Barma Water Resources

Advice to Macquarie River Food and Fibre on a literature review of the MDBA Northern Basin Review Science & Hydrological Reports

November 2016/Final Report

Prepared by:

Barma Water Resource Consulting Pty Ltd

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Executive Summary

BWR Pty Ltd was engaged by Macquarie River Food and Fibre Inc to undertake an independent technical review and analysis of Macquarie Valley specific hydrological documentation produced by the MDBA. The review takes into account matters detailed in the project brief received on the 27th of July 2016. Outcomes of this review will:

1. Provide information to better inform decision makers regarding the likelihood of outcomes for the Basin Plan being achieved and thereby providing information to support an increase in SDL for the northern Basin; and
2. Document the limitations to achieving outcomes for the Basin Plan to inform future reviews.

The review has been undertaken separately to the review conducted by BWR for the Northern Irrigators Association, the findings of which can be found in the report BWR 2016 -Advice to the Northern Irrigators Alliance on a literature review of the MDBA Northern Basin Review Science & Hydrological Reports.

Based on a review of the NBR Macquarie Valley hydrologic modelling the flowing conclusions can be made:

Review Gaps

The following gaps have been found with respect to Macquarie Valley literature review of the MDBA Northern Basin Review Science & Hydrological Reports.

1. The Macquarie volume of long-term diversion reduction and entitlement recovery required to meet SFI targets has not been calculated in any of the modelling presented to date which is a specific gap in the NBR review process with respect to the Macquarie. Rather the volume of long-term average use already recovered (84 GL/Yr) has been represented in the model and then the achievement of the demand series through evaluation of the specific flow indicators has been checked. Consequently, the 84 GL/yr (Including the local reduction amount of 65 GL/yr) is well in excess of what is required from the Macquarie to meet the lower limit of the SFI target range.
2. The latest 2014 IQQM model has not been incorporated into the MDBA's modelling framework for the NBR. The results from the latest 2014 IQQM model would suggest that the losses through the marshes are greater than previously modelled (using the NBR Macquarie IQQM) and that the level of connectivity between the regulated Macquarie and the Barwon Darling is substantially less that previously thought.

Review Soundness

In the case of the shared contribution to the Barwon Darling it is likely that the modelled assumptions relating to where water can be realistically ordered and delivered to in the

Macquarie represents an unrealistic scenario. Real world delivery practices are most likely to result in orders not being delivered with the same degree of certainty as exhibited in the model.

Based on the observed streamflow data of Table 3, the contribution from the regulated section of the Macquarie to the Barwon Darling is very small at approximately 16% of the total Macquarie-Castlereagh System inflow. This figure is likely to reduce further if only regulated releases were considered, and uncontrolled tributary inflows downstream of Burrendong Dam were removed from the totals.

Given the small contribution of regulated inflows to the Barwon Darling relative to unregulated inflows and the degree of connectivity between the Macquarie–Castlereagh system being less than previously thought, a reduction in the Macquarie–Castlereagh shared contribution amount or reapportionment across other tributaries should be considered by the MDBA and NSW DPIWater.

The shape of the demand hydrograph used in the MDBA modelling is likely to be different to that delivered in practice. However this is not likely to effect the achievement of the Macquarie SFIs which are defined as cumulative volumes as opposed to flows exceeding a threshold.

Efficiency of approach to achieving the desired ecological outcomes

The approach used by MDBA uses hydrologic metrics to describe ecological outcomes. In the case of the Macquarie, the approach used by MDBA:

- Uses hydrologic metrics as indicators of ecological outcomes
- Represents a pattern of environmental water delivery which is highly unlikely to be replicated in practice
- Represents a pattern of water recovery which differs from actual. Although this is not expected to impact upon model results in terms of frequency of SFI achievement.
- Has not evaluated the minimum recovery amount required to achieve SFI targets
- Has not taken into account the potential use of works to deliver similar ecological outcomes.

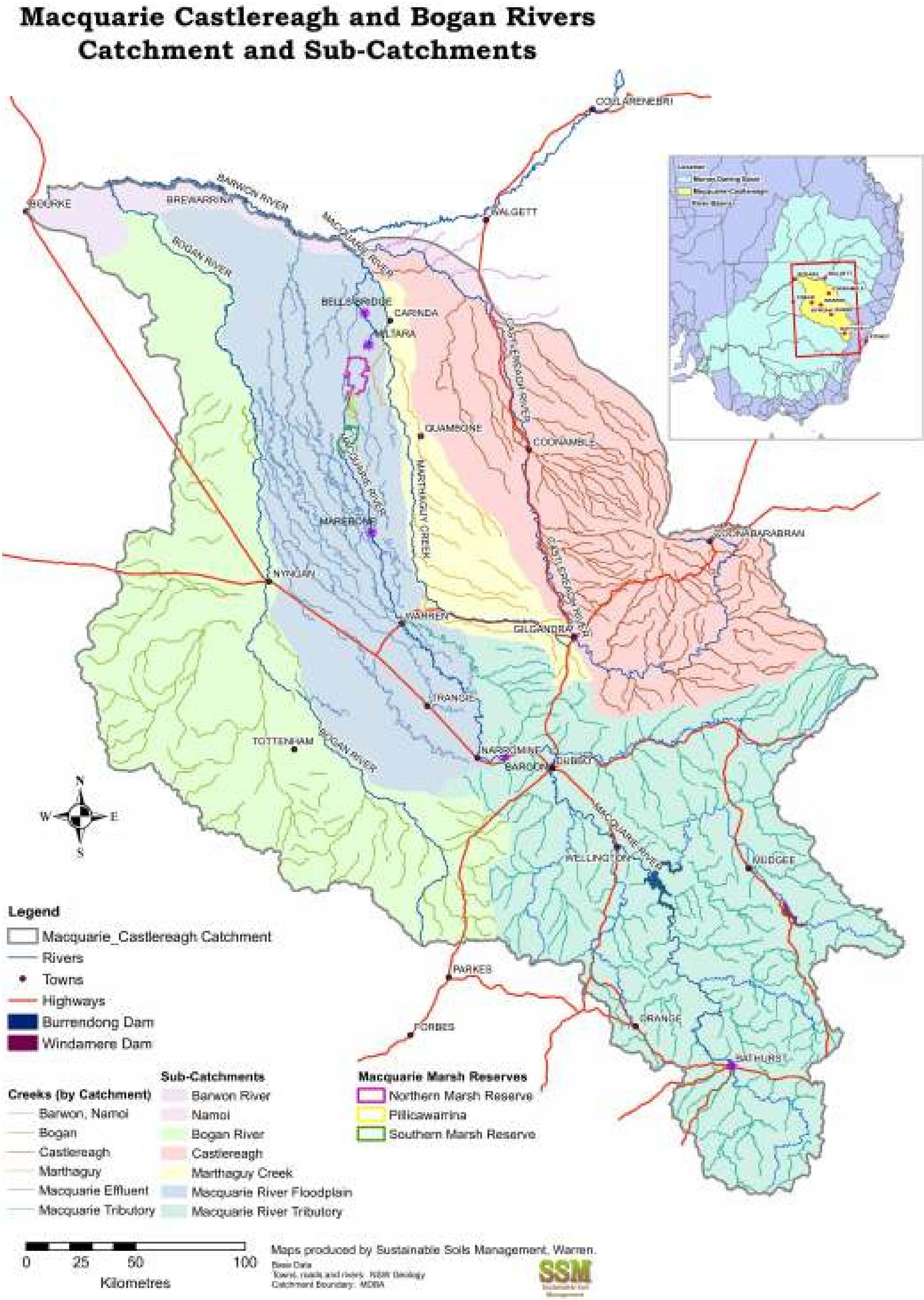
The MDBA's modelling includes a number of assumptions, including flow coordination, operational practices and environmental demand patterns that will not be achievable in practice. Delivering ordered volumes of water from Burrendong Dam at the appropriate time and location is highly unlikely due to attenuation losses and variable travel times.

If a more realistic representation of environmental water delivery practices were incorporated into the Macquarie IQQM model it is likely that modelled SFI achievement with the Barwon Darling would be lower than current modelling suggests.

Based on the preceding conclusions the following recommendations are made:

Recommendations

1. MRFF should request MDBA to provide additional information relating to the uncertainty surrounding the Macquarie Marshes inundation extents associated with SFI volumes to ensure that envisaged environmental outcomes align with SFI total inflow volumes. It is suggested that an analysis similar to the one carried out in the MDBA 2016 report *Floodplain & Vegetation Inundation using Landsat Satellite Imagery: Lower Balonne & Middle Darling* be undertaken. OEH may have already conducted an analysis similar to this and if so results should be made available to MRFF in order to provide confidence in the SFI Inflow volumes.
2. MRFF should request that MDBA undertake a sensitivity analysis of the water recovery volumes in order to evaluate the minimum recovery amount required to achieve SFI targets in the Macquarie.
3. Given the small contribution of regulated inflows to the Barwon Darling relative to unregulated inflows and the degree of connectivity between the Macquarie–Castlereagh system being less than previously thought, a reduction in the Macquarie–Castlereagh shared contribution amount or reapportionment across other tributaries should be considered by the MDBA and NSW DPIWater.
4. MRFF should consider asking MDBA to adopt the latest more detailed 2014 IQQM model and revise the booster factors which are applied to Barwon Darling inflows.
5. If the more detailed 2014 model is adopted, any revision to booster factors that are used in adjusting Barwon Darling inflows from tributary models should be supported by an assessment of the rating curve associated with the flow data to which they are applied, to ensure that the booster factors sensibly reflect rating curve inaccuracy, and have not been arbitrarily determined.
6. MRFF request that the most recent observed data (2009 to 2016) be used to sanity check the modelled data.



