

Review of the Hydrological Modelling Frameworks used to inform Potential Basin Plan Amendments

These Basin Plan amendments are those proposed for:

- Northern Basin Review; and
- SDL Adjustments

FINAL REPORT

September 2016

(including November 2016 Addendum)

MURRAY–DARLING BASIN AUTHORITY

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1. INTRODUCTION

1.1. Background to this Review

The Water Act 2007 (Cwth) legislates for the preparation and implementation of a Murray-Darling Basin Plan. The Plan sets legally enforceable limits on surface and groundwater use, known as sustainable diversion limits (**SDLs**) that are consistent with the environmentally sustainable level of take. The Plan adopted by the federal water minister in November 2012 defines a baseline diversion limit (**BDL**) and specifies a basin-wide reduction in diversions by 2750GL/yr below the BDL level in order to achieve the SDLs.

The Plan provides for the Authority:

- (a) to propose adjustments to the SDLs;¹ and
- (b) to carry out reviews of the Basin Plan.²

These are separate processes and either may ultimately lead to amendments to the Basin Plan. These two processes are currently underway within the Authority and comprise:

- (a) SDL Adjustments (SDLA) – adjustments to the SDLs which would result from implementation of a package of measures comprised of supply³, efficiency⁴ and constraint⁵ projects within the southern connected system.⁶ Chapter 7 of the Basin Plan stipulates the method to be applied in calculating the adjustment amount.⁷ This calculation method is based largely on hydrological modelling. During 2014-2015 the Authority commenced investigation of the proposed SDL Adjustments based on this method in consultation with the Basin States.
- (b) Northern Basin⁸ Review – in finalising the Basin Plan in 2012 the MDBA recognised there was less knowledge available at that time for the Northern Basin than for the Southern Basin. Consequently the Basin Plan provided an opportunity for additional research and investigation in the Northern Basin leading to potential changes in the SDLs in this region. Such a review has been underway for some time and comprises environmental science assessments, social and economic assessments and hydrological modelling. The hydrological modelling component of the Northern Basin Review is a key assessment tool which will be used to estimate changes in river flows under a range of water recovery scenarios and from which environmental outcomes can be inferred.

¹ Refer Chapter 7 of the Basin Plan and Section 23 of the Act.

² Refer subsection 6.06 of the Basin Plan and subsection 50(2) of the Act.

³ Supply measures directly generate an increase in SDLs (i.e. reduced water recovery) and are predominantly environmental works, changes in river operations or evaporative savings.

⁴ Efficiency measures provide more water to the environment by reducing consumptive use in ways that will not lead to negative social and economic impacts. Efficiency measures include, for example, improving the effectiveness of on-farm irrigation or piping delivery channels in irrigation areas.

⁵ Constraints are principally impediments to flow delivery, e.g. channel capacity constraints to avoid overbank flows and third party impacts. The removal of constraints can improve the ability to deliver environmental water outcomes and they can therefore interact beneficially with supply and efficiency measures.

⁶ The southern connected system refers to the Murray River, the Darling River from Menindee Lakes and downstream, and the Murrumbidgee and Goulburn-Loddon-Broken-Campaspe systems (and excludes the Lachlan and Wimmera systems which are normally disconnected from their downstream river systems).

⁷ Schedule 6 details the specific features of the method to be applied (unless the Authority and the Basin Officials Committee agree to use another method – which the reviewer understands has not occurred). This is referred to as the 'default method'.

⁸ The Northern Basin refers to all of the Queensland rivers within the Basin, the Barwon-Darling system above Menindee Lakes, and all of the NSW river systems to the north of the Lachlan. The remainder of the Basin is referred to as the Southern Basin.

Because of the key role of hydrological modelling in the above two processes, the Authority has commissioned this current review of the suitability of its hydrological modelling frameworks for use in the two processes described above.

1.2. Terms of Reference for this Review

The terms of reference (**ToR**) for this review are reproduced in **Appendix A**.

The key objective of this review is to “*assess whether all hydrological model-based components of the SDLA assessment framework and the Northern Basin Review are technically sound and compliant with relevant aspects of the Basin Plan*”.⁹ Consequently the review has undertaken a three-step process:

Step 1: identification of “*hydrological model-based components of the SDLA assessment framework and the Northern Basin Review*”. These components are described in **Chapter 2** below together with an explanation of some relevant terms. A number of the modelling components were already key components of the modelling framework utilised during the preparation of the Basin Plan or have been separately reviewed. Accordingly some of the modelling components described in **Chapter 2** are not part of the current review.

Step 2: assessment of whether the modelling components which are the subject of this review are “*compliant with relevant aspects of the Basin Plan*”. In respect of the SDL Adjustments these aspects are contained within Chapter 7 and Schedule 6 of the Basin Plan. For the Northern Basin Review these aspects are detailed in subsection 6.06 of the Basin Plan. This assessment of compliance is reported in **Chapter 3** below.

Step 3: assessment of whether these components which are the subject of this review are technically sound, transparent, repeatable, objective, practical and fit for purpose. This assessment is reported in **Chapter 4** below.

Note that it is not the objective of this hydrological modelling review to vet any particular SDL Adjustment quantity or any numerical revision of the SDL in any valley within the Northern Basin. Rather the purpose of this review is to identify whether the MDBA’s modelling framework is an appropriate tool from which to make these determinations in the future.

1.3. Hydrological Modelling Components Excluded from this Review

As noted in the ToR the following modelling components were not the subject of this review. This is because they have been the subject of previous reviews and validity checks:

- the 24 River-system models that cover the Murray-Darling Basin;
- the Integrated River System Modelling Framework (**IRSMF**);
- the Ecological Elements method developed by the CSIRO-led project team; and
- the method for determining the Environmentally Sustainable Level of Take (**ESLT**).

Although not the subject of this review, brief descriptions of these components are included within **Chapter 2**.

⁹ Refer paragraph 4 on page A1.

1.4. Activities Undertaken and Documents Reviewed

The review was undertaken from June to September 2016. It included various meetings, interviews and correspondence with the following MDBA personnel:

- (a) Mr Paul Carlile, Director Hydrology and Modelling Coordination, MDBA;
- (b) Mr Pradeep Sharma, Acting Senior Director, Water Resources, River Management, MDBA;
- (c) Mr Gavin Pryde, Assistant Director, Eco-hydrology Analysis Branch, MDBA;
- (d) Mr Jong Lee, Director Basin Plan Modelling, MDBA; and
- (e) Dr Matt Coleman, Assistant Director, Environmental Management, MDBA.

The reviewer also attended a meeting with some members of the Northern Basin Advisory Committee on 23 September 2016 at which various issues relating to the modelling for the Northern Basin Review were discussed.

The MDBA made available a range of documents for the review. Those of most relevance are listed in **Appendix B**.

The Authority also provided an early draft of an unpublished report on the hydrological modelling being undertaken for the Northern Basin Review (refer document B18 in **Appendix B**).

2. OVERVIEW OF MODELLING COMPONENTS AND KEY TERMS

This chapter addresses 'Step 1' of the review identified in **Section 1.2** above.

2.1. Overview of Modelling and its Review

The Basin Plan provides a high level framework within which Governments can prepare plans and strategies to manage the Murray-Darling Basin's water resources in a coordinated and sustainable way. A fundamental concept in preparing and evaluating these plans and strategies involves consideration of their performance over "*historical climate conditions*".¹⁰ This is the 114 year period up to June 2009. Consequently in order to fulfil the Basin Plan's requirements it is necessary to simulate performance of water management processes across the Basin over this 114 year period. Of necessity this involves the development of a range of computer simulation tools of which hydrologic modelling tools are foundational.

Since the establishment of the Authority, past appraisals of the majority of major water infrastructure and water management strategies within the Basin have used hydrologic modelling simulations to test the performance of the infrastructure and strategies. As a result the Authority and the relevant State water agencies have developed considerable expertise in the preparation, operation and validation of hydrologic models of the Basin's water resources.

¹⁰ Clause 1.7 of the Basin Plan defines "historical climate conditions" to be "the climatic conditions for the period July 1895 to June 2009 represented by the best available records of hydrological and meteorological information for that period".

Within the context of the Basin Plan, a key purpose of hydrological models has been to represent and test environmental water requirements, examine altered water management policies, assess changes in flow regimes and examine potential hydrologic changes to water users and the environment.

Given the wide variability in climatic conditions and water management regimes across the Basin, these hydrologic models are complex. The models have also undergone a long history of development and verification with stakeholders in the Basin. Whilst all models are only approximations of reality and some shortcomings of the models have been identified, these shortcomings have generally not been significant and the models are widely regarded within the hydrologic modelling industry as the best available.

This current review of the hydrologic modelling frameworks used for the SDL Adjustment and the Northern Basin Review projects has been undertaken in the light of this history of model development and use. The key objectives of the review are to examine the specific model characteristics that relate to the SDL Adjustment and Northern Basin Review, without re-visiting components of the modelling framework which are already well accepted and/or have successfully passed previous peer reviews or evaluations.

2.2. Integrated River System Modelling Framework (IRSMF)

As part of the CSIRO's Sustainable Yields Project, the MDBA and CSIRO built a basin-wide hydrologic modelling platform by 'stitching together' some 24 individual catchment models of the Basin's major river systems.¹¹ This linked modelling platform was known as the Integrated River System Modelling Framework (IRSMF).

Whilst the linkage of models was basic, the IRSMF allowed, for the first time, the surface water hydrology of the whole Basin to be simulated over the common period for which historical records were available.

The Basin States provided two model scenarios as a starting point:

- (a) *without development scenario* — all aspects of development have been removed from the model, including infrastructure and consumptive use (i.e. the best available estimate of the natural river system, but without accounting for land use changes and on-farm development);
- (b) *baseline scenario* — 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.

Jointly, these two scenarios demonstrate the impact of human development (to 2009) on flows throughout the Basin.

In terms of the Basin Plan, building and testing of this modelling framework required approximately two years of work. MDBA were then able to use the framework to examine a number of Basin Plan scenarios including for the recovery of water and its use for environmental purposes. The inclusion of new environmental demands to make use of recovered water required modifications to the IRSMF which are discussed under **Sections 2.3.2 and 2.4.2**

¹¹ These models had previously been developed by the States, MDBA and Snowy Hydro Limited.

The IRSMF was subject to a peer review in 2010 in order to assess its suitability for use in underpinning development of the Basin Plan.¹² Whilst the suitability of the IRSMF for this purpose was confirmed during that review, some issues were identified where additional model improvements were likely to be required.

Although the MDBA's 2012 modelling report¹³ on the application and extension of the IRSMF for the Basin Plan describes the manner in which some of these shortcomings identified in 2009 were addressed, the reviewer understands there has been no formal peer review of the version of the IRSMF used for the Basin Plan including improvements made since 2012. Nevertheless this is not considered a significant deficiency as such models are normally subject to ongoing improvements and the reviewer understands the improvements have been relatively minor and have been carried out in consultation with the State water agencies.

Formal assessment of the IRSMF is not part of the Terms of Reference for the current review. However, subject to further consideration by the MDBA, the reviewer considers there may be merit in documenting the changes to the IRSMF which have occurred since 2009 so that the need (if any) for peer review of the current version of the IRSMF could be identified.

2.3. Model-Based Components of the SDLA Assessment Framework

2.3.1. Interim SDL Benchmark

The Basin Plan defines "*benchmark conditions of development*" to be those development conditions including the infrastructure, rules and practices that were "*assumed in the benchmark model described in Schedule 6 when the model was used to set the unadjusted SDLs for the Basin Plan*".¹⁴ These benchmark conditions include certain measures that were not in effect but were expected to be in place by 2019.

