany these databases to facilitate easy replication and understanding. We collaborated with RQ14.1 to ensure we have data consistency across projects, promoting future research reproducibility. The spatial geodatabases contain over 600 data layers and include data on important biodiversity assets such as Species and Ecological Communities of National Environmental Significance, vegetation, and wetlands as well as data on protected and managed areas, hydrology and climate velocity.

RQ10.2 leveraged these geodatabases to evaluate representation of important biodiversity assets within protected areas and other managed areas (Key Biodiversity Areas and Ramsar wetlands). This is an important prerequisite for identifying additional priority areas for targeted conservation management to complement the existing protected area network. We found that only 14% of the basin falls within protected areas, Key Biodiversity Areas, or Ramsar wetlands. Additionally, only a very small fraction of biodiversity assets within riverine areas are potentially able to be actively managed with flow releases from dams and reservoirs.

RQ10.2 also assessed the potential vulnerability of important biodiversity assets to climate change using a spatial dataset representing climate velocity. Climate velocity measures the speed at which climatic conditions, such as average temperature or precipitation, changes in each location. We found that most biodiversity assets including species, ecological communities, and important

wetlands occupy habitats that will likely see a significant shift in climate, particularly an increase in temperature and decrease in precipitation.

The final step for RQ10.2 is conducting a series of conservation prioritisation analyses to identify areas of high conservation value for implementation of targeted management actions, for example environmental watering. We are accounting for vulnerability, connectivity, and multiple targets in our analyses.

Our project has enjoyed extensive stakeholder input through workshops, presentations, and the EUAG. We have presented the work at the MD-WERP Annual Symposium, inaugural Water Research Workshop, produced a detailed report for the Representation and Vulnerability Analysis, drafted a scientific paper and delivered a series of comprehensive spatial geodatabases to the MDBA.

RQ11.3 Predicting change in floodplain habitat availability at the Basin scale

Floodplain ecosystems are critical landscape elements of the Murray–Darling Basin, contributing both ecological and social benefits. Floodplain biota in the Murray–Darling Basin have evolved life-history traits that align with characteristics of the timing, duration, and magnitude of the flood-pulse. However, historic, and current water resource development combined with climate change has altered the natural flood regime throughout the Murray–Darling Basin, reducing the connection between rivers and their floodplains, and resulting in suboptimal habitat conditions for floodplain-dependent biota.

The overarching aim of project RQ11.3 is to understand the relationships between flow, rain, and other catchment variables and how they may impact floodplain inundation and therefore habitat availability. We can then use these relationships to predict inundation under different flow scenarios. The outcomes of this project will benefit environmental flow management in the Murray–Darling Basin at a whole of Basin scale.

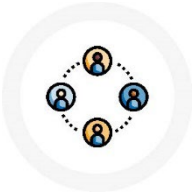
The objectives of this project were to first, use Landsat imagery to quantify basin wide floodplain inundation in different habitat types, over a 30-year period. The second objective was to develop a statistical technique to uncover relationships between floodplain inundation, flow, rainfall, and other catchment variables. The third objective was to use these relationships to predict floodplain inundation under different climate change and management flow scenarios. All the above objectives have been completed and presented in a final draft report. This report has been submitted for feedback, before a final report is published.

So far, the findings of the study suggest:

1. While important, flow is not the only determinate of floodplain inundation. Physical catchment characteristics, alongside levels of anthropogenic disturbance are also important predictors of floodplain inundation.
2. Alterations in low-moderate flows may have large impacts on floodplain inundation patterns.

3. The effect of the different flow scenarios on floodplain inundation was not uniform across the Basin, suggesting the need for context-dependent environmental flow planning.

Theme 4: Social, Economic and Cultural Outcomes



People rely on healthy ecosystems for their wellbeing and survival. Degraded landscapes and waterways affect the social, emotional, physical and financial health of people and communities. Theme 4 focuses on the social, economic and cultural benefits of river health, and research questions, summary of outputs and outcomes can be found in Table 5.

Table 5. Summary of key research questions (RQ), outputs and outcomes for Theme 4: Social, Economic and Cultural Outcomes.

Key questions	Key outputs and outcomes
RQ12. What is the relationship between the condition of the riverine ecosystem and social, economic and cultural values? RQ13. What are the cultural, economic and social outcomes for First Nations peoples and how can they be improved? RQ14. How can communities adapt to and be more resilient to a future with less water? What makes a community more resilient and adaptable to a future with less water?	Improved understanding of the value of healthy river ecosystems to mental health and cultural wellbeing of people and communities, and to recreation and tourism in the Basin. Identified First Nations aspirations, access to and use of water, developed water action plans and designed a real-world water delivery process. Improved understanding of First Nations' knowledge of water and perspectives on the relationship between water access, agency, self-determination and wellbeing. A new basin-wide social and biophysical data platform that will enhance research. New social mapping of community pathways for resilience, and production of 'story maps' to increase understanding of how communities navigate change.

Although the role of agriculture-related capital in the Basin is well understood, it is critical to understand the roles of other forms of human, social, financial, physical and natural capitals. The first component of the research maps these other forms of capital and investigates the relationship between healthy rivers and mental health, recreation and tourism.

First Nations peoples experience many technical, legal and relationship barriers to the cultural and economic opportunities provided by Basin water. The second component investigates how to improve First Nations' access, use and pursuit of water.

The way people and communities frame or understand challenges and opportunities plays a significant role in how resilient and adaptive they are. This final component of research investigates what makes a community better able to adapt to environmental and social challenges and how shared understandings about a future with less water emerge in Basin communities.

Progress and Achievements

Environmental factors have been a strong driver of delays to some Theme 4 projects, as an important part of the research consists of talking to communities, many of which were impacted by the floods. In addition, some projects have been delayed, ensuring adequate culturally sensitive engagement with First Nations groups.

The results coming from Projects RQ12.2 and RQ14.3 are demonstrating the importance of water to Basin communities from different perspectives. This knowledge will be a very important input to the Basin Plan Review.

A strong collaborative relationship has developed between the Research Consortium and the broader MDBA. This has drawn early attention to the impact pathways of some of the projects and supporting local community participation in the research projects while also managing risk. Examples include:

- Participation of researchers for Projects 12.1 and 14.3 in a workshop with the MDBA Regional Engagement Officers to discuss and understand social impacts of flooding in Basin communities.
- Project RQ14.3 collaborating with RQ14.2 and the MDBA-led Basin Condition Monitoring Program Community Oral Histories project, due to their strong synergies and interdependencies.

The mental health benefits form improvement to riverine ecosystem health (RQ12.1) project will improve our understanding of the mechanisms that mediate the relationship between mental health and healthy riverine ecosystems, specifically via human exposure to riverine environments, interaction with ecological restoration programs and their physical and social effects, and influence over environmental outcomes.

- Modified the sampling strategy due to the flooding in the Basin leading to a change in the relationship between people and e-water. The project is no longer relying on e-water releases for the survey and will instead leverage the existing longitudinal data and respondents of the Regional Wellbeing Survey (RWS) to understand water use, water connection and wellbeing.
- Finalised the conceptual model of the pathways between water flows and riverine condition, human use and response to changes in the riverine environment, and how this impacts mental health.
- Presented to the MDBA Social Economic Community of Practice (CoP).

The recreational and tourism value of healthy rivers (RQ12.2) project aims to establish and quantify the link between riverine ecosystem health and tourism/recreation visitation rates for valleys, local towns, and special interest sites (e.g., National Parks, Ramsar wetlands) across the Basin.

- Extracted more than 370,000 geo-located Flickr photo posts (date stamped from 1960 through to March 2022) for locations across the Basin.
- Aggregated geo-located photoposts into 'photo user days' and mapped at 11.2km grid square resolution across the Basin.
- From RQ14.1 sourced geographic (e.g. road distances and travel times to metropolitan population centres and rural towns), socio-economic (e.g. tourist facilities in localities) and biophysical data (e.g. the normalised difference vegetation index (NDVI) as a metric of 'green-ness', river flows, land uses) and mapped at the same grid resolution.
- Developed proposal for an additional component building on the current research to be undertaken in 2023-24.
- Presented to the MDBA Social Economic CoP.

The Development of a First Nations' ecosystem accounting framework with NBAN (RQ12.3) project was removed in late 2022 following the MDBA's decision to finalise their contractual arrangements with NBAN in November 2022.

The First Nations water-based outcomes in the southern Basin (RQ13.1) project was intended to identify options for influencing and strengthening existing programs, policies and relationships (e.g. CEWH partnerships, Murray–Darling Basin environmental water management planning, state Aboriginal water policy commitments) while paving new impact pathways to increase First Nations access to and/or ownership of water, and influence in the water sector (e.g. develop partnerships with (new) water sector actors, and contribute to the 2026 Basin Plan Review). Two research activities which were planned to be funded by MD-WERP and delivered in partnership with MLDRIN were:

1. First Nations Water Action Plans, investigating and documenting First Nations' water access and management outcomes (aspirations and/or actual) in up to four case studies; barriers to achieving these outcomes; and tangible pathways to overcoming these barriers.
2. Planning a water delivery using a real-world water delivery planning process to identify regulatory, policy, procedural and relational obstacles in planning a First Nations-led water delivery and work to respond to and overcome those obstacles. [13]

Progress in 2022-23 included completing the Activity 1 engagement plan and Human Ethics Approvals granted.

The First Nations water-based outcomes in the northern Basin (RQ13.2) project was to be delivered in collaboration with NBAN. However, following the MDBA's decision to finalise their contractual arrangements with NBAN in November 2022 significantly affected plans for the roll out of Project RQ13.2. Project partners met with MDBA staff, NBAN members and other Indigenous water experts, to seek a solution. Discussions were held with small teams of researchers and Indigenous

[13] Note, in October 2023 MLDRIN notified La Trobe University that it would be withdrawing from RQ13.1. As such, this project is no longer proceeding, recognising that the ICIP for project design rests with MLDRIN.

experts in the Gwydir wetlands and Bourke region to scope alternative projects to proceed in 2023-24.

The Basin-wide socio-economic, socio-demographic and biophysical data platform (RQ14.1) project is compiling a Basin-wide set of time-stamped GIS layers containing biophysical data on the condition of rivers, lakes, wetlands and floodplains, together with potentially relevant socio-demographic, socio-economic and geographic factors. The researchers are collaborating with Theme 3 Projects RQ10 and RQ11.3 and Theme 4 Project RQ12.2 to deliver this project.

- Completed the data platform (as a GIS database) structure and assembled a proportion of data files.
- Completed maps of various socio-economic concepts such as visitation rates to locations across the Basin.
- Developed a draft practice note suggesting appropriate geographical scales for the retrieval, processing and aggregation of socio-economic, socio-demographic and biophysical data to support socio-economic analyses across the MD-WERP, and into the future.

The Pathways to community resilience (RQ14.2) project seeks to demonstrate the diversity of water-reliant outcomes valued by communities that can be subsequently prioritised and protected through more effective water planning for an uncertain future. In doing so, it aims to provide a foundation that empowers communities and informs future water management decision-making by both communities and external actors.

- Received ethics approval for non-First Nations engagement, later amended to include First Nations engagement in these communities.
- Identified and reviewed key data sources to better understand the key issues arising in the focus communities of Griffith, Loxton and Walgett, and support engagement.
- Conducted preliminary investigations to understand the capacity to visualise water assets and changes in water extent for the purposes of focus groups, including basic maps derived from historic satellite data through the Project RQ14.1 team.
- Identified key contacts and community interest groups from which prospective focus groups will be drawn.
- Commenced engagement with the Griffith community focus groups.
- Explored relevant literature to support the appropriate methodology and understanding for development and submission of an overarching ethics application for youth-focussed virtual engagement.
- Engagement with the OneBasin CRC to ensure awareness of the MD-WERP project in Loxton and Griffith, where the CRC has Regional Hubs, and seek opportunities for synergies with the endeavours of the OneBasin CRC research program.

The Navigating change (RQ14.3) project seeks to identify the diverse underlying values people attach to their environments – particularly water –, the ways these are revealed in periods of change, and how conflicts around values have been accommodated and managed.

- Progressed interviews with non-Indigenous residents in Griffith.
- Planning undertaken for interviews with Loxton residents.

The MD-WERP is supporting the Australian Research Council Understanding the water cultures of the MDB (RQ14.4) project by providing $100,000 in grant top-up funds. The research team is undertaking historical research of water management practices and values in 4 locations: the Barmah Choke, Hattah Kulkyne National Park, the Yanco Creek area of the Murrumbidgee, and the Lower Lakes.