Map 1 – Macquarie-Castlereagh and Bogan Rivers catchment and sub-catchments

1 Introduction

BWR Pty Ltd (BWR) was engaged by Macquarie River Food and Fibre Inc (MRFF) to undertake an independent technical review and analysis of Macquarie Valley specific hydrological documentation produced by the Murray Darling Basin Authority (MDBA). The review takes into account matters detailed in the project brief received on the 27th of July 2016. Outcomes of this review will:

1. Provide information to better inform decision makers regarding the likelihood of outcomes for the Basin Plan being achieved and thereby providing information to support an increase in the Sustainable Diversion Limit (SDL) for the northern Basin; and
2. Document the limitations to achieving outcomes for the Basin Plan to inform future reviews.

The review has been undertaken separately to the review conducted by BWR for the Northern Irrigators Association, the findings of which can be found in the report *BWR 2016 -Advice to the Northern Irrigators Alliance on a literature review of the MDBA Northern Basin Review Science & Hydrological Reports*. Material from that report has been referenced in this review where appropriate.

This report addresses the project requirements relating to hydrologic outcomes in both the Macquarie and the Barwon Darling. In particular:

- Reviewing the robustness of the hydrologic science used in the review and the identification of any gaps;
- Determining if the hydrological assumptions are sound; and if this is the most efficient way to achieve the desired ecological outcomes.

The following reports have been reviewed in compiling this report:

- The proposed 'environmentally sustainable level of take' for surface water of the Murray - Darling Basin: Method and outcomes (November, 2011).
- Hydrologic modelling to inform the proposed Basin Plan: Method and results (February, 2012).
- Assessment of environmental water requirements for the proposed Basin Plan: Macquarie Marshes (2012) (sections related to Site Specific Flow Indicators (SFIs) and hydrology).

Extracts from the in preparation report "Hydrological description and outcomes reported in MDBA 2016a" were also made available by MDBA.

2 Northern Basin Review - Macquarie River Hydrology

2.1. Water Recovery Volumes

The aim of this part of the analysis is to sense-check' the hydrological requirements for the Macquarie Valley that the MDBA have stipulated, particularly as it relates to a change in valley recovery from 16 GL (MDBA, 2010) to 65 GL (MDBA, 2012).

Guide to the proposed Basin Plan 2010[1]

The first estimate of Environmental Water Requirements for the Macquarie appeared in the Murray–Darling Basin Authority 2010, Guide to the proposed Basin Plan: Technical background. The estimate had a range of 26 GL (high uncertainty) to 174 GL (low uncertainty). This estimate was based upon the diversion reduction required to achieve end of system flows that were greater than or equal to either 60% of the without development flow (for the high uncertainty case), or 80% of the without development flow for the low uncertainty case. The low uncertainty case was not viewed as practical by the Authority as it considered that it would not optimise economic, social and environmental outcomes.

Applying the high uncertainty method across all Basin Catchments results in a water recovery estimate of 3,856 GL. At the time of production of the guide, the MDBA presented results for three SDL scenarios for recovery amounts of 3,000 GL/Yr, 3,500 GL/Yr, and 4,000 GL/Yr. For the 3000 GL/Yr case the water recovery estimate for the Macquarie reduced to 20 GL/Yr. This was based on 3000/3865 of the 26 GL/Yr estimate presented in the previous paragraph.

Applying the same method to the 2750 GL Basin Plan recovery target would indicate a Macquarie water recovery target of 18.5 GL/Yr.

Advice from MDBA is that the main issue with this approach was that it didn't consider the specific needs of each catchment.

Hydrologic modelling to inform the proposed Basin Plan 2012

The approach to determining recovery volumes was modified between 2010 and 2012. Environmental water requirements relating to the specific needs of each catchment were derived. Demand series were then placed in the models in order to deliver flows to meet these requirements. Three demand time series to produce flows in excess of the baseline were developed for the Macquarie:

1. The first for the Macquarie Marshes, which was designed to meet the flow indicators in Table 1 at Marebone (Map 1). This requested a volume of

[1] MDBA 2010 – Guide to the proposed Basin Plan – Overview, MDBA publication no: 60/10, Murray-Darling Basin Authority, Canberra.

16.2 GL/y in addition to baseline flows measured at upstream of the Marebone Break.

2. The second for the Barwon shared contribution. This requested a volume of 28 GL/yr, is also located upstream of the Marebone Break in addition to the flows produced after the inclusion of the Macquarie Marshes demand time series in the previous point.

3. The third time series is for baseflow requirements as specified downstream of Burrendong storage. This series requested a volume of 1.2 GL/yr.

These three demand volumes are not directly cumulative, as they are measured at three different sites, and cannot be aggregated to estimate the long-term flow requirement, or the volume of longterm diversion reduction and entitlement recovery required to deliver the flow.

The associated Macquarie volume of long-term diversion reduction and entitlement recovery required to meet these targets has not been calculated in any of the modelling presented to date. Rather the volume of long-term average use already recovered (84 GL/Yr) has been represented in the model and then the achievement of the demand series through evaluation of the specific flow indicators have been checked.

Consequently, the 84 GL/yr (Including the local reduction amount of 65 GL/yr) is well in excess of what is required from the Macquarie to meet the lower limit of the SFI target range. *Note: It is BWR's view that there is likely to be a view from environmental agencies that any recovered volume in excess of the minimum required to meet the local and shared reduction targets will be able to be utilised elsewhere in the valley.*

2.2. Macquarie Valley Site Specific Flow Indicators (SFIs)

The aim of this part of the review was to assess the Site Specific Flow Indicators (SFIs) and hydrology requirements for the Macquarie Valley, and where possible determining if the water recovery target is accurate for achieving the stipulated SFIs. The Macquarie flow indicators are presented in Table 1, and Figure 1 together with their frequency of achievement under the:

- Without Development Scenario
- The Baseline Scenario (Riverbank Water Treated as Consumptive Use)
- Benchmark 1 (Local reduction amount of 65 GL/Yr only)
- Benchmark 2 (Local and shared reduction amount of 84 GL/Yr)

The volumes associated with each indicator have been based upon an assessment of areas of inundation for selected flow volumes in the Macquarie Marshes (based on Bowen and Simpson 2009 and NSW Department of Environment, Climate Change and

Water 2010d). The relationship between inflow volume and inundation extent has been derived from analysis of Landsat imagery of the marshes from 1979 to 2006. It is likely that the relationship has a high degree of scatter.

MRFF should request MDBA to provide additional information relating to the uncertainty surrounding the inundation extents associated with SFI volumes to ensure that envisaged environmental outcomes align with SFI total inflow volumes.

The achievement rates for the four SFI's in the Macquarie Valley indicate that two of the SFI's achieved the target range, and two were within 5% of the target range (Table 1, Figure 1) under the Baseline Scenario. This indicates that the Macquarie-Cudgegong Water Sharing Plan (DIPNR, 2004) (WSP) provided significant consideration to environmental requirements. If Benchmark 1, including only the local reduction target, without any additional recovery is included, the target range is met across all 4 SFI's.

Table 1 – Macquarie River Valley Specific Flow Indicators and Achievement Rates

Indicator	Target Range	Without Development	Baseline (Riverbank Water Treated as Consumptive Use)	Benchmark 1 with local reduction amount only	Benchmark 2 SFI Frequency of Achievement
Achieve a total in-flow volume of 100 GL over 5 months between Jun to Apr.	80-85%	91%	80%	87%	85%
Achieve a total in-flow volume of 250 GL over 5 months during Jun to Apr.	40-50%	66%	35%	46%	48%
Achieve a total in-flow volume of 400 GL over 7 months during Jun to Apr.	30-40%	48%	27%	36%	37%
Achieve a total in-flow volume of 700 GL over 8 months during Jun to May.	17%	18%	17%	18%	18%

