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MURRAY–DARLING BASIN AUTHORITY

Hydrologic modelling for the Northern Basin Review - summary

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Postal Address: GPO Box 1801, Canberra ACT 2601
Telephone: (02) 6279 0100 international + 61 2 6279 0100
Facsimile: (02) 6248 8053 international + 61 2 6248 8053
Email: engagement@mdba.gov.au
Internet: www.mdba.gov.au

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Cover image: Darling River near Bourke, NSW (photo by Josh Smith Photography)

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Contents

What is this report about?

This report, Hydrologic modelling for the Northern Basin Review, describes how water will flow through the northern Murray–Darling Basin when different volumes of water are available and for different patterns of water recovery. The results of the modelling has been used for environmental, social and economic assessments as part of the Northern Basin Review. This report is one of a suite of reports prepared as part of the review.

What is in this report?

This report provides an evaluation of nine water recovery scenarios considered for the northern Basin. It also outlines the approach taken by the hydrological modelling, including refinements to specific parts of the modelling methodology used for the Basin Plan in 2012 and additional scenarios to Basin Plan options.

What is the Northern Basin Review?

The Basin Plan seeks to deliver vibrant communities, productive industries and healthy rivers. The Northern Basin Review provides information to support this vision; and specifically reviews the current Basin Plan recovery target of 390 gigalitres (GL) of water for the river systems of the northern Basin.

Recommendations of the review may lead to resetting the amount of water to be recovered from the northern Basin.

Is the Northern Basin Review about more than water recovery volumes?

Yes. Northern basin communities have explained that any solution to a healthy working Basin must consider more than a volume of water. Consideration of the management activities required to complement water allocations also need to be taken into account

What is hydrological modelling?

A hydrological model is a computer based simulation of the flows and behaviour of water along a river system, taking into account:

- the movement of water through the river channel, floodplains and wetlands
- losses and gains as water moves through the landscape
- how we manage the storage, supply and use of water for various purposes.

What information is this report based on?

The modelling framework was built collaboratively with CSIRO in 2009–10 to link 24 individual catchment models developed by the Basin state governments, the MDBA and Snowy Hydro Limited. The MDBA has since enhanced the capability of the framework to better meet the needs of Basin Plan development. The framework enables a complete examination of surface water resources in the Murray–Darling Basin.

What else is in the Northern Basin Review?

The hydrological modelling results summarised in this report were used to assess environmental, social, cultural and economic impacts associated with different water recovery scenarios in the northern Basin. There are separate bodies of work describing research from the other areas of work. A report titled 'Triple Bottom Line Framework' outlines the steps used to integrate the varying research undertaken during the Northern Basin Review.

Do communities have a say?

Yes, they do. For any proposed amendment to the Basin Plan, there is a public consultation process. As part of that process, people have opportunities to make a submission outline their support or feedback on the proposed amendment. The MDBA use submissions to finalise the proposed amendment. The MDBA submits the proposed amendment to the Commonwealth Minister for Agriculture and Water Resources.

Executive summary

This report on hydrological modelling is one part of the research program undertaken as part of the Northern Basin Review. It describes a set of water recovery scenarios that explored a wider range of sustainable diversion limits (SDLs) and water recovery options than was possible prior to the release of the Basin Plan.

The modelling generated a wealth of information on which to base environmental, social and economic assessments on the effects of the range of water recovery scenarios for the northern Basin.

The modelling focused primarily on the Barwon–Darling and Condamine–Balonne river systems. Generally it showed that flow outcomes will be directly related to the volume of water recovered across the whole of the northern Basin. The modelling has also indicated that both the pattern of recovered water and the strategy underlying the use of environmental water will also be important factors in flow outcomes.

Background

In 2012, the Commonwealth Government adopted the Basin Plan, providing the first integrated framework for water planning in the Murray–Darling Basin. The Basin Plan aims to restore healthy river systems for the benefit of the communities, industries and the environment.

A central component of the Basin Plan is the establishment of long-term average SDLs that specify the maximum amount of water that can be taken from surface and groundwater resources. At the Basin scale, SDLs restrict the consumption of surface water resources to a long-term average volume of 10,873 GL per year, requiring the recovery of 2,750 GL of water for the environment. Of this recovery volume, 390 GL are to be sourced from the river systems of the northern Basin. The SDLs will take effect in 2019 when water resource plans, compliant with the Basin Plan, are passed into legislation in each Basin state.

The SDLs adopted in 2012 were informed by a number of information streams, including an assessment of environmental, social and economic outcomes. Underlying this information were the results of a MDBA hydrologic modelling work program that commenced in 2009 and was reviewed and refined through to 2012. The purpose of the modelling was to inform the decision on the SDLs by demonstrating the simulated ecological outcomes that could be achieved with the water recovery program under the Basin Plan.

Northern Basin Review

Upon finalising the Basin Plan, the MDBA agreed to conduct further research and investigations on the SDLs for the northern Basin, through the review provisions in Chapter 6.06 of the Basin Plan. This recognised that surface water resources in the northern Basin had been developed and managed differently to the southern Basin — the proportion of northern Basin flows regulated by dams was much lower and many of the water licences in these regions were associated with unregulated conditions. As a result, the implementation of the Basin Plan in the northern Basin required a different approach.

The primary purpose of the Northern Basin Review was to determine if new information indicates a case for changing the SDLs from those recommended in 2012. While the science was the best available at the time, the MDBA felt that a review provided a chance to fill some of the identified information gaps. The review encompassed the northern Basin region as a whole, with a focus on the Barwon–Darling and Condamine–Balonne catchments.

The Northern Basin Review began in 2013 and was supported by all Basin government ministers for water. The review included a consultation program with northern Basin communities and jurisdictions to incorporate local views regarding the ongoing implementation of the Basin Plan. Also central to the review was an investment in new knowledge through the development of a three-branched research program – environmental science, social and economic assessment, and updated water recovery modelling. Both the engagement and research programs provided updated information to the MDBA for its re-examination of Basin Plan SDLs in the northern Basin.

New knowledge and research

The research program developed by MDBA for the Northern Basin Review focused on three main areas:

- **Environmental science program** — to help better understand the needs of birds, fish and floodplain vegetation in the Barwon–Darling and Condamine–Balonne river systems. This included new research and review of the most current knowledge on ecological responses to flows.
- **Social and economic assessment** — to explore likely impacts of water recovery on communities and industries. This included economic modelling to define the relationships between irrigated area and employment at the farm level, in related farm supply industries and in the non-agricultural private sectors for communities across the northern Basin.
- **Updated water recovery modelling** —to evaluate the hydrological outcomes associated with alternative SDL settings for the Basin Plan, and to inform the environmental, social and economic assessments.

The overall purpose of the research program was to investigate the environmental, social and economic outcomes associated with a number of water recovery scenarios, as an alternative to the SDLs set by the Basin Plan.

Hydrologic modelling

The role of hydrological modelling in the Northern Basin Review was to simulate hydrologic (i.e. flow) conditions for a range of water recovery scenarios for the northern Basin. The outputs from the hydrologic modelling were then analysed using the environmental, social and economic assessment frameworks developed for the Northern Basin Review. This provided a substantial set of outcomes related to each scenario, allowing the Authority to determine the relative merits of each scenario through a triple-bottom line assessment tool.

The modelling framework, known as the Integrated River System Modelling Framework, was built collaboratively with CSIRO in 2009–10 to link 24 individual catchment models developed

by the Basin state governments, the MDBA and Snowy Hydro Limited. The MDBA has since enhanced the capability of the framework to better meet the needs of Basin Plan development, enabling a complete examination of the surface water resources in the Murray–Darling Basin.

The overall modelling framework used for this purpose was unchanged from that which informed the Basin Plan in 2012. However, individual models were updated in consultation with state governments. The modelling work completed for the review included refinements to specific parts of the modelling methodology and an increased number of scenarios.

For the development of the Basin Plan, Basin state governments provided two models as a starting point, representing:

- **Without development conditions** — all aspects of development of water resources have been removed from the model, including infrastructure and consumptive use. This is the best available estimate of the natural river system but without accounting for land use changes and on-farm development.
- **Baseline conditions** — the best estimate of water management operations prior to the Basin Plan. This scenario includes all entitlements, water allocation policies, water sharing rules, operating rules and infrastructure such as dams, locks and weirs as of June 2009 or as specified in Schedule 3 of the Basin Plan.