- Gained ethics approval for interviews with First Nations peoples under Griffith University's ethics protocol.
- Completed a weeklong field visit to the Yanco Creeks area of the Murrumbidgee in April 2023, coordinated by the Yanco Creeks Tributary and Advisory Committee.
- Completed a second trip to the Yanco Creeks area in June 2023 and interviewed approximately a dozen landowners, several fishers and First Nations peoples from the area.
- Completed a field trip to the Lower Lakes for interviews with fishers and boat pilots in June 2023.
- Held a workshop to plan out a book on water cultures of the MDB and commenced drafting a proposal for publishers.
- Launched 'The Water Cultures Network of the MDB' was launched with a web presence and twitter account, with 94 members at the end of May 2023.
- Professor Sue Jackson gave an interview on water cultures of the MDB on Radio National in March 2023.

Case Studies

RQ14.3 Navigating Change

This project generates insights about communities' experience of social and environmental change, and related shifts in environmental policy. It considers the impacts of change on individuals, families, and communities. These insights will help shape water management for a future with less water under climate change. It is being conducted by oral historians from La Trobe University.

The project generates understanding about how people have understood, managed, and adapted to significant change in the past, including a focus on any tensions arising, and the kinds of changes they anticipate in the future. There has been a significant investment in producing knowledge of the social, economic, and cultural conditions of the Basin. But the focus has almost entirely been on a stocktake of current conditions, including how water recovery has impacted

Basin economies. Much less work has been done to understand how communities can adapt and become more resilient to a future with less water.

The project will hold up to 60 extensive interviews with Basin residents in three communities (Griffith, Loxton, and Walgett). The communities were selected for their representing different degrees of vulnerability to climate change impacts. These characteristics mean that while there are only three communities involved, the insights are recognisable to many more communities representing similar vulnerabilities. The La Trobe University team analysis will identify the diversity of values that characterise different vulnerabilities and ways of valuing the environment and how these values are used to navigate adaptation to environmental pressures. Participants will include First Nations, dry land farmers, irrigators, and town dwellers. Outputs from this research include formal reporting to the MDBA and story maps for each participating community. The maps are a tangible record of the stories with photo media, in an accessible form.

Since its inception towards the end of 2022, the project has completed 50% of the interviews in Griffith and Loxton. Key emerging themes evident in the interview data and common to both communities are:

- concerns about the impacts of corporate farming
- concerns about the impacts of separating water from land
- valuing of healthy water systems and related programs such as carp infestation reduction.

Specific to Griffith is anger about the relationship with government in past water management approaches. Specific to Loxton is support for water saving work such as replacing channels with pipes. The research is revealing that communities that are more dependent on irrigation for their water supply have less flexibility about water management regimes. Communities that are more exposed to salinity issues, are very focussed on environmental conditions that underpin ecosystem health. Negotiations with First Nations peoples are in progress to ensure a culturally appropriate approach to the research, fitting each local community.

This research will inform the development of scenarios that recognise a diversity of values and vulnerabilities, taking into account how communities respond to and manage change. Scenarios that better describe social and economic outcomes will help minimise impacts of changes in water availability and maximise the benefits of improvements in water management including working with community strengths. The project's insights will assist the MDBA to develop strategies and policies that move communities to synergies that drive climate change resilience.

RQ12.2 Recreational and tourism value of healthy rivers

The objective of this project is to establish and quantify the link between riverine ecosystem health and tourism/recreation visitation rates for valleys, local towns, and special interest sites (e.g. National Parks, Ramsar wetlands) across the Basin. The project is being conducted by environmental economists at Griffith University as partners in the MD-WERP La Trobe University Consortium.

Tourism generates around $8 billion per year across the Basin (2020 Basin Plan Evaluation). Despite tourism's substantial contribution to local Basin economies, and widespread agreement that tourism/recreation visitation numbers depend on healthy riverine ecosystems, it has not yet been possible to quantify this link and thus estimate the additional tourism and recreation value that could potentially be generated by improving riverine ecosystem health.

This study compiled a dataset of geo-located, time-stamped photo posts from the Flickr social media site to produce a proxy metric of monthly visitation rate through time across the Basin. A preliminary data extraction test identified almost 14,500 geo-located, time-stamped Flickr photo posts along environmental water delivery paths in the Macquarie and Lachlan catchments. This early test indicated that a substantial dataset could be assembled across the Basin which, once controlled for confounding factors and calibrated with Tourism Australia Research visitor data, could provide an estimate of the economic benefit that local communities could potentially obtain from improved riverine ecosystem health.

Since its inception in July 2022, the project has assembled a large data set of monthly counts of 'photo user days' as a proxy metric of visitation rate across 8,200 11.32 x 11.32km grid cells across the Basin between January 2013 and March 2019 and conducted a variety of regression models to account for confounding factors. It is currently researching the nature of credible quantitative links between visitation rates and riverine ecosystem health, using spatial count data regression to control appropriately for the multiple confounding factors. It will then calculate the additional tourism/recreation expenditures that could potentially follow in local economies across the Basin from improvements in environmental/riverine condition. The project will write up results as an academic paper for a peer-reviewed journal, and submit a report to the MDBA including a plain English summary

To optimise social, economic, cultural and environmental outcomes it is important to understand one of the major pathways by which flow regimes influence these outcomes: ecosystem services. Ecosystem services include recreation and tourism benefits that arise from healthy and functioning ecosystems. This project will generate insights into how to produce new and improved measures of the flow of recreation-related ecosystem service benefits to people and the financial and social value of the benefits people receive, especially at locations receiving environmental water.

6. Progress in the Tactical Investment Stream

MD-WERP is supporting the Australian Government to address emerging and high priority issues in the Murray–Darling Basin by investing in practical, short-term (6-12 months) projects in water management, river operations and Basin Plan implementation. The projects are being delivered by a range of research and delivery partners.

The Tactical Investment Stream allows the Australian Government to respond to short-term knowledge needs during the life of the MD-WERP. The projects are usually carried out 'in-house' by Australian Government partners, or in partnership, and if necessary, the whole project may be contracted to another supplier. The initial approach for tactical investment involved a broad call for submissions across Australian Government partners. The governance and process has been streamlined to ensure projects are aligned with the overarching objectives of the MD-WERP.

