Submission on proposed Basin Plan amendments for the Northern Basin

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1.0 Executive Summary

This submission concludes that there is insufficient evidence for a reduction in the proposed water recovery target from 390 GLs to 320 GLs from the rivers of the Northern Basin. To reduce the water recovery will further impact on environmental assets, including Ramsar-listed sites, migratory shorebirds and ecosystem services. Recommended reductions in water recovery will also cost the broad community economically and socially.

Scientific evidence supports an increase in environmental flows to achieve sustainability for the environmental assets of the Northern Basin and the Murray-Darling Basin, beyond the 390GLs per year. The proposed reduction of 70 GL per year will continue to drive ongoing degradation of northern basin environmental values and ecosystem services provided by rivers, requiring future adjustments to provide more water for the rivers, particularly with the increasing effects of climate change of increasing temperatures and potential changes to run-off. This submission identifies eight major concerns which clearly show there is insufficient evidence for a recommendation to reduce the environmental flow target of the Northern Basin of the Murray-Darling Basin. The submission provides 10 reasons for supporting this position of rejecting the recommendations for reductions in water recovery.

1. **Poor condition of environmental assets of the Northern Basin of the Murray-Darling Basin**
   - All current scientific evidence continues to identify long-term decline in the ecosystems (floodplains, wetlands, channels, waterhole, riparian areas) of the rivers of the Northern Basin.
   - These floodplains were among those recently assessed as critically endangered in an IUCN risk assessment of endangered.
   - Hydrological modelling inadequately assesses ecological impacts to floodplain environments.
   - Australia's internationally listed wetlands under the Ramsar Convention in the Northern Basin (Gwydir wetlands, Macquarie Marshes, Narran Lakes) will continue to change their ecological character, mainly as a result of reductions in flow.
   - Initially a scientific assessment by the Murray-Darling Basin Authority identified that 6,000-7,000 GL per year would be required to return the environmental assets of the Murray-Darling Basin to sustainable ecological health. This was reduced by almost half to 3,000-4,000 GL per year in the Basin Guide. Eventually, the Australian Government considered 2,800 GL, even lower than the minimum proposed, was a reasonable target. This was further reduced to 2,750 GL before the Queensland Government agreed to sign up to the Basin Plan, a reduction from the Northern Basin. Reduction of the target by another 70 GL represents a further significant reduction in environmental flows which will exacerbate environmental decline.

2. **Downstream impacts on communities, the River Murray and the Coorong, Lower Lakes and Murray Mouth Ramsar site**
   - Recommendations for reduced reductions of flow by 7GL to Menindee Lakes, 4GL to South Australia and 3GL to the Coorong, Lower Lakes and Murray Mouth Ramsar site will continue to exacerbate long-term environmental problems which were the basis

of the Murray-Darling Basin Plan. There was no modelling of these impacts on these downstream assets.

3. Inadequate use of environmental Science

- There is no new science to support a reduction in water recovery. Recent and historical science predominantly indicates the need for more water to be recovered.
- There was poor assessment of the current state of scientific knowledge for the Northern Basin and inadequate integration of this knowledge into decision-making process in terms of including multiple lines of evidence.
- Commissioned scientific research for the Northern Basin Review was not adequately integrated into assessments or decision-making.
- The independent review of the science only focused on two catchments in the Northern Basin and its results were not adequately incorporated into the assessment.
- There was an absence of any climate change impacts, despite well understood impacts, particularly on evaporation affecting surface water reliability. This was despite modelling during the development of the Murray-Darling Basin Plan.

4. Failing the Ramsar wetlands – a state, national and international responsibility

- Current water recovery is not sufficiently providing for the ecological character of internationally listed wetlands, including the Macquarie Marshes, Gwydir wetlands and Narran Lakes.
- The Australian Government has informed the international community (Article 3.2 notification) that there has been a likely change in ecological character as a result of water resource and other developments in the Macquarie Marshes and Gwydir wetalnds.
- A reduction in the water recovery target will exacerbate degradation of the Macquarie Marshes and Gwydir wetlands and ensure that Narran Lakes in the future will also require a formal notification of a decline in ecological character.
- The proposal that the Macquarie River catchment is overallocated for environmental water ignores all current evidence in the peer reviewed literature and long-term analyses of inundation patterns.
- There is clear scientific evidence that only about half of this wetland remains with many iconic organisms, such as river red gums and breeding of colonial waterbirds is serious decline.
- The sustainable management of Ramsar sites was a major rationale for a federal role in the management of the rivers of the Murray-Darling Basin, through the *Water Act 2007*, taking over responsibilities of the states under the Constitution. It will reflect a failure in the Water Act 2007 and the Basin Plan.

5. Environmental targets not met

- The best case scenario is that only 22 of the 43 targets of the current Murray-Darling Basin Plan, in the Northern Basin will be met under recommended water recovery targets. This represents a significant failure. The major goal of the Basin Plan, supported by the Water Act 2007, was to restore the sustainability of the Murray-Darling Basin, including its wetlands, rivers and dependent organisms, ecological

processes and ecosystem services. A substantial body of rigorous work underpins this analysis, setting targets for each of the river systems.

- Environmental targets generally poorly represent the complexity of river systems and meeting of these targets can be misled by inadequate measurement of duration, and flood sequences.
- There are no floodplain targets which allow for adequate determination of impacts on the floodplain.
- Environmental targets represent only a minimum.

6. Fails migratory shorebirds – a state, national and international responsibility

- The reduction in water recovery will further decrease habitats for migratory shorebirds species, many of which are in perilous decline.
- Water resource development is a major cause of this decline in the Murray-Darling Basin with many of the key sites in the Northern Basin further declining in their value for waterbirds through the recommendation to lower the environmental water recovery target in the Northern Basin.
- Australia's international responsibilities for migratory shorebirds was another major rationale for a federal role in the management of the rivers of the Murray-Darling Basin, through the *Water Act 2007*, taking over responsibilities of the states under the Constitution.
- Migratory shorebirds rely on wetlands such as the Macquarie Marshes, Narran Lakes, Gwydir wetlands, Menindee Lakes, Tallywalka lakes and Darling Anabranch lakes to provide resources while overwintering in Australia. The reduction in the water recovery target will decrease this international obligation, given that migratory shorebird species are in perilous decline.

7. