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Understanding possible adaptation options in response to climate change

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Acknowledgments

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

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

Executive summary

Climate change projections indicate that the Murray-Darling Basin will be hotter with lower average annual rainfall and reduced runoff but increased number of extreme events. The combination of these impacts mean that adaptations are likely to be required to maintain the resilience of the communities and environment.

Adaptation can occur by individuals and businesses taking action to ensure their own resilience but also by industries and institutions, including governments, seeking to manage the impacts of climate change equitably. A wide range of adaptations are currently being considered by all actors within the Basin – individuals, businesses, industries and institutions. In this report, we review the adaptation options to mitigate climate change impacts on basin outcomes being considered by institutions and develop a system to classify these options. The classification system is developed to inform the selection of case-studies that are being developed through the Climate Adaptation Theme of the Murray-Darling Water and Environment Research Program.

In addition to identifying the adaptation options, an understanding of their expected impacts under historical and future climates is required to support policy making. Describing the impacts of adaptation options is complex. Traditionally, river systems models have been used to assess policy and operational changes on river systems in the Basin. Therefore, river system models may support assessment of climate adaptation options, but other tools may also be required. In this document, we also review how evidence for the impacts of adaptation options can be compiled to support policy making, with a focus on the role of river system models.

Our review and analysis of adaption options has developed a classification system based on the range of adaptation options that are currently being considered by the Basin's water management institutions and identifying commonalities and differences. The adaptation options are categorised according to the objectives they seek to address, under a changing climate, and by a range of additional dimensions. Most options being currently considered focus on addressing particular objectives at a river reach or regional scale, they have short implementation times and are likely to deliver benefits rapidly with a high degree of confidence. To mitigate against potential for maladaptation, future MD-WERP case studies should therefore investigate the wider consequences of adaptation options by enabling the assessment of regional impacts on a wide range of objectives and outcomes or by linking the regional impacts to whole-of-basin outcomes.

Many of the adaptation options being considered can be represented in river system models, such as those developed in eWater Source, which enables assessment of their impacts under climate change on hydrological metrics. However, not all adaptation options identified by our review can be represented in river system models and there are currently gaps in the ability to translate hydrological metrics to indicators of Basin outcomes. Some of these gaps can be addressed by using models and other tools to post-process hydrological timeseries generated by river system models, such as those being developed and integrated into the MD-WERP Climate Adaptation Toolkit. However, other modelling tools may also be required.

1 Introduction

Projected climate changes are anticipated to result in increased temperatures and lower rainfall across large parts of the Murray-Darling Basin (MDB). Changes in both temperature and rainfall are expected to result in decreases in runoff and water available for all users. Adaptation to the projected climate changes is likely to be required to maintain the resilience of communities and the environment.

Adaptation can occur at a range of levels. Individuals and businesses can take actions to ensure their own resilience to projected future changes. Industries and institutions, including governments, will also need to adapt to projected future changes to address community scale vulnerabilities and ensure the impacts of climate change are managed equitably. Adaptations can be related to a variety of objectives and manifestations of climate change. For example, horticultural businesses may adapt by planting varieties that have lower chill requirements or changing locations, while other water managers are considering how the impacts of reduced inflows on environmental assets can be mitigated using infrastructure and altered management. Here we focus on adaptation options that are related to achieving the Basin Plan that are predominantly related to the flow related impacts of climate change.

The range of adaptation options that are available to individuals, businesses, industries and institutions to deal with the flow related impacts of climate change is large and vary considerably in their scope, scale and potential impact. As a part of the Murray-Darling Basin Water and Environment Research Program (MD-WERP), we are investigating a range of adaptation options and their potential impacts on Basin values via a series of strategically designed case studies. The case-study approach allows individual adaptation options to be explored at the most appropriate granularity. However, as only a limited number of case-studies are possible, the selection and development of case studies requires a guiding framework. A classification system of available adaptation options that considers the variability in scope, scale and potential impacts, will provide guidance to the selection of case studies. Case studies to be investigated in subsequent years of the MD-WERP will be identified collaboratively with the Commonwealth agencies.

To support policy making, the Murray-Darling Basin Authority (MDBA) requires insight into the impacts of adaptation options on basin outcomes. This involves understanding of the efficacy of adaptation options under current and future climates, including how communities or industries might respond and therefore influence the extent to which options and policies can influence desired outcomes. River system models are commonly used by the MDBA to assess the impacts of policy and operational changes on river system outcomes. Therefore, river system models may be a suitable tool for compiling evidence on the efficacy of climate change adaptation options. Given the wide range of adaptation options that are available, a stocktake of how evidence on their impacts on basin outcomes can be compiled is required that includes an analysis of the role of river system models.

This report provides a conceptual foundation for characterising and analysing climate adaptation options. We firstly review the climate adaptation options that are being considered in the Basin by governments and other institutions and develop a system of classifying these options. We then review how evidence on the impacts of the combination of climate change and adaptation can be compiled, with a particular emphasis on the role of river system models as an analysis tool.

2 Classification of adaptation options

This section identifies current and planned climate adaptation options that could be undertaken by government, industry or the community and develops a system to classify these options. The focus of the adaptation options considered are those that can support the achievement of the Basin Plan aim of "*healthy, working rivers that support productive and resilient water-dependent industries, healthy and resilient ecosystems and communities with access to sufficient and reliable water supplies",* in the face of a changing climate. Climate change may influence the volume, timing and variability of water available to support healthy working rivers, but may also directly impact industries, ecosystems and communities. Therefore, we consider options related to the strategic, tactical and operational management of water and those that are related to direct institutional influences on ecosystems and communities. Firstly, we summarise the approach adopted to develop the classification system and then apply it to provide insights into the classes of adaption options being considered in the MDB.

2.1 What is the approach?

To develop a characterisation of the potential climate adaptation options, a literature review was completed. This review was not systematic but instead focused on a select number of state-based future water use planning documents that contained a large range of potential management options (from which 'adaptation options' were derived). The intention was to produce and present in a tabulated form, a sample of adaptation options that represent options being explored or suggested from a policy perspective. To capture as much information as possible, this review does not make any attempt to pre-emptively filter adaptation options based on their perceived viability. As a result, some adaptation options may be beyond the scope of MD-WERP due to legislative capabilities (e.g., major reform to water trading rules), issues of scale (e.g., site-specific infrastructure works such as dam alterations), or modelling capabilities (i.e., where adaptation options cannot be including into existing modelling frameworks).

Given many of these options were generated from region- and catchment-specific water management plans, they were often very specific. When this was the case, a more general interpretation of that measure was created, while ensuring that details and nuances of original options were included. For example, if the original description was 'Build a new pipeline between creeks X and Y to support the supply of water to Town A' then the general interpretation included in the table might be 'Enhancing water supply systems including new pipelines and water supply channels.'

The table of adaptation options was generated iteratively. For each water management document, management options were identified and then extracted. Adaptation options were then created that described each management option (often with broad interpretations). New adaptation options were only added to the table if no existing measure in the table adequately described the management option. Numbers were assigned to each adaptation measure, which were used to link back to the extracted management option lists. These links demonstrate where the intent of the management option would be achieved by an adaptation measure. In some cases, more than one adaptation measure would apply to management options. Each adaptation measure was briefly described, and its objective was defined.

2.2 Dimensions of classification

In categorising the various adaptation options, we used several dimensions to differentiate among the options. Definitions for each dimension used, along with the categories used within each are outlined in Table 1.

Table 1 Definition of dimensions used to classify adaptation options, including categories within each.