TP03. Evaluation of Causes of Reduced Flow through the northern Basin

Completed

This project was initiated to explain the cause of reduced flow in the northern Murray–Darling Basin. It synthesised existing hydrological knowledge of the northern Basin, identified limitations in that knowledge and recommended methods to overcome the limitations.

The outcomes of this tactical investment project may be used to inform future and larger research projects, including those that will underpin future modelling and policy responses, and the 2026 Basin Plan Review.

Progress and Achievements

The final report provides a background of the northern Basin communities, water resources and water uses. It describes the history of water resource development, water resource planning and regulation, and scrutiny of water resource management in the northern Basin. Trends in climate and landscape rainfall and runoff across the northern Basin are presented, along with trends and changes in the Barwon-Darling River.

There is a reasonably good general understanding of the water balance in the northern Basin, that is, water inputs and outputs in the system at different time scales and at different locations, from measurements, modelling and integrating multiple types of information. However, there are gaps in knowledge, particularly for some water fluxes or components and at the detailed level required to address issues that have been discussed. While addressing these gaps may not significantly change the quantum of the larger volumetric assessments, it would better inform options to manage the river system more effectively especially in times of water stress. The report describes recommendations to help overcome some of these knowledge gaps.

Equally important is the need for more transparent engagement and communication with communities and stakeholders to build confidence and trust in the knowledge, data and models. This will then shift the conversation from about uncertainty and debates on the broad knowledge to a more positive engagement and discussion about solution, choices and adaptation to overcome challenges in providing a scarce and limited resource to multiple uses.

- Synthesised current hydro-climate knowledge of the northern Basin.
- Characterised (and quantified based on current data and knowledge) the various water fluxes/components (and the range of uncertainty) and changes in the fluxes through time to develop a conceptual model.
- Engaged with key stakeholders to compare perceptions versus key findings and recommend methods that can enhance the understanding and quantification of the key factors influencing flows in the northern Basin.
- Published the final report TP03. Explaining the causers of reduced flow in the northern Basin in February 2023 on the MD-WERP website.

TP07. Innovation Sweep, Scoping and Development of Drone-based Waterbird Monitoring

Completed

The Basin Plan outlines several obligations to maintain and improve water-dependent ecosystems including waterbird breeding and populations. Ensuring waterbird breeding events occur is also critical to maintaining the ecological character of Ramsar sites and other wetlands. To help assess the success of water management initiatives there is need to accurately and routinely monitor waterbird numbers and breeding events. Additionally, there is a lack of systematic continuous surveys of breeding, making Basin-wide analysis and trend analysis difficult.

This project had two components: develop a tool to automatically count colonial nesting waterbirds from drone imagery for a test site; and conduct an innovation sweep of new and upcoming technologies that can be used for monitoring and evaluation, particularly in regard to the expected outcomes of the Basin-wide environmental watering strategy.

Progress and Achievements

During the first part of the project, researchers from the University of Adelaide's Unmanned Research Aircraft Facility successfully developed a tool designed to automatically count colonial nesting waterbirds from drone imagery. The automatic detection tool was developed alongside the Australian Institute of Machine Learning and was trained and testing using high resolution drone images of a straw-necked ibis colony at a breeding site at Mullins Swamp in South Australia. The outcomes of this project demonstrated significant potential, with the tool able to estimate the size of the colony with greater than 90% accuracy. The project also identified that this kind of software can be made accessible for people who may not have high levels of computer literacy, expanding the range of settings in which the tool could be applied.

The innovation sweep provides a synthesis of emerging technologies that may provide solutions to the challenges of environmental monitoring within the Murray–Darling Basin at the landscape scale. It is targeted towards on-ground managers of natural areas within the Basin seeking to further develop their monitoring toolkit by incorporating cutting-edge technology and research. The innovation sweep successfully identified a list of emerging technologies that have the potential to be used to monitor ecological outcomes of interest to the MDBA at the landscape scale. This includes a range of advanced sensing technologies, machine learning assisted data analysis and modelling approaches enhanced by artificial intelligence (AI) with the potential to inform decision making for long-term management projects such as environmental watering.

The sweep found that the range of technologies may be most useful when partnered and used together – for example, autonomous platforms may collect long-term data on water levels that can be quickly and efficiently examined using machine learning-based analysis. The results of this analysis could then be fed into sequential decision-making and reinforcement learning models to assist managers in identifying best-practice environmental watering strategies.

- Published the final report TP07. Nesting waterbird colony population size monitoring using automated counts on drone imagery in November 2022 on the MD-WERP website.
- Software code made available on the MDBA's GitHub page so researchers and others can use the technology for their own purposes, with or without waterbirds.
- Published the final report TP07. Innovation sweep - Technological insights for the Murray–Darling Basin Authority in November 2022 on the MD-WERP website.
- Announced the publication of the final reports via an MDBA media release in February 2023, also published in the MDBA Newsroom. The release was picked up by several news agencies, Dr Matthew Coleman gave multiple radio interviews, and the University of Adelaide gave a radio interview.

TP09. Waterbird Foraging Habitat

In progress

Waterbird populations across the Basin require appropriate management of both breeding and foraging habitats to ensure that there are adequate food resources available for breeding and recruitment. This project will better inform environmental water management delivery for the foraging habitat requirements of obligate and non-obligate colonial nesting waterbirds.

The technical advisory group for this project included waterbird researchers, environmental water managers and members from science, policy and monitoring areas in the Australian and Basin state governments.

Progress and Achievements

The research involved refining a conceptual lifecycle model for targeted waterbird groups, remote sensing analysis and identifying likely climate change impacts on availability of foraging habitat. The final report will describe methods for identifying and prioritising foraging habitats for potential management to support waterbirds throughout their lifecycle, and make several recommendations for continuing to refine this prioritisation method into the future with improved spatio-temporal, updated shallow water mapping methods. Submission of the final report and acceptance by the MDBA was expected in July 2023.

Key findings of the project include:

- obligate feeders travel much smaller distances (median of 1 km, 766 ha zone) to forage than generalist non-obligate feeders (median of 4.5 km, 6,361 ha zone)
- there are clear inundated habitat preferences between obligate and non-obligate colonial waterbirds for foraging
- the availability of foraging habitat varies significantly in space and time, with a decline in preferred shallow foraging habitat for obligate feeders at around half of all colony locations and increases at several lake system sites.