Jointly, these two scenarios reveal the impact of human development (at pre-Basin Plan conditions) on the flow regime of water in the Murray–Darling Basin.

The general modelling approach adopted for Basin Plan development from 2009 to 2012 was to modify the baseline models to produce a set of specific Basin Plan scenarios. By modelling these different scenarios, each water recovery level could be assessed and compared. This approach was a key component of the method used to determine the environmentally sustainable level of take (ESLT; MDBA 2011). A description of the modelling that contributed to the development of the Basin Plan is given by MDBA (2012a).

The same approach was adopted for the Northern Basin Review, but it was updated to include new environmental science, and a larger set of modelled scenarios were completed. For each scenario, the model was modified to represent a different volume of recovered water or an alternative approach for managing environmental water. Under all scenarios, the modelled river system received the same series of daily inflow, rainfall and evaporation data over the 114-year modelling period (1895–2009).

Once completed, each scenario provided a large dataset of daily time series, which showed the day-to-day behaviour of the river system, where this ‘behaviour’ included aspects such as flows in the river on each day or the volume of water held in public storages, or the daily irrigation extraction from the river system. This day-to-day behaviour was then linked to different environmental, social and economic outcomes. That is, each scenario displayed a set of hydrologic outcomes, which was then translated to a set of triple bottom line outcomes using the environmental, social and economic assessment framework.

An example of modelled flow is provided in Figure E1. This hydrograph compares three scenarios, showing modelled flows in the Darling River at Bourke over the same 12-month period. The red line traces the flow under baseline conditions (i.e. water sharing arrangements

prior to the Basin Plan), while the blue region shows the flow added under one of the modelled Basin Plan options (in this case, 390 GL of water recovery). For reference, the dashed line shows the same period under without development conditions (i.e. a representation of the river system with all aspects of development have been removed).

There are a number of conclusions that can be drawn from this 12-month example:

- development throughout the river system has significantly reduced flow at this location (a comparison of the dashed and red lines)
- Basin Plan activities can restore a portion of flows over most of the year (the blue shaded region)
- the majority of the additional volume through modelled environmental water delivery has occurred during existing flow events
- recovering water for the environment has also provided another small flushing flow event towards the end of the year

Making these types of comparisons over a 114-year period provided a general set of conclusions regarding each modelled Basin Plan scenario. The 114-year modelling period encompassed a wide variety of seasonal and flow conditions (ranging from the wet period in the 1950s to the drought in the 2000s), allowing a detailed analysis of the performance of each modelled scenario under a wide spectrum of possible future flows.

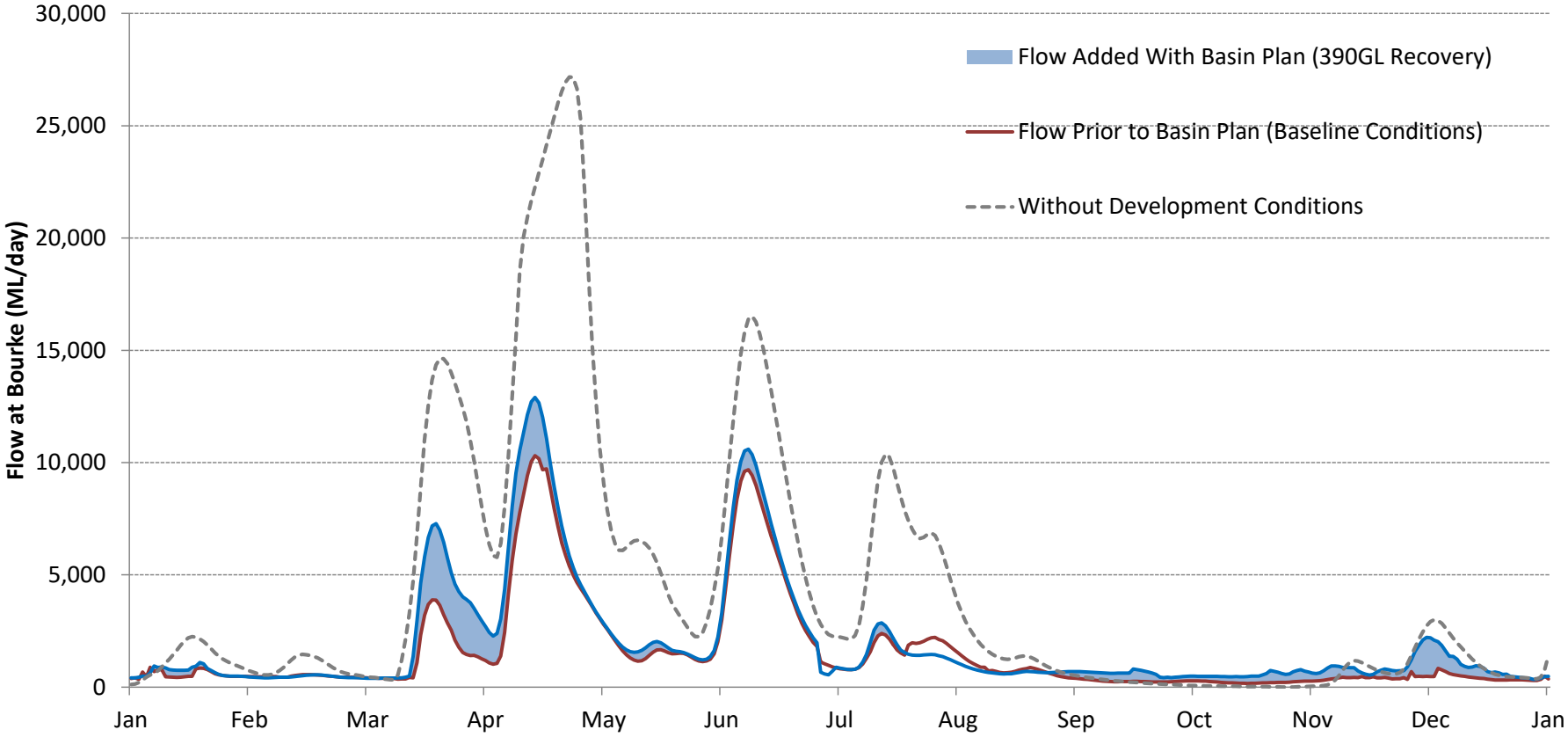

Figure E1: Example 12-month period of modelled daily flows

Modelling for Basin Plan development and the Northern Basin Review

A significant amount of time was required during the Basin Plan development (2009–12) to build and test the hydrological modelling framework. Hence only a limited number of scenarios testing different SDLs for the Northern Basin were simulated (MDBA 2012a). The combined results from the modelled scenarios and environmental flow work were presented to the Authority during 2011–12. This modelling work informed the Authority's decision on a northern Basin wide recovery volume of 390 GL. This volume comprised 247 GL to meet local outcomes in each catchments (i.e. local recovery), plus 143 GL shared across the northern Basin to meet broader system outcomes in the Barwon–Darling (i.e. shared recovery).

However, it was recognised that this information, although the best available at the time, provided only the initial basis for a recommendation by the Authority. It was noted that there are 'levers' other than a straightforward water recovery volume that can be used to influence flow outcomes, such as the pattern of water recovery, and strategies underlying the use of this water. The time frame for Basin Plan development did not allow these options to be fully explored.

The modelling program for the Northern Basin Review was built to address these knowledge gaps. The program focused on the Barwon–Darling and Condamine–Balonne systems, noting that a number of options were explored for other catchments as part of this process. Overall, the number of modelled water recovery scenarios increased from five to 24 for the Condamine–Balonne; and from two to nine for the whole-of-north. The hydrologic modelling of these scenarios, combined with the companion bodies of work exploring environmental, social and economic outcomes, provided a broad information base for the Authority to re-examine northern Basin SDLs.

The primary purpose of modelling the whole-of-north scenarios was to examine flows through the Barwon–Darling, however these modelling runs were also used to explore options in the other northern catchments. Across the whole northern Basin, the modelling explored water recovery scenarios ranging from 278 GL (no further buyback) up to 415 GL. For the Condamine–Balonne, the scenarios modelled were selected to represent recovery options ranging from 65 GL (an estimate of recovery achieved to date — i.e. no further buyback) up to 176 GL.

In addition to enhancing the information base underlying the SDLs, the modelling explored some aspects of the ongoing implementation of the Basin Plan. Some of the scenarios modelled were designed to examine if the location of future water recovery is likely to have affect system-wide outcomes. Other scenarios examined the impacts in the Barwon–Darling of adopting alternative management strategies for environmental water. Many of the key policy settings underlying these scenarios were based on feedback received from Basin jurisdictions and the community.