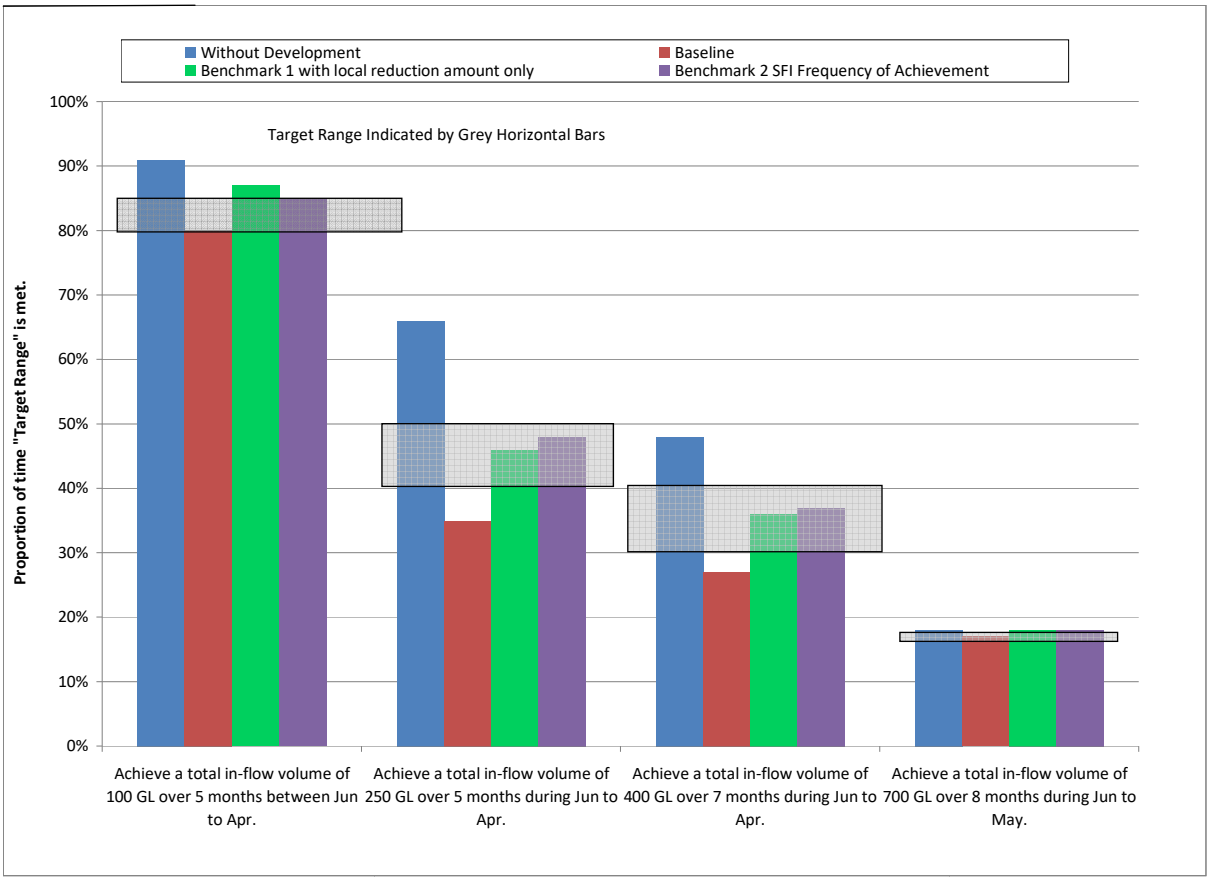


Figure 1. Comparison of Macquarie River Valley Specific Flow Indicators and Achievement Rates using the MDBA NBR Marshes Bucket Model (MDBA 2012).

This level of achievement exceeds the 2010 Basin Plan lower bound of the target range for all four of the SFIs. It is MRFF view that this indicates further water recovery requirements in the Macquarie Valley are not required, which is supported by the fact that only 15% of the total flow is extracted for production (Figure 2).

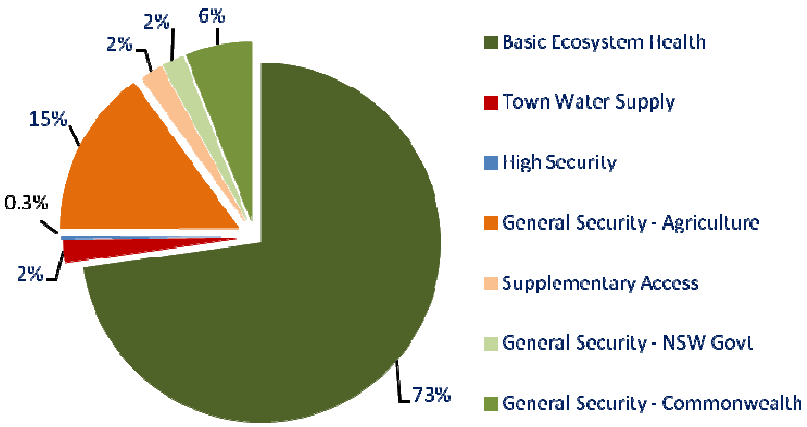


Figure 2. Current Resource Distribution (2016) for the Macquarie-Cudgegong Regulated Rivers – Long Term Average Flows (IQQM)

The MDBA have not modelled a scenario in which only the NSW River Bank recovery volume contributes to meeting the SFI Targets for the Macquarie. The River Bank volume (approximately 21.6 GL/Yr) is about one quarter of the total recovery amount (84 GL/Yr). Without modelling of this scenario the frequency of the achievement of SFI targets can only be inferred through a linear interpolation of the achievement frequencies under the Baseline and the Benchmark (with local reduction only) scenarios. This would indicate that a scenario in which only the Riverbank Volumes contributed to the Macquarie SFI targets would result in small increases in SFI target achievement in the order of 2 to 3% beyond the baseline. This small increase would help achieve target range for the 400 GL SFI (Figure 1) so that 3 of the 4 Macquarie SFI targets had been met prior to any additional water recovery under the Basin Plan.

As indicated in the previous section, water recovery volumes required to meet the three demand series in the model appear to have not been directly assessed. Rather the current recovered volume was represented in the modelling and then the frequency of achievements of SFIs was then cross checked.

The frequency of achievement of SFI's is greater than the target range for three out of four of the SFIs (Table 1) when current recovery (84 GL/yr) is evaluated. This together with the fact that water recovery volumes required to meet the three demand series in the model has not been directly assessed would suggest there is scope for recovery volumes to be less than those assumed in the Basin Plan. MRFF should request that MDBA undertake a sensitivity analysis of the water recovery volumes needed to meet the SFI frequency targets.

2.3. Macquarie IQQM Benchmark Model

For the NBR, MDBA used a consolidated model for Macquarie Castlereagh region, which was prepared for the Murray Darling Basin Sustainable Yields project by combining different models for the Macquarie, Castlereagh, Bogan and Marra Ck (Map 1). The model was constructed by NSW DPI Water and provided to MDBA in December 2009. The Macquarie Marshes were represented by a single headwater storage node in the model, that is, one bucket which is overly simplistic and does not reflect the way the system works.

In 2014 NSW DPI Water provided a revised Macquarie IQQM to the MDBA. This model has a more detailed representation of the Macquarie Marshes and has been based upon a detailed hydrodynamic model of the marshes Long term average diversions from the 2014 model were similar to that of the old 2009 model currently used by MDBA (Figure 3).