TP12. Riverbank Stability and Erosion

In progress

This project will help address increasing community concern and negative media relating to bank erosion along the River Murray. The project has 3 key elements:

1. Desktop synthesis of bank condition and the scientific knowledge of the influences on erosion within the different reaches of the river and major anabranches from the confluence with the Swampy Plains River at the upper end of the system to the Murray Mouth. This is an internal report to inform development of the public communication material (element 2).
2. Preparation of communication material for communities to help with positive engagement and increased understanding of the complexity of the erosion issue.
3. Scoping of a strategic plan for monitoring erosion along the River Murray to fill the knowledge gaps and/or to address community concerns and support understanding of the issue with robust, fit-for-purpose information.

Progress and Achievements

The desktop synthesis report was completed in August 2022 and identified a range of erosion processes and drivers along the River Murray. The preparation of communication material is well underway with supplier Animate Your Science (AYS). AYS are producing two animated videos and

one infographic to effectively communicate the complexities of erosion along the River Murray. The communication materials are expected to be completed in March 2024, and Element 3 will be progressed in the second half of 2023-24.

TP13. Summary and Analysis of Blue-green Algal Trends in the Basin

Completed

Although blue-green algal blooms are a natural part of most aquatic environments throughout the Basin, there is increasing community concern that blue-green algae blooms are becoming more common, lasting longer and becoming more severe. Basin communities perceive more frequent recreational use alerts and restrictions. Communities are asking what can be done to better manage blue-green algae blooms, whether the water is safe to drink and swim in, and whether the problem is getting worse.

This project has two elements that will help build knowledge and support communication about blue-green algae.

- Analysis of recent trends in blue-green algae blooms to investigate if blooms are happening more often, lasting longer or becoming more severe. This will:
    - improve collective understanding of changing risks to water quality and to river users caused by algal blooms
    - better support jurisdictions to consider existing and emerging risks to shared water resources
    - identify further knowledge needs.
- Summary of current knowledge about blue-green algae bloom dynamics, impacts and current management options, as well as limitations.

The aim of the project is to develop a summary document describing the latest science and management around blue-green algae blooms for use by Basin communities.

Progress and Achievements

The report was finalised with publication expected later in 2023 on the MD-WERP page and the MDBA's water quality webpage.

The project found that since 1997, blue-green algae has significantly increased in abundance along the River Murray. The 2 upper-most sites and 3 most downstream sites recorded the greatest increases in blue-green alga during the Millennium Drought, whereas mid-river sites showed the greatest increases following the Millennium Drought. Basin blue-green algae trends did not show an overall increase or decrease within any of the 4 Basin states (Queensland, New South Wales, Victoria, South Australia).

All monitored sites along the river, and most Victorian sites, reported increases in blue-green algae since 1997, however Queensland and New South Wales showed no clear trends at either the site, river or catchment level. The research also showed that changes have occurred in the dominant, potentially toxic blue-green algae types responsible for algal blooms in the River Murray. Chrysosporum is currently responsible for most blooms where previously Dolichospermum and/or Microcystis were dominant in bloom formation.

The project's findings provide a clearer picture of the state knowledge about blue-green algae across the Murray–Darling Basin and highlight that Basin trends, although variable, are increasing in abundance. The research further identified there is a need for continued monitoring and more consistency in sampling methodologies and monitoring frequencies across the Basin.

TP17. Operational Ranges of the River Murray Fishways

Initiated

This project will boost understanding of the operational ranges of the River Murray fishways in relation to flow and level. While it is known that variability in weir pool levels can impact the operational performance of fishways, the relationship between operations and fish passage (i.e. weir pool levels and which fish passage is impeded and optimised respectively) is not well understood. The project will:

- summarise a review and assessment of fishway performance and operational limits across the expected hydrological flow range for the River Murray fishways
- characterise fishway conditions and effectiveness for proposed Weir Pool Manipulation (WPM) levels across the expected hydrological flow range
- develop operational guidance notes that detail lock/weir operation relative to fishway operational limits with respect to real-time measurements of Tail Water Level and Head Water Level.

It is anticipated that the project deliverables will be used by Basin governments to:

- ensure transparency and robustness of decision-making in managing river system operations
- inform trade-off decisions for annual weir pool variability planning and implementation (i.e. enhancing fishway performance and/or maximizing associated WPM benefits)
- inform referrals by river operators, on behalf of Basin government agencies, to New South Wales DPI Fisheries to seek approvals for temporarily impeding fish passage during a proposed WPM event
- evaluate river level variability impacts on fishway performance, including proposed WPM trials

- inform Sustainable Diversion Limit Adjustment Mechanism (SDLAM) projects and supply shortfall strategies
- prioritise knowledge gaps and their criticality to fishway performance
- determine whether future investment in investigation of expansion of the operational range of fishways is warranted.

Progress and Achievements

This project was endorsed by the Governing Panel in December 2022 and scoping of service providers was undertaken.

7. Communication, Adoption, Transparency and Engagement Investment Stream

MD-WERP has continued to build awareness of the program and develop pathways towards adoption through a number of communication and engagement activities.

MD-WERP Website

As a key transparency tool, the MD-WERP website is the primary public interface.[14] Over the 12-month period its visitation rates tripled from 619 unique visitors in the 2021-22 to 2,656 unique visitors in 2022-23. The most downloaded document was T1.FS1 Synthesis of indirect impacts of climate change in the Murray–Darling Basin (185 downloads) followed by T2.8a.2 Water forecasts of risk in the southern Murray Darling Basin for water management (130 downloads). In addition to the main page, the highest pages visited have been Hydrology, Tactical Investment Projects, and the MD-WERP Annual Symposium 2022.

As noted in Sections 5 and 6, a total of 13 strategic research and tactical research deliverables were published on the MD-WERP website in 2022-23.

The Annual Progress Update 2021-22 was published in December 2022 to provide a short, high-level summary of program progress and financial information. The annual progress update was downloaded 97 times between December 2022 and 30 June 2023.

Summary information and presentations from the inaugural 2022 Annual Symposium were published in December 2022. Up to 30 June 2023, this page had been visited 224 times, with the video watched 92 times. Videos were also shared on social media by the Consortium Directors and the MD-WERP Governing Panel Chair.

[14] In May 2024 the MD-WERP web content was transferred from the Get Involved website to the MDBA website.

