Australia's National Science Agency

CSIRO submission to the Productivity Commission on the National Water Reform 2024

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Executive Summary

In this submission, CSIRO provides information in relation to key water security and management challenges for Australia, in areas reflecting CSIRO's scientific capacity. It highlights outstanding knowledge gaps or technical challenges for future water reform in relation to:

- **Climate:** Climate and hydrological extremes affect the delivery of water, the functioning of water markets and environmental outcomes of our river systems. Australia needs up-to-date climate information and fit-for-purpose projections of future water availability to increase water security, restore ecosystem function and services, and address social and economic vulnerabilities. Key challenges relate to:
  - **Floods** – Understanding how the frequency and intensity of floods change under an extreme climate, and accurate mapping of how floodwaters move across a landscape, helps to educate, and engage communities, and support informed decisions about land use, insurance, and emergency preparedness.
  - **Drought** – Managed Aquifer Recharge (MAR) is an internationally proven, low-cost solution that could improve drought resilience across regional Australia. Additional evidence and experience are needed for MAR to be scaled up nationally.
  - **Bushfires** – Bushfires generate large loads of sediment and contaminants (ash, nutrients, organics, and metals) that may impact on aquatic ecosystems. Integrated management is needed to ameliorate impacts of bushfires on aquatic systems under increasingly frequent extreme fire weather conditions.
  - **Water forecasting** – Access to reliable long range (months to seasons) and short-medium range (hours to days) water forecasts is needed to prepare for extreme hydroclimatic events, and secure water for consumptive and environmental uses.
- **Environmental management**: Integration of environmental water and complementary natural resource management requires collection and analysis of long term and large-scale monitoring data to understand how flow and non-flow drivers influence population and ecosystem function.
- **Cultural water**: Indigenous communities are co-leading research with CSIRO using participatory planning and implementation, with the aim of building the capacities of Aboriginal and Torres Strait Islander communities to secure their interests in water.
- **Water supply**: Innovation and socio-technical considerations are needed to ensure access to safe and reliable drinking water, and to support investment decisions in rural and remote areas. In cities, water needs to 'do more' for liveability, sustainability, and resilience to droughts.
- **Digital water**: Digital information and tools are needed to streamline water markets, support evidence-based decision making, innovation and continuous improvement in water resource management.

CSIRO would welcome an opportunity to discuss this submission with the Productivity Commission, as well as broader topics of relevance to this review process.

Introduction

CSIRO welcomes the opportunity to provide input to the Productivity Commission's consultation on the National Water Reform 2024.

Over the past 15 years, CSIRO and partners have delivered a suite of integrated water resource assessments to underpin regulatory decisions and development decisions, beginning with the landmark Murray-Darling Basin Sustainable Yields Project in 2007-8.

CSIRO continues to undertake major regional-scale studies to support policy makers and river managers to understand and manage the system's ecological assets of significant environmental, cultural, social, and economic value.

In this submission, CSIRO provides information in relation to key water security and management challenges for Australia, in areas reflecting CSIRO's scientific capacity. The submission summarises the relevant scientific progress to date and highlights outstanding knowledge gaps or technical challenges for future water reform in relation to:

- **Climate change**: how to address risks to future water resource planning from climate change, and what technical solutions exist to better prepare Australia for extreme hydroclimatic events, enhance water security, and ensure efficient management of water for consumptive and environmental uses across multiple spatial and temporal scales.
- **Environmental management**: how to integrate flow and non-flow drivers to integrate understanding of environmental flows with complementary natural resource management practices to achieve multiple environmental objectives and outcomes.
- **Cultural water**: actions to build the capacities of Aboriginal and Torres Strait Islander communities to play a significant role in water management through the co-design and co-leadership of scientific research, and by promoting collaboration, partnership, and intergenerational transfer of water knowledge.
- **Water supply**: socio-technical challenges of providing access to safe and reliable drinking water for rural and remote communities; opportunities to improve the liveability, sustainability, and resilience to droughts of our cities, and how to build social license to operate for water infrastructure with diverse communities, often in remote parts of Australia.
- **Digital water**: opportunities to improve the efficiency of digital water market infrastructure, data and trading processes to better adapt to seasonal variability and climate change, and on-going investment in new digital technology to support evidence-based decision making, innovations and continuous improvement in water resource management.

CSIRO would welcome an opportunity to discuss this submission with the Productivity Commission, as well as broader topics of relevance to this review process.

CSIRO response to the Inquiry

1 Adapting to climate change

Climate change is a key risk for water resource planning in the future, as it has the potential to increase water scarcity, compromise ecosystem function and services, and heighten social and economic vulnerabilities. Up-to-date climate information and fit-for-purpose projections of future water availability are needed to assess climate adaptation options for future water resource plans.

An opportunity exists to modernise the National Water Initiative (NWI) to better account for climate change as a key risk for water resource planning. Incorporating climate change impacts into water resource planning is essential to build resilience and adaptability in the face of evolving environmental conditions. Improving understanding of the impacts of climate change on water availability, quality, and distribution could help decision-makers to develop sustainable and adaptive strategies to ensure a reliable and equitable supply of water for current and future generations. Failure to account for these changes may lead to increased water scarcity, compromised ecosystems, and heightened social and economic vulnerabilities.