As the modelling progressed, each scenario added to the information base regarding Basin Plan outcomes. The modelling work was designed to adjust to these learnings. The initial scenarios therefore examined a fairly broad range of SDL options, and their environmental, social and economic outcomes were used to progressively refine subsequent scenarios to explore through the modelling.

The Northern Basin Review included an extensive public engagement process to ensure local experience and expert knowledge formed part of the final decision. The modelling benefited from the active involvement of partner groups, such as Basin governments (through the Northern Basin Inter-Governmental Working Group) and community representatives (such as the Northern Basin Advisory Committee, Lower Balonne Working Group, and Northern Basin Aboriginal Nations). This process emphasised the importance of 'complementary measures' to enhance the overall outcomes of the Basin Plan. These measures, related to reforms other than water recovery, included options such as market-based mechanisms or alternative environmental flow protection measures. The modelling provided the opportunity to explore the potential of these measures to enhance Basin Plan outcomes.

Which models were used for the Northern Basin Review?

As is standard practice, Basin state governments continue to update their models to better represent river systems. Model updates are generally made if new calibration data is obtained, or if an aspect of the river system experiences a significant change. Ongoing model updates are an important aspect of water resource planning and management, and the MDBA gratefully acknowledges the collaborative approach adopted by Basin state modellers.

The general approach of the Northern Basin Review was to update the knowledge base from 2012 levels. This principle was applied to the modelling framework, but was adopted with the qualifier that each model had been subjected to sufficient quality assurance and peer review.

The models used for the Northern Basin Review are mostly those used for as part of Basin Plan development, but with updates and improvements to address issues identified at that time. Some of them were minor repairs to errors discovered after the Basin Plan modelling, and some were the incorporation of recommendations from independent audit of Cap models. In general, if any updated model had significantly changed the BDL and had not yet under gone an independent peer review, it was not adopted for the Northern Basin Review.

The Northern Basin Review focus was on understanding relative changes in hydrology under various scenarios. Based on modelling experience gained through similar past projects, the MDBA believe that the use of different versions of models is unlikely to have changed the relative outcomes significantly enough to lead to a different conclusion for the review.

What were the assumptions underlying the modelling?

Independent reviews confirmed that the modelling platform being used for the Northern Basin Review is fit-for-purpose[1]. However, as with all models, the outputs from the Basin Plan modelling framework are dependent on the underlying assumptions and uncertainties.

The models that underpin the Basin Plan modelling framework were provided by the Basin state governments, and have been the subject of development, calibration and testing for up to 40 years. The MDBA and Basin state governments acknowledge that the models contain inherent

[1] Podger, GM, Barma, D, Neal, B, Austin, K and Murrihy, E (2010), River System Modelling for the Basin Plan Assessment of fitness for purpose. CSIRO: Water for a Healthy Country National Research Flagship, Canberra, December 2010
Bewsher (2016) Review of the Hydrological Modelling Frameworks used to inform Potential Basin Plan Amendments, prepared for the Murray–Darling Basin Authority, 2016

uncertainties, which are generally determined by the extent of available calibration data (i.e. gauged flows, diversions, storage releases and spills, evaporation, rainfall, and so on).

It is also acknowledged that there is generally less calibration data at hand across the northern Basin compared with catchments further south, and that the northern catchments also have a more variable climate, both of which affect the model calibration. Notably, three of the northern Basin catchments contain large wetland and floodplain systems at their lower end, hence the losses and travel times of flow-through events are highly dependent on how wet or dry the system is before a flow event.

Despite these difficulties, the models remain the best tool available for a long-term planning task such as the Basin Plan.

The MDBA modified certain aspects of the state-provided models to represent a number of possible permutations of the Basin Plan. Each scenario required two core changes to be made to the existing baseline models:

1. **water recovery** — represent a complete process of water recovery for the environment across the northern Basin
2. **water use** — represent an environmental watering strategy.

Both of these activities are still ongoing. The pattern of any future water recovery is not certain, and the strategies underlying future environmental water use across the Northern Basin are still being developed. To include them in the model, the MDBA was therefore required to anticipate the outcomes of ongoing processes. The models therefore included estimates of the future patterns of water recovery and use. Where possible, these estimates were informed by actions that have been in practice.

For this reason, the models do not predict the outcomes of the Basin Plan. They are instead an indication of the outcomes that could be achieved. The actual outcomes will depend on future policy choices to be made as the Basin Plan continues to be implemented.

Water recovery

Water recovery was represented in the models by removing a mix of entitlements from the consumptive pool in each catchment. The overarching assumption for the modelling was that any future recovery would build on the existing portfolio of environmental water held by the Commonwealth. That is, ‘existing recovery’ formed the starting point for the modelled scenarios.

For the purposes of modelling, existing recovery was assumed to include the recovery that had already been achieved under the Basin Plan (268 GL as of December 2015), plus an additional 10 GL of recovery that was estimated to be achievable through future investment in infrastructure upgrades — a total of 278 GL.

The modelled scenarios explored total recovery options ranging from 278 to 415 GL. The 278 GL model scenario included the existing volume of recovery that had been achieved in each catchment. For those scenarios exploring recovery volumes greater than 278 GL, it was

assumed that future recovery would largely[2] follow the default shared component distribution formula described by the Basin Plan. That is, they followed a principle of 'existing + default' recovery.

It was recognised that the assumptions regarding the distribution of future water recovery could affect the outcomes achieved by the Basin Plan. For this reason, a subset of specialised scenarios was completed in which the 'existing + default' assumption was varied to test the sensitivity of Basin Plan flows to the location and type of recovered water.

The Basin Plan modelling process ensured SDL compliance was maintained in all catchments. In some cases this required model adjustments to mitigate growth in use (for example, when modelling the recovery of water upstream of Beardmore Dam at St. George on the Balonne River). In practice, state water authorities may follow a different approach to ensure SDL compliance. If so, the year-to-year flow and diversion patterns may be different, but the overall change in flows outcomes is expected to be similar.

Environmental water use

Modelling a fully-implemented Basin Plan also required assumptions about future environmental watering practices. For unregulated regions the approach was to assume that long term average flow would increase through compliance with the SDL.

The process was more complex for regulated rivers. In these catchments, water recovery makes up a share of the available water resource in storage, for which the environmental water holder must choose a desired pattern of releases. The process of making environmental water releases includes a variety of practical considerations such as allocation announcements, existing flows in the river, channel sharing arrangements, system constraints, and so on. It is not clear how this process will develop as the Basin Plan continues to be implemented over coming years.

The ESLT method (MDBA 2011) adopted for the Basin Plan used environmental science as a foundation for the assumed modelled watering strategy. Under this approach, the pattern of environmental water requested from upstream storages in the model was based on the site-specific flow indicators, where these indicators represented broader environmental water requirements of river valleys or reaches. Figure E2 shows an example environmental release pattern (shaded blue) requested in the model, referred to as the 'environmental demand time series'.

[2] The only caveat to this assumption was to exclude the Paroo, Warrego, Nebine, Moonie and Intersecting Stream systems from additional recovery, as it would have little impact on flows downstream through the Barwon–Darling. This caveat was included to streamline the modelling process and maximise the number of scenarios that could be completed for the review. Given the relatively small volumes involved, this would have only a marginal impact on model results.