Scale	
A description of the spatial scale at which the adaptation measure would apply (may be multiple)	Basin
	Region
	Reach
	Site
Scientific certainty	
A description of how certain it is that the adaptation measure would achieve the stated objective	Certain
	High
	Moderate
	Low
	Uncertain
Time for benefit	
An estimation of how long it would take for benefits to accrue following the implementation of the adaptation measure	Immediate: < 1 year
	Rapid: 1-2 years
	Moderate: 3-5 years
	Slow: 5-10 years
	Very slow: >10 years
Time to implementation	
An estimation of how long it would take to implement each measure, such that it would achieve the objective	Immediate: < 1 year
	Rapid: 1-2 years
	Moderate: 3-5 years
	Slow: 5-10 years
	Very Slow: >10 years
Permanence	
A description of whether the implementation of the adaptation measure will be required permanently or for a short period to achieve the objective	Temporary
	Ongoing
	Variable
Water type	
The type of water the adaptation will affect	Groundwater
	Surface Water
	All
Adaptation action type	
A description of the action required to implement the adaptation measure (may be multiple)	Policy/Governance
	Physical works
	Research/Increasing Knowledge
	Planning
	Communication
	Water delivery operations
	Water trade
Responsibility	
A description of the party responsible to implement the adaptation measure (may be multiple)	Federal Government
	State Government
	Local Government
	Catchment Management Authorities (CMAs)
	Landholders
	MDBA
	Water corporations
	Aboriginal corporations
	Other

2.3 Classification of adaptation options

As a part of the classification of adaptation options, we identified 63 types of options based on the documents outlined. These fell into six broad categories:

- Achieving environmental outcomes and obligations
- Water security and storage
- Water allocation, sharing and trade
- Water use and delivery efficiency
- Regional community resilience
- First Nations use, rights and management of water

Across those six broad categories, there were adaptation options that spanned the dimensions against which we classified (Figure 1). The overall level of scientific certainty was high, with all options assessed as moderate or high certainty. Most benefits were relatively rapid in terms of time to accrue benefits, but there was a mix of times to implementation. Most options were intended to be ongoing and most targeted both surface and ground water. Policy and governance, and physical works were the two most common action types. Reach and region were the most common scales at which adaptation option were targeted and the majority were the responsibility of state governments, although a range of actors were responsible for one or more adaptation options.

Achieving environmental outcomes and obligations included options aimed at delivery and planning of environmental watering, management of water quality and temperature and the restoration of habitat, among others. Most adaptation options targeted a reach scale, often with high scientific certainty. Both the time to achieve benefit and to implement the adaptation option tended to be relatively rapid, with most options being ongoing and targeting surface water. Many options involved physical works, but there was a mix of action types. State government had responsibility for most options identified.

Water security and storage included options targeting new water sources or storage measures (e.g., desalination and managed aquifer recharge). Most adaptation options targeted a region and there is high scientific certainty in achieving the objective. Time to accrue benefits was relatively rapid, but time to implementation tended to be slow. Most options were intended to be ongoing and to target both ground- and surface water and included physical works. Most water security and storage options are the responsibility of state governments or water corporations.

Water allocation, sharing and trade included options targeting the way water is used in the Basin. This included regulatory measures such as water sharing and trade rules but also changes in land use and conversion of land from irrigated to dryland and vice versa. Options focused at the region or Basin scale had a moderate to high degree of scientific certainty. Time to accrue benefits varied, as did time to implementation. Each option identified was ongoing and most targeted both surface and ground water.

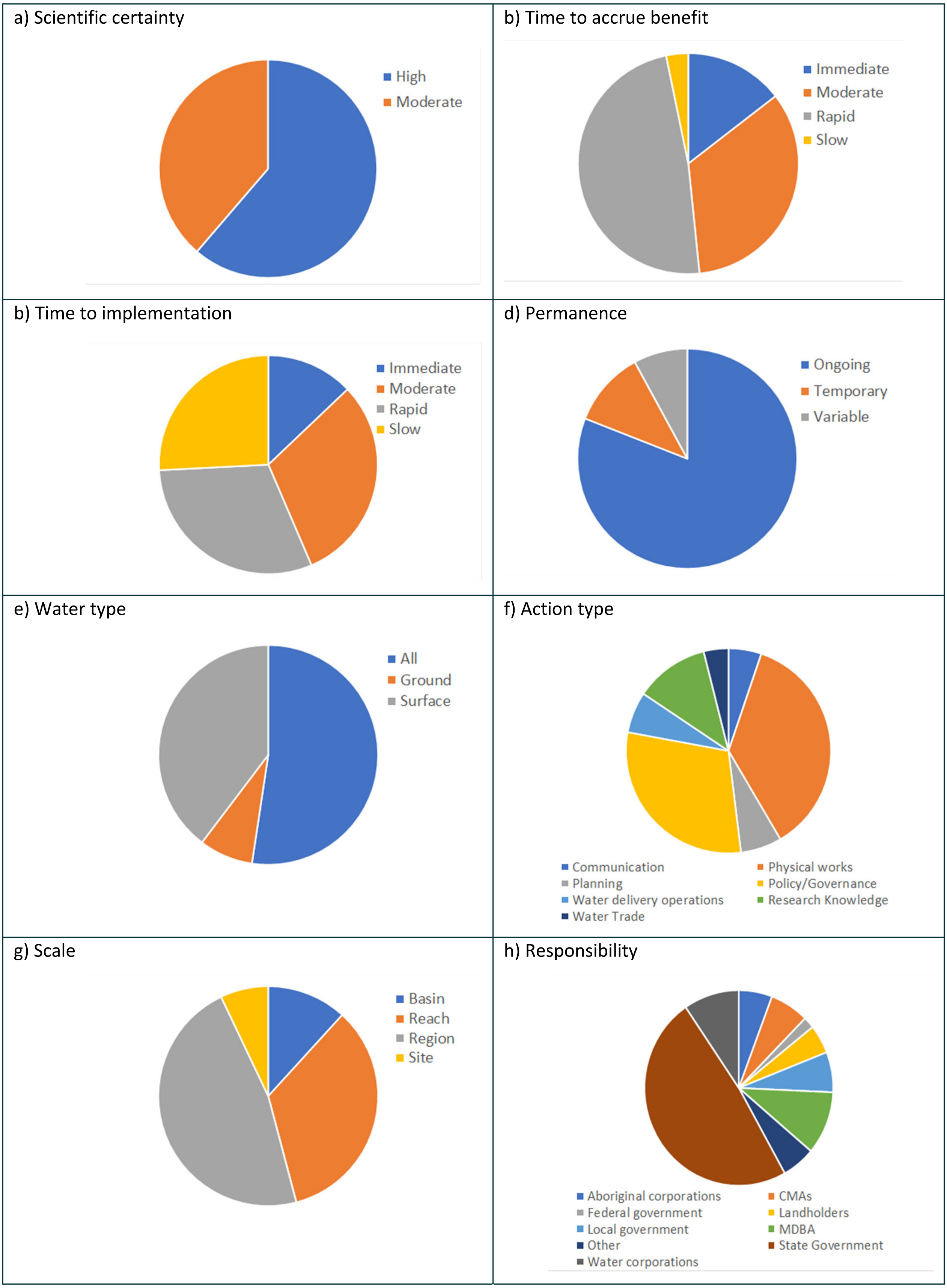

Figure 1 Categorisation of adaptation options against the dimensions assessed

Water use and delivery efficiency focused on the knowledge and systems supporting water supply and use. Adaptation options tended to focus at a regional scale, with high scientific certainty. Benefits were likely to accrue rapidly, but time to implementation varied. Most options were ongoing and most targeted surface water or both ground and surface waters. Most involved physical works and there was a mix of institutions responsible for the options included.

Regional community resilience was largely focused on town water supplies. These options were aimed at a regional scale and had moderate or high scientific certainty. Most were rapid in terms of time to accrue benefits and to implementation. There was a mix of permanence of the options, but all targeted both surface and ground water. Actions tended to be policy or governance related and tended to be the responsibility of local or state government.

Aboriginal people's use, rights and management of water included several adaptation options focused on the implementation of programs to increase options for participation and autonomy in water management. These options tended to focus at a reach or regional scale, with moderate to high levels of scientific certainty. Most had moderate time to accrue benefits and to implement. Each was intended to be ongoing and to target both surface and ground water. There were a mix of action types, including policy and governance, research and increasing knowledge, physical works and communication. Aboriginal corporations and state governments tended to share responsibility for these options.

The full list of adaptation options and their respective classifications are given as Appendix A.

3 How can the effect of implementing adaptation option categories be assessed?

The previous section described how options to adapt to climate change can be categorised. Here we focus on describing how the impacts of different classes of adaptation options on Basin economic, environmental, social and cultural outcomes can be assessed. River systems models are commonly used by the MDBA to assess the impact of policy options on the Basin's hydrological outcomes and support analysis of trade-offs. As many of the adaptation options identified are in response to the flow related impacts of climate change, we place particular emphasis on the role of river system models in the assessment process. Firstly, we consider how adaptation options can be considered conceptually and their impacts on indicators of hydrological and Basin outcomes can be assessed. We then describe the role of river system models in the assessment process, identifying how different classes of adaptation options can be represented in these models and classes of adaptation options that cannot be assessed using river system models.