A key aspect of assessing the impacts of climate change on water resources and devising adaptation strategies to mitigate these impacts, is access to reliable sources of information. CSIRO delivers up-to-date climate change information, such as through the Climate Change in Australia website (CSIRO 2015) and more recently the National Partnership for Climate Projections (DCCEEW 2023).

It is also important that the climate information used to assess climate adaptation options, uses fit-for-purpose projections of future water availability. Examples of CSIRO climate adaptation projects include the Murray-Darling Water and Environment Research Program (WERP) (MDBA 2023), Victorian Water and Climate Initiative (VicWaCI) (DEECA 2023) and numerous reports to government agencies responsible for water resource planning such as the Murray Darling Basin Authority (MDBA) (Chiew et al. 2022a; Zhang et al. 2020) and the Victorian Department of Energy, Environment and Climate Action (DEECA 2021).

2 Possible solutions for extreme climates

Floods

Floodplain inundation modelling is a critical tool for informed decision-making, risk reduction, and the sustainable management of water resources under a changing climate. Failure to account for extreme events may lead to increased loss of human life, economic losses, compromised ecosystems, and heightened social and economic vulnerabilities. Providing accurate flood information helps to educate and engage communities about flood risks, supporting informed decisions about land use, insurance, and emergency preparedness.

A key challenge for future water resource planning under changing climates is to explicitly include detailed floodplain inundation modelling. By understanding the potential impacts of infrequent and unpredictable overland floods, decision-makers could develop sustainable, resilient, and adaptive strategies to ensure a safe and secure environment for current and future generations. Failure to account for changes in the frequency, intensity and distribution of extreme events may lead to increased loss of human life, economic losses, compromised ecosystems, and heightened social and economic vulnerabilities. CSIRO is building a detailed hydrodynamic flood inundation model to understand flood risk factors in the Northern Rivers region of NSW and to identify flood mitigation options for the National Emergency Management Agency (CSIRO 2023a). CSIRO also works in partnership with the Australian Climate Service to deliver flood-ready outcomes, to support decision making for recovery and resilient investments after floods occur.

By understanding how floodwaters move across a landscape, authorities can:

- Identify areas prone to inundation
- Assess potential damage
- Implement effective risk reduction mitigation measures.

Flood inundation modelling provides essential data needed to design infrastructure that is resilient to extreme floods, such as dams, levees, and urban developments. Accurate floodplain inundation modelling is important to maintain and enhance biodiversity of flood-prone regions, under a changing climate.

Floodplain inundation modelling contributes to effective emergency response and preparedness. Understanding the potential extent and depth of flooding, helps emergency services to:

- Plan for evacuations
- Allocate resources strategically
- Develop response strategies to minimise the impact on communities and infrastructure.

The results of detailed flood modelling can be used to educate and engage communities about flood risks, helping build a more resilient and aware community. Providing residents with accurate information about potential inundation areas helps them to make informed decisions regarding land use, insurance, and emergency preparedness.

Floodplain inundation modelling improves understanding of how floods change water availability, groundwater recharge, and overall water balance in a system. Detailed floodplain inundation modelling data provides a scientific basis for water resource management policies related to land use planning, zoning regulations, and building codes in flood-prone areas to promote safe and sustainable development in regions susceptible to flooding. Understanding how the frequency and intensity of floods may change under a changing climate is important when developing adaptive strategies to protect communities, infrastructure, and natural ecosystems.

CSIRO has advanced expertise and IT infrastructure needed to undertake detailed and complex floodplain inundation modelling at scale. Recent examples include:

- Northern Rivers Resilience Initiative, funded by the National Emergency Management Agency (CSIRO 2023a)
- Floodplain inundation modelling for the Cooper Creek, funded by the then Department of Agriculture, Water and the Environment (Vaze et al 2021)
- Floodplain inundation modelling scenarios for future climate and infrastructure development scenarios for the Cooper Creek floodplain, funded by the Gas Industry Social and Environmental Research Alliance (GISERA) (GISERA 2022)
- Floodplain inundation mapping and modelling in the northern regions of the Murray-Darling Basin (Dutta et al. 2016)
- Floodplain inundation history using a consistent time series of water depth maps across the Murray-Darling Basin (Penton et al. 2023)
- Floodplain Inundation Modelling for the Edward-Wakool Region (Vaze et al. 2018).

Droughts

Managed Aquifer Recharge (MAR) is an internationally proven, low-cost solution that could improve drought resilience across regional Australia. Despite 25 years of experience using MAR for alternative urban water sources, the full potential of MAR is yet to be realised at a national scale. Experience suggests that demonstration schemes are needed to evaluate the hydrologic and economic effectiveness and identify any changes to water planning and trading rules needed for MAR to be scaled up nationally as an operational drought resilience solution.