These conditions will be defined by the benchmark model. The benchmark model is based on Run 847¹⁵ and includes 'mandated' changes¹⁶ and additional (non-mandated) changes as agreed to by the Basin Officials Committee. The current version of this model is referred to as the 'Interim SDL Benchmark'.

2.3.2. Automation of Environmental Event Selection Tool

During the preparation of the Basin Plan, the inclusion of environmental demands within the model was achieved by examining the differences between the baseline and without development scenarios described in **Section 2.2**, and introducing timeseries of demands at key hydrological indicator sites in an attempt to reinstate part of the without development flow behaviour. These demands were only introduced in the regulated systems because in unregulated systems there is no opportunity to supply additional water from headworks storages to meet the new demands.

¹² Refer document B2 in **Appendix B**.

¹³ Refer document B6 in **Appendix B**.

¹⁴ Refer definition in Section 7.02 of the Basin Plan. The Basin Plan notes that "the Authority will, in consultation with the Basin Officials Committee, prepare and publish a report detailing the benchmark conditions of development as soon as practicable after the Basin Plan is made". The reviewer understands that this report is presently in draft and the latest version is that listed in item B11 of **Appendix B**.

¹⁵ This is the model run used to simulate the BP-2800 scenario. This model run is referenced in S6.02 of Schedule 6 of the Basin Plan.

¹⁶ These are listed in Schedule 6 of the Basin Plan – refer **Section 3.1.2** below. A further description of the mandated and non-mandated changes can be found in Section 3.2.1 of the 'Trial Application' report listed in item B13 of **Appendix B**.

The timeseries of environmental demands at each hydrological indicator site used for the Basin Plan runs was developed manually through an iterative procedure. This is described in Chapter 4 of the MDBA's 2012 modelling report.¹³ This process was referred to as the Environmental Event Selection Tool (EEST) and was encapsulated in various principles and standardised procedures in an attempt to reflect to a limited extent, the actual decisions made by an environmental water manager including for:

- accounting for site-to-site hydrologic connectivity (i.e. return flows likely to be available for use downstream);
- aligning similar water events across sites within the same year so that return flows are of most use across multiple sites;
- selecting watering events which have priority because of the antecedent conditions in the particular year; and
- making no allowance for knowledge of future hydrologic conditions (thus mimicking actual river operations).

These principles were applied when selecting events to ensure:

- the frequency of selected events are driven by the target frequencies selected for each indicator site;
- the length of dry periods between watering events was minimised; and
- water use is controlled by an environmental account.

Whilst the EEST process assisted in providing some repeatability nevertheless it remained somewhat subjective. In fact the reviewer understands one of principal criticisms of the EEST was that two operators of the EEST could produce two different demand time-series. In addition because the process was manual and iterative, it was very time consuming.

Consequently the MDBA have codified the operation of the EEST into a software module which ensures repeatability of the process and reduces the time taken to develop environmental demand time-series.¹⁷

2.3.3. Automation of Environmental Event Removal Tool

Any supply contribution considered as an SDL Adjustment involves a reduction in the average annual volume of environmental water used. In order to test this change within the SDL Adjustment assessment framework, a new set of environmental demands which are consistent with the revised recovery volume have to be developed.

In considering how these revised environmental demands were to be developed, the reviewer understands the MDBA identified six principles to guide preparation of the environmental event sequences included within the model:¹⁸

- (a) *Event removal* – the event sequences will be produced by removing events from the benchmark sequences;
- (b) *Event prioritisation* – events are prioritised for removal based on the original prioritisation functions utilised in the SDL benchmark, with those of lowest priority being removed first (subject to the 'limits of change awareness' which is discussed below);
- (c) *Limits of change awareness* – this principle ensures that the event removal process remains consistent with the 'limits of change' constraints (refer **Section 3.1.5**

¹⁷ A further description of the automation of the EEST can be found in Section 3.2.2 of the 'Trial Application' report listed in item B13 of **Appendix B**.

¹⁸ Based on email advice to the reviewer on 9 August 2016 from Mr Gavin Pryde of MDBA. This followed previous discussions with Messrs Carlile, Pryde, Lee and Coleman during the course of the review.

below);¹⁹

- (d) *Re-prioritisation* – after the removal of an event, the events in subsequent years are re-prioritised to reflect the removal;²⁰
- (e) *Maintenance of baseflows* – the limits of change allow for the bankfull/overbank component of the flow regime to change in response to a supply measure, however they also require the baseflow to be maintained at benchmark levels. (See **Section 3.1.5** below). In recognition of this constraint the reviewer understands the baseflow demand series remains unchanged between the benchmark scenario and SDL Adjustment scenarios;
- (f) *Maintenance of freshes* – because of the requirement for no reduction in outcomes for fresh events – see **Section 3.1.5** below – the method of water delivery to downstream sites was unchanged.²¹

2.3.4. Environmental Outcomes Scoring

A key component of the development of the SDL Adjustment Mechanism in the Southern Connected system has been the preparation of a system to score environmental outcomes of different flow regimes. The principles underpinning the development of this scoring system are described in Schedule 6 of the Basin Plan. This scoring system was a consideration in the development of the Environmentally Sustainable Level of Take (**ESLT**) method.²²

The flow regime characteristics for the flow event targets in the ESLT method comprise both the frequency of occurrence of the events and the length of dry spells between the events. Scores are generated for each flow regime characteristic at the reach scale and at the region scale.²³ Environmental scores are then calculated based on preference curves which describe a relationship between environmental outcome and a flow statistic such as frequency or dry spell.²⁴ The principal advantage of such a scoring system is that flow statistics and ecological element scores are weighted by the spatial area each flow indicator or works operation inundates. The ecological elements spatial scoring framework therefore enables spatial trade-offs between environmental outcomes to occur at the region scale.

Schedule 6 outlines the default method to be used for assessment of environmental equivalence and specifies that the method must be science based, independently reviewed

¹⁹ The effect of this principle is to 'slow' the removal of events from each flow indicator as they approach the limits of change, such that other flow indicators are preferentially targeted for event removal. Once the maximum number has been reached, this function also ensures that all other events for this flow indicator are not available for removal.

Further the reviewer understands that the application of this principle does not alter the order in which events are removed from a given site, but instead changes the inter-site event removal order. The main benefit of this function is that all flow indicators reach their respective limit towards the end of the event removal process. This refinement has ensured that, if the limit of change for a flow indicator is breached, environmental water can be re-distributed at a site to repair the breach. This refinement is consistent with provision outlined in subsection 6.07(b)(iii) of Schedule 6 of the Basin Plan – see **Section 3.1.5** below.

²⁰ In relation to this re-prioritisation the MDBA advised the reviewer that the event selection algorithm underlying the benchmark event sequence contains heuristic properties. That is, as the algorithm moves through the 114-year sequence, it uses past event selections to guide the choices in future years. Applying the event removal principles (a), (b) and (c) impacts this heuristic process. Accordingly re-prioritisation was necessary.

²¹ The reviewer understands that, if required, a second model iteration was added in which specific benchmark fresh events were re-instated through demand series (events are included in a demand series only if required to satisfy the limits of change).

²² Refer MDBA 2011 publication in item B3 of **Appendix B**. This report outlines the methods and modelled outcomes of the ESLT process.

²³ These regions are:

- (a) the Northern Basin region – all rivers upstream of Menindee Lakes; and
- (b) the Southern Basin region – the River Murray upstream of the boundary of the Coorong, Lower Lakes and Murray Mouth Ramsar site and all connected tributaries apart from the Northern Basin; and
- (c) the Lachlan and Wimmera Rivers (which are normally disconnected from downstream Valleys), if supply contributions are proposed within these valleys.

²⁴ For example, achievement of a target frequency of inundation may score 100 points, with this score reducing towards zero for frequencies below the achievement of the target. The Basin Plan specifies that "science based, independently reviewed, fit for purpose metrics for weighting environmental significance of the flood dependent area will be used in the method".

and fit-for-purpose. A CSIRO-led consortium was engaged by MDBA to develop the 'ecological elements' of the scoring method consistent with the requirements of the Basin Plan. The method was developed in consultation with Basin governments in the Southern Basin region.²⁵

Evaluation of the environmental scoring method is not within the terms of reference of the current review as it has been previously independently reviewed.

2.4. Model-Based Components of the Northern Basin Review

2.4.1. Development of 'Northern Standard'

The model run for the Basin Plan was based around a scenario in which 2,800 GL/yr of water was recovered and actively managed for the environment. This scenario was known as 'BP-2800' and it assumed recovery of 450 GL/yr from the Northern Basin. Whilst the model run was used to inform the Basin Plan and remains the only Northern-connected scenario publicly released by MDBA, the Basin Plan assumes reduction of 2750GL/yr of which some 390GL/yr is recovered from the Northern Basin.

The Barwon–Darling model was modified for the BP-2800 scenario to include an increase of existing pumping thresholds of consumptive users. The main purpose of this modification was to ensure the long-term average diversions in the region matched those required by the SDL. This change was also a representation of flow protection in the Barwon–Darling, as it allowed a portion of the environmental water delivered from the tributary valleys to be protected from extraction by consumptive users.

Whilst BP 2800 included the best available information at the time it is unsuitable for use for more detailed Basin Plan investigations. This is because the modelled water recoveries were overstated and various changes were needed (e.g. to pumping thresholds) to achieve the adopted 2750GL/yr recovery.

Consequently for the Northern Basin Review it was necessary to develop a new initial SDL model scenario which is referred to as the 'Northern Standard'. The reviewer understands that this also provided the opportunity to introduce other needed model changes to better represent river system behaviour²⁶ and environmental watering under the Basin Plan.

The most notable changes included to form the Northern Standard scenario are as follows:

- (a) *existing recovery* – the recovery volume modelled in each valley is built from the level of environmental water recovery achieved to date. This is a change from the overall 'pro-rata' approach used in scenario BP-2800;
- (b) *SDL's outlined in the Basin Plan* – in the BP-2800 scenario the Condamine–Balonne model included a reduction in diversions of 203 GL/yr. To reflect an overall recovery

²⁵ A full description of the method is provided in document B12 listed in **Appendix B**. This document includes the results of some initial testing undertaken by CSIRO using model data for reaches at Riverland-Chowilla Floodplain (South Australia) (River Murray Lower reach) and Gunbower-Koondrook-Perricoota Forest (River Murray Upper Central reach) (Victoria and New South Wales). The reviewer understands a subsequent and more comprehensive review of the method, including its performance during the trial and subsequent revisions to the initial method is documented in the 'SDL Adjustment Ecological Elements Method Trial Implementation Review' (Overton et al, 2015).

²⁶ These included implementation of some of the recommendations of a review conducted by Barma Water Resources. This review assessed the Baseline Diversion Limit (BDL) assumptions included with the model generally to replicate 2009 development conditions in all the valleys within the Basin. (Refer 'Independent review of models to assess their representation of the baseline conditions specified in the Basin plan and estimating BDLs'. Final Report. Prepared for the MDBA by Barma Water Resources Pty Ltd. June 2012).

volume of 390 GL/yr reduction in diversions, the Condamine-Balonne diversion were reduced to 142 GL/yr (in-valley volume of 100 GL plus a pro-rata downstream component);

- (c) environmental watering strategy – BP-2800 did not include downstream environmental demands in the Border Rivers and Namoi systems and this has now been rectified. The environmental watering strategy in the Northern Standard model is similar to that in BP-2800 scenario in that it seeks to combine unregulated and regulated environmental water to provide environmental outcomes, but targets delivery of environmental flows to meet requirements at Bourke.