3.1 Assessing adaptation options

3.1.1 Adaptation options in a modelling context

Autonomous adaptations are those implemented by individuals or groups of individuals, primarily for their own benefit. Autonomous adaptations can be driven by several factors of which the adaptation to climate change is just one. Other factors that will drive autonomous adaptations include markets and prices for products and competition for land or other resources. These autonomous adaptations will directly influence Basin outcomes, particularly economic outcomes, but may have only local effects on water management.

In modelling terms, autonomous adaptations will typically define future boundary conditions for river system operations, including defining requirements for consumptive water, particularly where water is needed, how much, when and for what.

Institutional adaptations are those implemented by governments and their departments, or other institutions with a role in water management. These adaptations are designed to meet wider community needs or outcomes and will typically have regional or larger-scale effects on water management.

To understand the impacts of many institutional adaptation options will require analysis of their consequences for river system management and operations, and how these are likely to flow on to Basin outcomes. River system models can be used to support this analysis.

3.1.2 Assessing hydrological impacts of adaptation options

Adaptation options can be assessed at different levels (Figure 2). Both autonomous and institutional adaptation can have hydrological impacts on river systems. These hydrological impacts are summarised using metrics that are derived from time-series output of river system models. The assessment process involves establishing scenarios that describe a combination of climatic conditions and management arrangements (e.g., infrastructure, water demands, system operation rules) and generating long-term simulations. Typically, a baseline scenario is established that may reflect current management arrangements and historical climate to serve as a reference point. For applications in the MDB, the baseline scenario is typically characterised by the current level of development and a 110-year historical inflow sequence. The impact of adaptation, or future climate change, is then characterised using alternative scenarios that can be compared to the baseline.

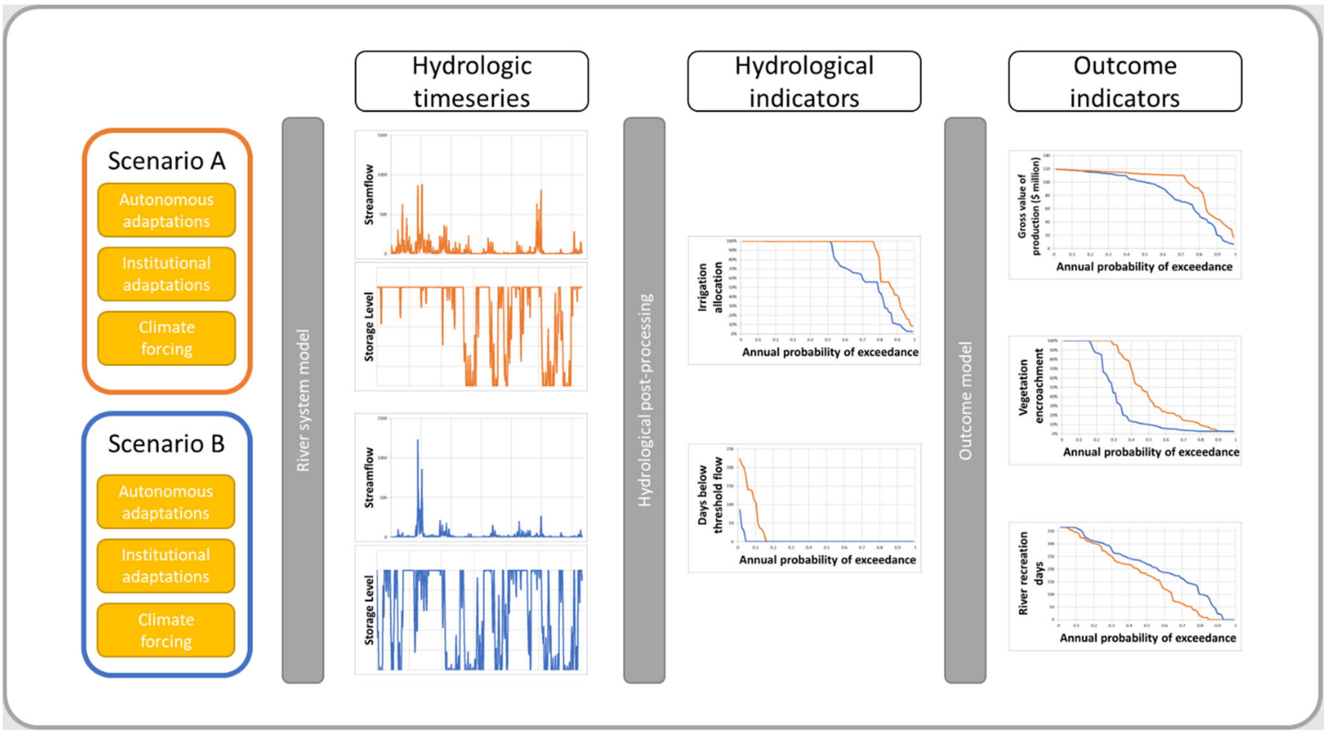

Figure 2 Schematic representation of assessment of adaptation options and climate scenarios. For two scenarios, that may comprise alternative climate sequences or combinations of adaptation options, the translation of hydrological time series to hydrological indicators and Basin outcome indicators is illustrated.

A multitude of metrics are available to assess impacts of environmental change, policy change, or management change on river systems.

Some of these metrics reflect average system performance. For example, the environmentally sustainable level of take (ESLT) is characterised as the maximum amount of surface and ground water that can be taken from the Basin for agricultural and human consumptive use *averaged over the long term*. Therefore, the impacts of climate change and adaptation on such metrics can be summarised using a single number.

Many other metrics of system performance, particularly those related to risks of system operation, characterise the system variability. For example, assessments of urban and town water supplies use metrics that describe the severity, frequency and duration of water shortages that require restrictions on water use.

Agricultural or rural water supply assessments also will typically characterise system variability, as annual water allocations are zero unless there is sufficient resource to allow a higher allocation. The metrics of system variability are often expressed graphically, with key points able to be extracted for numerical comparison. Figure 3 graphically represents reliability for three scenarios of high reliability water entitlements for a hypothetical system:

- The top (black curve) represents the current situation

- The green curve represents a possible future scenario with existing water management rules (say after climate change or reafforestation)
- The blue curve represents the future scenario with amended water management rules (such as greater reserves).

Key points from the curves could be:

- Probability of 100 % allocation (say 97 % for black, 38 % for the other two curves)
- Lowest allocation
- Probability of zero allocation
- Probability of >50 % allocation
- Probability of >80 % allocation.

In this case, the probabilities are equivalent to the proportion of years in which each indicator is met in the output of a long-term river system model simulation.

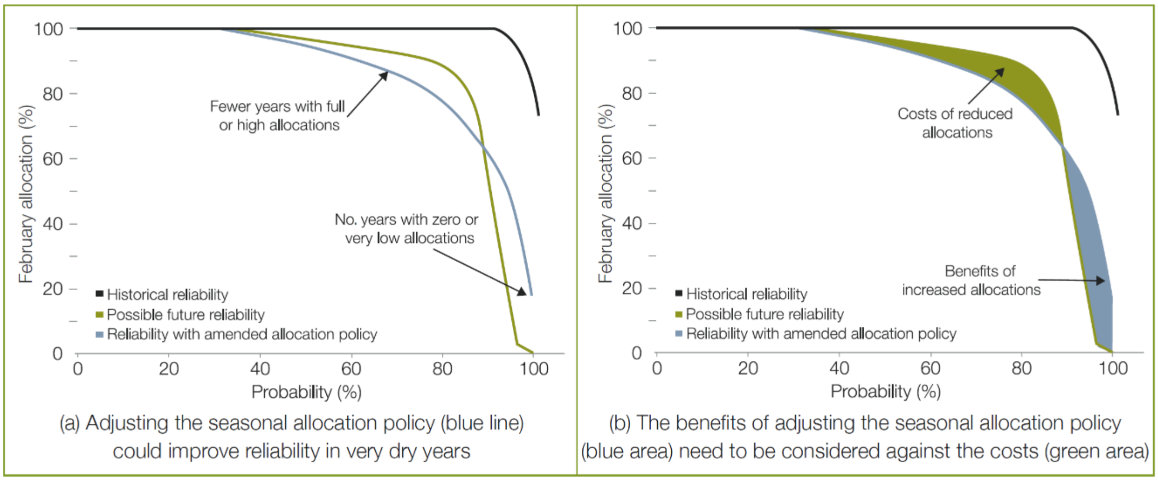

Figure 3 Impact on reliability of supply from adjusting the system reserve policy (schematic only).
Reproduced from Chapter 5, Northern Region Sustainable Water Strategy, Victorian Department of Sustainability and Environment, 2009

Many of the hydrological metrics used to assess environmental outcomes are also subject to variability and river system model output can be used to generate analysis similar to that produced for water supply. For example, the duration and frequency of periods of low or high flow can be derived to inform impacts on environmental outcomes (e.g. Figure 2).