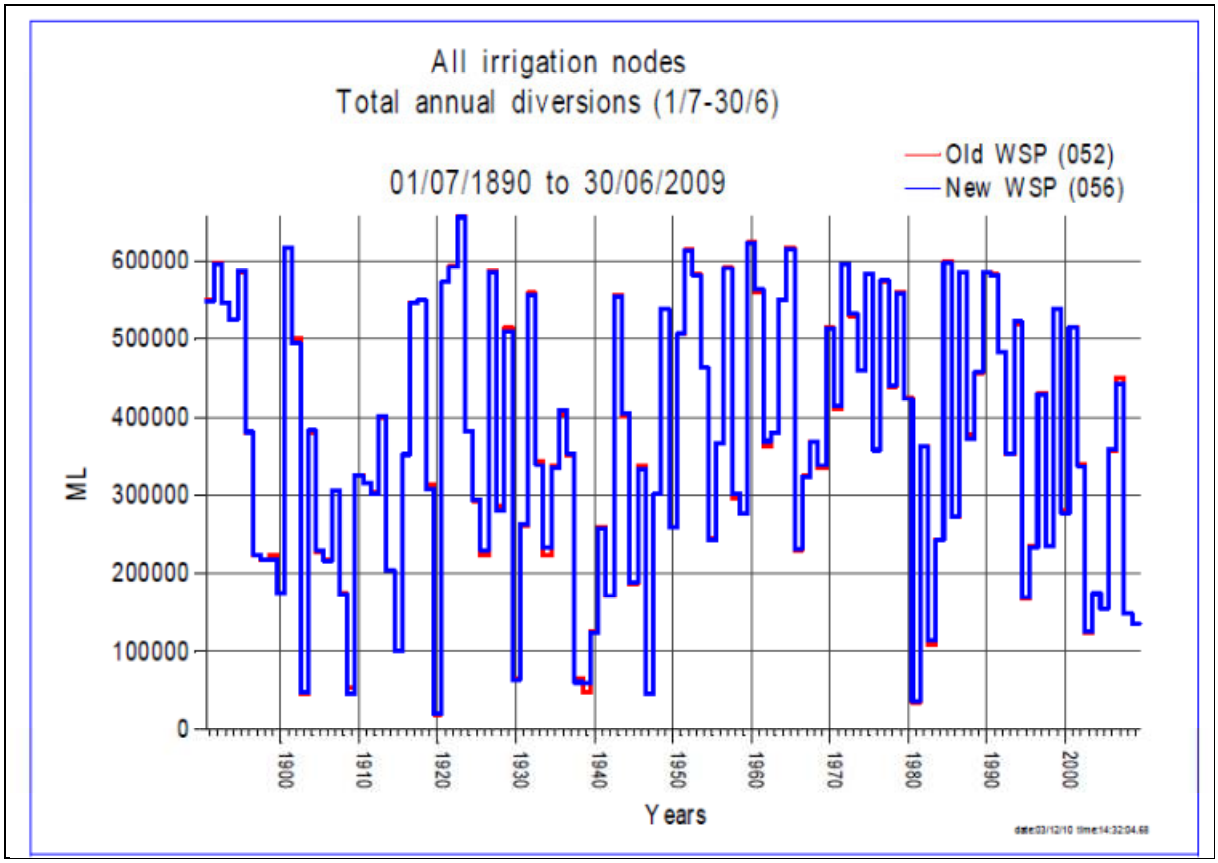


Figure 3 – Comparison of Old and New Model Diversions

Whilst diversions from the two models are similar, the same cannot be said for end of system flows. The 2014 model (the **Detailed IQQM WSP Wetland Model**) produces end of system flow estimates some 40% lower than the NBR 2009 model (Table 2). Note: that flows at Marebone (Map 1) are lower for the new detailed model due to modelled Burrendong Inflows sequences being some ten percent lower than for the NBR model (Pers com DPIWater).

Table 2 – Comparison of End of System Flows from the NBR 2009 Model and the 2014 Detailed IQQM Wetland Model (GL/Yr) 1895 to 2009

	(1) NBR Bucket Model (Current Dev)	**(2) Detailed Wetland WSP Model (Current Dev)**
Macquarie @ Marebone	494.1	413.9
Macquarie @ Carinda	114.3	79.4
Marthaguy @ Carinda	142.9	71.0
Marra Ck @ Billybingbone	50.2	25.2
Total (Flows to Barwon Darling)	**307.4**	**175.6**

The 2014 Detailed IQQM Model provides a far better representation of observed end of system flow volume. Recent (2009 to 2016) flows in the Macquarie indicate that as little as 1% in dry years (Figure 4); and 6% in wet years (Figure 5) of the flow volume reach the end of the Macquarie system[2](Map 1).

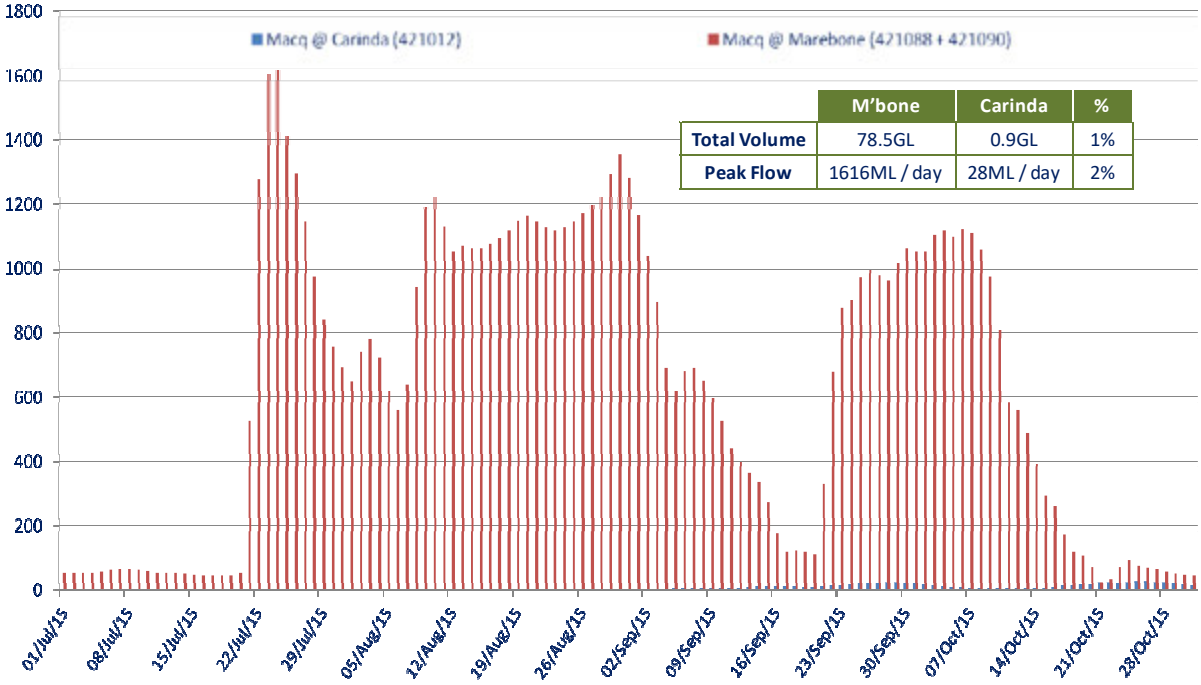


Figure 4. River flow data July to October 2015 during environmental watering event.

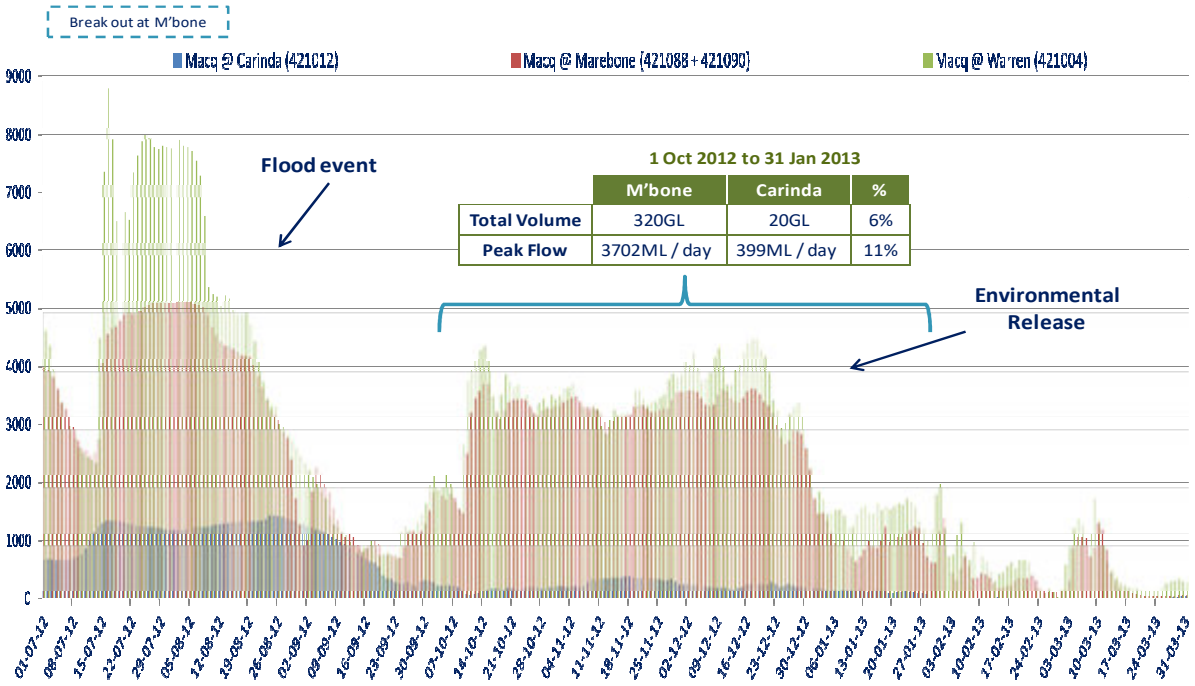


Figure 5. River flow data from October 2012 to January 2013 during environmental watering event.

[2] New South Wales Department of Primary Industries, Office of Water (website), http://realtimedata.water.nsw.gov.au/water.stm?ppbm=SURFACE_WATER&rs&3&rskm_url (accessed 22 March, 2016)

The results from the latest modelling would suggest that the losses through the marshes are far greater than previously modelled and that the level of connectivity between the **regulated** Macquarie and the Barwon Darling is substantially less than previously thought. Further discussion relating to inflows into the Barwon Darling from the Macquarie Castlereagh Bogan system is presented in the following section.

2.4. End of System Flows

The aim of this part of the review was to analyse the MDBA's assumptions and conclusions in relation to the Macquarie's end-of system flows and connectivity to the Barwon - Darling (including the volume and time taken for regulated releases to reach Carinda);

The modelled IQQM inflows to the Barwon Darling consist of:

- Marthaguy Creek at Carinda,
- Macquarie River at Carinda,
- Marra Creek at Billybingbone Bridge

A comparison of these was made for the NBR 2009 bucket IQQM model and the more detailed 2014 wetland version of the Macquarie IQQM in the preceding section.

Additional Sacramento rainfall runoff model inflows to the Barwon Darling have been generated for the:

- Castlereagh at Coonamble, and the
- Bogan River at Gongolgon.

Comparisons between the NBR bucket IQQM Model, the more recent detailed wetland model, and observed flows have been made for the purposes of this review. Results are presented in Table 3 over a time period from 1/1/2000 to the 30/06/2009. A comparison of observed flows at Marebone and Carinda (Map 1) with those from the detailed wetland model is also presented in Figure 6 and Figure 7 for two time periods.

End of system flows for the Macquarie River section of the Macquarie Bogan Castlereagh Sustainable Diversion Zone for the detailed wetland model are only 60% of the NBR bucket model as expected (due to having more detailed information for the marshes). Observed flows exceed the more recent detailed wetland model in some instances but never exceed the old NBR IQQM model (Table 3). Total observed inflows are closer to the more recent detailed wetland model when compared to the NBR IQQM model. Furthermore, the proportion of modelled total **regulated** section flow that contributes to the Barwon Darling is very small at approximately 11% for the detailed model (Table 3).

It must be emphasised that the end of system flows are not solely made up of regulated dam releases. There are a number of tributaries, which flow into the Macquarie River downstream of Burrendong Dam (including the Bell and Little rivers) (Map 1), that contribute flows to the system. These inflows, which are unregulated and cannot be controlled, increase the end of system flows of the regulated system and must be

considered when measuring the impact that regulated dam releases have on flows at the end of the system. If these flows were excluded, the proportion of regulated releases that contribute to the Barwon Darling would be far less than the 11% quoted in the previous paragraph.

Table 3 - Average annual End of System Flows of sub-catchments in the Macquarie Bogan Castlereagh SDL Zone. Comparison with Gauged Data (GL/Yr).

	(1) NBR Bucket Model (Current Dev)	**(2) Detailed Wetland Model (Current Dev)**	**(3) Observed [3]**
Macq @ Carinda	53.8	38.3	41.2
Marra Ck @ Billybingbone	11.7	1.4	10.7[2]
Total (Reg Inflows)	**65.6**	**39.7**	**51.9**
Marthaguy @ Carinda	66.0	21.3	42.6
Castlereagh at Coonamble	21.2	21.2	27.3[3]
Bogan at Gongolgon[1]	267.2	267.2	204.5
Total (Unreg Inflows)	**354.4**	**309.7**	**274.4**
Total (all Inflows)	**420.0**	**349.4**	**326.3**

1: Contains a small volume of regulated water from Duck and Gunningbar Ck.
2: Is largely water from tributory flows and high flow events (S. Sritharan, pers .comm.) which is considered an unregulated flow but included as Marra Ck offtake is located at Marebone.
3: Observed Flows at Gungalman. Coonamble data not available for common period.

The 2014 Detailed Wetland Model illustrates that larger outflows at Carinda are produced by flood type events that occur at Marebone, whilst smaller regulated events produce very small outflows. This relationship closely reflects observed outflows (Figure 6 and Figure 7); indicating the 2014 Detailed Wetland Model is a superior model to the 2009 NBR Bucket Model for the purpose of understanding the Macquarie system.

[3] Observed Historic Streamflow Data NSW Water Info Website - http://waterinfo.nsw.gov.au/

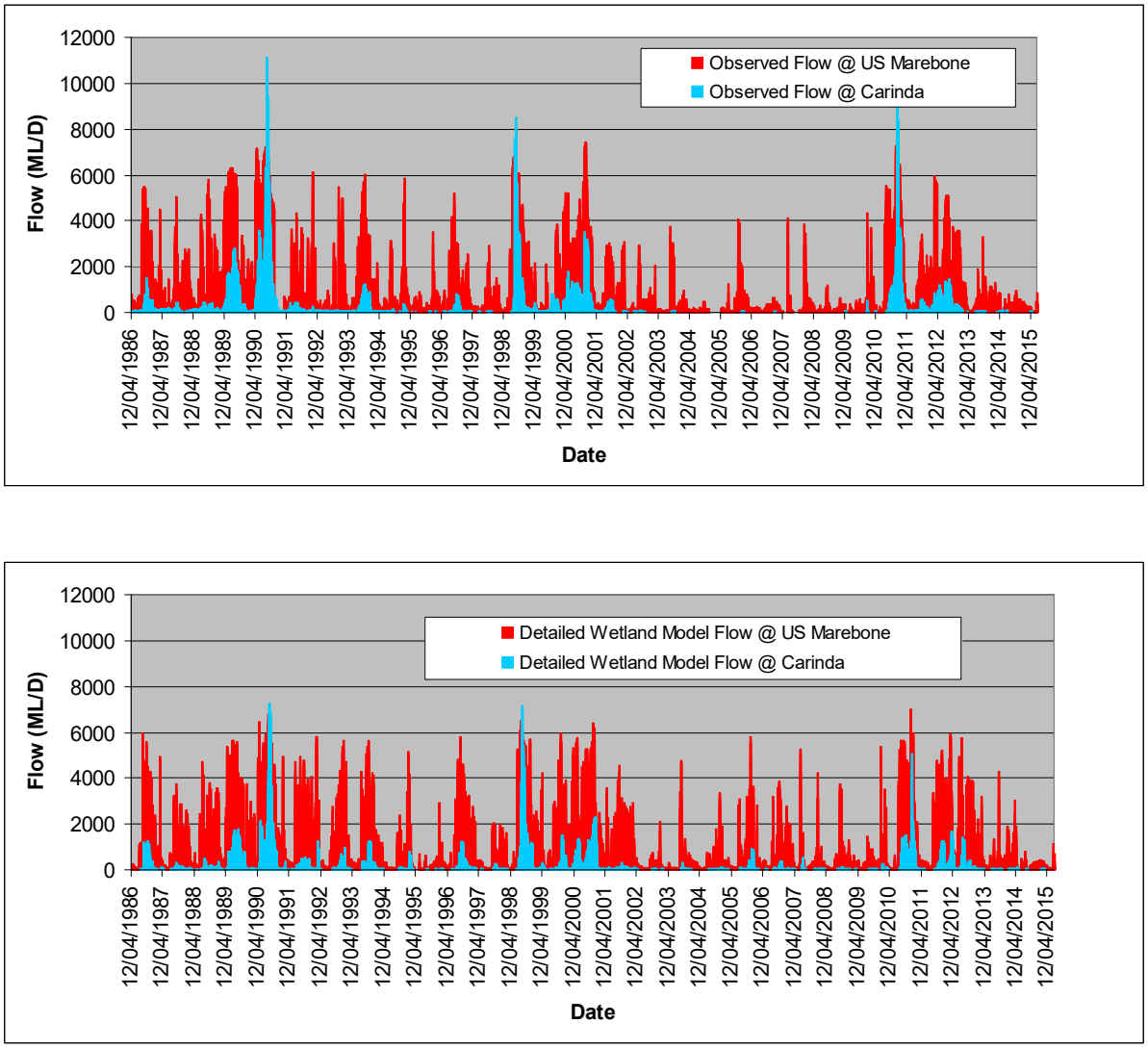


Figure 6 – Comparison of Observed Flows at Marebone and Carinda with those produced by the Detailed Wetland Model April 1986 to April 2015.

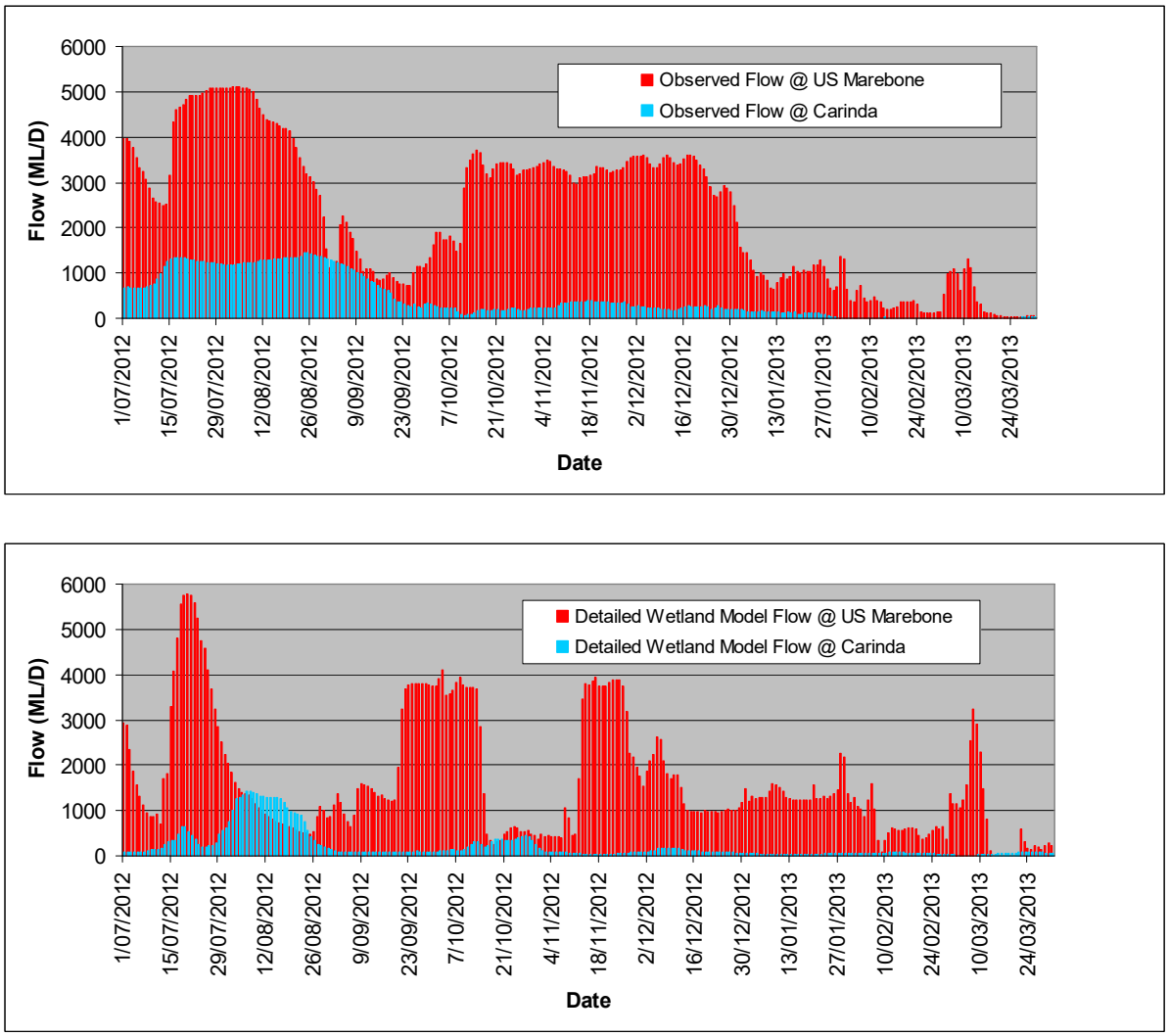


Figure 7 - Comparison of Observed Flows at Marebone and Carinda with those produced by the Detailed Wetland Model July 2012 to March 2013.

A comparison between the volume of inflow and outflow for observed and detailed modelled flows over the period July to October 2015 indicates that the relative change in volume and peak between Marebone and Carinda is very similar between observed and modelled flows (Table 4).

Table 4 – Comparison of Observed and Detail Wetland Modelled Event Characteristics July to October 2015.

	Observed			**Modelled**		
	Marebone	**Carinda**	**%**	**Marebone**	**Carinda**	**%**
Total Volume (GL)	319.65	25.89	8%	214.70	14.30	7%
Peak Flow (ML/D)	3721.70	399.02	11%	4092.80	446.55	11%

2.5. Flow limitations and travel time

The Marebone gauge is located midway along the lower Macquarie floodplain near the southern end of the Macquarie Marshes (Map 1). It is approximately 200 km from Burrendong Dam and 150 km from the Barwon River. The Carinda gauge is located near the northern end of the Macquarie Marshes, approximately 100 km from Marebone, and 50 km from the Barwon River (Map 1).

The start of environmental releases from Burrendong Dam in July 2015 arrived at Marebone on 21/7/2015 and the first rise was recorded at Carinda in early September some 6 weeks later (Figure 4). Similarly, the start of environmental releases in October 2013 reached Marebone around the 10th of October and a rise at Carinda arrived 4 weeks later (Figure 5).

When combined with flow volumes under a dry scenario, only 1% of a 67 GL release of regulated water was observed to reach Carinda and took 6 weeks to make its way out of the Marshes from Marebone; and under a very wet scenario, only 6% of the environmental flow passed through the Marshes and the journey took around 4 weeks. During flood events a greater proportion of the total flow reaches the Barwon. This illustrates to poor connectivity of the regulated Macquarie River to the Barwon.

The Linked Time Demand Series modelling assumes that water can be released from storages in the Northern Basin including Burrendong Dam and be linked to trigger flows at St George in the Condamine/Balonne system when these flows reach the Darling River near Bourke. MRFF and BRW Pty Ltd believe this assumption to be incorrect as all of the contributing rivers have further to travel and have less fall in their last 350 km than does the Condamine/Culgoa system (Figure 8). MRFF have stated that they have requested a copy of the modelling and assumptions from the MDBA and that they have not been provided to date. However, given the material supplied by the MDBA to BWR Pty Ltd and the details provided in the MDBA's Hydrologic Modelling Report to Inform the Basin Plan, BWR Pty Ltd is satisfied that the regardless of whether the assumptions are correct or incorrect, the methodology behind the modelling has been explained in sufficient detail for the purposes of this review.

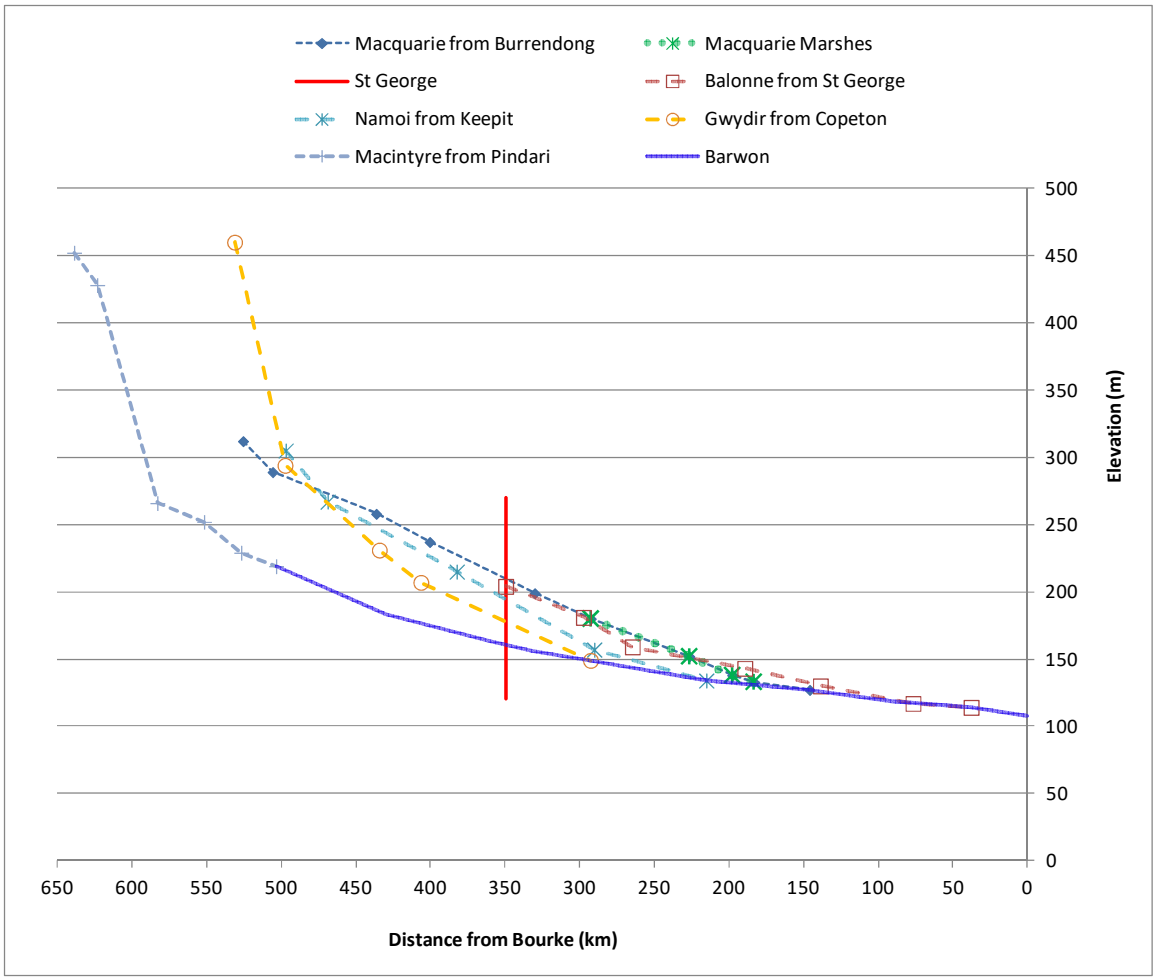


Figure 8. Comparison of fall in elevation against distance from Bourke for Major Rivers in the Northern Murray Darling Basin.

Further throttling the capacity of the Macquarie system to provide end of system flows is delivery constrictions along the river and for environmental flows to not create any third party impacts. The maximum flow at Marebone must not exceed 3,100 ML/day (Sri Sritharan, pers comm.) to avoid overbank losses, and just downstream at Oxley once flows exceed 900 ML/day water breaks out the Oxley Break further reducing flows into the Marshes.

The Macquarie Marshes contain a semi-permanent wetland. The area inundated varies with river flow rates, and when water recedes a core area of 10 to 15,000 ha remains inundated for extended periods. Daily water use by this core area of Marsh is of the order of 500 ML/day during cooler months, rising to 1,500 ML/day during summer, and increases with water inflows and as additional marsh area is inundated. This varying demand matches the supply, thereby effectively using or consuming the entire daily flow other than during flood events.