Managed Aquifer Recharge (MAR) is an internationally proven, low-cost solution that could improve drought resilience across regional Australia (Seidl et al. 2024). Over the past 25 years, CSIRO has supported Australia's implementation of MAR by using alternative urban water sources (such as stormwater runoff and recycled water) for irrigation and drinking water supplies.

Water banking using MAR can give communities and industries, like agriculture and regional towns, greater water security by storing water underground for later use during drought. Underground water storage can avoid expensive and timely water cartage when regular water sources dry up. MAR is a low-cost, low-energy water supply option, that can replenish over-exploited aquifers, and provides natural water treatment with no evaporation loss, algae, or mosquitoes (Vanderzalm et al. 2022).

Despite successful applications for urban water storage, to date, MAR schemes in Australia remain small scale and are largely in Western Australia and South Australia. CSIRO estimates up to an additional ~4 km^3 could be stored in surficial aquifers near major watercourses in the Murray-Darling Basin (Gonzalez et al. 2020). This potential storage volume is equivalent to 16% of the total accessible surface water storage, meaning no new dams would need to be built. Extending this work, the CSIRO Rapid appraisal of managed aquifer recharge opportunities for agriculture project (Page et al. 2021), funded by the National Water Grid Authority, identified areas prospective for large scale storage (>50 GL/year). The project also identified areas where recharging smaller amounts to dampen intra-annual water variability could provide critical irrigation support of fixed-root perennial crops (i.e. high value horticulture) throughout one or more consecutive dry seasons.

However, challenges to the large-scale adoption of MAR in Australia remain. Clogging is a key risk for MAR schemes and a reason why MAR schemes become less effective over time. Understanding the causes and prevention of MAR scheme clogging is vital to the long-term success of these schemes. CSIRO is investigating the causes of, and operational solutions to, clogging of MAR systems at a national scale (National Water Grid 2023).

There is a need for large-scale demonstration MAR schemes to report on the hydrologic and economic effectiveness, risks, and any impacts. CSIRO is supporting research to validate regional MAR demonstration schemes through the Drought Resilience Mission. This includes preliminary field investigations, forming alliances with local water entitlement holders, state government and the community. The MAR demonstration schemes will show what is needed to build the recharge infrastructure and run the scheme over successive recharge and recovery cycles. This knowledge is needed for investment in MAR infrastructure and to scale up across other jurisdictions nationally.

MAR schemes also present a unique challenge for water planning and trading rules. Operators need to be able to carryover unused surface water allocations via MAR with secure title and transfer water between surface water flows and groundwater storage, often over successive water years. To provide appropriate incentives for MAR schemes, it will be important to ensure that the legal status of the right to recharge, store and recover water, and the rules and costs for groundwater extraction are clear and transparent (Page et al. 2023). Institutional arrangements and financial structures for MAR schemes in the USA can provide guidance for Australia. MAR demonstration sites could enable concurrent development of policy and institutional arrangements, as well as critical experience to serve as models for wider adoption.

Bushfires

> Bushfires generate large loads of sediment and contaminants (ash, nutrients, organics, and metals) that may impact on water quality and aquatic ecosystems. Short-term impacts include dead fish, turbidity, elevated nutrients, and high sediment loads. At catchment and basin scales, a more holistic approach is could help to manage long-term impacts of increased extreme fire weather and the duration of the fire season across south-eastern Australia.

Extreme fire weather and the duration of the fire season across south-eastern Australia has increased over the past few decades (Wang et al. 2022). Bushfire impacts on water quality may cause both short-term (acute) and long-term (chronic) impacts on aquatic ecosystems through generation of large loads of sediment and contaminants (ash, nutrients, organics, and metals) from the burned catchment (Biswas et al. 2021, Lyon and O’Connor 2008).

After the Black Saturday fires in 2019-2020, turbidity in the Murray River peaked at about 80 times above baseline levels, along with elevated nutrient concentrations (Biswas et al. 2021). Lake Hume received an estimated 600,000 tonnes of sediment per month after the bushfire, along with total zinc, arsenic, chromium, nickel, copper, and lead concentrations above the 99% toxicant default guideline values (DGVs) for freshwater ecosystems. Severe impacts on the growth, reproduction, as well as death of fish (European carp and Murray cod) and other aquatic biota, were observed in the Murray River after the fires (McInerney et al. 2020). The dead fish had sediment and ash trapped in their gills.

Long-term term effects include potential toxic algal (cyanobacteria) blooms in summer and increased microbial activity that depletes dissolved oxygen levels in the water column (also known as hypoxia). Widespread hypoxia can lead to large-scale fish kills, as seen previously following large fires. At catchment and basin scales, a more holistic approach will be important. This could include riparian zone revegetation to trap sediments, reduce nutrient loads, instream temperatures and the supply of carbon to rivers from leaves and litter that fuel instream food webs. Streams that support endangered aquatic species with limited distributions would be the focus of fire preparation activities. This may also include removal of barriers to protect some fish populations and release of water from storages to ameliorate poor water quality.