3.1.3 Assessing Basin outcomes

While it is important to understand the hydrological consequences of climate change and adaptation options, ultimately communities will observe and respond to the impacts on Basin outcomes. Therefore, it is critical to assess how climate change and adaptation options will impact on Basin outcomes.

Understanding consequences for Basin outcomes requires the translation of the hydrological impacts to changes in the condition of Basin assets and values. This translation requires appropriate models and tools. The models and tools that relate hydrologic metrics to changes in the condition of Basin assets and values vary considerably in conceptual and computational complexity, according to the geography and class of asset.

Some river system models have functionality to include simple impact models, and therefore directly generate predictions of changes to assets and values. For example, ecological response models (Powell et al., 2013; Webb et al., 2010) can be defined to quantify the environmental values of different components of ecosystems. The basic principle involves defining a mathematical equation which calculates a numerical value of ecological response as a function of some modelled attribute of the water system. This attribute could, for example, be flow, duration of wet or dry spells, flow velocity or area of inundation. Powell et al. (2013) provide an example for terrestrial vegetation encroachment to a stream $(cover)$ for a given year (i), based on work by (Webb et al., 2010):

$$\sqrt{cover_i} = v_0 e^{\left(-m\frac{T_i}{f_i}\right)} + \alpha * w_i + \gamma * \bar{S}$$

where v_0 is the vegetation cover expected under zero inundation, T_i is the total number of inundation days, f_i is the number of events, w_i is the ratio of inundation days that occur in winter, $\bar{S}$ is the bank slope of the site, and m, α and γ are location specific parameters.

However, there are many complex impact models and assessment tools that cannot be simply recoded into river system models and therefore need to be run independently. The Climate Adaptation Toolkit (Dwyer et al. 2022) is being designed to support this translation and enable geographical and scenario comparisons. Conceptually the toolkit will take hydrological time-series generated by river system models and translate these to Basin outcome measures, such as ecological condition or regional economic output.

3.1.4 Feedbacks

In many instances, feedbacks may exist between the Basin outcomes and the operation of the river system. For example, water trading may facilitate the movement of water from one region to another in response to changes in economics of agricultural enterprises resulting from changes in water availability, production costs or prices of farm outputs. Currently, there are very few frameworks that enable the modelling of these feedbacks and those that do exist do not make use of operational river system models. The limited frameworks to model feedbacks can constrain the ability to assess impacts of adaptation options and understand trade-offs. Factors influencing the ability to assess impacts include the prediction horizon and the latency of the feedback. Greatest uncertainty in the assessments of impacts and trade-offs will be for adaptation options that lead rapidly to feedbacks and also for long-term predictions where slowly evolving feedbacks have sufficient time to manifest.

3.2 The role of river system models in assessing adaptation options

3.2.1 River system models

River system models are mathematical representations of water management systems that are used for water resource management planning. Within the MDB, existing river system models are implemented in one of three different modelling packages: eWater Source, IQQM and REALM. The concepts underpinning the three modelling packages are similar and we use the eWater Source terminology and schematics in the remainder of this section to illustrate the concepts.

Within a river system model, key infrastructure, management components and processes of a catchment or water system are represented by nodes and links (Figure 4). The links represent water transport paths or link management processes to the water network. Nodes represent processes (e.g., inflows, losses or demands), infrastructure (e.g., reservoirs, weirs, bifurcations, offtakes) or management rules, such as minimum flow requirements. Some management decisions are also made in specially designed modules such as environmental water portfolio management, water resource management (e.g., seasonal allocations) and urban demand restriction management. Basic configuration is achieved through the Graphical User Interface (GUI) for each element; however, these data can be overridden at run time through text instructions. The instructions, termed *Scenario Input Sets*, can be configured in the GUI or read from a text file. This allows multiple scenarios to be readily configured and run independently. Detailed description of the models and computational procedures are readily available (e.g., wiki.ewater.org.au/display/SD41/Scientific+Reference+Guide).

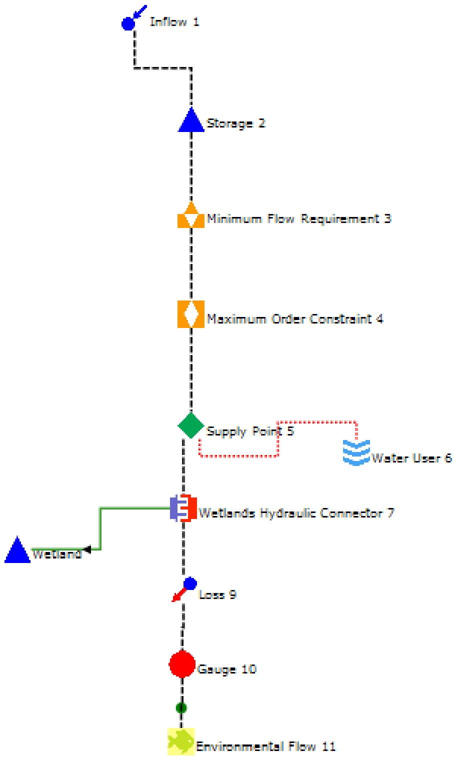

Figure 4 River system schematic showing the range of infrastructure, management components and processes that can be represented in an eWater Source model.

Some models are set up to integrate catchment rainfall-runoff models within river system models (Figure 5). Each sub-catchment and land use/soil type (called a Functional Unit) has its own rainfall-runoff model. The nodes and links described above can be mapped onto the catchment model or the runoff from the catchment model can be mapped to key points on the schematic view (Figure 4). Either way, the underlying management and simulation principles remain the same, as there is a common set of computer code.

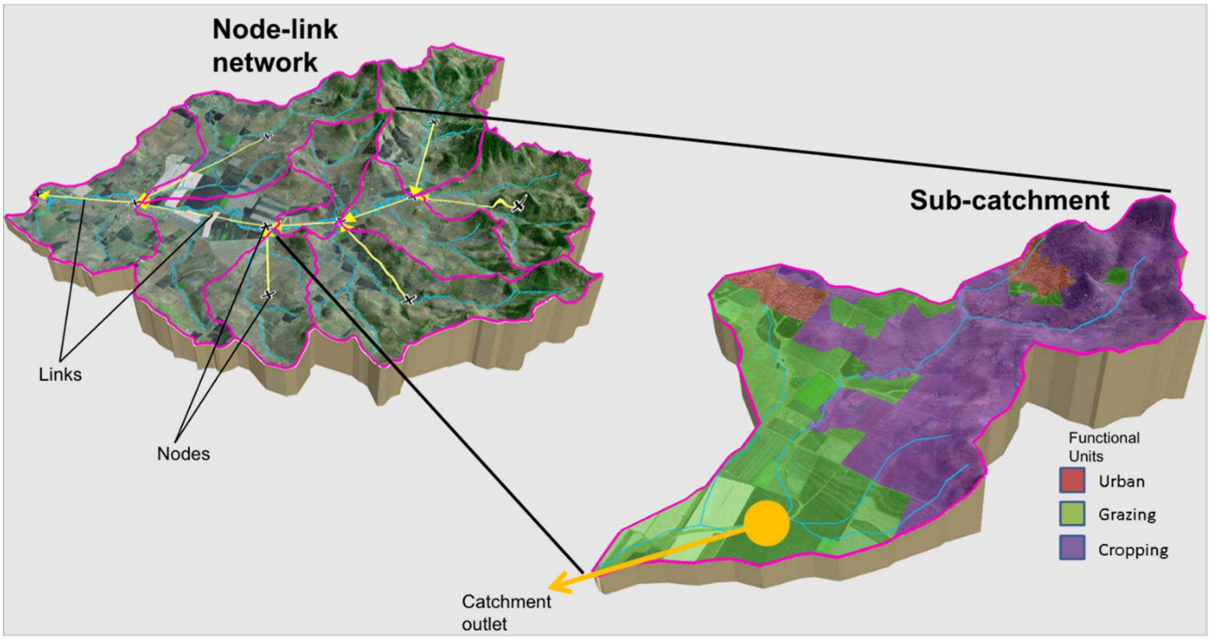

Figure 5 Representation of a catchment rainfall-runoff model integrated with a river systems model. Node-link network is depicted in yellow. Rainfall-runoff models are applied to sub-catchments and generate runoff that becomes inflow to the river systems model at inflow nodes. Sub-catchment models can consist of functional units that describe the rainfall-runoff responses of different land uses and hydrogeology.