2023 Annual Symposium

Planning for the second Annual Symposium (to be held 19-20 July 2023) progressed well with invitations sent to over 246 invitees. The second symposium is designed to take attendees through a narrative journey beginning with a high-level introduction to Australian Government priorities, the importance of science and knowledge in the 2026 Basin Plan Review, and the importance of MD-WERP research in this.

Poster sessions will be an integral part of this symposium to allow attendees to engage with the research and researchers at a project level. A key outcome of the poster sessions is to allow policy makers/end users to consider opportunities, barriers and risks to adopting the new knowledge.

Engagement and Adoption

A key objective of MD-WERP is to promote the Australian Government's investment in research and development to improve Basin Plan outcomes and scientific knowledge. A number of key groups and committees were engaged throughout 2022–23, including:

- Edition #3 (December 2022) and edition #4 (May 2023) of the MD-WERP e-newsletters were distributed to more than 200 stakeholders including the Governing Panel, Research Consortium, tactical project leads and end user advisory groups. The newsletters were also published on the MD-WERP website with the edition #4 newsletter downloaded 62 times, and edition #3 newsletter downloaded 53 times.
- Presentation by the Program Delegate to the Basin Community Committee in April 2023.
- Communication products made available at the MDBA River Reflections Conference held in June 2023.

First Nations Engagement

As part of LTU tender response, they partnered with MLDRIN and NBAN to lead work on First Nations Research. In late 2022 the partnership with NBAN was withdrawn following the MDBA's decision to finalise their contractual arrangements with NBAN in November 2022. Other avenues for research and engagement in the northern Basin are being explored, including leveraging existing relationships and approaching individual Nations, with positive progress being made in developing proposals for Themes 1 and 4.

In addition, factors including COVID-19 delaying co-design workshops, government officers building familiarity with the specific engagement desires of First Nations people, and the comparative novelty of the work being proposed significantly delayed LTU's development and Governing Panel's endorsement of the primary First Nations research question (RQ13). This

impacted on progress of research and relationships. LTU and MLDRIN continued development of the collaboration agreement in 2022-23.[15]

MD-WERP recognises its strong obligations to conduct culturally appropriate and safe research and to appropriately manage Indigenous Cultural and Intellectual Property (ICIP). MD-WERP is deeply committed to meeting these obligations, including appropriately resourcing First Nations and relevant organisations involved in MD-WERP to contribute to culturally appropriate research. MD-WERP partners recognises that all parties are on a collective ongoing learning journey with regard to this part of the program. Formal deed agreements with the Research Consortium partners, CSIRO and La Trobe University, explicitly outline requirements for the management of ICIP.

To ensure a consistent approach and understanding across the program, Indigenous law firm Terri Janke and Company (TJC) conducted a desktop review and provided recommendations relating to MD-WERP's management of Indigenous Cultural and Intellectual Property (ICIP), and cultural training for the Research Consortium. TJC was unsuccessful in its efforts to consult with some of the key stakeholders, and as such, the report recommended the preliminary findings be strengthened through further collaboration with key First Nations stakeholders. A cultural training audit across the 4 strategic research themes and Consortium partners was also completed. The Program is committed to support cultural training going forward through initiatives such as the Cultural Capability Hub.

End User Advisory Groups (EUAGs)

Forming strong links between researchers and end users is a crucial component of the program. Each of the 4 strategic research themes has an EUAG (for Theme 4 this is the Social Economic CoP) which draw on a broad range of end user perspectives, expertise and experiences. The EUAGs comprise end users from the Australian Government (DCCEEW, CEWH, MDBA), state governments and the research sector who have an interest in the theme.

The EUAGs create opportunities for policy makers and researchers to allow for ongoing co-design and feedback on the research. They are also vital for research impact – having end-users involved throughout the program is key to ensuring that key users of the research are ready to adopt and apply the new knowledge as soon as it becomes available.

[15]In October 2023 MLDRIN notified La Trobe University that it would be withdrawing from RQ13.1. MLDRIN continues to be involved in MD-WERP as a member of the La Trobe University-led consortium, and the Social and Economic Community of Practice (Theme 4 End User Advisory Group).

8. Governance and Administration

The program has complex, multi-layered governance involving government and non-government organisations. Successfully delivering a 5-year cross-agency program requires a robust framework of authority and accountability applied by the different levels of governance to ensure that the research creates value, and the investment delivers against Australian Government objectives. This requires thorough communication and collaboration between all players.

The MD-WERP governance structure remains as agreed in 2020–21 (Figure 1), updated only with administrative changes due to internal restructures and a Machinery of Government – effective 1 July 2022 – changing the Australian Government department responsible for water from Department of Agriculture, Water and Energy (DAWE) to the Department of Climate Change, Energy, the Environment and Water (DCCEEW).

- In 2022-23, the Governing Panel met 4 times and the ELT met 7 times.