3 Managing under climate extremes

Climate and hydrological extremes affect the delivery of water, the functioning of water markets and environmental outcomes of our river systems. A challenge for managing water under climate extremes is how to use ensemble forecasts in decision making. CSIRO is developing long range (months to seasons) and short-medium range (hours to days) water forecasting to better prepare Australia for extreme hydroclimatic events, enhance water security, and to ensure efficient management of water for consumptive and environmental users.

Climate and hydrological extremes can manifest as high impact events, such as droughts and floods, and as moderate impact events, such as shorter-term heatwaves or rainfall and flow shortages. These events affect the delivery of water, the functioning of water markets and environmental outcomes of our river systems. Climate change projections suggest these extremes are likely to intensify in coming decades (Chiew et al. 2022b; Prosser et al. 2021). Water infrastructure solutions cannot manage these extremes alone. They benefit from being complemented by operational water forecasting and decision systems that can anticipate and respond to events in real-time. It is important for these systems to forecast future hydrological conditions and impacts, including uncertainty, and then use forecasts to inform decisions and the communication of responses and impacts.

Water forecasting is a distinct field, separate from climate and weather forecasting. It combines modelling of catchment processes with climate and weather forecasts, leading to more accurate forecasts of water flows. To help manage extremes, it is important for water forecasts to represent the uncertainty, most usually in the form of an ensemble of possible model outcomes. CSIRO has played a foundational role in developing ensemble water forecasting methods for Australia. These methods combine process-based hydrological models with climate and weather forecasts and advanced statistics to predict streamflow from hours to months in advance (Bennett et al. 2014, 2017; Bennett, Robertson, et al. 2016, 2021; Bennett, Wang, et al. 2016, 2021; Li et al. 2013, 2016, 2017, 2021). The CSIRO water forecasting methods have been extended to forecast reservoir and groundwater levels (Robertson et al. 2024).

The Water Information Research and Development Alliance (WIRADA), a research partnership between the Bureau of Meteorology and CSIRO from 2008 to 2016, enabled the development and translation of new methods into operational services. Highlights include monthly and seasonal streamflow forecasts (the Bureau 2024a; Feikema et al. 2018), ensemble 7-Day streamflow forecasts (Hapuarachchi et al. 2022), and continent-wide forecasts of soil moisture and runoff (the Bureau 2024b). CSIRO is working with other major water agencies such as Hydro Tasmania and the Murray-Darling Basin Authority to build operational forecasting systems for managed river systems where forecasts need to consider interactions between hydrological processes and operator decisions.

Understanding how best to use ensemble forecasts in decision-making for managing water under climate extremes can be challenging. CSIRO is developing methods for both long range (months to seasons) and short-medium range (hours to days) time horizons to assess real-time water management risks and support decision-making in the face of forecast uncertainty (Ng et al. 2023; Turner et al. 2017). Accurate water forecasting will be important to:

- Prepare Australia for extreme hydroclimatic events
- Enhance water security
- Ensure efficient management of water for consumptive and environmental users.

4 Environmental management

The conservation and restoration of freshwater and other flow dependent ecosystems requires management of environmental water and complementary natural resources. CSIRO is collecting, integrating, and analysing long term and large-scale monitoring data and modelling approaches to better understand how to manage aquatic ecosystems across Australia. New knowledge and decision-making frameworks will likely be needed for environmental managers to meet the diverse range of environmental values and community priorities across Australia.

There has been a rapid evolution in water management practices and the science that supports the environmental objectives and outcomes over the past 17 years under the NWI (Productivity Commission 2021). The management of water for environmental outcomes – especially in the Murray-Darling Basin – is often focused on water quantity and timing. Despite aquatic ecosystems being degraded by both flow and non-flow factors, there are limited examples of on-ground management that integrates multiple objectives or multiple realms (Linke et al. 2019). Possible threats to conservation and restoration of freshwater and other flow dependent ecosystems (Linke and Hermoso 2022) include:

- Flow regulation or extraction
- Climate change
- Overexploitation of freshwater systems
- Invasive species
- Point source pollution
- Land use change.

While theoretical consideration has been given to integrate environmental flow science with other protection measures (Nel et al. 2011; Cresswell et al. 2017; Pittock et al. 2018), it remains a challenge for effective land and water planning and policy frameworks, that are principally driven by management of single threats.

A key element of the recommended national water reforms is to integrate management of environmental water and complementary natural resource management (8.2). To achieve this objective, it will be important to improve understanding of the influence of flow and non-flow drivers on population and ecosystem function, in addition to suitable policy and management frameworks. CSIRO is collecting, integrating, and analysing long term and large-scale monitoring datasets that improve understanding for resource management, objective setting, monitoring and evaluation for aquatic ecosystems across Australia as part of the:

- River Murray Channel Monitoring Project (DCCEEW 2022)
- Commonwealth Environmental Water Holder (CEWH) Flow Monitoring, Evaluation and Research (CEWH 2023)
- MDBA and CSIRO Ecosystem Functions Project (CSIRO 2023b)
- Northern Australian Water Resource Assessments (CSIRO 2023c).