Many river system models can represent water quality as well as water quantity. There are many dimensions of water quality and only some of these can be robustly represented in river system models. Some existing river system models within the Basin currently represent river salinity and other conservative water quality constituents, for example the Source Murray Model. However, ability to represent many other water quality parameters is in its infancy and not widely implemented, for example processes related to hypoxic blackwater.

3.2.2 What types of adaptations can be assessed using river system models?

River system models can be used to understand the consequences of many adaptation options related to water storage, water sharing, water use and delivery efficiency. Where river system models are coupled with catchment rainfall-runoff models, there is also the ability to assess the impacts of climate change and adaptation on catchment runoff and, hence, river system inflows.

3.2.3 How can the impacts of different adaptation options be investigated?

Existing river system models have a wide variety of water sources, demands, infrastructure and operating rules embedded. Therefore, investigating some adaptation options may be as simple as changing a parameter in an existing model while others may require different model configurations or structures. Here we summarise some of the key adaptation options that have been identified and describe how they can be investigated in river system models.

Additional catchment storage

Additional catchment storage can be added in the form of new or enlarged reservoirs, weirs or other means of storing streamflow for use at later times.

These features are explicitly represented in river system models. Adding new catchment storage requires the structure (node-link network) of river system to be altered, while enlarging an existing storage will require the reservoir definition tables, including dimensions, spillway and outlets, to be respecified.

In addition to specifying the catchment storage, the specification of any Resource Assessment, which defines entitlement volumes and reservation and allocation procedures, requires updating to reflect the increase storage availability. This step is also required for changes to entitlement mixes or water sharing rules.

Rebalancing entitlement mix and water sharing rules

Changing the mix of entitlements or water sharing rules is primarily concerned with how much water is held in different entitlement types (e.g., high or medium priority) and how water is reserved for and allocated to those entitlement types.

The combination of the volume of an entitlement type and the procedures used to reserve and allocate water to the entitlement ultimately determine its reliability. Therefore, changing the mix of entitlements without changing the procedures to reserve or allocate water will result in changes to the entitlement reliability.

Within eWater Source, entitlement volumes and reservation and allocation procedures are defined in the Resource Assessment system.

Enhancing water supply system efficiency

The efficiency of water supply systems can be modified by reducing losses in water delivery infrastructure, for example through piping or lining of channels, or modifying operations to reduce system losses. Quantifying reductions in losses can be difficult for some small-scale infrastructure improvements, while they can be readily identified and modelled for other improvements, e.g., pipelining stock and domestic supply systems.

Modelling enhancements to the water supply system efficiency needs to reflect the nature of the efficiency improvement. In river system models, losses are represented using loss nodes that model how much water is lost in the transmission of water through a reach. These can be constant, or an analytical or tabular function of flow that may vary seasonally.

Reductions in losses through piping or lining of existing channels may simply require the existing loss model to be modified, based on observed or assumed loss reductions.

However, if new pipe or channel infrastructure is introduced to reduce losses, then these additional physical connections need to be introduced into the node-link network structure of the river system model.

Reducing constraints on delivery of water

The capacity of river or delivery system channels, and restrictions on minimum or maximum flow rates can constrain the ability to supply water to meet extractive and environmental demands from upstream sources. Many constraints on channel capacities and flow rates are currently represented within river system models through explicit maximum or minimum flow nodes, channel capacities at confluences and splitters, and the specification of infrastructure such as dam outlets or spillways sizes. The effects of these constraints are assessed at each simulation time step imposed on flow orders that are passed upstream.

A range of different methods are available for relaxing delivery constraints that may involve changing operating rules, modifying existing infrastructure (e.g., increasing outlet or spillway dimensions) or introducing new infrastructure (e.g., bypass channels).

From a modelling perspective, where new infrastructure is introduced to reduce constraints on water delivery, then this infrastructure needs to be introduced into the node-link network structure of the river system model and appropriately configured.

However, where constraints can be relaxed through changing operating rules or modifying existing infrastructure, then the specification of the operating rules or infrastructure can be simply configured in existing model nodes.

Environmental watering strategies

The management and use of held environmental water to deliver environmental outcomes in the Basin is an evolving field. Environmental watering strategies seek to deliver a wide range of outcomes and, as a result, influence numerous hydrologic metrics. Historically, river system models have had little ability to represent different environmental watering strategies other than minimum flow constraints that are typically achieved using planned environmental water. The ability to represent environmental watering strategies in river system models is continually improving, with concepts such as dam translucency and triggering of environmental flow events to be delivered using held environmental water now available in eWater Source, for example.

Modelling adaptation options related to environmental watering strategies can require either model reconfiguration to introduce new environmental flow nodes into the node-link network structure or changing the specifications in existing environmental flow nodes. There is also the functionality to handle the prioritisation of environmental flow actions across water resource system. This prioritisation process considers water available in environmental accounts, environmental water demands generated at environmental flow nodes and relative priorities of environmental flow nodes.

Land-use change

Land-use changes can occur due to institutional and autonomous adaptations. Land-use changes may influence catchment inflows or the location, magnitude and timing of demands for water. Catchment inflows are often generated independently of river system models using conceptual rainfall-runoff modelling. In many cases, these rainfall-runoff models do not explicitly represent land-use impacts on runoff; rather catchments are represented as a simple lumped unit with common properties. Explicit parameterisations for different land-uses within rainfall-runoff models is possible, including within eWater Source. Such parameterisations would enable the impacts of changes in the distribution of land uses on runoff to be assessed. However, as these models are typically calibrated to observations, any parameterisation of land uses that have not existed historically would be highly uncertain.

Water demands are explicitly represented in river system models as demand nodes attached to supply point nodes. Demand nodes can use models to determine how much water is ordered as a function of water availability, crop areas, crop type (characterising water requirements as function of time of year or phenological stage) and climate forcing. Therefore, the impact of changing land use on the magnitude and timing of water demands can be represented by changing crop types and areas. Demands can also be provided as time series that reflect equivalent computations external to the river system model. Changes in the location of water demands may require additional demand nodes to be introduced into river system models in regions where no current demands exist. Alternatively, water licences (and hence availability) between existing demand nodes could be redistributed, for example where water is traded between existing users. Currently no river system or hydro-economic models describe the dynamic long-term changes in land use as a response water availability or other economic drivers.

3.2.4 Adaptation options that cannot be represented by river system models

Not all adaptation options can, or should, be represented by river system models. Some adaptation options directly influence Basin assets and values, and are independent or only loosely dependent on change in climate and hydrological processes or metrics. Examples of these adaptation options include:

- fish restocking and protection measures, including installing fishways,
- protection and restoration of aquatic, riparian or terrestrial habitats,
- installation of wetland regulators.

Assessment of the impacts of these adaptation options on Basin assets and values require different modelling frameworks, such as dynamic ecological state and transition models that can be applied to fish population or vegetation dynamics, to which climate and/or river system model output may be just one driving variable. Many such models exist, and new models are currently being developed in the Basin through projects in the FlowMER Project, Ecosystem Functions Project, and MD-WERP Ecology Theme.