The reviewer endorses the development of the Northern Standard which is clearly an improvement on BP-2800. Nevertheless it is only one of many scenarios that are under investigation within the Northern Basin Review. The term ‘standard’ may imply some type of ‘benchmark’ status which the reviewer understands does not exist.²⁷

2.4.2. *Timeseries of Environmental Demands*

In general terms, the delivery of water to meet demands in the models are achieved through a system of ordering where downstream demands are passed upstream to a water storage. Releases are then made after due allowance has been made for travel times, water availability, losses and operational constraints. This process mimics somewhat the process that river operators undertake in practice.

In order to deliver environmental water to achieve desired environmental outcomes within the Basin Plan, the models make use of a suite of timeseries of environmental demands at various locations. These timeseries contain information about the magnitude and temporal pattern of environmental water. Within regulated (i.e. supplemented) river systems, these environmental orders are then passed upstream to water storages in the same manner as orders for other consumptive uses. In unregulated (i.e. unsupplemented) systems there is no opportunity to make specific releases to meet environmental demands.

The water recovery process in regulated systems provides a share of the available water resource in storage for environmental purposes. To enhance environmental outcomes downstream of the storages, environmental water held in storage is released in a certain pattern and the releases allow for a variety of practical considerations such as allocation announcements, existing flows in the river, channel sharing arrangements, and system constraints.

At a downstream location where a specific pattern of environmental flows is to be delivered, the pattern is derived from consideration of site-specific flow indicators (SFIs). These SFIs were developed as part of the Environmentally Sustainable Level of Take (**ESLT**) method.²² This process was referred to as the Environmental Event Selection Tool (**EEST**) and was encapsulated in various principles and standardised procedures in an attempt to reflect to a limited extent the actual decisions made by an environmental water manager (refer to **Section 2.3.2**).

The EEST provided a means to select a number of possible environmental flow events for re-instatement. Once selected these events comprised a 114 year timeseries of environmental demands which could then be included in the modelling framework. The demands generated by the EEST were based on a yearly volume of available environmental water (that was

²⁷ As there is limited documentation at this time and as it is not within the terms of reference of this review to critique all the changes that have been included within the Northern Standard, this review makes no assessment as to whether the components of the Northern Standard have been appropriately optimised.

determined based on the assumed water recovery scenario). This initial water account was subsequently refined by operating the EEST iteratively with the model (refer **Section 2.4.5** below).

Demand timeseries were included in the Border Rivers, Gwydir, Namoi, and Macquarie catchments, as these rivers contain a significant level of flow regulation due to structures such as dams and weirs. Demand series were sometimes included at multiple locations in each of these catchments, each associated with different aspects of water use. For instance, environmental watering in the Namoi model included demand series for base-flows, a demand series to request environmental flows for riparian outcomes in the Lower Namoi, and another demand series to request flow events to enhance environmental outcomes downstream in the Barwon–Darling.

For the regulated catchments, demand timeseries were developed to meet both local (i.e. within catchment) outcomes and downstream (i.e. Barwon-Darling) outcomes. These two outcomes are discussed in **Sections 2.4.3** and **2.4.4** below.

2.4.3. Demand Timeseries for Local Outcomes

The reviewer understands that to date the MDBA has used the procedure discussed above to prepare environmental demand timeseries the key regulated systems being the Border Rivers, Namoi, and Macquarie catchments. The SFIs for these systems were located at Mungindi (Border Rivers), Bugilbone (Namoi) and Marebone Break (Macquarie).

In the Gwydir system two separate EESTs were developed. The Mallowa Creek EEST followed the method described previously, and is unchanged from those used as part of Basin Plan development.

However the EEST developed for the second site within the Gwydir (i.e. the Gwydir wetlands) used an alternative method which was developed particularly for the Northern Basin Review. This recognised that releases from Copeton Dam to meet environmental demands in the wetlands would result in unacceptable inundation of private landholdings. Consequently the approach was altered so that the desired volume of environmental water was delivered over a much longer time period than would have occurred naturally, thus avoiding breaching the operational constraints in the Lower Gwydir.

2.4.4. Demand Timeseries for Downstream Outcomes

A timeseries of environmental water demands are provided near the bottom end of each of the regulated systems in order to achieve environmental watering in the Barwon-Darling. The principal SFI for the Barwon-Darling is at Bourke.

Flows through the Barwon-Darling system are almost entirely reliant on inflows from upstream tributaries. In order to maximise environmental outcomes some amount of 'flow coordination' for releases from the tributaries is desirable. However there are practical operational difficulties in coordinating such releases in order to enhance environmental flows in the Barwon-Darling system.

Because of these difficulties, the reviewer understands the MDBA modelled two possible water delivery strategies:

- (a) Strategy 1 assumed a fully managed system was in place whereby coordinated releases were made from each tributary so as to supplement unregulated flows in the Barwon–Darling in order to meet the environmental demand timeseries at Bourke and elsewhere. (These unregulated flows included an allowance for increased flows

resulting from implementation of the Basin Plan in the upstream unregulated catchments). Development of demand timeseries with the Barwon–Darling EEST included the added complexity of coordinating regulated releases from multiple catchments with varying levels of connectivity, conveyance and travel times that are highly dependent on antecedent conditions.

- (b) Strategy 2 assumed low flow connectivity between the various tributary systems and the Barwon–Darling. In this strategy individual demands targeting the delivery of low flows to the Barwon–Darling were developed for each individual regulated catchment. The demand series for Strategy 2 were far simpler, targeting lower flows and developed without the use of a separate EEST. The individual demands for each catchment were independent of each other and as such no flow co-ordination was assumed.

It is not within the terms of reference for the current review to assess the practicality of implementing these strategies and particularly Strategy 1. There are currently no operating arrangements and there is possibly insufficient knowledge of losses and travel times to allow Strategy 1 to be implemented at present. However the MDBA advised the reviewer that Strategy 1 had been predicated on significant advances in knowledge and the desire to maximise the efficiency of water recovered.

In addition they advised that the actual watering strategies to manage and utilise the water recovered across the Northern Basin are still undergoing development. Therefore whilst the extent of coordination between catchments that could be practically achieved has not yet been determined, the two modelled strategies are useful as they illustrate the sensitivity of the Barwon-Darling environmental outcomes to flow coordination.

2.4.5. Iterative Modelling Process

As explained in **Section 2.4.2** above, each Environmental Event Selection Tool (EEST) utilised a yearly volume of available environmental water. This defacto accounting mechanism was a first-pass estimate only. It existed external to the modelling framework, hence it could not adapt to the daily accounting decisions and flow changes that occur dynamically in the model, and could not accurately include factors such as allocations and carry-over.

To ensure unintended change to the pattern of take of other users in the system did not occur, and to ensure that each scenario complied with the desired SDL, an iterative modelling procedure was adopted to refine the demand timeseries based on the model output. This iteration step focused mainly on the downstream demand timeseries to ensure the demand pattern was balanced against the amount of recovered environmental water.

3. CONSISTENCY OF MODELLING APPROACH WITH BASIN PLAN

This chapter addresses ‘Step 2’ of the review identified in **Section 1.2** above.

3.1. SDL Adjustments

The key modelling requirements for the SDL Adjustments are detailed in Chapter 7 and Schedule 6 of the Basin Plan. These requirements are outlined below.

3.1.1. *SDL Adjustment Overview*

The SDLs will constitute limits from 1 July 2019 and were derived after considering infrastructure and other measures that were in operation or expected to be in operation by 2019. The SDLs set in 2012 were informed by the scientific understanding of the Basin's hydrology and ecology at that time.

The Basin Plan makes provisions for the MDBA to propose adjustments to surface water SDLs if certain additional changes in infrastructure and other measures are planned by 30 June 2016 and will come into operation by 30 June 2024. The reviewer understands that a range of such changes have been proposed and have been under consideration for some time. This includes the 36 supply and constraint measures, and the efficiency measures program, for which Messrs Martin and Turner carried out a 'Stocktake Report' in August 2015.²⁸

Clause 7.15 of the Basin Plan details how the total increase in the SDLs resulting from all the supply measures is to be calculated. This is essentially the difference between two model runs, one with the benchmark conditions of development and the other with these conditions modified by the addition of the supply measures. These model runs are undertaken assuming a repeat of the historical climate conditions and with strict requirements to ensure there are equivalent environmental outcomes and no detrimental impacts to the reliability of supply to water users.

The Basin Plan describes a 'default method' which is to be used to calculate the supply contribution. This is discussed further below. Whilst the Basin Plan allows for other methods to be used if approved, the reviewer has only considered the default method in this review as it has been used to date and there is no indication that other methods are under consideration.

3.1.2. *Default Method*

Schedule 6 of the Basin Plan sets out the default method by which the supply contributions is to be calculated for the purposes of determining a SDL Adjustment.

The Default method utilises a 'Benchmark Model' which is described in S6.02 of the Schedule 6. This is model 'Run 847'²⁹ with various refinements including the following which are referred to as the 'mandated changes':

- (a) amending the overall reduction from 2800 GL/year to 2750 GL/year;
- (b) including simulation of rules for the delivery of water from the Lower Lakes into the Coorong;
- (c) incorporating Upper South East inflows as at 30 June 2009;
- (d) updating the environmental watering event time-series in the environmental event selection tool;
- (e) removing the Living Murray works and measures. (Consequently the full benefit of these works and measures can be considered for an SDL Adjustment);

²⁸ Refer document B14 in **Appendix B**.

²⁹ 'Run 847' was the SDL model used to set the 2800GL/yr reduction referred to in the Basin Plan. The baseline scenario model run was 'BP-2000' which represented the starting point against which the effect of implementing the SDLs within Basin Plan was assessed. This scenario was best available estimate of the current use of water resources of the basin as at 2009. It reflected the water sharing arrangements that were in place in June 2009.

- (f) incorporating environmental demand sequences that manage for maximum dry spell as well as frequency; and
- (g) setting environmental flow demands for the Goulburn River.

Beyond the mandated changes listed above, further refinements referred to as non-mandated changes can be undertaken in consultation with Basin jurisdiction through the Basin Officials Committee.

3.1.3. Reliability of Supply

Section 7.15(d) of the Basin Plan requires that the application of any supply measure must ensure that there are no detrimental impacts on the reliability of supply of water to the holders of water access rights. Section 6.02(2) of Schedule 6 of the Basin Plan further clarifies that it is the 'pattern of reliability of supply' which is the focus of this test.

However, the pattern of 'reliability' is not strictly defined. Instead reliability is measured by the States and water users based on a variety of different metrics usually related to the announced allocations (e.g. the frequency of full allocations in a particular month of the year).

Because there is no unique metric or suite of metrics for reliability, the reviewer understands that the assessments of reliability that have been undertaken to date for the SDL supply measures have utilised both a suite of reliability metrics and an expert review of model results by Basin state water managers.³⁰

3.1.4. Environmental Scoring Method

In applying the default method the indicator sites and corresponding river reaches to be considered, are those used in the development of the Environmentally Sustainable Level of Take (ESLT) method.²² This scoring method has previously been discussed in **Section 2.3.4** above.

When considering SDL Adjustments, its region score must be better than, or equivalent to the benchmark model score.

3.1.5. Limits of Change

It is important to understand that in applying the method to calculate SDL Adjustments, the Basin Plan specifies limits on the changes in environmental scores or outcomes that can occur. These limits effectively constrain the extent of the SDL supply contribution that can occur. These limits are for the purpose of modelling SDL Adjustment and do not necessarily represent environmental watering or management targets.