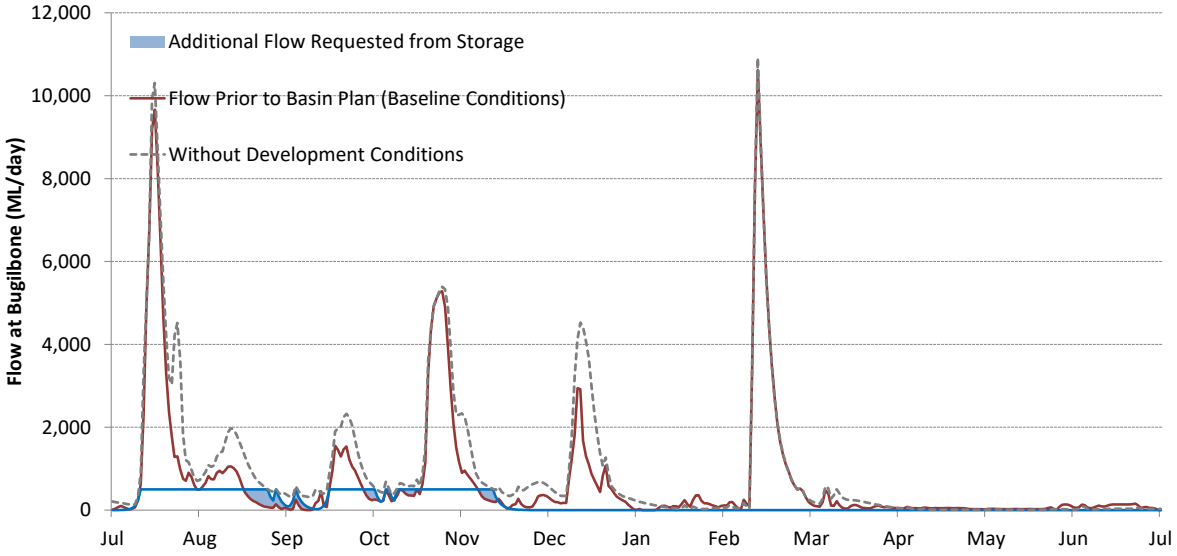

Figure E2: Example environmental demand time series, showing a requested flow event in the Lower Namoi (measured at Bugilbone) over a 12-month period. The blue region shows the additional environmental flow requested for delivery to supplement existing flow events.

Principles for modelling use of regulated environmental water

Using environmental science to underpin the requested release pattern was one of seven core principles governing the use of regulated environmental water in the models. These principles (listed below) were designed to anticipate a plausible set of characteristics under which future environmental watering strategies will sit within the existing entitlement framework.

1. **Science** — environmental releases will be based on available environmental science, using specific flow indicators.
2. **Flow variability** — the release pattern will aim to restore a variety of ecologically important flows (i.e. baseflows, freshes and, in some catchments, overbank events).
3. **Supplementing flow** — environmental releases will be timed to supplement existing flow in the system.
4. **Water accounting** — environmental releases will be ordered against recovered entitlements, and these entitlements will be subject to the same accounting arrangements experienced by other users in the system (i.e. an allocation based on the volume of the available resource).
5. **Reliability** — using water for the environment may sometimes increase losses through the system, but the modelling process has been designed such that this will not impact the long-term reliability of other users in the system.
6. **Local and downstream outcomes** — the environmental water holder will deliver water for local outcomes (e.g. for the Gwydir Wetlands and Macquarie Marshes) and, in some years, for downstream outcomes (in the Barwon–Darling).
7. **Learning** — the efficiency of environmental water use will continue to improve as a result of ongoing interactions between environmental water holders and river operators and improved knowledge regarding environmental flow delivery.

These principles were informed by environmental watering events that have occurred in recent years. They are consistent (or at least near-consistent) with existing practices, with the exception of principles 6 and 7. The inclusion of principles 6 and 7 recognises that

environmental watering, although an active element across the Northern Basin for the past few years, is still a relatively young process and is expected to adapt over coming years in response to improving technology and developing practical experience. These two points anticipate an environmental watering strategy that attempts to deliver whole-of-North outcomes (principle 6) with high efficiency (principle 7).

The efficient use of environmental water for whole-of-system outcomes is an overarching principle of the Basin Plan, but in the northern Basin it represents a change (to some degree) to existing operational capacity. Current operational practices have not been designed to deliver regulated water through a catchment and downstream to the Barwon–Darling. And from a practical perspective, flows through the Barwon–Darling usually require contributions from multiple catchments, but the unique geomorphology of each catchment, in conjunction with the highly variable nature of the climate and river flows, introduces a relatively large degree of uncertainty to the forecasted travel times and losses of individual flow events.

For this reason, two possible strategies were modelled under principles 6 and 7.

- Strategy 1 (whole-of-north coordinated) represented a highly-managed system in which a two or three catchments work proactively to coordinate flows into the Barwon–Darling. This would require improvements in forecasting tools and experience, and substantial changes to existing operational practices.
- Strategy 2 (catchment scale), in which environmental releases were made in each catchment individually to maintain low flow targets in the Barwon–Darling (from the Interim North-West Unregulated Flow Management Plan; Barwon–Darling Water Sharing Plan), representing a management strategy more in-line with current operating practices.

Actual watering strategies to manage the water recovered across the northern Basin are still undergoing development. It is not yet clear the level to which cross-catchment coordination will be implemented in practice — the two modelled strategies together encompass a broad range across the ‘forecasting and coordination spectrum’. Both strategies are considered to be achievable in practice, but Strategy 1 would require a larger commitment of investment towards flow forecasting and coordination capacity over coming years.

Results and conclusions

The Northern Basin Review modelling work program included a set of whole-of-north scenarios to investigate flow changes in each catchment of the northern Basin, including the Barwon–Darling. But the program also included a focussed set of scenarios examining water recovery options specifically within the Condamine–Balonne. The sections below summarise the conclusions for the Barwon–Darling and Condamine–Balonne catchments.

Barwon–Darling

The Barwon–Darling is a large semi-arid river system draining the northern section of the Murray–Darling Basin. A schematic map of the region is given in Figure E3. The flow regime in this river is one of the most variable in the world, with low flows punctuated by episodic flood events that inundate extensive areas of floodplain. Due to the hot and dry climate, and the largely flat geomorphology of the catchment, the Barwon–Darling receives very little in-catchment runoff. Flows in the river are therefore almost entirely reliant on inflows from tributary catchments.

Each tributary catchment has a unique set of characteristics such as climate, inflows, geomorphology, downstream connectivity, level of regulation, and proportion of take from the river system. As a result, the types of flow contributed downstream by each catchment are also unique. Development of the water resource, through the construction of on-river infrastructure such as dams, and diversion from the river, has changed the contribution of each tributary system to the Barwon–Darling river system. Under baseline conditions (i.e. prior to the Basin Plan), long-term average watercourse diversions across the northern Basin were 2,541 GL/y (23% of total inflows).

There are four primary levers that can be used to influence the flow of water through the Barwon–Darling system:

- the volume of water recovery across the northern Basin;
- the pattern of water recovery (i.e. location and entitlement type) across the northern Basin;
- the management of water into the Barwon–Darling; and,
- the management of water through the Barwon–Darling.

During the development of the Basin Plan (2009–12), only the first lever was explored. Two whole-of-north scenarios were completed as part of the development of the Basin Plan, representing northern Basin recovery volumes of 390 and 440 GL. Both of these scenarios were identical in recoveries from each catchment, except for a difference of 50 GL from the Condamine–Balonne. Therefore these scenarios only provided an initial set of information to inform the SDLs recommended for the northern Basin in 2012. Also, they did not reveal the extent to which flows could be influenced by altering the recovery pattern between catchments, or the types of entitlements recovered within the catchments, or by the assumed environmental water management strategy.

Scenario sets for Northern Basin Review

The scenarios modelled for the Northern Basin Review provided a significantly stronger information base to inform the chosen SDLs. Whole-of-north modelling was required to understand water flows in the Barwon–Darling because of the low level of inflow within the catchment. Nine whole-of-north scenarios were completed to investigate the first three of the levers listed above, while the fourth lever (management of water through the Barwon–Darling) was examined through a separate analysis of model output data.

The whole-of-north modelling work was divided into three distinct sets of model scenarios. As a general guide, the environmental, social and economic findings from the first two sets of modelled scenarios were provided to the Authority, which then narrowed the range of options to be modelled in the third ‘refined scenarios’ set. The scenario sets are summarised below.

1. **SDL range-finding**
   These scenarios quantified the overall relationship between recovery volume and flow, and were analysed with the updated environmental, social and economic assessment frameworks under the Northern Basin Review.

2. **Alternative policy settings**
   Three scenarios were completed to test the effects of altering one of the underlying policy settings — specifically, the assumed distribution of future water recovery, and the

assumed management pattern for delivering water to the Barwon–Darling (i.e. a comparison of environmental flow management Strategies 1 and 2). The scenarios indicated that both recovery pattern and the management strategy can be used to influence flow outcomes.

3. **Refined scenarios**
   The final two scenarios were built using the environmental, social and economic results from previous model scenarios (SDL range-finding and alternative policy settings). These scenarios encompassed the narrowed range of options under consideration by the Authority in the final stages of the Northern Basin Review.

The distribution of water recovery by catchment for each of the nine modelled scenarios is listed in Table E1 and shown graphically in Figure E4.

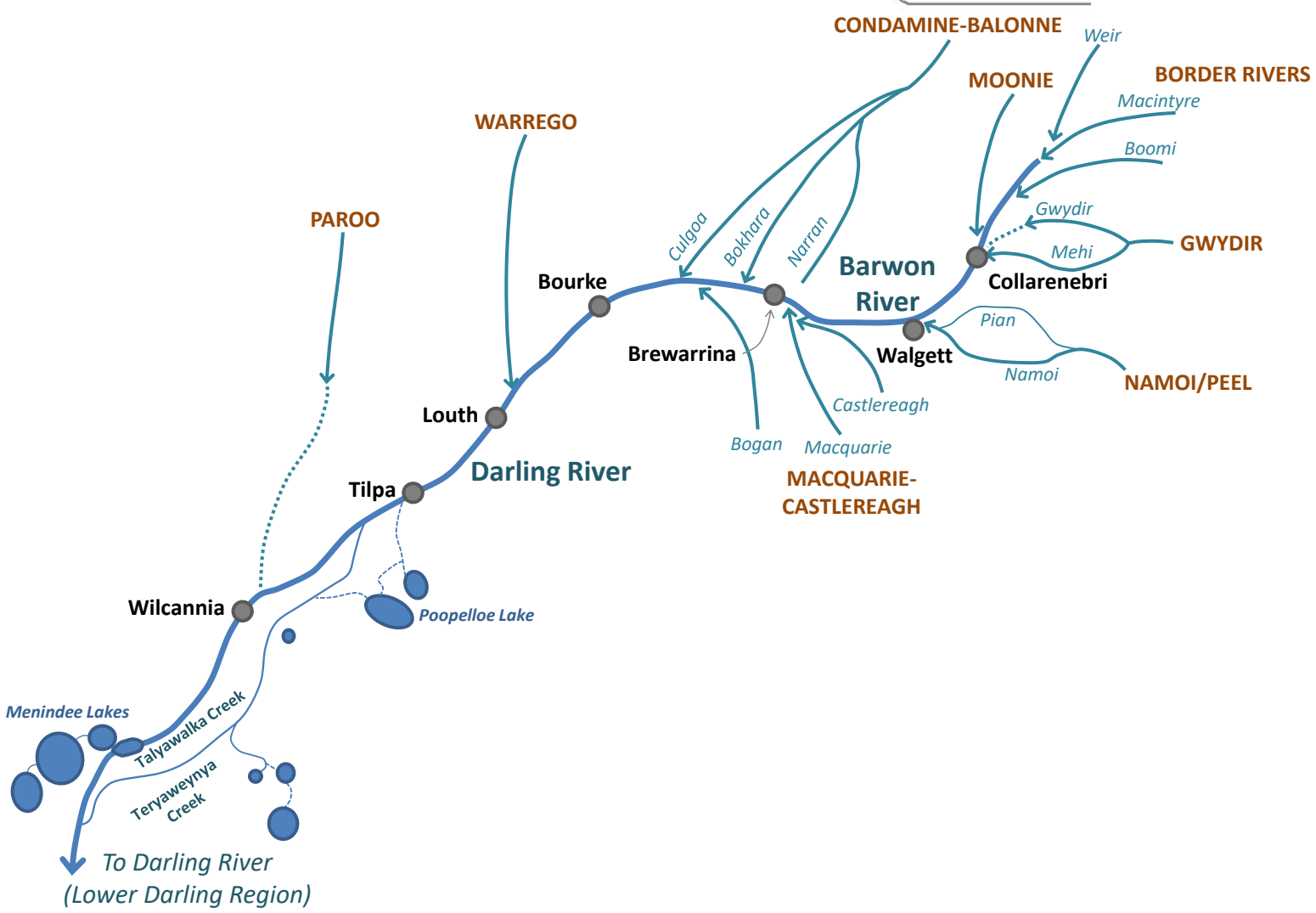

Figure E3: Schematic map of the Barwon–Darling system and its main tributaries

Table E1: Catchment water recovery distributions represented in the Northern Basin Review model scenarios; grey cells indicate catchment recoveries that are unchanged from current recovery volumes and were not altered through the modelling work program.

SDL Resource Unit		Modelled recovery (GL) (Model Run Number) and model scenario set							
		278 GL (1113) Scenario D	320 GL (1112) Scenario E	320 GL (1111) Scenario G	320 GL (1115) Scenario J	345 GL (1103) Scenario I	350 GL (1114) Scenario C	390 GL (1089 & 1110) Scenarios B & H	415 GL (1108) Scenario A
		Set 1: SDL range-finding	Set 1: SDL range-finding	Set 2: Alternative policy settings	Set 3: Refined scenarios	Set 3: Refined scenarios	Set 2: Alternative policy settings	Set 1 (1089) Set 2 (1110)	Set 1: SDL range-finding
QUEENSLAND	Paroo	0	0	0	0	0	0	0	0
	Warrego	8	8	8	8	8	8	8	8
	Nebine	1	1	1	1	1	1	1	1
	Moonie	2	2	2	2	4.5	2	2	2
	Condamine–Balonne	65	90	115	115	100	100	142	150
	Queensland Border Rivers	15	21	21	21	35	25	23	25
	Queensland Total	**91**	**122**	**147**	**147**	**148**	**136**	**176**	**186**
NEW SOUTH WALES	Intersecting Streams	8	8	0	8	8	8	8	8
	Gwydir	48	48	51	47	47	56	56	59
	NSW Border Rivers	3	7	13	7	7	16	16	18
	Namoi	13	20	20	20	24	24	24	28
	Macquarie–Castlereagh	83	83	77	55	74	83	83	88
	Barwon–Darling	31	31	12	36	36	28	28	28
	NSW Total	**187**	**198**	**173**	**173**	**196**	**214**	**214**	**229**
Whole-of-north Total		**278**	**320**	**320**	**320**	**345**	**350**	**390**	**415**

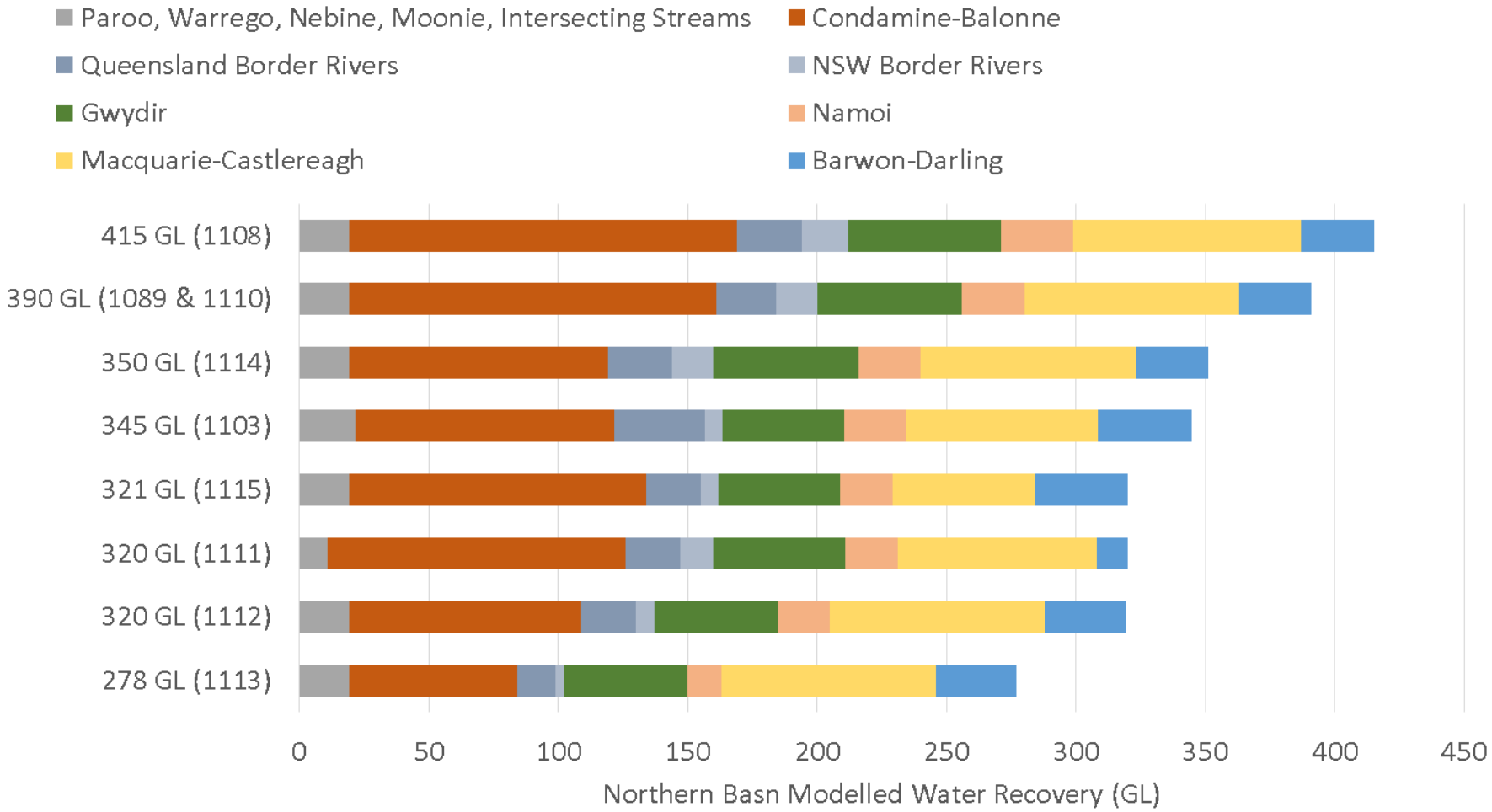

Figure E4: Water recovery distributions represented in each of the Northern Basin Review whole-of-north model scenarios (note that scenarios 1089 and 1110 both represented the same 390 GL recovery pattern, but explored different strategies for environmental water delivery)

Whole-of-north scenarios — main conclusions

- Water recovery across the northern Basin will result in increased flows through the system.
- Whole-of-north recovery volume (i.e. the SDLs) was the primary driver of flow outcomes through the Barwon–Darling.
- Certain policy settings (such as the spatial pattern of recovery, or the adopted environmental water management strategy) can tilt flow outcomes towards a certain type of flow, but this played a secondary role to the recovery volume.
- Current water sharing plan arrangements are expected to protect environmental water over the long term, however complementary measures (such as event-by-event protection, or market-based arrangements between the Commonwealth Environmental Water Holder and Barwon–Darling consumptive users) could enhance environmental outcomes and allow for reduced economic impacts.

The modelling in Scenario Set 1 (SDL range-finding) indicated that flows into and through the Barwon–Darling increased in response to further water recovery across the northern Basin. The whole flow regime experienced this increase, noting that majority of improvement occurred for in-channel flows in the range of 1,000–25,000 ML/d (measured at Bourke). Flows outside this range are also expected to increase but to a lesser extent.

Recovery volume was the main lever of flow outcomes, but certain policy settings were found to have a 'secondary lever' role to influence flow outcomes as indicated by modelling in Scenario Set 2 (alternative policy settings). Specifically, both the spatial pattern of recovery throughout the northern Basin and the adopted strategy for managing environmental water have the capacity to tilt the balance of flow outcomes towards certain parts of the flow regime.

This is a result of the inherent characteristics of each tributary catchment across the northern Basin. Some of these characteristics are natural (such as the geomorphology of each catchment, or its level of connectivity downstream to the Barwon–Darling), while others are related to human development (the capacity of public storages to capture and regulate flow, and the nature of extraction from the river system). Each characteristic influences the ability of a catchment to contribute flow downstream.

A general conclusion is that water recovery in catchments with the greatest level of connectivity with the Barwon–Darling has the greatest capacity to provide more flow through this system. These 'high connectivity' catchments were identified to be the Moonie, Border Rivers and Namoi catchments, and the Barwon–Darling itself.

However, this general conclusion is based purely on a volumetric 'return-per-GL' perspective, and does not discount the downstream contribution of other catchments. The natural flow regime through the Barwon–Darling is complex, relying on contributions from all upstream catchments. Hence, while the Gwydir, Macquarie and Condamine–Balonne catchments display a lower level of downstream connectivity with the Barwon–Darling (primarily a result of the complex distributary stream network forming large floodplains at the end of both systems), their contribution downstream is often vital.

For example, the Macquarie Marshes (located towards the end of the Macquarie system) absorb large flow events, after which the water slowly drains downstream. Flow events passing

downstream from the Macquarie system therefore generally take the form of low flows over a long period (i.e. weeks or months) and occur during median-to-wet periods. These events provide ecologically important base flows through the Barwon–Darling, or often form a foundation that is augmented by the more rapid, high-peaked events originating in the Border Rivers and Namoi systems.

Recovery from all upstream catchments will enhance flow through the Barwon–Darling. Preferentially recovering water from specific catchments can favour the restoration of certain types of flow (and hence certain environmental outcomes), but, when limited by volume, trade-offs from other types of flow are likely to result.

The extensive public engagement conducted for the Northern Basin Review emphasised the importance of protecting environmental water from extraction when passing through the Barwon–Darling. Existing water sharing plan arrangements in this system include an annual extraction limit to ensure consumptive use cannot increase, despite the increased inflows expected to occur due to environmental water recovery and delivery occurring in the tributaries.

However, these arrangements provide a 'long-term protection mechanism' only. Modelling indicated that, under this mechanism, increased inflows will result in a changed pattern of take through the Barwon–Darling. Periods of low flow displayed increased take, counter-balanced by decreased take during higher flow periods. Assuming SDL compliance, this approach would ensure that the environment experiences 'wins and losses' that will balance out in the volumetric sense over the long-term.

The current approach essentially trades environmental water from the low to the high end of the flow regime, but the resulting environmental outcomes are not clear. Complementary measures could be used to preferentially restore certain flows, and it is possible that this could enhance overall environmental outcomes. Examples of complementary measures include event-by-event protection, or a market-based arrangement between the Commonwealth Environmental Water Holder and Barwon–Darling consumptive users. These measures would need to be implemented in a way that negated or offset any associated third party impacts.

Condamine–Balonne

The Condamine–Balonne region lies mainly in southern Queensland and extends about 100 km south-west into New South Wales. A schematic map of the region, including structural features and flow constraints, is given in Figure E5.

From a water management perspective, the Condamine–Balonne is pre-dominantly an unregulated region with a relatively high level of extraction. There is some regulated take from the system, the majority supplied by Beardmore Dam and Jack Taylor Weir to the St George Water Supply Scheme. But most irrigation production relies on diverting unregulated flows into large privately-owned off-stream storages, particularly downstream of St George. Within the pool of unregulated use, there is a wide spectrum of entitlement conditions, each associated with certain types of flow rates (i.e. flow heights). Under baseline conditions (i.e. prior to the Basin Plan), long-term average watercourse diversions under full uptake of entitlements from the Condamine–Balonne were 713 GL/y (42% of inflows to this catchment).