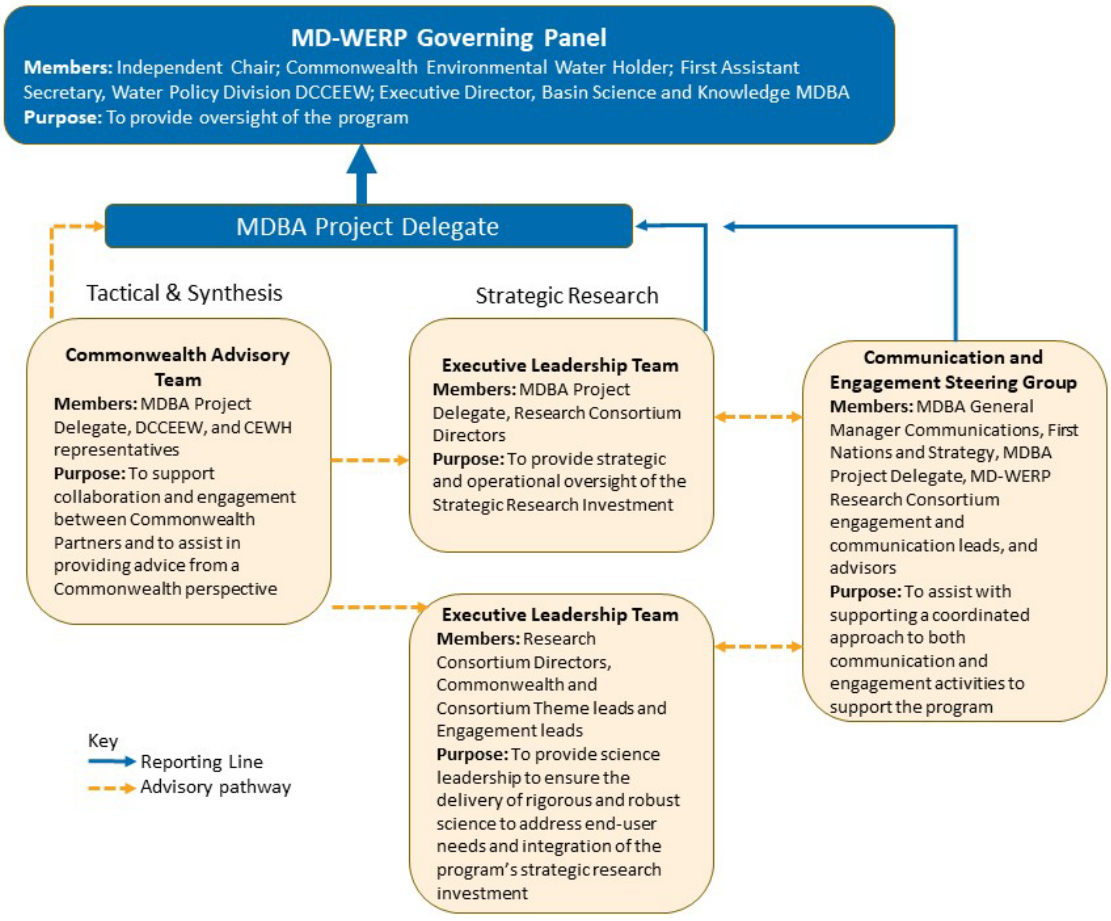


Figure 1. MD-WERP governance structure as at 30 June 2023

Program administration is managed by the MDBA to support delivery of the program. Budget, systems, reporting, secretariat duties and overarching contract management are delivered by the MD-WERP Implementation Team.

The team's primary focus in 2022–23 has been to implement the Program's RIPs and uplift the program management, supported by ongoing refinement of the program's governance, investment approach, risk management and planning. This included:

- uplift of the program management
- review and alignment of the MD-WERP Risk Management Plan with the MDBA Risk Management Framework and Policy
- secretariate support for Governing Panel and ELT meetings
- initiate the program's mid-term evaluation.

9. Financial Summary

A total of $4,276,924 was spent in 2022-23 (Table 6). The Consortia invested $1,949,338 as FTE in-kind contribution to the MD-WERP in 2022-23 (Table 7), equivalent to 31% of the total investment for 2022-23.

Table 6. Actual expenditure in 2022-23

Expense	Actual expenditure (GST exclusive)
Strategic Research	
Theme 1. Climate Adaptation*	$640,965
Theme 2. Hydrology	$1,205,152
Theme 3. Environmental Outcomes	$794,904
Theme 4. Social, Economic and Cultural Outcomes	$610,002
RQ14.4 ARC top-up grant to Griffith University	$100,000
Strategic Research TOTAL	$3,351,023
Tactical Investment	
TP03. Evaluation of causes of reduced flow through the northern Basin	$90,000
TP07. Innovation sweep, scoping and development of drone-based waterbird monitoring	$40,000
TP09. Waterbird foraging habitat	$135,760
TP12. Riverbank stability and erosion	$25,670
TP13. Summary and analysis of blue-green algal trends in the Basin	$122,200
Tactical Investment TOTAL	$413,630
Communication, Adoption, Transparency and Engagement	$149,701
Program Administration	$362,570
GRAND TOTAL	**$4,276,924**
* Second milestone payment delayed and will be reported as expenditure in 2023-24	

Table 7. Consortium in-kind staffing contributions for 2022-23

Theme	FTE contribution
Climate Adaptation (CSIRO)	$680,167
Hydrology (CSIRO)	$702,490
Environmental Outcomes (LTU)	$566,681
Social, Economic and Cultural Outcomes (LTU)	
Consortium in-kind TOTAL	**$1,949,338**

10. Program Glossary

Term	Definition
Adoption	The uptake of information, concepts, tools or practices (innovations) that have been generated predominantly through research.
Advisory Committee on Social, Environmental and Economic Sciences (ACSEES)	The MDBA's independent scientific advisory body comprising 8 committee members focused on delivering advice on Basin Plan implementation and the broader scientific context of the MDBA's work, including environmental watering, First Nations, adaptive management, climate change and the monitoring and evaluation of Basin Plan outcomes.
Chair	Independent Chair who provides strategic oversight of the program and leads the MD-WERP Governing Panel.
Co-design	Purposely designed to include end users throughout the life of the program to ensure it maintains its relevance.
Commonwealth Advisory Team (CAT)	A group established to support collaboration and engagement between Australian Government Partners and to assist in providing advice from a Commonwealth perspective.
Commonwealth and Engagement Steering Group	A group established to assist with supporting a coordinated approach to both communication and engagement activities to support MD-WERP.
Communication, Adoption, Transparency and Engagement Framework	A framework developed to guide the development of all communications, engagement, transparency and adoption activities; it outlines expectations at program and project/thematic level.

Term	Definition
Commonwealth Environmental Water Holder (CEWH)	The CEWH is an independent statutory position established under the *Water Act 2007* to manage the Australian Government's water entitlements in the Murray–Darling Basin. The CEWH leads, and is supported by, the Environmental Water and Aquatic Ecosystems Division of DCCEEW. The Division supports the CEWH to deliver water across the Basin to meet environmental priorities and targets set out under the Basin Plan.
Australian Government Partners	A collaboration between Australian Government agencies to help deliver the program, comprising the MDBA, the CEWH, and DCCEEW.
Department of Climate Change, Energy, the Environment and Water (DCCEEW)	Australian Government department partnering in the research program with the MDBA and CEWH.
End Users	Individuals, groups and organisations for whom the findings and outputs of MD-WERP will have direct relevance and consequences to their work programs.
End User Advisory Groups (EUAGs)	Established to assist in developing a shared vision for the research program, including impact pathways, research questions and connected teams. Groups are comprised of ends-users from the Australian Government (DCCEEW, CEWH, MDBA), state governments and the research sector who have an interest or expertise in a particular research stream.
Evaluation	Systematic determination of the quality or value of something. Evaluation will be used to determine the value of the program and its activities. Formative evaluation through the life of the program will inform ongoing improvements, with summative evaluation being conducted to capture the overall worth of the program at its closure.
Executive Leadership Team (ELT)	A leadership group comprising the MDBA Project Delegate, and Research Consortium leads to provide strategic and operational oversight of the Strategic Research Investment.
Governing Panel	An executive leadership group established to provide strategic oversight of the program, comprising an independent Chair, the Commonwealth Environmental Water Holder, Head of Division of the Water Policy Division (DCCEEW), and Executive Director of Basin Science and Knowledge (MDBA).
Impact Pathway	Outlines the key inputs, activities, outputs and expected outcomes and impacts for each research theme and the relevant research questions in ensuring the research continues to be used and developed by others after the four-year program.

Term	Definition
Knowledge Prospectus	Identifies 14 priority research questions across the 4 themes of Climate Adaptation, Hydrology, Environment, and Social, Cultural and Economic. It was developed in 2020 through an independent consultative process involving a range of participants including the Basin governments, academia and the community.
Monitoring	Observing or checking the progress of something over a period of time. In the context of MD-WERP, monitoring may include performance monitoring or operational monitoring depending on the question it is being used to address. Monitoring will inform evaluation and reporting.
Murray–Darling Basin Authority (MDBA)	Responsible for administering the program, in collaboration with Australian Government Partners, DCCEEW and CEWH, Basin stakeholders, and the Research Consortium.
MDBA Delegate	MDBA Executive Director, Basin Science and Knowledge, responsible for the program. Provides strategic guidance and leadership and oversees budget allocation, program investments, research design, and monitoring, evaluation and reporting.
MDBA Project Delegate	MDBA General Manager, Science Acquisition, responsible for administering the program with the support of the MD-WERP Implementation Team.
Murray–Darling Water and Environment Research Program (MD-WERP)	A 5-year (2021–25), $20 million Australian Government funded research program designed to help inform water and environment management decisions, which will improve outcomes for the Basin and its communities.
MD-WERP Implementation Team	Provides support to the MDBA Project Delegate in administering the program by managing the program administration, program streams, providing secretariat support, and engaging with key stakeholders and program partners.
Memorandum of Understanding (MoU)	Funding for MD-WERP is provided under a Memorandum of Understanding between DCCEEW and the MDBA. The MDBA administers the program under the guidance of the MD-WERP Governing Panel.
Monitoring, Evaluation, Reporting and Improvement (MERI) Framework	Outlines the rationale, scope and approach for monitoring and evaluating the activities carried out under MD-WERP, the reporting activities and feedback loops for program improvement.
Murray Lower Darling Rivers Indigenous Nations (MLDRIN)	A confederation formed in 1998 of First Nations from the southern part of the Basin. It is comprised of representatives of the Barapa Barapa, Dhudhuroa, Dja Dja Wurrung, Latji Latji, Maraura, Mutti Mutti, Nari Nari, Ngarrindjeri, Ngaiwang, Ngintait, Ngunnawal, Nyeri Nyeri, Tati Tati, Wadi Wadi, Wamba Wamba, Waywurru, Weki Weki, Wergaia, Wiradjuri, Wolgalu, Wotjobaluk, Yaitmathang and Yita Yita.

Term	Definition
Northern Basin Aboriginal Nations (NBAN)	A confederation formed in April 2010 that comprised of First Nations from the northern part of the Basin. As at August 2020 NBAN was comprised of Traditional Owner nominated representatives from the Barunggam, Bidjara, Bigambul, Budjiti, Euahlayi, Githabul, Gomeroi, Gunggari, Guwamu (Kooma), Jarowair, Kambuwal, Kunja, Kwiambul, Malijangapa, Mandandanji, Mardigan, Murrawarri, Ngemba, Ngiyampaa, Wailwan and Wakka Wakka Nations.[16]
Reporting	Giving an account of something that has been observed, heard, done or investigated. Reporting will be used to track risks and disseminate monitoring and evaluation findings. Reporting will feed into ongoing improvement of activities and broader evaluation of the program. Reporting plays a critical role in ensuring transparency.
Research Consortium	Comprised of CSIRO and La Trobe University, each with additional collaborators, to lead and deliver the strategic research stream of the program over 4 themes: climate adaptation, hydrology, environmental outcomes, and social, economic and cultural outcomes.
Research Implementation Plan (RIP)	An outline of the research questions to be answered and the research planning for how these questions will be answered, including a defined impact pathway to outline the key inputs, activities, outputs and expected outcomes and impacts for each theme and the relevant research questions.
Research Theme	Four themes that form the strategic research stream of the program including: 1) climate adaptation 2) hydrology, 3) environmental outcomes and 4) social, economic and cultural outcomes.
Research Question	A set of agreed research questions identified by the *Knowledge Prospectus* across the 4 research themes that have clear links to priority knowledge gaps and critical user needs.
Science Leadership Team (SLT)	A group established to provide science leadership to ensure the delivery of rigorous and robust science to address end-user needs and integration of the program's research investment.
Strategic Research Investment	One of 4 program streams involving a collaboration between the Australian Government and the Research Consortium to co-design, co-invest and deliver applied research across 4 themes. The strategic research component of the program will invest in priority research needs to improve the long-term management of the Murray–Darling Basin.

[16] Northern Basin Aboriginal Nations (NBAN) Submission: Inquiry into the National Water Reform, dated 21 August 2020.

Term	Definition
Streams	Four program funding streams that comprise MD-WERP including 1) Strategic Research 2) Tactical Investments 3) Communications, Engagement and Adoption, and 4) Administration.
Sustainable Rural Water Use and Infrastructure Program	The Sustainable Rural Water Use and Infrastructure Program (SRWUIP) is a national program investing in rural water use, management and efficiency, including improved water knowledge and market reform, and water purchase for the environment. SRWUIP funding is managed by DCCEEW. Funding for the MD-WERP is provided by DCCEEW from SRWUIP Bill 1.
Synthesis Activities	Creation of explainer products and activities that bring together information from across the program and communicate new and existing science for a variety of audiences.
Tactical Investment	Delivery of short-term and responsive outputs to assist decision and policy makers on water management, river operations and Basin Plan implementation.
Theme Team	Comprising an MDBA Theme Lead and Theme Coordinator to oversee and support the strategic research investment of the program on behalf of the Commonwealth Partners, and to liaise with the EUAGs in the co-design, monitoring, evaluation and adoption of the research.