River system models primarily focus on describing the management of surface water. Within the MDB, groundwater provides a significant quantum of consumptive water use and many groundwater dependent ecosystems exist. The role of groundwater in river system models is limited to being a source of loss or gain from a river reach and an alternative water source. Climate change and adaptation options are likely to change groundwater levels which will have consequences for both groundwater dependent ecosystems and consumptive water use. Understanding these impacts requires some form of groundwater model that can represent the climate and management impacts on recharge and groundwater levels. Groundwater models with different levels of complexity exist for the MDB. Conceptual or data-driven groundwater models are likely to provide a first pass assessment, however detailed process-based models may be required to fully understand interactions between surface and ground water, particularly under novel climate conditions.

Water use by urban water systems tends to be considerably smaller than other water uses in the Basin. Some adaptation options related to urban water use can be represented within regional-scale river system models, for example change in catchment storage. However, other adaptation options, for example changes to restriction policies, are unlikely to be represented in regional-scale river system models but will be reflected in local-scale modelling used for planning water urban water systems. These local-scale models can be analogous to regional river system models but with more detailed representation of infrastructure and operating rules.

A class of adaptation options exists that does not have a direct impact on water management but can identify opportunities to improve water management, for example enhanced monitoring and knowledge development and sharing. These options are designed to improve understanding of systems, for example improving understanding of water availability or system losses. Improved understanding may reduce uncertainties of processes or parameters of river system models. Therefore, while these adaptation options will potentially change any outcome assessments and identify alternative adaptations, the impacts of these adaptation options are very difficult to quantitatively assess.

4 Summary, implications and next steps

This report has developed a classification system for climate change adaptation options. This classification system for climate adaptation options is envisaged to guide the selection of future case studies within the MD-WERP Climate Adaptation Theme. The classification system has been established by reviewing the range of adaptation options that are currently being considered by the Basin's water management institutions and identifying commonalities and differences. While many of the options identified are related to managing climate change impacts, they can be broadly categorised according to the objectives they are seeking to address, e.g., achieving environmental outcomes and obligations or water security. The adaptation options themselves are then further categorised according to a range of additional dimensions.

An analysis of the adaptation options currently being considered raises important considerations for the selection of future WERP case studies. Most adaptation options are focussed on addressing particular objectives or problems, are overwhelmingly focussed on regions or river reaches, have a high degree of confidence in their impacts, have short implementation times and are likely to quickly deliver benefits. This highlights that adaptation to climate change is being considered at local and regional scales to address specific problems or objectives. Focusing adaptation on specific local or regional issues creates the potential for maladaptation, where a region becomes more vulnerable to climate change impacts. Future case studies should therefore investigate the wider consequences of adaptation options by enabling the assessment of regional impacts on a wide range of objectives and outcomes or by linking the regional impacts to whole-of-basin outcomes.

The first case study that is in development for the Macquarie River Valley will seek to demonstrate how the wider consequences of climate change and adaptation can be assessed. Future case studies that are currently being scoped will seek to enhance analysis, for example by considering how First Nations outcomes can be robustly and respectfully assessed and provide a wider whole-of-basin assessment, for example by investigating how water trade may need to adapt under a changing climate.

Understanding the impacts of adaptation options requires a suite of modelling tools that can represent current water management systems and are sensitive to changes in climate and management. River system models, such as those developed in eWater Source, provide an important tool that can relate changes in climate and river operations and management to hydrological metrics in regulated river systems. In this report, we have summarised how some of the key categories of adaptation options identified can be represented in river system models to provide evidence of their expected impacts. However, not all adaptation options identified by our review can, or should, be represented in river system models and there are currently gaps in the ability to translate hydrological metrics to indicators of Basin outcomes.

Some of these gaps can be addressed by using models and other tools to post-process hydrological time series generated by river system models, such as those being developed and integrated into the Climate Adaptation Toolkit. However, other modelling tools may also be required. For example, groundwater models are necessary to fully understand climate and management impacts on groundwater levels and dependent ecosystems, and the implications of climate change for urban water supplies may need more detailed process representation that is possible in a regional river system model. Almost all models used require boundary conditions that describe where, how and when water will be within the Basin. While the current state of these boundary conditions can be estimated with some certainty, there are significant limitations in the ability to describe how these will dynamically evolve in the face of changing climate and highly uncertain other determinants, such as markets and prices for products and competition for land or other resources.

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Appendix A Classification of adaptation options

	Adaptations Measure	Description	Objective	Scale	Scientific certainty	Time for benefit	Time to implementation	Permanence	Water Type	Adaptation action type	Responsibility
Achieving environmental outcomes and obligations											
1	Fish breeding and restocking	Hatchery production and translocation of native fish species	Supplementing or reintroducing populations of native fish	Reach	Moderate	Immediate	Immediate	Temporary	Surface	Physical works	State Government / MDBA
2	Fishways	Installation of fish passage infrastructure at regulating structures (e.g. weirs, dams etc.)	Enabling migration of fish species, supporting native fish life history requirements	Reach / Region	High	Immediate	Rapid	Ongoing	Surface	Physical works	State Government / MDBA
3	Fish protection measures	Install infrastructure, such as screens onto irrigation pumps and diversions channels	Limiting the diversion of native fish into irrigation infrastructure	Reach	Moderate	Immediate	Immediate	Ongoing	Surface	Physical works	State Government / MDBA
4	Aquatic habitat restoration	Reinstate habitat features important to freshwater animals including aquatic vegetation, small and large woody habitat and hard rocky structures.	Improve instream habitat for freshwater biota	Site	High	Immediate	Immediate	Temporary	Surface	Physical works	State Government / Catchment Management Authorities
5	Riparian habitat restoration	On-ground activities at targeted high priority locations to restore, conserve and protect riparian habitat and re-establish threatened species	Provide habitat for semi-aquatic biota and improve riparian ecosystem functions such as nutrient retention and bank stabilisation	Reach	High	Slow	Moderate	Ongoing	Surface	Physical works	State Government / Catchment Management Authorities
6	Channel works	Channel restorations works that rectify incised and eroded channel profiles.	Reinstate and stabilise natural channel profiles	Site / Reach	High	Rapid	Rapid	Ongoing	Surface	Physical works	State Government / MDBA
7	Land holder incentives	Provide incentives to landholders to improve land conservation, including the rehabilitation of riparian, wetland and floodplain ecosystems. Examples include: - Buy-back schemes for land restoration - Soil control works (erosion mitigation) - Fencing of riparian habitats - Invasive species control (e.g. willow removal)	Mitigate impacts of intensive agriculture and reinstate natural habitats.	Site / Reach	High	Moderate	Moderate	Variable	Surface	Policy/Governance Physical works	State Government / Local Government
8	Groundwater dependant ecosystem protections	Identifying and protecting important groundwater dependant ecosystems (e.g. springs and aquifers)	Protect vulnerable groundwater habitats during dry periods	Site / Reach	High	Moderate	Moderate	Ongoing	Ground	Policy/Governance	State Government / Catchment Management Authorities
9	Increase floodplain/wetland connectivity	Removal of system constraints, such as unapproved flood work infrastructure, to improve lateral connectivity of channels with associated floodplains and wetlands.	Improve delivery of water to floodplain and wetland habitats, benefiting ecological processes.	Reach	High	Moderate	Moderate	Ongoing	Surface	Physical works	State Government
10	Improve connectivity with downstream systems	Establishing additional end of system flow targets Using environmental water to achieve connectivity objectives States working together to develop connectivity targets	Enable critical human and environmental needs to be met downstream during extreme dry periods.	Reach / Region	Moderate	Moderate	Moderate	Ongoing	Surface	Policy/Governance	State Government