The importance of natural flow regimes for supporting environmental function is relatively well understood worldwide. However, understanding how changes in flow affect river ecosystem function and form remains challenging. This is in part because of the diversity of river systems, habitat types, and species. The management objectives can also vary between jurisdictions, ranging from rehabilitating river flows to sustainable development. The value systems and priorities of communities may also differ between locations and across stakeholders. As such, what may be important in one system may not be so in another. The collaborative CSIRO and MDBA funded Ecosystem Functions project (CSIRO 2023b) addressed knowledge gaps in key ecosystem functions at basin-scale to inform improved management and delivery of water for the environment in the Murray-Darling Basin. Novel lateral and longitudinal hydrological connectivity models for the Murray-Darling Basin, that could be applied nationally, were developed (Sengupta et al. 2023).

CSIRO leads inter-disciplinary research, at large spatial and/or temporal scales, that seeks to holistically inform and assess a range of environmental objectives. In the Murray-Darling Basin, the Flow MER program has improved understanding of ecological responses to held environmental water, which in turn underpins future objective setting. Elsewhere, in often sparse and data poor regions, the following approaches could provide the best possible science to support management:

- eDNA
- Remote sensing
- Modelling.

CSIRO's ecology work in northern Australia brings together these approaches with system level conceptual and analytical predictive modelling to understand and assess the potential environmental, social, and economic impacts and risks of water resource and irrigation development (CSIRO 2019). Similar integrated monitoring and research programs in other parts of the country can provide access to new knowledge and decision-making frameworks for environmental water managers and other stakeholders, thus providing a robust platform to inform agreed environmental outcomes. As new approaches become possible, CSIRO remains at the forefront of science to support sustainable water management in Australia and globally.

5 Cultural water

CSIRO is committed to building the capacities of Aboriginal and Torres Strait Islander communities to secure Aboriginal and Torres Strait Islander people's interests in water. The overarching goal is to empower Indigenous communities to co-lead research through participatory planning and implementation, ultimately facilitating robust decision-making and elevating the importance of First Nations perspectives in addressing cultural water questions and requirements.

CSIRO is committed to building the capacities of Aboriginal and Torres Strait Islander communities to play a significant role in water management. As recommended in the national water reforms (Productivity Commission 2021), it will be important to secure Aboriginal and Torres Strait Islander people's interests in water. Employing a carefully crafted strategy that leverages Indigenous science and collaborators, CSIRO's approach involves co-leading research initiatives to foster relationships and initiate new research in the cultural water domain. This goes beyond traditional engagement strategies by implementing the Indigenous Science and Engagement Program, to delve deeper into ecological and water management across contested water areas. The overarching goal of the Program is to empower Indigenous communities to co-lead research through participatory planning and implementation, ultimately facilitating robust decision-making and elevating the importance of First Nations perspectives in addressing cultural water questions and requirements.

This includes the CSIRO:

- Reconciliation Action Plan 2021–23 (CSIRO 2022) with 17 core actions (across 90 deliverables) is building stronger relationships with Aboriginal and Torres Strait Islander people through knowledge sharing, education, employment opportunities and mutually beneficial partnerships.
- Indigenous Research Grants Program kick-starts science projects and increases Indigenous-led science by fostering collaborative partnerships for priorities identified by Aboriginal and Torres Strait Islander people. An external evaluation found the program showcases best practice for a grants program where Aboriginal and Torres Strait Islander people are involved as research participants or business partners.
- Indigenous Employment Strategy, based upon contemporary Australian research (Bourke 2019), focuses on strength-based models of employment that build capability from innovation and accountability and helped deliver a 25 per cent increase from 2022 to 2023.

Our focus is on collaboration to cultivate partnerships with Aboriginal and Torres Strait Islander individuals and experts, constructing robust knowledge about water management and cultural water. The initiative employs Indigenous science strategies projecting research futures 40 years ahead, enhancing Indigenous science capabilities at a grassroots level. This approach incorporates small, medium, and large-scale multi-disciplinary science studies to better understand the inherent values in cultural water. Emphasising skill-building in areas such as research, data analysis, and effective communication, the approach equips community members with the tools for active participation in water planning processes.

This commitment is reinforced by intergenerational knowledge transfer to ensure the continuity of cultural water practices into future generations, fostering two-way learning opportunities that advance Indigenous scientific capability and address key national challenges in Aboriginal and Torres Strait Islander water management. Authentic partnerships, rooted in trust and mutual respect, have the potential to overcome historical barriers and facilitate more effective collaboration.

6 Remote water supply

Unequal access to safe and reliable water supplies in remote areas of Australia, and more specifically in First Nations communities, disproportionately affects Aboriginal and Torres Strait Islander peoples. A national approach to regional and remote water supply has the potential to contribute to Closing the Gap and address inequities in economic and health outcomes in remote communities.