They are set out in S6.07 of Schedule 6 which states:

The following limits of change in score or outcome will apply in the method under the historic climate conditions:

- (a) *for each region of the Basin—no reduction in the benchmark environmental outcome scores, although some reductions in individual elements may be permitted if they are offset by increases in other elements;*
- (b) *for each reach:*

³⁰ For the suite of reliability metrics being used to assess impacts on Victoria's, New South Wales' and South Australia's water users refer Tables 47, 48 and 49, respectively, of the 'Trial Application' report listed in item B13 of **Appendix B**.

- (i) where the benchmark model run achieves or exceeds the target frequency range for a flow indicator, achievement of the target frequency range must be retained and the frequency result must not vary by more than 10% of the benchmark result; and
- (ii) where the benchmark model run does not achieve the target frequency range for a flow indicator, the frequency result must not vary by more than 10% of the benchmark result, and not fall below the baseline model result; and
- (iii) where the benchmark model run provides little improvement in frequency for a flow indicator (less than 50% progress toward the target range from the baseline model result), the frequency result must not vary by more than 15% of the benchmark result, and not fall below the baseline model result; and

Note: Where a flow indicator exceeds these limits of change, but other indicators at the site are within the limits of change, modelling under the method will redistribute the use of environmental water amongst flow indicators to balance outcomes with respect to subparagraphs (i) to (iii). Consistent with section S6.06(3) redistribution of environmental water will occur to the minimum extent necessary to ensure that the limits of change are met and not to otherwise affect environmental flow outcomes in the benchmark model.

- (iv) where a supply measure or combination of measures can achieve the ecological outcomes sought by the plan as represented by an ecological target or targets, and a flow indicator or indicators and associated benchmark model results, then subparagraphs (i) to (iii) do not apply to that flow indicator or indicators;
- (c) for the Coorong, Lower Lakes, Murray Mouth—maintenance or improvement of the following:
 - (i) Lake Alexandrina salinity: less than 1500EC for 100% of the time and less than 1000EC for 95% of days;
 - (ii) Barrage flows: greater than 2000 GL per year on a three year rolling average basis with a minimum of 650 GL in any year, to be achieved for 95% of years;
 - (iii) Barrage flows: greater than 600 GL over any two year period, to be achieved for 100% of the time;
 - (iv) Coorong salinity: South Lagoon average daily salinity less than 100 grams per litre for 96% of days;
 - (v) Mouth openness: Mouth open to an average annual depth of 1 metres (-1.0 m AHD) or more for at least 90% of years and 0.7 metres (-0.7 m AHD) for 95% of years;
 - (d) for all base flows and fresh requirements within each reach—no reduction in outcomes achieved in the benchmark run.

Note: These limits of change are for the purpose of modelling SDL adjustment and do not necessarily represent environmental watering or management targets.

3.1.6. Application within the Modelling Framework

Because of the requirements described in **Sections 3.1.2 to 3.1.5**, the process of determining an SDL Adjustment volume requires numerous iterations within the modelling framework. The attached **Figure 1** illustrates this iterative process and was provided by the Authority during interviews conducted as part of this review. In particular it demonstrates how initial estimates of the SDL Adjustment volumes require adjustment in order to satisfy the limits of changes whilst also complying with both the environmental score and the reliability constraints.

Based on the interviews that have been conducted with the MDBA staff and the documentation provided in the 'Trail Application Report' the reviewer has not identified any inconsistencies of approach with the Basin Plan when calculating SDL Adjustments.

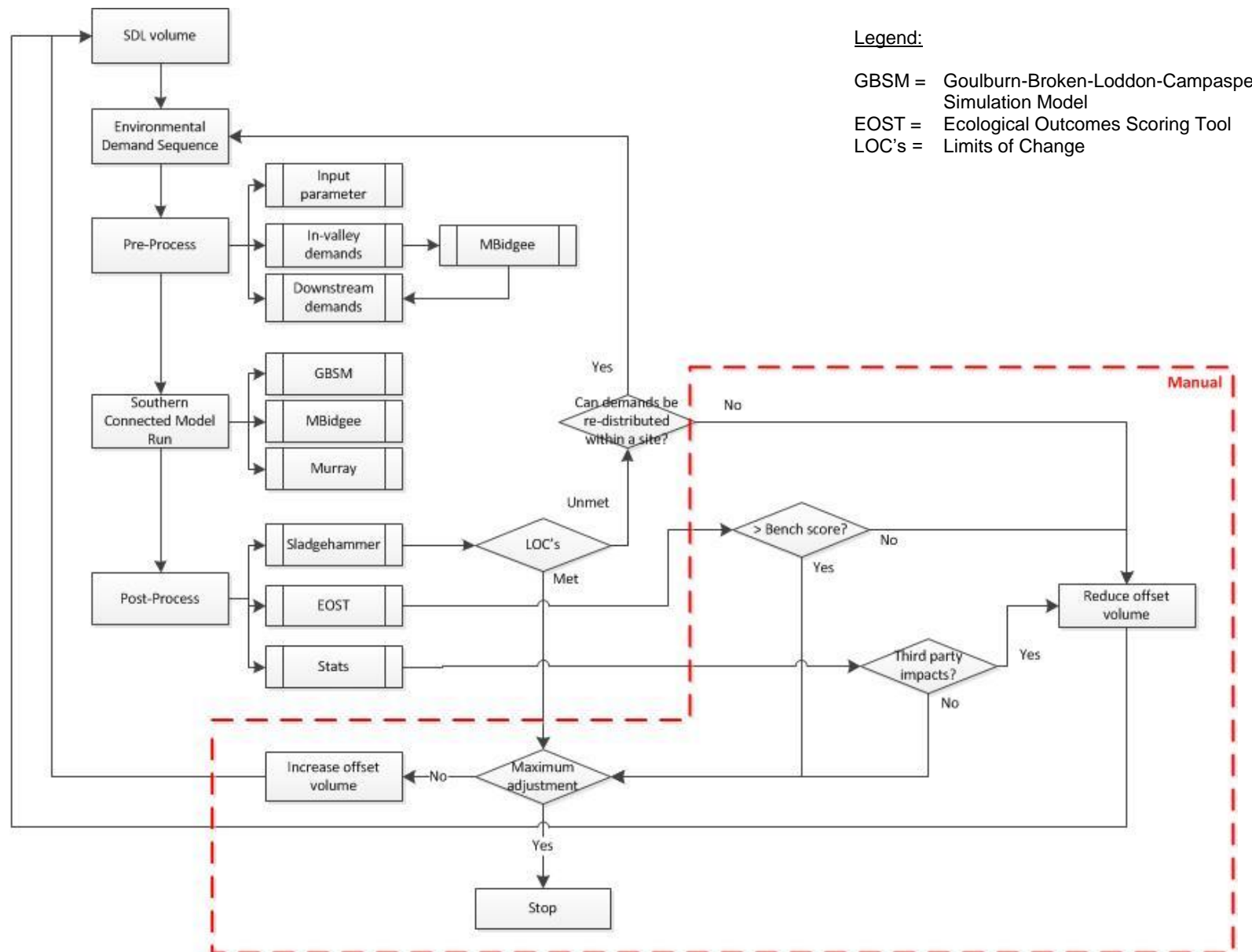


Figure 1: SDL Adjustment Modelling Procedure

(Source: Mr Jong Lee, MDBA)

3.2. Northern Basin Review

3.2.1. Background to the Northern Basin Review

In terms of the Northern Basin, the Basin Plan currently sets 3,468 GL as the limit of water that can be extracted across the Northern Basin on average per year. The current water recovery target of 390 GL/yr for the north is made up of 247 GL/yr for local catchments (known as in-valley or local recovery amounts) plus a further 143 GL/yr to be found across the catchments for downstream needs and is referred to as the shared reduction amount.

In finalising the Basin Plan, the MDBA agreed to do further research and investigations on the settings of the Northern Basin to see if there is a case for changing them. While the science was the best available at the time, the MDBA considered a review provided a chance to fill some of the gaps in information. The review encompasses the Northern Basin region as a whole with a focus on the Condamine–Balonne and Barwon–Darling catchments. The primary setting under investigation is SDL — that is, mapping the relationship between recovery volume and changes in river flow patterns. In each connected valley of the Basin the SDL involves consideration of water recovery for local environmental outcomes and water recovery for downstream environmental outcomes.

For the Northern Basin Review the key modelling requirements are detailed in subsection 6.06 of the Basin Plan. This subsection of the Basin Plan empowers the Authority (in consultation with the Basin States and other interested persons) to conduct research and investigations into the SDLs and other aspects of the Basin Plan, in order to inform reviews of the Basin Plan including for changes to SDLs in some areas.

In relation to such reviews for the Northern Basin, the Basin Plan specifically notes that “*the Authority intends to conduct research and investigations by 2015 into aspects of the Basin Plan in the northern Basin, including the basis for the long term average sustainable diversion limits for surface water and groundwater SDL resource units*”³¹

3.2.2. Modelling Documentation

There is currently no formal documentation of the modelling undertaken for the Northern Basin Review but the reviewer understands a report is in preparation. An early draft of this report has been shown to the reviewer (refer item B18 in **Attachment B**).

As the modelling framework is essentially the same as that used during the preparation of the Basin Plan and includes the enhancements described in **Sections 2.2** and **2.4** above, this review endorses the modelling framework as it is equivalent or superior to that used for the Basin Plan.

3.2.3. Deficiencies and Inaccuracies in the Existing Models

Whilst it is not within the terms of reference of this review to assess the IRSMF that forms the basis of the modelling for the Northern Basin Review, it is appropriate for some comments to be made about the manner in which the modelling framework is to be used particularly having regard to known deficiencies and inaccuracies in the individual models that make up the IRSMF.

³¹ Section 6.06(1) of the Basin Plan. It is also noted that Section 6.06(3) of the Basin Plan requires that when such reviews are undertaken that they must have regard to “*the management of climate change risks and include an up to date assessment of those risks, and consider all relevant knowledge about the connectivity of surface and groundwater, the outcomes of environmental watering and the effectiveness of environmental works and measures*”.

These deficiencies and inaccuracies in the models are identified in this section. This is then followed by **Section 3.2.4** which addresses the potential for these deficiencies and inaccuracies to impact on the outcomes of the Northern Basin Review.

All hydrologic models are only approximations of reality and it is always possible to make improvements to models (although the 'return' on the improvement effort may not warrant making such improvements). The existing suite of models within the Northern Basin is no exception.

A number of previous assessments³² have identified model deficiencies for particular applications. For the purposes of the Basin Plan, the 2010 report 'River System Modelling for the Basin Plan, Assessment of fitness for purpose' is the most relevant.³³

The model issues identified in the 2010 assessment which are of most relevance to the Northern Basin Review include the following extracts from the 'key messages' section of the report:

- (a) *"previous independent audits of Cap models ... and water sharing plan models ... found that models were suitable for their intended use. These reviews also concluded that model performance is poor for periods of low flow"*;
- (b) *"most of the models perform reasonably well under without-development conditions with the Macquarie region the main exception (that over estimates volume)"*;
- (c) *"average without-development conditions are also represented poorly in the Namoi and the Namoi is therefore not suitable for modelling environmental demands"*;
- (d) *"the Namoi unaccounted losses and gains are large which suggested that the model would benefit from a calibration with more realistic estimates of ungauged inflows and losses"*;
- (e) *"care should also be taken in using models for any low flow environmental water demands"*;
- (f) *"the models and methods used to develop SDLs for the MDB are considered to be world's best practice, given the scale of the modelling work and the time constraints. Peer review by water management committees, experts and as part of the MDBSY³⁴ project, has found them adequate for their intended use (i.e. developing water-sharing plans). However in developing the SDLs the models may be pushed beyond levels of certainty with respect to water management rules and climatic conditions. Checks need to be instituted to ensure that models are not pushed beyond their limits"*;
- (g) *"in all cases models could be improved by a more consistent method of calibration and extending calibrations into the more recent drier period. The focus of future improvements should be in better accounting for losses in the losing parts of systems with an aim to improving low flow estimates of these models"*

³² There are at least ten models of the various Queensland and NSW tributaries, including the model of the Barwon-Darling, which are of relevance to the Northern Basin. All these individual models have been independently audited by the reviewer over the last decade. These were audits of the suitability of the models for the purposes of the Basin 'cap' – refer to Schedule E, Cap On Diversions of the Murray-Darling Basin Agreement (i.e. Schedule 1 of the Commonwealth Water Act, 2007). In addition to these audits, the State water agencies have also carried out internal reviews and in some cases, additional external reviews, of the suitability of the models for a range of water sharing plan purposes. Whilst some deficiencies in the models were identified during these audits and reviews, and in some cases various improvements were made as a result, none of these deficiencies were so significant to prevent the models being used by Queensland, NSW and by other bodies including CSIRO and the MDBA.

³³ Refer document B2 in **Appendix B**.

³⁴ This refers to the CSIRO's Sustainable Yields Project within the Murray-Darling Basin – refer **Section 2.2**.

The reviewer understands that these deficiencies and inaccuracies were recognised by the MDBA when using the models to prepare the Basin Plan in 2012.

3.2.4. Comparative Approach used in Modelling

One of the primary uses of the modelling framework for the Northern Basin Review is to identify the potential benefits of various volumes of recovered water to deliver additional environmental watering benefits to downstream areas within the tributary catchments and within the Barwon-Darling system. In each case the volume of recovered water and the additional environmental water deliveries are determined by a comparative model analysis. This analysis is based on the differences in model results between:

- the baseline diversion limit (**BDL**) model established by the Basin Plan;³⁵ and
- the particular SDL model scenario under investigation including for the reduced water use entitlements achieved by water recovery and the introduction of increased environmental demands.

The following comments are made about this differencing procedure:

- (a) in order for the differences to reflect only the impacts of the water recovery and the additional environmental watering, it is essential that all other aspects of both models are identical. This includes their water management rules and their hydrologic characteristics (e.g. flow losses and flow behaviour);
- (b) because the BDL model outcomes have already been enshrined in legislation, and because of the need to maintain the same management rules and hydrologic characteristics as noted in (a), the reviewer understands that it was inappropriate for changes to be made to the IRSMF to address the deficiencies and inaccuracies noted in **Section 3.2.3.**, except where these changes would not alter the BDLs and could occur outside the States' models within the IRSMF;³⁶
- (c) whilst deficiencies and inaccuracies exist in both the BDL and SDL models, the process of differencing tends to reduce the impact of these deficiencies and inaccuracies on the outcome.³⁷ It is well established that the 'relative' accuracy resulting from the difference between two models will be superior to the 'absolute' accuracy of the individual model in simulating real world behaviour;
- (d) despite the discussion above, the deficiencies and inaccuracies in the underlying models must be considered when evaluating the modelling outcomes. In this regard the reviewer understands that the MDBA will also utilise other non-modelling procedures and information when recommending revised SDLs for the Northern Basin;

³⁵ The Basin Plan adopted by the federal water minister in November 2012 defines a baseline diversion limit (BDL), which for most of the surface water SDL units, is the diversion permissible by the respective state water management laws that existed on 30 June 2009. Consequently the BDL model being considered in the Northern Basin Review is based on 2009 management rules and diversion levels, not the current rules and diversion levels.

³⁶ For example, the deficiency identified by the 2010 assessment – see item (c) in **Section 3.2.3** – relates to the suitability of the Namoi model (when operated under 'without-development' conditions) to be used to determine environmental demands. The reviewer understands that at the time this assessment was carried out (which was prior to later modelling for the Basin Plan), environmental demands were being determined by the same procedure used in the CSIRO's Sustainable Yields Project. Subsequently the method of determining demands was changed to the 'pick-a-box' system used in the Basin Plan. This method has been further improved during the Northern Basin Review (refer **Sections 2.4.2 to 2.4.4**). Whilst the deficiencies in the Namoi model remain, the impacts of these deficiencies on the modelling of environmental demands and the outcomes of the Northern Basin Review have been reduced.

³⁷ This assumes that the same deficiencies and inaccuracies are present in both the BDL and the SDL models, which will normally be the case.

- (e) where the water sharing plan (**WSP**) rules have changed subsequent to 2009 (e.g. as in the case of the Barwon-Darling) it is not appropriate for these changes to be incorporated in models used for the comparative modelling approach being discussed here. Nevertheless these changes will be relevant to the future water resource plans that are to be prepared under the Basin Plan.³⁸

The information presented above and in item B18 of **Attachment B** as well as the discussions of modelling procedures that were undertaken during the review, did not indicate any inconsistencies of the modelling approach with the requirements of the Basin Plan.

4. ASSESSMENT OF MODELLING FRAMEWORKS

The review's responses to the items listed under the 'Scope of Work' section of the Terms of Reference are provided in **Table 1**. This table also provides specific responses to the matters listed in 'Step 3' of **Section 1.2** above.

³⁸ By 1 July 2019 some 36 water resource plans (WRPs) across the entire Basin will need to be prepared, one for each WRP area, consistent with the requirements of Chapter 10 the Basin Plan. Hydrological models will form a key component of the preparation and implementation of these WRPs. The WRPs will manage surface water resources within the SDLs and the requirements of the Basin Plan. The WRP models are yet to be developed and will likely include the components of the current WSP' rules and subsequent changes to WSPs that occur between now and 2019 in order to accommodate the SDLs.

Table 1: Response of Review to Terms of Reference (see Appendix A)

Item	Terms of Reference	Review's Response
1	The SDLA modelling framework's and modelling processes (as represented in Calculating the supply contribution for SDL Adjustment: A trial application of the 'default method') implemented by the MDBA are:	
(a)	compliant with the Default method specified in Schedule 6 of the Basin Plan;	Examination of the 'Trial Application' report and the interviews with MDBA staff conducted during the review indicates the modelling that is being undertaken is fully consistent with the 'Default Method' – refer Section 3.1.2 .
(b)	appropriate for calculating the 'supply contribution' as defined in Section 7.15 of the Basin Plan;	For the purposes of Section 7.15(2), the 'applicable method' is the 'default method' as there has been no agreement given (or sought) to use another method. The procedure for calculating the supply contribution of SDL Adjustment measures is illustrated by Figure 1 . As discussed in Section 3.1 above the review has identified that the modelling frameworks are appropriate for calculating the supply contribution.
(c)	transparent, repeatable and objective; and	Documentation is limited at the present time as the process is not complete. Transparency would be improved through provision of further documentation which will occur as the SDL Adjustment process is concluded. Repeatability and objectivity have been enhanced (relative to the modelling undertaken for the Basin Plan) by the codifying of procedures for the automation of environmental event selection and removal.
(d)	technically sound and fit-for-purpose	The SDL Adjustment modelling has built on the modelling undertaken for the Basin Plan. The modelling has been enhanced through the automation of the environmental event selection and removal tools, and the consideration of the reliability and limits of change constraints listed in Schedule 6 of the Basin Plan (see Figure 1). It is the opinion of the reviewer that these enhancements to the Basin Plan models are technically sound and fit-for-purpose.
	In assessing the above, the reviewer should consider whether the methods and approaches used to:	
(e)	develop the Benchmark scenario and adjustment scenarios are consistent with Section 7.15 (1) as well as S6.01 and S6.02 of Schedule 6 of the Basin Plan;	See review comments provided under 1(a) and 1(b) above. The methods and approaches are consistent with Section 7.15 (1) and S6.01 and S6.02 of Schedule 6 of the Basin Plan.
(f)	produce environmental demand time series and adjust environmental water entitlements are technically sound and have been developed and applied consistently	<u>Event Selection</u> The environmental event selection tool (EEST) and its automation have been discussed in Section 2.3.2 above. The reviewer understands that during its development, the Authority's staff

Item	Terms of Reference	Review's Response
	<p>between the benchmark and supply measure modelling scenarios;</p>	<p>made numerous comparisons between the events selected by the automated and manual tools. One such limited comparison of results was documented in the discussion paper listed in item B10 of Appendix B.</p> <p>In terms of the technical soundness of the automated tool this review has identified that:</p> <ul style="list-style-type: none"> (a) despite its subjective nature, the manual EEST has been previously considered to be of sufficient accuracy for development of SDLs for the Basin Plan; (b) the automated tool is understood to have been developed consistent with the selection principles utilised in the manual tool, and consequently does not select events in a manner that is inconsistent with what might have been achieved with the manual tool; and (c) the key advantage of the automated EEST is that the selection of events is repeatable and independent of the operator. <p>Whilst confidence in the use of the automated tool would have been enhanced through documentation of comparisons between the outcomes of the manual and automated tools, the reviewer endorses the use of the automated tool as part of the SDL Adjustments project.</p> <p><u>Event Removal</u></p> <p>The event removal tool has been discussed in Section 2.3.3 above. The reviewer's assessment of this tool is as follows:</p> <ul style="list-style-type: none"> (a) the reviewer supports the automation of what would otherwise be a 'manual' process. The automation ensures the process is repeatable and provides time savings; (b) the process of event removal is necessarily complex in order to conform with the stringent requirements of the 'default method' and the 'limits of change' which are set out in Schedule 6 of the Basin Plan; (c) the complexity of the process is not assisted by the lack of clear documentation. Further documentation may need to be prepared in due course; (d) the process which has been described to the reviewer and documented above does, in his opinion, meet the requirements of the Basin Plan. It is possible that other processes could also be developed to achieve event removal. Nevertheless the reviewer does not consider this to be necessary. It should also be noted that the process is unlikely to result in event outcomes that would have been obtained if the EEST had been applied initially with lower environmental demands. Whilst this initially seems incongruous, it is in the reviewer's opinion the proper outcome of the application of Schedule 6's requirements particularly those associated with the limits of change. <p>Accordingly the reviewer considers the automated event removal tool to be 'fit-for-purpose'.</p>
(g)	<p>analyse modelling outputs are technically sound ways to calculate flow statistics used as part of applying the</p>	<p>The process of converting modelling outputs to flow statistics is undertaken using standard routines which the MDBA has utilised for many years including during preparation of the Basin Plan. These</p>

Item	Terms of Reference	Review's Response
	default method for calculating a supply contribution (see Schedule 6 of the Basin Plan);	are widely accepted as technically sound ways to calculate flow statistics and have been examined as part of numerous modelling assessments. Any errors in these routines would have already been identified. Consequently the reviewer considers the methods used to calculate flow statistics to be technically sound.
(h)	analyse modelling outputs are technically sound ways to determine detrimental impacts on reliability of supply of water to the holders of water access rights	Assessments of impacts on reliability of supply have been undertaken using a variety of reliability metrics as discussed in Section 3.1.3 above. In addition reliability impacts have also been assessed through expert reviews undertaken by the States' water managers. In the opinion of the reviewer these are appropriate means to assess reliability impacts and are consistent with the requirements of Section 7.15(1)(d) of the Basin Plan.
2	The modelling methodologies used by the MDBA to support the Northern Basin review are:	
(a)	transparent, repeatable, practical and objective;	Documentation is limited at the present time as the process is not complete. Transparency would be improved through provision of further documentation which will occur as the Northern Basin Review process is concluded. Repeatability, practicality and objectivity have been enhanced (relative to the modelling undertaken for the Basin Plan).
(b)	evidence based, technically sound, fit-for-purpose and incorporate statistical approaches which are widely accepted as best practice	The technical soundness and 'fit-for-purpose' characteristics of the modelling frameworks are assured because these frameworks are enhancements of those used during the Basin Plan and which have already been considered appropriate for use. The statistical approaches used in analysing model outputs have been undertaken using standard routines which the MDBA has utilised for many years including during preparation of the Basin Plan. These statistical approaches are widely used by State water authorities, agencies and consultants to analyse hydrologic model outputs from long-term simulations.
	In assessing the above, the reviewer should consider whether the methods and approaches used to:	
(c)	produce environmental demand time series and representation of water recovery strategies are evidence based, technically sound and fit-for-purpose;	<u>Environmental Demand Timeseries</u> The method used in the Northern Basin to develop environmental timeseries for both local and downstream demands has involved an enhancement of the environmental event selection tool (EEST) previously used in the preparation of the Basin Plan. The procedure of identifying environmental watering opportunities by comparing the hydrographs generated by the 'without development' and 'baseline' scenarios remains the same. The biggest challenge for the procedure in the Northern Basin is the manner in which demand timeseries are generated at the bottom of the regulated tributaries in order to meet environmental demands in the Barwon-Darling (at Bourke).

Item	Terms of Reference	Review's Response
		<p>It must be recognised that there are currently no management arrangements in place that would allow the necessary 'flow coordination' to take place so that releases from the tributaries could be synchronised to achieve environmental flow targets in the Barwon-Darling. Nevertheless these could be developed in the future. Leaving aside the institutional arrangements that would be needed, the hydrological issues associated with such flow coordination procedures present some challenges. These are the prediction of flow losses and flow routing, the influences of operational constraints such as limited channel capacity, and the uncertainty and variability introduced by antecedent moisture conditions.</p> <p>The current hydrological models simulate flow losses, routing and operational constraints on a daily basis using the best available science. These models are the principal simulation tools underpinning the current water sharing plans in NSW and Queensland. Whilst the influence of antecedent moisture conditions is only crudely represented in the models, a range of techniques are available to determine the uncertainty and variability in the models' predictions of environmental flows in the Barwon-Darling.</p> <p>The procedures in the EESTs are not as sophisticated as the models' because they are based on average travel times and constant flow losses. Nevertheless the process of iteratively operating the EESTs with the models allows initial estimates from the EESTs to be refined by the models. These iterations are also important for water accounting because the models have not yet been updated to provide for environmental water accounts.</p> <p>There are recognised deficiencies and inaccuracies in the State models used in the modelling framework which are progressively being improved. Nevertheless the impacts of these current deficiencies and inaccuracies on the outcomes of the Northern Basin Review are mitigated by the comparative modelling approach discussed in Section 3.2.4.</p> <p>There is also the issue of 'protection' of environmental flows passed along unregulated reaches where the existing irrigator access rules would allow extraction within licenced flow ranges. The reviewer understands that no flow protection arrangements have been included within the current scenarios under consideration within the Northern Basin Review. However an individual irrigator's access would be limited to his entitlement which in turn is subject to the MDBA's 'cap' on diversions and the water sharing plan access limits. These capping mechanisms are included in the models and ensure diversions from individual valleys remain at 1993/94 levels of demand and that the water sharing plan limits are not breached. The existing models therefore have the ability to identify the extent to which those irrigators with access to environmental water have an advantage over those irrigators without such access. (As State water resource plans are developed under the Basin Plan, additional procedures may need to be introduced to manage any inequities that are identified).³⁸</p>

Item	Terms of Reference	Review's Response
		<p>In conclusion, the existing hydrological models and the methods and procedures including the EESTs that have been prepared for the Northern Basin Review have the capability to reasonably predict the hydrological outcomes of the proposed SDL scenarios. Whilst some uncertainties in the models' simulation of hydrological connections between Barwon-Darling and its tributaries remain, in the opinion of the reviewer the models and the methods and procedures are technically sound and fit for purpose.</p> <p><u>Water Recovery Strategy</u> To date the water recovery has been simulated in the model based on the characteristics of environmental water recovery that has been achieved to the present time. This is a change from the overall 'pro-rata' approach used in the BP-2800 scenario. Nevertheless the method for simulation of the recovery volumes in the model is by adjustment of the entitlements. This is the same method as was used in the Basin Plan modelling. The method is technically sound and fit-for-purpose.</p>
(d)	analyse modelling outputs are technically sound ways to calculate flow statistics;	The process of converting modelling outputs to flow statistics is undertaken using standard routines which the MDBA has utilised for many years including during preparation of the Basin Plan. These are widely accepted as technically sound ways to calculate flow statistics and have been examined as part of numerous modelling assessments. Any errors in these routines would have already been identified. Consequently the reviewer considers the methods used to calculate flow statistics to be technically sound.
3	<p>The scope of the review is limited to the modelling processes implemented by the MDBA and does not include framework components already reviewed. These include:</p> <ul style="list-style-type: none"> (a) the 24 River-system models that cover the Murray-Darling Basin; (b) the Integrated River System Modelling Framework; (c) the Ecological Elements method developed by the CSIRO-led project team; and (d) the method for determining the Environmentally Sustainable Level of Take. 	Noted

5. SUMMARY AND CONCLUSIONS

This is an independent review of the Authority's hydrological modelling frameworks which are being used to support two separate processes that may lead to SDL amendments within the Basin Plan.

These two processes are the SDL Adjustments (as per Chapter 7 of the Basin Plan) and the Northern Basin Review (as per Section 6.06 of the Basin Plan).

The review's key findings are:

- (a) The modelling frameworks that are being used for the SDL Adjustment and the Northern Basin Review projects are largely based on the framework used during the preparation of the Basin Plan. The credentials of this framework have already been established during the preparation of the Basin Plan.
- (b) Work on both projects is currently underway within the Authority. The review has not identified any key weaknesses in the modelling frameworks or approaches that would prevent them from being used for the two projects in a manner which is consistent with the requirements of the Basin Plan. Accordingly the review endorses the use of the modelling frameworks to support each project.
- (c) Some changes in modelling frameworks and modelling approaches have been introduced since preparation of the Basin Plan. These changes are as a result of refinements to processes used for the Basin Plan or as a result of automation of some previous manual processes. In the case of the SDL Adjustments, the changes are also in response to the specific legislative requirements of this project. In respect of the Northern Basin, changes have been required to allow better simulation of environmental water ordering from the tributaries to meet environmental water needs within the Barwon-Darling.
- (d) For both projects, the methods applied to model outputs to calculate flow statistics have been reviewed. These methods are based on long established procedures that have been used during the preparation of the Basin Plan and as part of numerous other modelling projects. The reviewer considers these methods to be technically sound and appropriate for the purposes of the SDL Adjustment and the Northern Basin Review projects.
- (e) Specifically in respect of the SDL Adjustment project, the review has also identified that:
 - the modelling framework and modelling processes are compliant with the 'default method' specified in Schedule 6 of the Basin Plan and are appropriate for the calculation of a supply contribution under the Plan;
 - the modelling methods used to produce the environmental demand timeseries (i.e. event selection and event removal) are technically sound and repeatable and can be used consistently between the Benchmark and supply measure modelling scenarios;
 - the methods used to analyse model outputs to determine impacts on supply reliability are technically sound and appropriate to the requirements of the Basin Plan.

- (f) Specifically in respect of the Northern Basin Review project, the review has identified that:
- the methods and approaches used to produce environmental demand timeseries and to simulate water recovery are consistent with the requirements of the Basin Plan and are technically sound and fit-for-purpose;
 - whilst some deficiencies and inaccuracies remain in the State models of the Barwon-Darling and its various tributary valleys, the comparative modelling approach diminishes the influence of these deficiencies and inaccuracies on the outcomes of the Northern Basin Review;
 - issues related to 'flow coordination' and 'flow protection' will be important considerations in the future development of management rules for environmental watering. The review has identified that the current modelling framework is capable of reasonably simulating outcomes of the initial watering concepts that have been assumed in the various scenarios currently under consideration for the Northern Basin Review.
- (g) For both the SDL Adjustment and the Northern Basin Review projects, this review has not sort to endorse any proposed numerical SDL changes. Rather it is a review of the suitability and capabilities of the modelling frameworks and proposed methods that will be used to produce these numerical SDL changes in the future.

APPENDIX A

TERMS OF REFERENCE FOR THIS REVIEW

Review of the hydrological modelling frameworks used to inform potential Basin Plan amendments

Background

Independent review is sought of MDBA's hydrological modelling frameworks used to support two separate processes that may lead to amendments to the Basin Plan:

- Sustainable Diversion Limit Adjustments (SDLA) – as per Chapter 7 of the Basin Plan; and
- Northern Basin review – as per Section 6.06 of the Basin Plan.

With regards to SDLA, Chapter 7 and Schedule 6 of the Basin Plan 2012 provides for the Authority to propose adjustments to the Sustainable Diversion Limits under Section 23A of the Water Act 2007 (Cwth). Chapter 7 stipulates the method to be applied in calculating the adjustment amount, with the specific features of the method provided in Schedule 6. During 2014-2015, the MDBA implemented this hydrological model-based method (known as the *SDLA assessment framework*) in consultation with Basin governments.

With regards to the Northern Basin review, in finalising the Basin Plan in 2012 the MDBA recognised there was less knowledge available for the northern basin than the southern basin. Subsequently, the Basin Plan (Section 6.06) provided an opportunity for additional research and investigation by 2015 into aspects of the Basin Plan in the northern Basin, including the long-term average sustainable diversion limits. The Northern Basin review comprises three key programs: environmental science assessments; social and economic assessments; and hydrological modelling. The hydrological modelling component has been used to estimate changes in flow under a range of different water recovery scenarios from which environmental outcomes have been inferred.

The MDBA would like an independent review to assess whether all hydrological model-based components of the SDLA assessment framework and the Northern Basin review are technically sound and compliant with relevant aspects of the Basin Plan. To achieve this, it is proposed that an independent review is carried out by a hydrologic modelling expert of:

- SDLA modelling framework and modelling processes; and
- modelling methodology used to support the Northern Basin review, including the setup of relevant modelling scenarios

Scope of Work

The scope of work of this independent review is to assess whether:

1. the SDLA modelling framework's and modelling processes (as represented in Calculating the supply contribution for SDL Adjustment: A trial application of the 'default method') implemented by the MDBA are:
 - (a) compliant with the Default method specified in Schedule 6 of the Basin Plan;
 - (b) appropriate for calculating the 'supply contribution' as defined in Sections 7.15 of the Basin Plan;
 - (c) transparent, repeatable and objective; and,
 - (d) technically sound and fit-for-purpose.

In assessing the above, the reviewer should consider whether the methods and approaches used to:

- (e) develop the Benchmark scenario and adjustment scenarios are consistent with Sections 7.15 (1) as well as S6.01 and S6.02 of Schedule 6 of the Basin Plan;
 - (f) produce environmental demand time series and adjust environmental water entitlements are technically sound and have been developed and applied consistently between the benchmark and supply measure modelling scenarios;
 - (g) analyse modelling outputs are technically sound ways to calculate flow statistics used as part of applying the default method for calculating a supply contribution (see Schedule 6 of the Basin Plan);
 - (h) analyse modelling outputs are technically sound ways to determine detrimental impacts on reliability of supply of water to the holders of water access rights
2. the modelling methodologies used by the MDBA to support the Northern Basin review are:
- (a) transparent, repeatable, practical and objective; and,
 - (b) evidence based, technically sound, fit-for-purpose and incorporate statistical approaches which are widely accepted as best practice.
- In assessing the above, the reviewer should consider whether the methods and approaches used to:
- (c) produce environmental demand time series and representation of water recovery strategies are evidence based, technically sound and fit-for-purpose;
 - (d) analyse modelling outputs are technically sound ways to calculate flow statistics;
3. The scope of the review is limited to the modelling processes implemented by the MDBA and does not include framework components already reviewed. These include:
- (e) the 24 River-system models that cover the Murray-Darling Basin;
 - (f) the Integrated River System Modelling Framework;
 - (g) the Ecological Elements method developed by the CSIRO-led project team; and
 - (h) the method for determining the Environmentally Sustainable Level of Take.

Approach and Methodology

The findings of the independent review are to be presented in a Final Report, supported by the following activities:

1. Inception meeting (Teleconference)

The purpose of the inception meeting is to:

- 1 Provide any clarifications or further details on the scope of work;
- 2 Agree on key elements of a project work plan particularly methods and timeframes for delivery of the Draft and Final Report;
- 3 Discuss evaluation criteria to be applied as part of the review;
- 4 Agree on content of the Final Report.
- 5 Discuss documents and other material to be provided by MDBA to support the review.

2. MDBA workshop(s)

The Independent Reviewer will make at least one visit to MDBA office to discuss/seek clarifications with relevant staff on applicable modelling frameworks, legislative requirements and their interpretation of the legislation, how the hydrological modelling has been applied and any other information or clarifications that the reviewer needs to complete this task.

3. Draft Report Summarising the reviews findings

Deliverables

The review will deliver a Draft Report to the Authority for comment on the findings

The review will deliver a Draft Report summarising its findings by 13th June 2016. . This report must include:

- A summary of the scope, methodologies and criteria applied by the review;
- An evaluation of the models and modelling methodology being used by the MDBA to determine SDL Adjustment amounts consistent with the SDLA assessment framework, specifically in regards to:
 - consistency with Chapter 7 and Schedule 6 legislation;
 - interpretation and implementation of objective and repeatable processes;
 - suitability for calculating the supply contribution; and
 - assumptions being appropriate and technically sound.
- recommendations on the suitability of the modelling processes used by the Authority to inform adjustments to Sustainable Diversion Limits as part of the *SDLA assessment framework* and the *Northern Basin review*; and,
- suggested improvements to enhance the robustness and accuracy of modelling processes to ensure the SDLA assessment framework and the Northern Basin review modelling methodology are technically sound and fit-for-purpose.

The review will deliver a Final Report by 27th June 2016. The Final Report must take into consideration comments received from the Authority.

APPENDIX B

PRINCIPAL DOCUMENTS EXAMINED DURING THIS REVIEW

Review documents (in chronological order):

- B1. *Proposed River Modelling Methods and Integrated River System Modelling Framework Design for use in Basin Plan Modelling.* Podger, G., Yang, A., Brown, A., Teng, J., Power, R. and Seaton, S. CSIRO: Water for a Healthy Country National Research Flagship. July 2010.
- B2. *River System Modelling for the Basin Plan Assessment of fitness for purpose.* Podger, G.M., Barma, D., Neal, B., Austin, K. and Murrehy, E. CSIRO: Water for a Healthy Country National Research Flagship. December 2010.
- B3. The proposed “environmentally sustainable level of take” for surface water of the Murray-Darling Basin: Methods and outcomes. MDBA publication no: 226/11. November 2011.
- B4. *Science Review of the estimation of an environmentally sustainable level of take for the Murray-Darling Basin.* Young WJ, Bond N, Brookes J, Gawne B and Jones GJ. November 2011.
- B5. *Basin Plan KEA Utility.* User Guide. MDBA, Basin Plan Division. November 2011.
- B6. *Hydrologic modelling to inform the proposed Basin Plan - methods and results.* MDBA publication no: 17/12. February 2012.
- B7. *Hydrologic modelling of the relaxation of operational constraints in the southern connected system: Methods and results.* MDBA. October 2012.
- B8. *Water Act (Cth) 2007 and Basin Plan,* November 2012.
- B9. *Explanatory Statement, Basin Plan,* 2012.
- B10. *Refinement of the EEST Automation Proposal.* Discussion paper presented to the Benchmark Modelling Working Group. MDBA. 31 October 2013.
- B11. *Benchmark conditions of development for adjustment of SDLs.* (Based on Benchmark model used for the trial implementation of the default method). MDBA Publication no. 25/13 – v2. Preliminary draft version 2. October 2014.
- B12. *Development of the Murray-Darling Basin Plan SDL Adjustment Ecological Elements Method.* Overton IC, Pollino CA, Roberts J, Reid JRW, Bond NR, McGinness HM, Gawne B, Stratford DS, Merrin LE, Barma D, Cuddy SM, Nielsen DL, Smith T, Henderson BL, Baldwin DS, Chiu GS and Doody TM. Report prepared by CSIRO for the MDBA. 2014.
- B13. *Calculating the ‘supply contribution’ for SDL Adjustment: A trial application of the ‘default method’ – Revised technical report.* MDBA. May 2015.
- B14. *SDL Adjustment Stocktake Report.* Warren Martin and Graeme Turner. August 2015.
- B15. *Interim advice on supply measures - November 2015.* MDBA. November 2015.
- B16. *Surface water: sustainable diversion limit (SDL) adjustment mechanism.* Article published by MDBA at www.mdba.gov.au/basin-plan-roll-out/sustainable-diversion-limits/surface-water. Downloaded June 2016.

- B17. *Northern Basin*. Article published by MDBA at www.mdba.gov.au/basin-plan-roll-out/northern-basin. Downloaded June 2016.
- B18. *Hydrologic Modelling for the Northern Basin Review*. MDBA. Early incomplete draft report in preparation. September 2016.

Addendum to:

Review of the Hydrological Modelling Frameworks used to inform Potential Basin Plan Amendments

These Basin Plan amendments are those proposed for:

- Northern Basin Review; and
- SDL Adjustments

22 November 2016



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Addendum

This is an addendum to the September 2016 report '*Review of the Hydrological Modelling Frameworks used to inform Potential Basin Plan Amendments*'.

This addendum was prepared to address issues raised by members of the Northern Basin Advisory Committee (NBAC).

These issues were provided to the reviewer:

- (a) in various emails to the reviewer from NBAC; and
- (b) at the meeting held between the reviewer and NBAC on 5 October 2016 in Canberra.

The reviewer's responses to the issues have been provided in **Table 1**. In addressing some of these issues the reviewer sought input from the MDBA and this information has also been included in **Table 1**.

Note that this addendum relates only to the Northern Basin Review and does not contain matters that are relevant to the review of hydrologic modelling frameworks used to inform the SDL Adjustment process.

Table 1: Response to Issues raised by Members of the Northern Basin Advisory Committee (NBAC)

Issue/Question	Source of Response	Response
Achievement of SFIs		
optimised so they overstate the frequency & likelihood of achievement	Drew Bewsher	Each model's parameters relating to flow timing, losses, routing, etc, are unchanged from the parameter values set by the State agency that developed the model. Accordingly these parameters have not been optimised to achieve SFI outcomes. Existing models only achieve SFIs at Bourke roughly 50% of the time. The practicality and feasibility of achieving 'flow coordination' and 'flow preservation' in actual practice are outside the terms of reference of the model review. (Refer Bewsher's Review Report pages 12 & 13, Section 2.4.4).
responsiveness of SFIs to the recovered volume is unknown	MDBA	The MDBA advised that a range of water recovery modelling scenarios were completed to inform the Authority's review of SDL's in the Northern Basin. Within these scenarios, only the water recovery volume is varied with all other assumptions and parameters associated with the hydrologic model remaining static. Any changes in the pattern of flows between the various recovery scenarios is as a direct result of changes to the amount of water recovered. The outcomes of these scenarios, including SFI results, have been presented to NBAC.
there seems to be little difference in SFIs achieved after 320 GL	MDBA	The water recovery volumes tested, range between 8 – 13% of the Baseline Diversion Limits. The limited change in SFIs for the Barwon Darling system reflects this relatively small variation in the recovery volumes represented in the various scenarios. It is also important to note that the range of environmental outcomes possible for a given volume of water recovery are dependent on where and what type of water entitlements are recovered. These factors will be considered by the Authority in reaching its decision.
no sensitivity analysis	MDBA	The ecological outcomes report gives a description of the environmental results associated with each of the model scenarios. The primary set of metrics underlying this analysis are the SFIs, but this report also gives a qualitative interpretation of the ecological differences between scenarios, based partly on sensitivity testing of the SFIs. The modelling report includes an analysis of the differences between scenarios over the whole flow regime. The results of the various water recovery and delivery scenarios show the sensitivity of the environmental outcomes to changes in recovery volume and entitlement characteristics. The results of these water recovery scenarios have been presented to NBAC. The Authority have been briefed on the uncertainty inherent in the SFIs and will take this into account when making their decision regarding the SDLs.

Issue/Question	Source of Response	Response
can the assumed pattern of environmental water delivery be replicated in the real world?	MDBA	<p>MDBA modelled two possible strategies of environmental water use. Strategy 1 (whole-of-North coordinated) represents a highly managed system in which catchments work proactively to coordinate flows into the Barwon–Darling. This would require a significant forecasting capacity upgrade, and substantial changes to existing operational practices. Strategy 2 (catchment-scale), in which catchments work individually to maintain low flow connectivity with the Barwon–Darling, represents a management strategy more in-line with current operating practices.</p> <p>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.</p> <p>The Commonwealth water recovery Strategy is expected to be revised following the finalisation of the Northern Basin Review.</p>
no quantification of risks/likelihood of results being achieved. This would allow the Board to place emphasis on other tools to deliver results.	MDBA	<p>Hydrologic modelling and associated scenario testing are one line of evidence for defining the range of outcomes possible under the Basin Plan. The analysis of all available information resulted in the identification of a range of other management actions to be considered as part of the Northern Basin Review</p> <p>As many of the other management actions require the involvement of a range of stakeholders, ultimately success will come down to a willingness for the Australian and State governments as well as the community to work together.</p>
<p>If the modelling is overstating the achievement of environmental outcomes then this leads to:</p> <ul style="list-style-type: none"> i. further negative impacts on irrigation communities (through the justification of increased environmental water recovery), ii. poor delivery of environmental outcomes, and iii. a lack of strategic rethinking about what is the right combination of tools & strategies (not just flows) to deliver & manage environmental outcomes for the North from the Basin 	MDBA	<p>Modelling is used to inform decisions through the relative difference in outcomes rather than the absolute outcome. While model outputs are used in both environmental and economic analysis, the Authority will consider multiples lines of evidence. This includes consideration of a number of non-flow related tools including temporary trade, use of on-farm storage, constraint relaxation and flow protection.</p>

Issue/Question	Source of Response	Response
environmental flows cannot be coordinated. How much does that change the model as coordinated flows account for 40% of targets in BD?	MDBA	Uncertainty exists with co-ordinated environmental water delivery modelled as part of the work informing the Northern Basin Review as this has not occurred before. In reality there will be some areas river operators could do better than the model in co-ordinating environmental water delivery and other areas where results in practice may be worse. Either way the MDBA and NSW supports attempts at co-ordinated environmental delivery as this ensures efficient use of environmental water and is confident this co-ordination will improve over time.
Model Climatic Period		
no one knows how often or not the modelled scenario conditions occur over the long term (i.e. 100 years).	MDBA	The model is run using actual climate conditions over the 114 year period 1895 – 2009. This period includes wet, medium and dry years. Actual climate conditions includes elements such as actual daily rainfall and evaporation. Modelling of water recovery scenarios assume that the climatic conditions experienced over the 114 year sequence are representative of both past and future weather patterns.
the model assumes a certain set of scenarios and as there hasn't been a Monte-Carlo analysis done, we don't really know how likely are the combination of scenario characteristics (climatic sequence, wet or dry rivers, etc)	MDBA	
using wet periods for model inputs and diversion over dry skews results giving a misleading measure of diversions	MDBA	
IQQM transmission losses are based on average conditions. This is a farce as the 33% of years since 1944 represent <5% of total volume and each of those years is less than one third of average annual flows. The scatter on transmission losses would be wide.	Drew Bewsher	The IQQM transmission losses used in the NSW and Queensland models are specified as a percentage of the flow within each reach of each model. These percentages vary with flow and were determined by the State agency which developed the model to best fit the observed historical loss behaviour. The loss percentage does not vary with antecedent conditions. In this sense it is an "average" loss. However the modelled losses do vary with flow magnitude so they are not the same each year. The modelled losses will be significantly different in the dry years mentioned in this question. (Refer Bewsher's Review Report page 25, Table 1, Item 2(c), para 3).

Issue/Question	Source of Response	Response
Water Recovery		
do the models replicate the actual pattern of water recovery?	MDBA	No. In most model scenarios the recovery pattern to date is represented at the catchment scale, however some of that recovery is contracted only and not yet achieved. Some scenarios ignored current recovery to test the extent to which the spatial pattern of recovery could affect flow outcomes in the Barwon-Darling.
what are the assumptions about future water recovery?	MDBA	A pro-rata recovery of entitlement types across the Basin is assumed where further recovery is modelled. Some of the scenarios aim to investigate the effect of recovering different entitlement types, in these scenarios the pro-rata recovery assumption has not been applied. Detailed design of all scenarios is set out in the Hydrological Modelling Report.
sensitivity of outcomes to recovery location is an issue	MDBA	The MDBA has completed a number of model scenarios that examine the effect of different spatial recovery options. Detailed design of all scenarios is set out in the Hydrological Modelling Report.
Barwon-Darling Model Issues Arising from Bewsher's Cap Model Audit		
Bewsher's audit says " <i>Barwon Darling IQQM is the key linking model The failure to improve model's replication of flow and diversion behaviour, has potential to discredit the hydrologic modelling capacity, not only within the valley but within the whole basin</i> ". His audit of the model says it needed major work and NSW has not done that work. These model problems include: validation of diversion data, no automatic water balance, no upgrading of validation, questions surrounding Colly diversions, inclusion of the 15 weirs (with 100 GL of storage), inclusion of town water supplies	Drew Bewsher	Bewsher has audited all the NSW and Queensland models which are used for cap compliance including the B-D model. All these audits identified deficiencies (of varying significance) in the models. However none of these deficiencies prevented the models from being used for cap compliance (with the B-D model receiving only provisional accreditation pending further improvements). The B-D model has already been used for the Basin Plan and has been used to set BDLs. This was the 2009 version of the B-D model. The 'comparative approach' (refer Bewsher's Review Report Page 20, Section 3.2.4) diminishes the impacts of the model deficiencies when used to assess water recovery volumes and environmental watering as part of the NBR. Bewsher's review concluded that whilst it is appropriate to use the 2009 B-D model for the NBR he did so on the understanding that the MDBA was aware of the model deficiencies and would also " <i>utilise other non-modelling procedures and information when recommending revised SDLs for the Northern Basin</i> " (Refer Bewsher's Review Report para (d), Page 20).

Issue/Question	Source of Response	Response
the Barwon-Darling cap model always had concerns and was only given provisional accreditation until end 2014. NSW had to address issues that have never been done	Drew Bewsher	See comments in the preceding row of this table.
Bewsher recommended inclusion of the Intersecting Streams in the model. This will encourage irrigators to increase water take	Drew Bewsher	<p>This recommendation related to cap accounting procedures. The Intersecting Streams are a separate 'Designated Valley' under Schedule E of the MD-B Agreement and have their own cap distinct from the B-D cap.</p> <p><u>Note:</u> As a response to this issue and wider concerns that irrigator behaviour might change in the future (or has already changed since the conditions represented in the 2009 B-D model), Bewsher understands the States will take account of these concerns when developing their 2019 water sharing plans (WSPs) and their WSP models, as part of implementation of the Basin Plan. Therefore it is not appropriate to alter the SDL scenario model to include these concerns for the reasons outlined in Bewsher's review – see commentary on 'comparative approach' (refer Bewsher's Review Report Page 20, Section 3.2.4) which is also discussed above.</p>
Additional Barwon-Darling Model Issues		
inflows from the tribs, especially the Castlereagh, Matharguy, Marra and the Bogan are poorly represented. This year's inflows from the Bogan have been significant.	MDBA	The Northern Basin is largely unregulated and has less reliable gauge and water loss information to base model calibrations on. This is particularly true in catchments like the Macquarie with large terminal wetlands where losses vary considerably depending on antecedent moisture conditions. This is compounded further by insufficient reliable gauging of river flows both upstream and downstream of such features. Nevertheless the comparative modelling approach diminishes the impacts of these inaccuracies and uncertainties..

Issue/Question	Source of Response	Response
the 2010 Podger et al 'Assessment of fitness for purpose' notes a multitude of major deficiencies. Why aren't these still valid?	Drew Bewsher	These deficiencies are commented upon in Bewsher's Review Report (refer Section 3.2.3 on page 19). These deficiencies were recognised by the MDBA when using the models to prepare the Basin Plan in 2012. The 'comparative approach' (refer Bewsher's Review Report Page 20, Section 3.2.4) diminishes the impacts of the model deficiencies when used to assess water recovery volumes and environmental watering as part of the NBR. As noted elsewhere in these responses, Bewsher's review concluded that whilst it is appropriate to continue to use the modelling framework for the NBR he did so on the understanding that the MDBA was aware of the model deficiencies and would also "utilise other non-modelling procedures and information when recommending revised SDLs for the Northern Basin" (Refer Bewsher's Review Report para (d), Page 20).
all these appear to be unresolved issues before we apply the 2012 version of BDWSP and the unknown changes to OFS, irrigator behaviour and the coordinated model outcomes of the NBR.	MDBA	<p>No, the 2012 version of the BDWSP has not been used, but it was tested. The comparative modelling approach diminishes the impacts of these inaccuracies and uncertainties. Consideration was given to new models since 2012, but to be adopted they must be:</p> <ul style="list-style-type: none"> • Sufficient time to ensure that any changes to the Baseline Diversion Limit were verifiable as the new versions of models had not been audited or assessed (e.g. new Barwon Darling model was not received until June 2016). • Comparability (important to maintain comparability with the 2012 modelling that informed the Authority's original decision). • Confidence (the new models were new, but not necessarily better or final).
has 2012 BD WSP been used? Are all the changes in the BD WSP in the model?	MDBA	
is there recognition of growth in storage?	MDBA	
has Bewsher determined that there was enough information from gauge data to support the model, particularly for the Barwon Darling? Insufficient gauging means the modelling is highly inaccurate.	Drew Bewsher	The deficiencies in the B-D gauge data are real and lead to some inaccuracies and uncertainties in the model results. Nevertheless the comparative modelling approach diminishes the impacts of these inaccuracies and uncertainties. Further the B-D model has been used to determine BDLs and can be used to investigate SDL scenarios subject to the qualifications noted above under the section 'Barwon-Darling Model Issues Arising from Bewsher's Cap Model Audit'.

Issue/Question	Source of Response	Response
<p>MDBA has been unable to complete a risk analysis of protection of environmental flows due to insufficient gauging data.</p>	<p>MDBA</p>	<p>As part of the Northern Basin Review, MDBA have completed an analysis of risks to achieving environmental flows in the Barwon–Darling. NBAC members were provided with the opportunity to be briefed on this work as part of a meeting in Sydney on September 23rd.</p> <p>This study noted that the analysis of flow gauge data is inconclusive in detecting flow changes in response to any changes to rules that have occurred in this system over recent years. It was noted that insufficient gauging data is one of a number of reasons for this outcome. Other possible reasons include the highly variable nature of the system, the assumptions regarding water user behaviour in the model being incorrect, and the change not occurring in the limited number of years since the rule was changed.</p> <p>As an ongoing principle, MDBA support a robust river gauging network with a high spatial resolution. This type of river monitoring data is important for many aspects of ongoing water management and the water reform processes.</p>
<p>if the standard deviation is about 360GL over northern basin does this not show the models are very inaccurate?</p>	<p>MDBA</p>	<p>Whilst some deficiencies and inaccuracies remain in the State models of the Barwon-Darling and its various tributary valleys, the comparative modelling approach diminishes the influence of these deficiencies and inaccuracies on the outcomes of the Northern Basin Review.</p> <p>To enhance the clarity of the response further clarification of this question particularly the source of the 360 GL figure may be required.</p>
<p>have MDBA adequately modelled the fact the northern system cannot be joined up?</p>	<p>Drew Bewsher</p>	<p>Further clarification of this question may be required. It is assumed that this question means “have the MDBA adequately modelled the processes of ‘flow coordination’ and ‘flow preservation’ in the Barwon-Darling”?</p> <p>Each model’s parameters relating to flow timing, losses, routing, etc, are unchanged from the parameter values set by the State agency that developed the model. Accordingly the prediction of the “joining up” of the northern system is replicated by the model. The practicality and feasibility of achieving ‘flow coordination’ and ‘flow preservation’ in actual practice are matters for governments to work through. (Refer Bewsher’s Review Report pages 12 & 13, Section 2.4.4).</p>

Issue/Question	Source of Response	Response
on actual data developed by Geoff irrigators can pump the BD dry in 1 in 3 years. Is that incorrect?	MDBA	<p>WSP conditions do not allow irrigators to pump the river dry. Access conditions for licenced entitlements are tied to a pumping threshold, below which irrigators cannot pump from the river. Assuming compliance with these conditions, the WSP ensures that water remains in weir pools.</p> <p>Also, the '1 in 3' estimate appears to be based on the assumption that all irrigators make maximum use of access rights (i.e. up to their 300% credit limit). This is a contrived situation in which all irrigators have at least 300% credit from previous years, and that this occurs during a year in which flow conditions allow them to access this credit to the maximum amount. Over the 114-year modelling period, these conditions never occur. Furthermore, a 'drain the river dry' outcome would require no further flow after maximum take has been achieved.</p>
model assumes capping of diversions but this is not reflected in management rules.	Drew Bewsher	All models used in the modelling framework are either cap models or subsequent versions of these models which include for cap. Note that all NSW's WSPs and all Queensland's WRPs and ROPs contain rules which ensure compliance with cap.
there has been a failure to responsibly model the system and prove legally to all the basin community that we could have trust in a better outcome than the default.	Drew Bewsher	For the reasons set out above and in his modelling review for the NBR, Bewsher does not agree that the NBR modelling has been irresponsible or not well-suited to the purpose to which it has been applied. Nevertheless Bewsher does agree with the author of this comment that more could be done to better explain the NBR's complex hydrology and the hydrological modelling that has been undertaken.
has consideration been given to the implications of floodplain exclusion caused by bunded areas in the lower Balonne floodplain and their positive effect on downstream flows?	Drew Bewsher	<p>The hydrologic effects of bunded areas in the lower Balonne floodplain are not explicitly simulated in the model but rather are implicitly accounted for in the models' routing calibrations. Nevertheless because not all of the current bunded areas are in the data sets used for the routing calibrations, their effects will not be fully simulated in the hydrologic model.</p> <p>As with some of the other model deficiencies that have been previously discussed, because the NBR involves a comparison of the BDL run with SDL scenario runs, the impact of the bunded areas on the outcome of the NBR will be diminished, but nonetheless still needs to be recognised.</p>
Transparency		
MDBA not sharing all assumptions so this reduces confidence	MDBA	All relevant modelling assumptions have been presented to NBAC previously and will be described in detail in the Hydrological Modelling report.