	Adaptations Measure	Description	Objective	Scale	Scientific certainty	Time for benefit	Time to implementation	Permanence	Water Type	Adaptation action type	Responsibility
11	Increase research of poorly understood ecosystem processes	Undertake research in areas that an understanding of fundamental process is lacking, for example groundwater processes.	Increase scientific knowledge of the processes to inform management actions	Reach / Region	High	Moderate	Rapid	Ongoing	All	Research/Increasing Knowledge	State Government / Research Institutions
12	Environmental water strategies - planning	Drought rules Co-ordination of environmental water releases	Achieving environmental outcomes and obligations	Region	High	Rapid	Rapid	Variable	Surface	Policy/Governance Planning	State Government / MDBA / Catchment Management Authorities
13	Environmental water strategies - delivery	Tools and systems to increase efficiency of water delivery through improved characterisation of environmental water delivery risks	Achieving environmental outcomes and obligations, including water quality.	Region	High	Rapid	Rapid	Variable	Surface	Water delivery operations	State Government / MDBA / Catchment Management Authorities
14	Independent environmental water holders	Environmental water holders should maintain independence from government, ensuring decision making is free from political interference	Achieving environmental outcomes and obligations	Basin				Ongoing	All	Policy/Governance	State Government / Federal Government
15	Redirection of supplementary flows	Introduce rules allowing environmental water managers to direct the environment's share of the supplementary flow to specific environmental assets	Improve environmental assets and overall ecosystem by enabling adaptive management	Reach	Moderate	Rapid	Rapid	Temporary	Surface	Water delivery operations	State Government
16	Water quality allowances	Institute entitlements/allowances that mitigate water quality issues that contribute to major outcomes for native fish and riverine productivity. Addresses: - Blue-green algae Blooms - Blackwater events - Reduce treatment costs	Improve water quality and avoid adverse water quality events	Region	Moderate	Rapid	Rapid	Ongoing	Surface	Policy/Governance	State Government / MDBA
17	Management of cold-water pollution	Implement technologies and infrastructure to mitigate cold water pollution, such as multi-level offtakes or thermal curtains.	Improving/rectify temperature dependent riverine processes below large dams (e.g. seasonal fish spawning)	Reach	High	Moderate	Slow	Ongoing	Surface	Physical works	State Government / Water Corporations
18	Regulating and environmental infrastructure	Construction of regulators/weirs/dams	Achieving environmental outcomes and obligations by managing flow variability	Reach / Region	High	Rapid	Moderate	Ongoing	Surface	Physical works	State Government / MDBA
19	Reducing constraints on delivery of managed water through the river channels	Reducing in-river barriers to the delivery of environmental water through: - Modification of weirs/bridges - Changes to channel capacity limits - Changes in operation rules (e.g. 6-inch rule)	Enhance water delivery to achieve environmental outcomes and obligations	Reach / Region	High	Rapid	Moderate	Ongoing	Surface	Policy/Governance Physical works	State Government / MDBA
Water security and storage											
20	Increasing water reuse and recycling	Urban and industrial water users generate wastewater that can be recycled for a range of uses	Increase efficiency of use and water security by diversifying water sources.	Reach / Region	High	Rapid	Moderate	Ongoing	All	Physical works	State Government / Water Corporations
21	Managed aquifer recharge systems	Temporary storage of storm water and river flows in aquifers	Increase efficiency of water use and storage by minimising evaporation.	Reach / Region	High	Moderate	Slow	Ongoing	All	Physical works*	State Government

	Adaptations Measure	Description	Objective	Scale	Scientific certainty	Time for benefit	Time to implementation	Permanence	Water Type	Adaptation action type	Responsibility
22	Dual water systems	Dual water systems enable water users to selectively access potable and non-potable water through different distribution networks.	Increase water security as well as efficiency of use.	Region	High	Rapid	Slow	Ongoing	All	Research/Increasing Knowledge Physical works	Water Corporations / Local Governments
23	Advanced water treatment technologies	Advanced water treatment options (e.g. reverse osmosis treatment) would improve access to non-potable surface and ground water sources for domestic uses. Examples include: saline groundwater or impacted surface water.	increase water security by diversifying water sources. Maintain and improve water quality.	Region	High	Immediate	Moderate	Ongoing	All	Physical works	State Government / Water Corporations
24	Reliable access to groundwater	Develop plans that would enable reliable access to groundwater, predominantly for towns where future water demands may exceed surface water capacity.	Increase water security for towns (and other users where appropriate) by diversifying water supply options.	Region	High	Immediate	Moderate	Ongoing	Ground	Physical works	State Government / Water Corporations
25	Increased water storage	Construction of new dams and/or raising the level of existing dam walls	Improving water security by increasing water storage capacity. New storages may also reduce water loss due to evaporation.	Region	High	Rapid	Slow	Ongoing	Surface	Physical works	State Government / Water Corporations
26	Desalination	Desalination of groundwater to make it suitable for domestic or industrial purposes.	Improve water supply reliability for town and industrial use	Reach / Region	High	Rapid	Moderate	Ongoing	Ground	Physical works	Water Corporations / Local Government
27	Fractured rock exploration	Undertake fractured rock explorations for potentially new sources of groundwater. Water would need to be treated prior to use.	Improve water supply reliability for town and industrial use	Reach / Region	Moderate	Moderate	Moderate	Ongoing	Ground	Physical works	State Government / State or National Geological survey
28	Increase access to deep water storage	Development of temporary infrastructure (e.g. pumps) that allows access to deep water storage below current outlets	Increase water security during drought via additional water supply.	Reach	High	Immediate	Immediate	Temporary	Surface	Physical works	State Government / Water Corporations
29	Town water security planning	Investigation of long-term water security requirements for town water supply, including deficiencies, potential new water sources and delivery mechanisms. This would enable the prioritisation of investments (i.e. supply infrastructure) that would provide a diverse water supply portfolio.	Improve town water security under future climate uncertainties	Region	Moderate	Rapid	Rapid	Ongoing	All	Policy/Governance Planning	State and Local Government
Water allocation, sharing and trade											
30	Sustainable diversion limit quantum	Volume of water entitlements licenced for consumptive use	Achieving environmental outcomes and obligations under a changed climate	Basin	High	Moderate	Slow	Ongoing	All	Policy/Governance	MDBA
31	Water sharing rules	Rules governing priority of allocating available water to entitlements under normal and dry conditions	Support water entitlement reliability – town and consumptive	Basin	Moderate	Moderate	Slow	Ongoing	All	Policy/Governance	State Government
32	Rebalancing entitlement mix	Characteristics (volume and reliability) of consumptive licences are adjusted to reflect changed climate	Support water entitlement reliability	Basin	Moderate	Moderate	Slow	Ongoing	All	Policy/Governance	State Government
33	Water infrastructure sharing rules	Rules governing the sharing of river channel capacity	Support water entitlement reliability	Basin	Moderate	Moderate	Slow	Ongoing	All	Policy/Governance	

	Adaptations Measure	Description	Objective	Scale	Scientific certainty	Time for benefit	Time to implementation	Permanence	Water Type	Adaptation action type	Responsibility
34	Review of regulated river water accounting and allocation process	Review different settings of the current water accounting and water allocation process	To meet changing demands resulting from increased climate variability, investigate options to more effectively meet basic landholder rights and the needs of stock and domestic water users.	Basin	Moderate	Moderate	Moderate	Ongoing	All	Policy/Governance	State Government
35	Accounting and management of interception activities	Interception is the capture of ground or surface water that would otherwise flow into a waterway. Interception can occur via farm dams, bores, or overland harvesting. Interception can reduce the water available to water entitlement holders, especially in fully allocated systems	Accurately estimate the extent of interception activities so entitlement arrangements are appropriate.	Region	Moderate	Slow	Slow	Ongoing	All	Policy/Governance Research/Increasing Knowledge	State Government
36	Use of return flows	Allow water that is returned to the system after use by entitlement-holder's to be reused downstream or traded	Achieving environmental outcomes	Region	Moderate	Rapid	Rapid	Ongoing	Surface		State Government
37	Land use change impact on water resources	Investigation of the potential impacts on water resources due to projected land use changes and population growth	Provide information to help decision-making processes regarding future land use in a region	Reach / Region	High	Rapid	Moderate	Ongoing	All	Research/Increasing Knowledge Planning	State and Local Governments
38	Restrictions, exchange rates or levies on temporary or permanent water trade	Creating systems that encourage water trade to minimise environmental consequences	Achieving environmental outcomes and obligations	Basin	Moderate	Moderate	Slow	Variable	All	Policy/Governance	State Government
39	Trade between entitlement classes	Enabling water users to create water entitlements that reflect their own risk appetite	Support water entitlement reliability	Region	Moderate	Moderate	Slow	Variable	All	Policy/Governance	State Government
40	Retirement of irrigation land	Water traded off irrigated land	Farm business profitability	Site	High	Immediate	Immediate	Ongoing	All	Water Trade	Landholders
41	New irrigation development	Water traded onto previously undeveloped land	Farm business profitability	Site	High	Rapid	Rapid	Ongoing	All	Water Trade	Landholders
42	Optimise water market operations	Optimise water trade operational arrangements with a view to increase efficiency, therefore reducing transaction costs - trade approval fees - trade approval processing times - regulation of trade related services (third parties)	Maximise gains provided by trade	Basin	Moderate	Rapid	Slow	Ongoing	All	Water Trade Policy/Governance	MDBA / Water Markets
Water use and delivery efficiency											

	Adaptations Measure	Description	Objective	Scale	Scientific certainty	Time for benefit	Time to implementation	Permanence	Water Type	Adaptation action type	Responsibility
43	Enhanced monitoring and data collection of ground and surface water resource	Improve data collection of water use by: - Refurbishing deficient existing monitoring infrastructure - Installing new infrastructure and utilising new technologies for water data collection - Incorporate water use data collected by industry (e.g. via Environmental Impact Statements)	Increase quantity of high-quality data to improve efficiency of water delivery and use	Basin	High	Rapid	Rapid	Ongoing	All	Physical works Research/Increasing knowledge	State Government
44	Data sharing and training programs	Training and information sessions on new climate data and modelling as well as access to any new water data sources	Better inform water managers about their water supply security to enable best possible discission making	Basin	High	Rapid	Rapid	Ongoing	All	Research/Increasing Knowledge	State Government
45	Understanding water use in unregulated systems	Increase the information available to resource managers by: - Introducing new metering regulations - Installing new monitoring gauges - Farm dam monitoring (i.e. increases in number and volume) - Hydrological modelling	Improve understanding of water use in unregulated water sources	Region	High	Rapid	Moderate	Ongoing	All	Research/Increasing Knowledge Physical works	Catchment Management Authorities
46	Enhanced river operations	Rules governing operation of river: during drought & Tools and systems to increase efficiency of water delivery through reduced dam releases and improved characterisation of delivery risks	Efficiency of water delivery and use Equity and fairness in access to water	Region	Moderate	Rapid	Rapid	Ongoing	Surface	Water delivery operations	River Murray operations / State water operations
47	Shortened irrigation season	Shorten the length of the irrigation season during successive of dry years	Enable irrigation districts to operate during dry periods	Region	Moderate	Rapid	Rapid	Temporary	Surface	Water delivery operations	Local water utilities
48	Carryover rules	Carryover allows entitlement-holders to store unused water allocation in water storages for later use	Improve water use efficiency and enable risk management by individuals	Region	High	Rapid	Rapid	Ongoing	All	Water delivery operations	State Government
49	Enhancing water supply systems	New pipelines and water supply channels. Modernisation of existing infrastructure, such as channel automation, lining, metering. Removal/decommissioning of unnecessary infrastructure.	Increase efficiency of water delivery and use. Increase water security by diversifying water sources.	Region	High	Rapid	Slow	Ongoing	Surface	Physical works	State Government
50	Farm water efficiency programs	Supporting efficiency of water use and delivery to farms	Enhance efficiency of water delivery and use	Reach / Region	High	Rapid	Slow	Ongoing	Surface	Physical works	State Governments
51	Cropping system changes	Changes to crop types and areas irrigated	Farm business profitability	Reach / Region	Moderate	Moderate	Slow	Ongoing	Surface	Physical works	Landholders
52	Farm irrigation efficiency improvement	Reduced farm water requirements	Farm business profitability	Reach / Region	High	Rapid	Slow	Ongoing	Surface	Physical works	Landholders
53	Salinity management	Manage impacts on dryland and irrigation salinity - Enhanced accounting and reporting of salinity impacts - Drainage programs	Prevent further adverse impacts from salinity, maintaining/improving farm profitability and environmental outcomes	Reach / Region	Moderate	Moderate	Moderate	Ongoing	Ground	Physical works	State Government / Catchment Management Authorities / Landholders
Regional community resilience											

	Adaptations Measure	Description	Objective	Scale	Scientific certainty	Time for benefit	Time to implementation	Permanence	Water Type	Adaptation action type	Responsibility
54	Community outreach for state significant projects	State Significant Developments and Infrastructure projects, such as coal mines, new dams or large road and rail projects, require access to water but may result in community concerns around the impact of the development on water sources	Provide transparency and accountability of water impacts from State Significant projects, increasing community confidence	Region	Moderate	Rapid	Immediate	Temporary	All	Communication	State Government
55	Maintenance of town amenities	Securing water supply to maintain town amenities such as local parks and recreational areas during extended drought periods	Improve regional community mental and physical health during dry periods by providing access to 'green' local amenities. Potential boost to local economy by maintaining ability to attract tourism	Region	Moderate	Moderate	Rapid	Ongoing	All	Policy/Governance	State Government / Local Council
56	Urban water restriction policy	Development of a comprehensive policy on water use standards and appropriate temporary water restriction triggers and levels for regional towns	Improve management of town water supply shortages during drought.	Region	High	Rapid	Immediate	Temporary	All	Policy/Governance	State Government / Water Corporations
57	Urban water conservation (residential & non-residential)	Households and industries implementing water conservation measures (e.g. shorter showers)	Reduce demand on urban water supply	Region	High	Rapid	Immediate	Ongoing	All	Policy/Governance	State Government / Water Corporations
Aboriginal people's use, rights and management of water											
58	Water knowledge sharing programs	Establishment of programs that increase the communication and the two-way sharing of knowledge between Aboriginal groups and water management agencies across all levels of government. This would include both ground and surface water.	Ensure that Aboriginal people's rights and interests are recognised in water management and policy	Reach / Region	High	Moderate	Rapid	Ongoing	All	Research/Increasing Knowledge Communication	Aboriginal corporations / All levels of Government
59	Culturally significant site identification	Identification, classification and mapping of culturally significant water-dependent sites by Aboriginal people.	Increase knowledge of culturally important sites for non-indigenous water managers, better enabling consideration of these sites in water management plans	Reach / Region	Moderate	Moderate	Moderate	Ongoing	All	Research/Increasing Knowledge	Aboriginal corporations / State Government
60	Aboriginal Water Advisory Committees	Establish Aboriginal Water Advisory Committee responsible for: - Guiding the purchase of water entitlements for cultural flows - Defining cultural flow requirements - Providing representation for the wider Aboriginal community that may be impacts by a particular watering plan - Provide a point of contact to encourage engagement between traditional owners and water managers	Improve representation of Aboriginal people in decision making and ensuring that outcomes are culturally appropriate	Reach / Region	High	Rapid	Rapid	Ongoing	All	Communication Policy/Governance Planning	Aboriginal corporations / State Government
61	Secure water allocations for Aboriginal communities	Financially supporting the purchase of water entitlements and infrastructure by aboriginal communities to be used for spiritual, cultural, environmental and economic outcomes, especially during dry periods	Increase community resilience by maintenance of key cultural activities and sites during periods of drought	Region	High	Rapid	Moderate	Ongoing	All	Policy/Governance	Aboriginal corporations / State Government

	Adaptations Measure	Description	Objective	Scale	Scientific certainty	Time for benefit	Time to implementation	Permanence	Water Type	Adaptation action type	Responsibility
62	Shared benefits program	Investigate opportunities for environmental flows to simultaneously achieve cultural outcomes. If shared benefits are identified, these would not replace specific cultural flows.	Providing cultural flow outcomes, maximising the benefits from environmental flows	Reach / Region	Moderate	Moderate	Moderate	Ongoing	All	Policy/Governance Planning	Aboriginal corporations / State Government
63	Indigenous Ranger Programs	Establish Indigenous Ranger Programs in which rangers undertake activities that aim to maintain and manage important aquatic systems. Activities could include: - Fish restocking and habitat restoration - Pest control - Environmental monitoring	Greater involvement of aboriginal people in management of aquatic systems while building closer relationships with water management agencies.	Reach / Region	High	Immediate	Rapid	Ongoing	All	Physical works Communication	Aboriginal corporations / State Government

Appendix B List of water management documents reviewed

New South Wales DPIE (2020). Draft Regional Water Strategy: Gwydir Long List of Options (Department reference number: PUB20/304), Parramatta. Retrieved from https://water.dpie.nsw.gov.au/__data/assets/pdf_file/0007/313288/draft-rws-gwydir-options.pdf

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