Access to a safe and reliable water supply is a basic human requirement for health and wellbeing, as highlighted by the United Nations Sustainable Development Goal (SDG) 6. Whilst Australia's capacity for water management has led to a good performance against SDG6, it has been recognised that there is unequal access to safe and reliable water supplies in remote areas of Australia, and more specifically in First Nations communities. This disproportionately affects Aboriginal and Torres Strait Islander peoples (DFAT 2018; Productivity Commission 2021). Poor reliability and quality of drinking water has flow-on effects for economic and health outcomes for communities in remote areas of Australia (Wyrwoll et al. 2022). Reliable and safe water of adequate quantity is essential for life, health, and economic development.

CSIRO reviewed current and emerging water treatment technologies for remote community water supply (National Water Grid 2024). The review matched water treatment options against the needs of communities to build a framework to measure the effectiveness of technologies to deliver safe and reliable drinking water for remote communities. Socio-technical challenges identified by the review (Doble et al. 2023) included:

- Identifying community needs and priorities and ensuring local input into decision making on water supplies and an effective mechanism for ongoing public health communication
- Matching water solutions to community needs and capacity of the available institutional arrangements
- Identifying and developing sustainable water resources with a volume and yield suitable for potable water supply and associated community uses, with a high-quality output, which are economically sustainable
- Developing water supply infrastructure, maintenance and monitoring of infrastructure and the water source, including water levels, water quality and extraction strategy

- Treating water resources to drinking water quality guidelines with technologies suitable for the water quality issues, communities, service providers and funders
- Adequate and appropriate monitoring to detect water quality issues
- Storing and distributing water to individual houses through infrastructure such as storage tanks and reticulation systems, and improving water use efficiencies
- Having a reliable system of funding, management, resourcing, maintenance, operations and repairs, and asset replacement before end of life
- Maintaining reliable and trusted oversight and response mechanisms to ensure quality assurance and timely rectifications should the above measures falter.

Recommendations for further work include to refine and further de-risk investment in remote water treatment technologies, intersecting socio-technical challenges with cultural, governance, climate, and other factors. A national water security framework has the potential to promote long term, coordinated and robust investments in water security for regional and remote communities, based on:

- Prioritisation of need through a national water assessment approach
- Application of rigorous, fit-for-purpose participation and engagement of communities
- Fit-for-purpose information and data on current, potential and future change in water availability of drinking water at appropriate scales
- Investment in research and delivery of suitable technologies and infrastructure that meet the current and long-term needs and local capacity requirements of communities.

A national approach to regional and remote water supply has the potential to contribute to Closing the Gap and address inequities in economic and health outcomes in remote communities.

7 Urban water

Our cities require water to ‘do more’ to underpin liveability, sustainability and resilience to droughts. Critical management challenges for urban water systems relate to managing extreme heat, maintaining urban amenity, and ensuring integrated planning by a complex stakeholder network. The CSIRO Living Labs use adaptive planning to assess risks and vulnerabilities, enable preparedness, and increase investment in urban resilience.

Historically, there has been a growing understanding of the need for cities to develop cost-effective and socially acceptable climate-resilient water supplies, flood management and sanitation. This had coincided with a greater need for integrated approaches to urban water management. More recently, urban planners and developers have been asked to maintain and restore pre-development hydrology and nutrient cycles, and to provide improved urban amenity (i.e. cooling, greening, recreational use, biodiversity outcomes). Critical management challenges for urban water systems relate to:

- **Extreme heat**: Water is critical for the cooling and greening of our cities. Extreme heat kills more people in Australia than all other natural hazards combined (including bushfires, floods, cyclones, storms, lightning). Heat wave mitigation measures increasingly include water for cooling through urban planning. Cooler parts of our cities provide increased benefits to infrastructure and communications, people (Myers et al. 2020), and biodiversity (DEECA 2023b) vulnerable to heat extremes. Water restrictions imposed during droughts put urban function, population, and biodiversity at risk in times of heat extremes. Under a changing climate, improved planning and regulation is needed to provide water for cooling during heat waves.

- **Urban amenity**: Water makes important contributions to human well-being, economic growth, and sustainable development in urban areas. Examples include recreational use of urban waterways and reservoirs for swimming, walking, cycling, kayaking or canoeing, and fishing (Sydney Water 2023, SA Water 2024). Water-sensitive urban design can integrate retention basins and wetlands into sports and recreational fields or use swales and tree pits. Recognition of the value of water for urban amenity and ecosystem services is needed to advance the livability, sustainability, and resilience of Australia cities (Tapsuwan 2021).
- **Integrated planning**: There are many stakeholders with roles and responsibilities in urban water planning (including planning departments, councils, utilities, developers) (Parliament of Australia 2022). CSIRO's research is focussed on integrated planning of urban environments with cross-sector and cross-jurisdictional partnerships that can tackle myriad sustainability and resilience challenges impacting our social and environmental systems. Examples include using future scenarios to prepare for future risks within Australian cities (Moglia et al. 2019) and urban water strategies to assist major urban water utilities (Dawson et al. 2018) to incorporate adaptive planning strategies to assess risks and vulnerabilities and enable preparedness (CSIRO 2024a). For example, updated governance arrangements could help to better manage stormwater for flood control and as an integrated water resource to achieve economic, cultural, environmental and social outcomes (Myers et al. 2023).