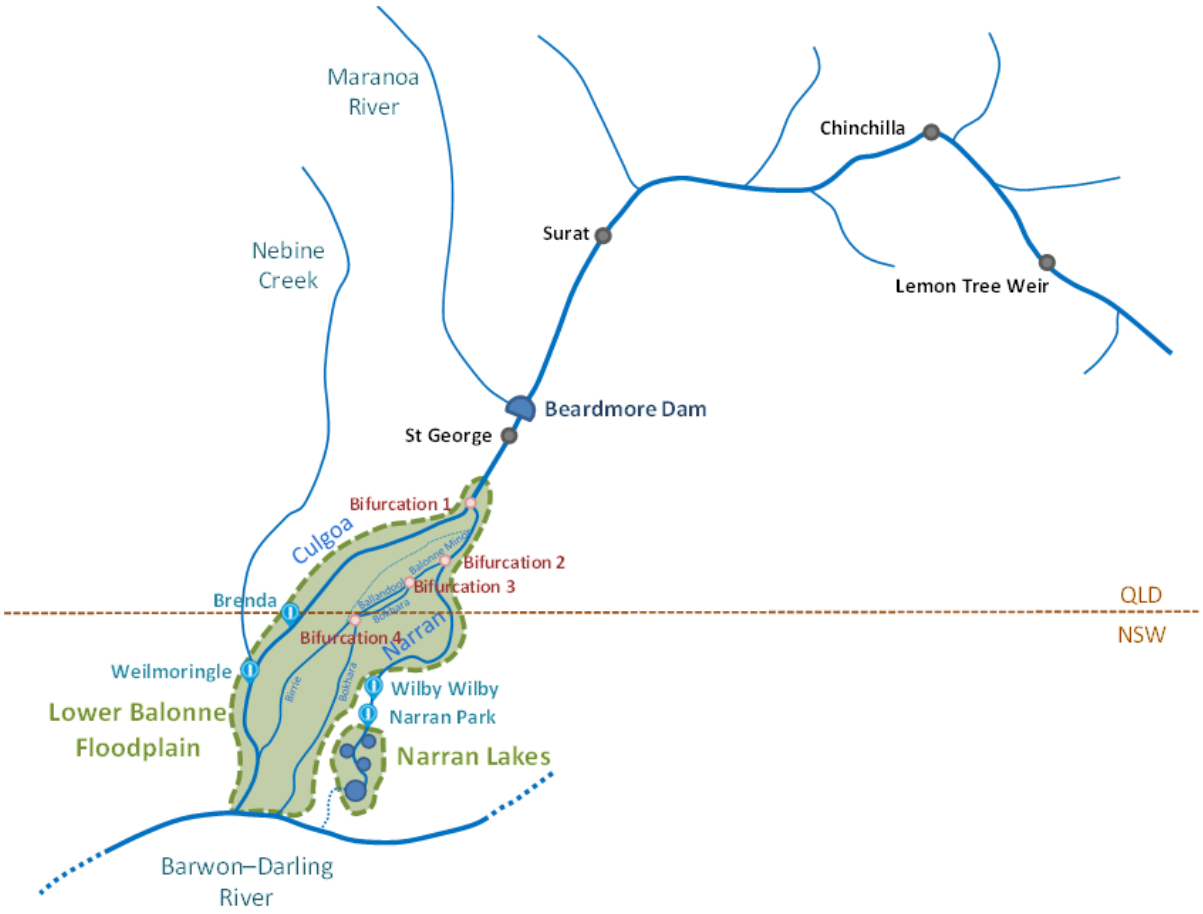

Figure E5: Schematic diagram for the Condamine–Balonne; the Lower Balonne Floodplain and Narran Lakes areas are outlined in green, and the locations to monitor modelled environmental flows are marked in light blue

During the development of the Basin Plan (i.e. prior to 2012), the MDBA modelled five scenarios exploring recovery volumes in the Condamine–Balonne of 60, 100, 130, 150 and 203 GL (MDBA 2012a). The purpose of these scenarios was to determine the relationship between *recovery volume* and *flow outcomes*.

But it was recognised at the time that, "the complexity of entitlement types, in combination with the generally unregulated nature of this system, suggests that the location and type of purchased entitlement will have a significant influence on the ability to meet the desired flow outcomes" (MDBA 2012a). That is, the evidence suggested that the flow outcomes in the Condamine–Balonne would be dependent not only on the *volume* of recovery, but also on the *pattern* of recovery — the unique nature of this system (unregulated but with a relatively high consumptive use and a wide spectrum of entitlement characteristics) provides multiple 'levers' to influence changes in flow.

The modelled scenarios completed for the Northern Basin Review have quantified the extent to which flow through the system can be influenced by altering the pattern of recovered water. The box below provides a summary of the *geographic location* scenarios, which indicated that the spatial pattern of recovery will influence the resulting flow.

Geographic location of Condamine–Balonne recovery — main conclusions

- Water recovery upstream of Beardmore Dam is viable. It has the capacity to enhance flows through the Lower Balonne Floodplain, where most of this increase is related to low-to-mid flows (i.e. mainly in-channel flows).
- However, this is subject to a protection mechanism — current arrangements do not protect water recovered upstream of Beardmore Dam from extraction by downstream users (over the long-term approximately one-third would be extracted). For this reason the modelling included a long-term protection mechanism for environmental water to ensure SDL compliance.
- Flows to Narran Lakes are best enhanced through water recovery along the Narran system (i.e. Balonne Minor from Bifurcation 1 to Bifurcation 2, and the Narran River).
- Water recovery upstream of Bifurcation 1 can also provide flows to Narran Lakes, but with a substantially lower rate of return (i.e. in the range 5–10%).
- Due to the terminal nature of the Narran Lakes, water recovery along the Narran system will pass downstream to the Barwon–Darling only during extremely wet conditions.

Furthermore, the *type* of recovered water can also influence outcomes, as summarised in the box below. Unregulated take in the Lower Balonne is typically broken into two categories: water harvesting and overland flow take. As a general nomenclature guide, water harvesting entitlements allow take from the river channel during low-to-mid flows, whereas overland flow entitlements are associated with extraction during overbank (i.e. mid-to-high) flow events. In this context, 'low, mid and high' refers to the flow height measured at Jack Taylor Weir (not at the site of user extraction), which is used to define the allocations made to entitlement holders in the Lower Balonne.

Condamine–Balonne entitlement mix scenarios — main conclusions

- The types of flow achieved depends on the mix of recovered entitlements.
- Recovery from water harvesters would preferentially restore in-channel flows; recovery from overland flow users would preferentially restore overbank flows.
- The recovery of overland flow users was found to preferentially restore flows greater than 8,000 ML/d (measured at Brenda on the Culgoa River), associated with the majority of specific flow indicators for the Lower Balonne Floodplain.
- Overland flow recovery was also found to provide improved floodplain grazier outcomes.
- Assuming that the recovery volume does not change, preferentially restoring certain flows by targetting entitlement type would be counter-balanced by a reduced response in other parts of the flow regime.
- These flow outcomes greatly influence environmental outcomes (as measured by specific flow indicators).

Queensland and the MDBA jointly investigated an alternative recovery approach called 'horizontal slicing'. Unregulated users in the Lower Balonne often hold entitlements that allow take from multiple flow windows, and horizontal slicing refers to the recovery of a segment of an entitlement (rather than a complete entitlement), where this segment is related to a specific flow window.

Horizontal slicing would allow specific flow windows — and therefore specific environmental outcomes — to be targeted by the recovery program. The purpose of the horizontal slicing scenarios was to investigate the capacity to preferentially restore certain flows through a targeted recovery program. The scenario results supported horizontal slicing as a recovery approach that could be further pursued.

Condamine–Balonne horizontal scenarios — main conclusions

- Horizontal slicing allows for the preferential restoration of certain types of flows.
- Preferentially restoring certain flows by targetting flow windows would be counter-balanced by a reduced response in other parts of the flow regime.
- Most environmental flow indicators at Brenda (for the Lower Balonne Floodplain) would benefit by preferentially recovering higher flow windows.
- These flow outcomes were also reflected in the environmental outcomes (as measured by specific flow indicators).
- Higher flow recovery was also found to provide improved floodplain grazier outcomes.

The findings from the geographic and entitlement mix scenarios were used to inform a refined set of scenarios[3] exploring SDL options ranging from 65 to 176 GL of recovery. The recovery breakdowns for the refined scenarios are listed in Table E2 and shown graphically in Figure E6. Some of the scenarios included the preferential recovery of specific entitlement types based on the environmental, social and economic assessment of prior model scenarios.

[3] Horizontal slicing was not included in these refined scenarios as this type of recovery has not yet occurred in practice, and there may be unforeseen implementation issues.

Table E2: Baseline diversion and water recovery for sub-catchments of the Condamine–Balonne based on modelled scenarios. The grey row indicates the sub-region that was not considered for recovery as part of this study. Model scenarios are identified by model run number (e.g. 845).