2.6. Barwon Darling Inflow Booster Factors

The use of end of system flow gauge data to calibrate tributary models and determine inflows to the Barwon-Darling model has tended to lead to underestimation of flows at key gauging stations along the Barwon-Darling River and inflows to the Menindee Lakes. This is considered to be due to the quality of the rating tables for high flows as well as due to significant flood flows bypassing the most downstream gauges of the tributary catchments. The Barwon-Darling model used in the NBR therefore includes additional flows which are a contribution of local catchment inflows during extreme wet conditions, as well as flows which have bypassed the downstream gauging stations of tributary valleys. These flows are generated using booster factors. The booster factors relevant to this review are shown in Table 5.

The factors in Table 5 consist of one factor applying to all flows above a flow threshold. Whilst application of the factors will improve inflow estimation to the Barwon Darling, the application of a single booster factor to flows above a certain threshold is likely to produce inflows estimates which are still subject to considerable uncertainty. Furthermore, in the light of the difference between end of system flows from the NBR modelling and those associated with the newer 2014 IQQM model and observed data these booster factors will likely require revision if MDBA move to the more recent detailed IQQM model. Any revision to booster factors should be supported by an assessment of the rating curve associated with the flow data to which they are applied, to ensure that the booster factors sensibly reflect rating curve inaccuracy, and have not been arbitrarily determined.

Table 5 - Factoring of Floodplain Flows Walgett - Bourke

Tributary Gauge	**Threshold Flow when Factoring Commences (ML/d)**	**Factoring up value**
Castlereagh River @ Coonamble (G.Stn 420005)	5,000	1.25
Marthaguy Creek @ Carinda (G.Stn 421011)	4,000	1.5
Macquarie River @ Carinda (G.Stn 421012)	3,000	1.5
Marra Creek @ Billybingbone Bdge (G.Stn 421107)	Nil	None
Bogan River @ Gongolgon (G.Stn 421023)	6,000	1.5

2.7. Conclusions and Recommendations

Based on a review of the NBR Macquarie Valley hydrologic modelling the flowing conclusions can be made:

1. The Macquarie volume of long-term diversion reduction and entitlement recovery required to meet SFI targets has not been calculated in any of the modelling presented to date which is a specific gap in the NBR review process with respect to the Macquarie. Rather, the volume of long-term average use already recovered (84GL/Yr) has been represented in the model and then the achievement of the demand series through evaluation of the specific flow indicators have been checked. Consequently, the 84GL/yr (Including the local reduction amount of 65GL/yr) is well in excess of what is required from the Macquarie to meet the lower limit of the SFI target range.

2. The results from the latest 2014 IQQM model would suggest that the losses through the marshes are greater than previously modelled (using the NBR Macquarie IQQM) and that the level of connectivity between the regulated Macquarie and the Barwon Darling is substantially less that previously thought.

3. The contribution from the Macquarie to the Barwon Darling is very small at approximately 11 to 16% of the total Macquarie-Castlereagh System inflow.

4. The MDBA's modelling includes a number of assumptions, including flow coordination, operational practices and environmental demand patterns that will not be achievable in practice. Delivering ordered volumes of water from Burrendong dam at the appropriate time and location is highly unlikely due to attenuation losses and variable travel times.

5. If a more realistic representation of environmental water delivery practices were incorporated into the Macquarie IQQM model it is likely that modelled SFI achievement with the Barwon Darling would be lower than current modelling suggests.

6. Given the small contribution of regulated inflows to the Barwon Darling relative to unregulated inflows and the degree of connectivity between the Macquarie–Castlereagh system being less that previously thought, a reduction in the Macquarie–Castlereagh shared contribution amount or reapportionment across other tributaries should be considered by the MDBA and NSW DPIWater.

7. Any revision to booster factors that are used in adjusting Barwon Darling inflows from tributary models should be supported by an assessment of the rating curve associated with the flow data to which they are applied, to ensure that the booster factors sensibly reflect rating curve inaccuracy, and have not been arbitrarily determined.

Based on the preceding conclusions the following recommendations are made:

8. MRFF should request MDBA to provide additional information relating to the uncertainty surrounding the Macquarie marshes inundation extents associated with SFI volumes to ensure that envisaged environmental outcomes align with SFI total inflow volumes.

9. MRFF should request that MDBA undertake a sensitivity analysis of the water recovery volumes needed to meet the SFI frequency targets in the Macquarie in order to evaluate the minimum recovery amount required to achieve SFI targets in the Macquarie.

10. MRFF should request that DPIWater/MDBA reconsider the basis for apportionment of the shared contribution in the Macquarie Castlereagh system the light of more recent modelling and observed flows indicating a lower degree of connectivity, and a small contribution of regulated flows relative to unregulated flows to the Barwon Darling.

11. MRFF should consider asking MDBA to adopt the latest more detailed IQQM model of the Macquarie river system and revise the booster factors which are applied to Barwon Darling inflows.

3 Identification of hydrologic gaps in the review

The hydrologic analysis undertaken by the MDBA uses the same methodology that applied prior to the making of the Basin Plan in 2012. That is an assessment of whether volumes of recovered water are sufficient to meet Specific Flow Indicators targets at select gauges. The hydrologic analysis was only one (albeit the major one) line of evidence used in establishing the Valley SDLs. Hydrologic gaps in the NBR relating to the Macquarie Valley are presented in the following sections.

3.1. Benchmark IQQM Model

As outlined in the previous chapter there is a more contemporary Macquarie IQQM model that should be used for assessment as part of the NBR. **MRFF should consider asking MDBA to adopt this latest more detailed IQQM model**.

3.2. Patterns of Water Recovery

In the river system modelling used to evaluate water recovery as part of the NBR, recovered volumes in the Macquarie are uniformly distributed across all regulated entitlements. That is to say, all regulated entitlements have been reduced by the same proportional amount. As such they do not represent the actual location of recovered volumes. As the Macquarie SFIs are based cumulative volumes, any changes in frequency of achievement through modelling the actual point of recovery locations are likely to be marginal. However, it is important to note that until recovery patterns which actually reflect actual individual recovery locations are incorporated into the models the true impacts of water recovery on third parties will still be subject to a degree of uncertainty.

3.3. Macquarie Marshes Environmental Flow Requirements

As outlined in Section 2, MRFF should request MDBA to provide additional information relating to the uncertainty surrounding the inundation extents associated with SFI volumes to ensure that envisaged environmental outcomes align with SFI total inflow volumes. **It is suggested that an analysis similar to the one carried out in the MDBA 2016 report *Floodplain & Vegetation Inundation using Landsat Satellite Imagery: Lower Balonne & Middle Darling* be undertaken. OEH may have already conducted an analysis similar to this and if so results should be made available to MRFF in order to provide confidence in the SFI Inflow volumes.**

3.4. Sensitivity of Achievement of SFIs to Recovered Volume

The NBR modelling has not examined the sensitivity of achievement of SFIs in the Macquarie to reduced recovered volumes. As outlined in Section 2.2, MDBA should correct this deficiency by modelling a range of recovery options within the Macquarie.

3.5. Altered operational arrangements and environmental demand patterns

Operational Assumptions

Differences between the modelled and real world representations of operational practices may result in differences in achievement of SFIs. In the case of the Macquarie river system model, delivery of flows to meet the Barwon Darling shared contribution environmental demand series assumes a very high degree on flow coordination between regulated release and unregulated tributary inflows, and the assumption that ordered volumes from Burrendong can be delivered at appropriate times and magnitudes a location close to the end of system. This is will not be achievable in practice to the extent that it is within the model. Consequently, as outlined in the BWR report to the Northern Alliance, the modelled frequency of SFI achievement in the Barwon Darling is likely to represent an upper bound.

In the case of the Macquarie SFIs, differences between the modelled and real world representations of operational practices are not likely to effect the achievement of the SFI targets. This is because Macquarie SFIs are based on cumulative volumes, as opposed to flows exceeding a threshold. This means that not being able to coordinate regulated releases with tributary inflows, and not being able to deliver the actual volume ordered is only likely to effect the time taken to achieve cumulative volume and not the amount itself.

Environmental Demand Patterns

The environmental demand patterns used in the Macquarie River System modelling are based on application of the ESLT method (MDBA, 2011). This method has been applied to all valleys. Demand patterns have been derived to reinstate selected without development flow events, to the extent necessary to achieve specific flow indicator flow thresholds or volumes. The shape of the hydrograph resulting from these demand patterns in the model will be different to that which results from actual delivery of environmental water. As stated in separate advice to the Northern Irrigators Alliance, MDBA have to date not assessed altering the assumed shape of the hydrographs associated with meeting environmental water requirements. It is likely that MDBA would view this as a fundamental change to the ESLT method and consequently this would be outside the scope of the NBR.

Application of more realistic environment water delivery patterns in the river system model is likely to reduce the frequency of achievement of those SFIs that are based upon flows exceeding a threshold for a given duration of time. The effect on SFIs that are based on cumulative volumes such as those associated with the Macquarie Marshes is likely to minimal.

4 Soundness of hydrological assumptions;

When assessing the frequency of achievement of each SFI a number of hydrologic assumptions have been made within the river system models of the Northern Basin. In particular assumptions relating to:

1. the location of delivered environmental water,
2. the timing and duration, and frequency of environmental watering requirements,
3. the assumed shape of an environmental watering event.

These assumptions are discussed in the following sections with respect to the Macquarie River Valley.

4.1. Location of Delivered Environmental Water

The location of sites within the models selected for delivery of environmental water have been assumed to be:

1. representative of the broader environmental needs of the valley or reaches.
2. representative of where water can be realistically ordered and delivered to.

In the case of the Macquarie and the Macquarie Marshes in particular, the assumption that the SFI volumes at Marebone are representative of the broader environmental needs of the marshes needs additional clarification. This was discussed in Section 2 which recommended that **MRFF should request MDBA to provide additional information relating to the uncertainty surrounding the Macquarie Marshes inundation extents associated with SFI volumes to ensure that envisaged environmental outcomes align with SFI total inflow volumes.**

The assumption of where water can realistically be ordered and delivered to in terms of flow magnitude and timing will be less accurate with increasing distance from the storage to the delivery point. This is a particular issue with respect to ordering and delivering water to the meet the Basin Plan modelled environmental flow requirements at tributary end of system locations and in the Barwon Darling. In the case of the Macquarie River system, the assumed most downstream regulated delivery point is Marebone (Map 1), just upstream of Macquarie Marshes on the main stem of the Macquarie River. It is highly likely that actual delivery of ordered volumes at this location will not be able to be achieved to the same degree of accuracy achieved within the model due to attenuation losses and variable travel times. If a more realistic representation of environmental water delivery practices were incorporated into the Macquarie IQQM model it is likely that modelled SFI achievement with the Barwon Darling would be lower than current modelling results suggest. As stated in the Northern Alliance review report, any more realistic assessment of delivery practices would require the benchmark models to be amended to better reflect current operational practices. This could include modifying the demand series in the models to either take into account

forecasting limitations such as attempted with the uncoordinated model scenario, or removing the environmental demand series and replacing them in the model with the actual management practices that are currently used to determine when held environmental water should be released. Whilst this may be unlikely to be achieved within the time frames available to the Authority as part of the Northern Basin review, it would provide a more realistic assessment of the Macquarie SFI achievement.

4.2. Timing and duration, and frequency of Environmental Water Requirements

In the Macquarie, MDBA has used the following broad methodology to determine hydrologic environmental water requirements:

1. The baseline flow time series was analysed for each indicator site and each water year (from 1895 to 2009) to identify all existing flow events that achieved the flow indicators;

2. The without development time series was similarly analysed to identify all flow events in that timeseries that achieved the flow indicators;

3. A comparison of outcomes from steps 1 and 2 was used to identify the environmental flow events that have been lost from the without development time series due to river regulation and extraction. This identified eligible events that could be reinstated in the model to meet the desired frequency of environmental watering;

4. The volume of water required to reinstate each individual lost event in the without development time series was then calculated;

5. Based on the volume of water available in any given year, the target frequency of watering, and the volume of water required to reinstate each flow event in the year, environmental watering events were selected for inclusion in the demand time series for the indicator site.

6. The volume of water recovered to date by the environmental water holder was then used to assess how often the environmental demand series were met.

As stated in Section 2, the Macquarie volume of long-term diversion reduction and entitlement recovery required to meet SFI targets has not been calculated in any of the modelling presented to date. **This is a specific gap in the NBR review process with respect to the Macquarie.**

4.3. Shape of an Environmental Watering Event

The shape of the hydrograph assumed in the demand time series has been based upon an assessment of the patterns of flow associated with the without development and baseline flow time series, the volume available and the flow threshold required at relevant SFI location. As discussed in Section 3.5 the shape of the demand hydrograph derived from this process is likely to be different to that delivered in practice.

5 Efficiency of approach to achieving the desired ecological outcomes

As stated in the Northern Alliance review report, the approach used by MDBA uses hydrologic metrics to describe ecological outcomes. Based on the findings of the previous sections the approach used by MDBA:

- Uses hydrologic metrics as indicators of ecological outcomes.
- Represents a pattern of environmental water delivery which probably cannot be replicated in practice.
- Represents a pattern of water recovery which differs from actual. Although this is not expected to impact upon model results.
- **Has not evaluated the minimum recovery amount required to achieve SFI targets.**
- Has not taken into account the potential use of works to deliver similar ecological outcomes. One such example could be through the use of an enlarged Burrendong valve to deliver overbank events for less volume.

At the time that the ESLT method was developed, the approach used represented the best available method for the time constraints that existed for the formulation of the Basin Plan. However, recent advancements in methods for assessing environmental outcomes may offer opportunities for a more sophisticated approach for assessment of ecological outcomes. **However, it is unclear at this stage whether such an approach when applied would demonstrate the need for additional water recovery, or that current recovery volumes were beyond that required for achievement of desired ecological outcomes.**

The longterm impact of the Basin Plan warrants the use of best science to determine water recovery amounts and environmental outcomes. Decisions should be informed by the best available data including that which have been available since the 2009 Basin Plan.

6 Identification any non-flow related barriers to achieving the desired ecological outcomes

Opportunities to enhance Macquarie Valley ecological outcomes through works and measures are quite limited, as most SFI targets are structured to achieve large scale floodplain inundation extents. However, works that may offer potential for increasing the valleys SDL include:

- On farm efficiency savings such as works to reduced evaporative losses in storages.
- Construction of public infrastructure that allows for increased inundation frequency and extent within the marshes.
- Removal of unlicensed banks and channels that divert flows away from core ecological targets.

7 Review Conclusions

7.1. Review Gaps

The following gaps have been found with respect to Macquarie Valley literature review of the MDBA Northern Basin Review Science & Hydrological Reports.

1. The Macquarie volume of long-term diversion reduction and entitlement recovery required to meet SFI targets has not been calculated in any of the modelling presented to date. Rather the volume of long-term average use already recovered (84GL/Yr) has been represented in the model and then the achievement of the demand series through evaluation of the specific flow indicators have been checked.

2. The latest 2014 IQQM model has not been incorporated into the MDBA's modelling framework for the NBR. The results from the latest 2014 IQQM model would suggest that the losses through the marshes are greater than previously modelled (using the NBR Macquarie IQQM) and that the level of connectivity between the regulated Macquarie and the Barwon Darling is substantially less that previously thought.

7.2. Review Soundness

In the case of the shared contribution to the Barwon Darling it is likely that the modelled assumptions relating to where water can be realistically ordered and delivered to in the Macquarie represents an unrealistic scenario. Real world delivery practices are likely to result in orders not being delivered with the same degree of certainty as exhibited in the model.

Based on the observed streamflow data of Table 3, the contribution from the regulated section of the Macquarie to the Barwon Darling is very small at approximately 16% of the total Macquarie-Castlereagh System inflow. This figure is likely to reduce further if only regulated releases were considered, and uncontrolled tributary inflows downstream of Burrendong Dam were removed from the totals.

Given the small contribution of regulated inflows to the Barwon Darling relative to unregulated inflows and the degree of connectivity between the Macquarie–Castlereagh system being less that previously thought, a reduction in the Macquarie–Castlereagh shared contribution amount or reapportionment across other tributaries should be considered by the MDBA and NSW DPIWater.

The shape of the demand hydrograph used in the MDBA modelling is likely to be different to that delivered in practice. However this is not likely to effect the achievement of the Macquarie SFIs which are defined as cumulative volumes as opposed to flows exceeding a threshold.

7.3. Efficiency of approach to achieving the desired ecological outcomes

The approach used by MDBA uses hydrologic metrics to describe ecological outcomes. In the case of the Macquarie, the approach used by MDBA:

- Uses hydrologic metrics as indicators of ecological outcomes.
- Represents a pattern of environmental water delivery which is highly unlikely to be replicated in practice.
- Represents a pattern of water recovery which differs from actual. Although this is not expected to impact upon model results in terms of frequency of SFI achievement.
- Has not evaluated the minimum recovery amount required to achieve SFI targets.
- Has not taken into account the potential use of works to deliver similar ecological outcomes.

The MDBA's modelling includes a number of assumptions, including flow coordination, operational practices and environmental demand patterns that will not be achievable in practice. Delivering ordered volumes of water from Burrendong Dam at the appropriate time and location is highly unlikely due to attenuation losses and variable travel times.

If a more realistic representation of environmental water delivery practices were incorporated into the Macquarie IQQM model it is likely that modelled SFI achievement with the Barwon Darling would be lower than current modelling suggests.

7.4. Identification any non-flow related barriers to achieving the desired ecological outcomes

Opportunities to enhance Macquarie Valley ecological outcomes through works and measures are quite limited, as most SFI targets are structured to achieve large scale floodplain inundation extents. However, works that may offer potential for increasing the valleys SDL include:

- On farm efficiency savings such as works to reduced evaporative losses in storages.
- Construction of public infrastructure that allows for increased inundation frequency and extent within the marshes.
- Removal of unlicensed banks and channels that divert flows away from core ecological targets.

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