The Enabling Resilience Investment approach (CSIRO 2024b) is used to generate place-based risk mitigation options along with fundable opportunities that create value, such as beneficial outcomes such as jobs, infrastructure, social cohesion, economic activity and incomes, for communities in cities, suburbs and rural and regional Australia (Wise et al. 2022). Examples of place-based, real-world research activities that focus on collaboration and advancing integrated planning include:

- Darwin Living Lab (CSIRO 2024c) – a 10-year collaboration between CSIRO, the Australian and Territory Governments and City of Darwin to test and evaluate heat mitigation measures and inform tropical urban design for Darwin. The team are using real world experiments to make measurable improvements in the city's liveability, sustainability and resilience.
- Sydney Science Park CSIRO Urban Living Lab (CSIRO 2024d) – in partnership with Celestino, to challenge and de-risk urban development to build a city supported by research. For example, the 'smart' wastewater system operated by Sydney Water monitors environmental factors and uses real-time information to predict weather conditions and deliver on-demand recycled water supplies for commercial, construction, and irrigation of open spaces.
- Bega Valley (CSIRO 2024e) – in partnership with Value Advisory Partners and the University of Adelaide worked with local government, businesses, communities, and NSW Government agencies to design plan disaster recovery activities that also builds capability for the future.
- Port Adelaide-Enfield Council (CSIRO 2024f) – in partnership with Value Advisory Partners and the University of Adelaide, worked with local government, businesses, communities, and SA

Government agencies to identify investment opportunities for coastal protection infrastructure that create value and reduce climate and disaster risk in the Inner and Outer Harbour areas of Port Adelaide.

8 Water infrastructure planning

The diversity of stakeholders, and the disadvantages faced by many remote communities, make ensuring that water infrastructure investment decisions are economically viable, ecologically sustainable, and culturally responsive challenging. Innovative visualisation technologies, such as Virtual Reality (VR) and Artificial Reality (AR) digital twins, could be used to better explore future scenarios envisaged by proponents for local landscapes and their benefits to communities and other stakeholders.

The national water reforms call for an expansion of investment objectives for water infrastructure to be assessed as economically viable, ecologically sustainable, and that infrastructure decision-making processes are culturally responsive to the interests of Traditional Owners (Productivity Commission 2021). An important step to consider is establishing and maintaining a social licence to operate. This is challenging due to the diversity of stakeholders and the disadvantages faced by many communities, particularly in remote parts of Australia where large infrastructure projects are often located (CSIRO 2024g). Traditional technical approaches, such as reports and digital maps, may no longer be fit-for-purpose to deliver information vital for communities, other stakeholders, and potential investors to understand possible future options, scenarios, and outcomes from development.

In these circumstances, seeking consensus is challenging as often stakeholders talk at cross-purposes and many may not understand basic biophysical concepts. For example, what does several thousand hectares of irrigation look like in landscapes managed at scales of tens, or hundreds, of thousands of hectares? What scale of water capture constitutes a 'dam'? How much land and what land would a 100-m high dam at a particular location inundate? What would the reservoir look like? What does a buffer zone look like? Scale, both temporal and spatial, makes it difficult for stakeholders to visualise how infrastructure developments may impact on a wide range of values, including sites of cultural significance, hydrological regimes of rivers, road traffic, existing ecological systems and how other industries may be impacted. There are simply no conventional techniques which allow their integration in a way which enables people (from different walks of life and some for whom English is not their first language) to conceptualise potential change.

Visualisation technologies, such as Virtual Reality (VR) and Artificial Reality (AR) digital twins, are being used to explore future scenarios envisaged by proponents for local landscapes and their benefits to communities and other stakeholders. Users can interact with changes to the landscape, understand their implications, focus on what matters to prevent unexpected outcomes from future developments, and hold proponents accountable for changes to plans. Users can also interact with tangible 3D printed objects for a multi-modal visualisation experience.

CSIRO is currently developing a digital twin VR in a catchment in northern Australia that can be linked to a hydrological model in the same catchment (Branchaud et al. 2023, Seo et al. 2023) to visualise changes in hydrology. The technology is being developed so that it can be more easily repurposed elsewhere. Potential development options being examined include developments ranging from existing small stock and domestic dams, to different sized off-stream storages, gully dams, weirs and (potentially) large, engineered, roller-compacted concrete dams and different types and scales of irrigated agriculture.

9 Water markets

Enhancing liquidity in any market is essential, requiring access to pre-trade information, along with a settlement time suitable for the market's specific needs. There is an opportunity for the water market to improve information availability and streamline underlying business processes, reducing duplication and achieving a purposeful acceleration in settlement processes.