Sub-region	Entitlement type recovered in model	Baseline diversion (GL/y) (scenario 845)	Water recovery (GL/y) (Modelled scenario run number and identifier)								
			1113 Scenario D	1112 Scenario E	1114 Scenario C	1111 Scenario G	1089/1110 Scenario B & H	1108 Scenario A	1109 Scenario F	1103 Scenario I	1115 Scenario J
Upstream Beardmore Dam (off main stem)	—	189.5	0	0	0	0	0	0	0	0	0
Upstream Beardmore Dam (on main stem)	Unregulated	97.0	7	15	10	19	10	10	15	10	10
St George	Supplemented medium priority	78.6	0	4	0	4	4	4	4	4	4
JTW to B1	Water harvester (i.e. unsupplemented)	123.9	15	18	15	24	25	25	30	15	24
	Overland flow (i.e. floodplain harvester)	18.0	0	0	0	0	13	13	15	5	0
Narran system	Water harvester (i.e. unsupplemented)	27.2	7	15	20	21	11	15	17	11	21
	Overland flow (i.e. floodplain harvester)	12.8	0	2	3	2	10	10	13	10	2
Lower Balonne	Water harvester (i.e. unsupplemented)	114.6	21	21	12	26	45	48	52	25	26
	Overland flow (i.e. floodplain harvester)	52.1	16	15	41	20	25	25	30	20	28
TOTAL		**714.5**	**65**	**90**	**101**	**115**	**143**	**151**	**176**	**101**	**115**

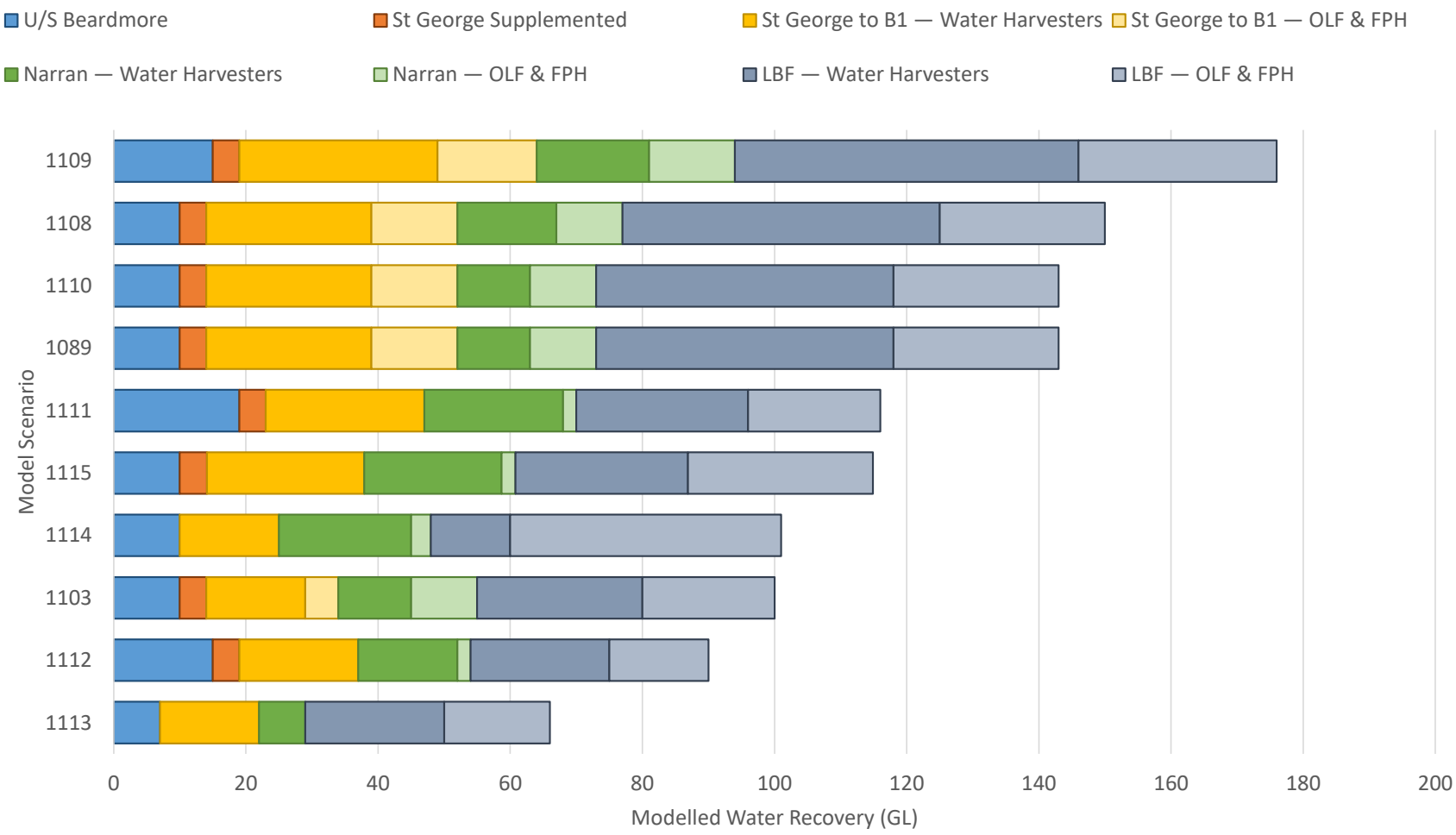

Figure E6: SDL options modelled for the Condamine–Balonne. The aggregated bar shows the total water recovered in the catchment, sub-divided by colour to represent sub-region and entitlement type recovered.

Most Condamine–Balonne environmental flow indicators improved as the volume of water recovery increased, indicating improved riparian and floodplain outcomes under the Basin Plan. The only exceptions were the low flow metrics measured towards the end of the Culgoa and Narran Rivers (at Weilmoringle and Narran Park respectively; see Figure E5). These metrics (related to waterhole refuges that are important for the maintenance of fish populations throughout the wider river system) displayed little improvement in response to the water recovery volumes tested.

The modelling results indicated that there was a risk that these waterhole refuges would not be sustained during extended dry periods. However, the modelling also suggested that an alternative mechanism (i.e. other than water recovery) could enhance waterhole outcomes. Existing water sharing arrangements include environmental, stock and domestic (ESD) releases from Beardmore Dam to provide low flows through the Lower Balonne, and there are multiple options available to enhance the associated outcomes. These options include:

- changes to rules and current operating practices relating to Beardmore Dam;
- the recovery of supplemented entitlements to allow for additional environmental releases from Beardmore Dam;
- the recovery and re-regulation of water recovery upstream of Beardmore Dam; and,
- market-based mechanisms such as the temporary acquisition of consumptive allocation, or the use of a private mid-river storage, or more permanent arrangements through options on licence holders.

Additional modelling work would be required to refine each option. This analysis would need to examine the changes in flows that could be achieved with each option, the associated environmental outcomes, and the capacity to which each option can be pursued collaboratively with other users in the system.

The model results were further investigated to explore the potential for alternative mechanisms to enhance other ecologically important flows through the system. An alternative mechanism (such as the temporary purchase of resource allocation or the use of private storages) would allow adaptive management to enhance environmental outcomes without the need for permanent water recovery. This analysis was based on identifying ‘hydrologic opportunities’ — that is, specific flow events that could have been enhanced through an alternative mechanism to achieve the desired ecologically important outcome.

Overall, it was found that alternative mechanisms could improve environmental outcomes in both the Lower Balonne Floodplain and Narran Lakes. Most of the identified opportunities were small-to-medium flow events to the Narran Lakes. A significant result from this analysis was that the frequency of opportunities to enhance existing flows was closely related to the enhancement capacity of each mechanism. For example, opportunities were found to occur in approximately 25% of years if the alternative mechanism provided an enhancement capacity of 10 GL along the Narran system.

Hydrologic opportunities in the Lower Balonne Floodplain were less frequent, and often occurred in years when the temporary acquisition of a significant proportion of total diversions would be required.

This hydrologic opportunity analysis provided a first-pass assessment of the potential of alternative mechanisms in general. Further work would be required to determine the practicalities of alternative mechanisms, specifically their position within existing water sharing arrangements, and the ability of an environmental water holder to follow this option within the water market.

Other Northern catchments

The work to inform the Northern Basin Review was focused on the Barwon–Darling and Condamine–Balonne catchments. However, the whole-of-north model scenarios also provided a set of Basin Plan options for the other northern catchments. Some of these scenarios explored options for water recovery volumes (as set out in Table E1), while others examined alternative entitlement mixes of water recovery, or a different strategy underlying the use of environmental water.

All scenarios for these catchments were analysed using the environmental, social and economic assessment framework, and the outcomes can be found in the relevant reports. The outcomes from this analysis were included in the triple bottom line decision making process conducted by the Authority.

Next steps

This report presents a summary of the modelling results provided to the Authority to inform its review of Basin Plan SDLs for the northern Basin. This is just one input into this review, along with community feedback, and environmental, social and economic results associated with a number of water recovery scenarios. More comprehensive modelling details are set out in the main hydrologic modelling report (MDBA 2016).

The Authority will decide whether a change to northern Basin SDLs is required in late 2016. If it is determined that a change is required, recommendations would be prepared for an amendment to the Basin Plan. The amendment process will take about 12 months. It will include the preparation of a plain English summary of the effect of the proposed amendment, inviting Basin state governments and the broader community to make submissions. Comments will also be sought from Basin governments.