The role of water trading is to increase the liquidity of water allocations. This allows, in times of water scarcity, buyers to collect enough water to deliver viable outcomes, while sellers receive some income while they wait for better times or engage in dryland activities. CSIRO has partnered with the Digital Finance Cooperative Research Centre (DFCRC) to enable the universal digitisation of all assets so they can be traded and exchanged directly and in real-time between any individual or organisation. Increased digitisation of water trading and settlement processes has the potential to improve pre-trade information availability and facilitate fast transactions, exemplified by some aspects of the Victorian Water Register's My Water portal.

A market that operates efficiently, easing trading and settlement processes, could attract financially motivated sophisticated traders, potentially undermining genuine water users. Therefore, the emphasis on a water trading system is best placed on fairness. This requires making trading information available to the right people, in a timeframe consistent with the trading resolution process, and ongoing market regulation and oversight. Keeping these matched is more important than outright speed.

The Bureau of Meteorology has been tasked with collecting and making available data for water trading. The quality of that data is highly dependent on the value of it to the original data custodians. CSIRO has conducted many projects in designing trustworthy software systems that support the use of data in complex business environments, improving data quality, sharing, standardisation, and compliance (Bandara 2021; Weber 2019; van Beest 2023). CSIRO's market design and social science expertise can examine the social impact of trading systems, to understand if the traders can access the data in a way that supports fair trade.

Emerging technological trends such as Federated API (Application Programming Interfaces) Marketplaces (a marketplace for APIs, not a marketplace for water) and DLT (Distributed Ledger Technology) (Hanson et al. 2017) are well-suited for multiple water markets tailored to different water use, trade speeds, bidding mechanisms, geographies, and jurisdictions. Therefore, rather than centralising the market solely for improved information availability and fast settlement, the digital uplift of existing marketplaces could be achieved by enabling the applications to drive standards. This bottom-up approach, supported by Commonwealth and local governments, is likely to effectively accommodate varying technological capacities, openness to change, and capacity to change among stakeholders, rather than allowing the exploitation of digital infrastructure by those with the capability to do so (Staples et al. 2017, Bratanova et al. 2019; Quinlivan 2022).

10 Digital water

New ways to build, map, acquire, analyse, estimate and forecast water data are needed to support evidence-based decision making, innovation and continuous improvement in water resource management. Making data accessible and tracking data provenance ensures benefits for a wide range of stakeholders.

Under the National Water Commission with the Raising National Water Standards Program in the 2000s, the focus was on building an evidence base for basin management. Since then, there have been advances in software for provenance, artificial neural networks (ANNs), digital twins and strategic design that could support better decision-making.

With investments to build infrastructure in the MDB to support environmental watering, planners and operators are increasingly in control of the fate of ecosystems. As decisions about where water is delivered become contested in the Murray-Darling Basin, software support to capture model provenance become important. The Provena software has been developed to track the provenance of data, model runs, results, workflows and decisions related to management interventions for the Great Barrier Reef (Yu et al. 2023). Opportunities exist to use this system and knowledge from its development in the Murray-Darling Basin.

The CSIRO Digital Water and Landscapes program is exploring, prototyping and testing emerging digital technology opportunities for water and landscape science and research (CSIRO 2024h). This includes new ways to:

- Estimate alluvial groundwater levels using artificial neural networks for different catchments and regions (Clark 2022; Fu 2023)
- Forecast water quality in river systems across selected river reaches using machine learning or digital twins for hydrologic and hydrodynamic models for water quality parameters
- Build Digital Elevation Models by merging different resolution (and accuracy) data to correctly model water flows across the Murray-Darling Basin
- Acquire and analyse streamflow observations using new APIs such as pybomwater.

Building systems with stakeholders is critical. The SenseT project provided access to high resolution and real-time weather, soil, river flow and water quality data that was used by irrigators during periods of low flow when water extraction restrictions can be applied (Ellison et al. 2019).

Closing statement

Water is a critical resource for the driest continent. Changes in our environment including sea level rise, increases in median temperatures, changed rainfall patterns, and changes in the intensity, frequency and distribution of climate extremes will increase pressure on water availability and quality for communities, industry, agriculture, and the environment.

CSIRO delivers research to help to better understand and manage the significant environmental, cultural, social, and economic value of Australia's water resources. This submission highlights outstanding knowledge gaps or technical challenges for future water reform in relation to key areas of CSIRO research:

- **Climate:** We are tackling the climate change challenge by improving climate knowledge and services, developing low emissions technologies, and helping to build resilient communities in Australia, our region, and the world.
- **Environmental management:** Our research helps to maintain the integrity of our environments, ensure our natural resources are used sustainably, halt the decline in Australia's biodiversity, and build a better understanding of our species and ecosystems for better management.
- **Indigenous science:** We're working with Indigenous communities and organisations to create Indigenous-driven science solutions that support sustainable futures for Indigenous peoples, cultures, and Country.
- **Digital water:** We're exploring, prototyping, and testing emerging digital technologies to build new capability and transform how water and landscapes are managed in Australia.
- **Water security:** Our research helps Australia to better manage its river basins and groundwater resources, and improve social, economic, and environmental benefits.

CSIRO would welcome further opportunities to engage with the Productivity Commission in areas where we can provide scientific and technical advice.

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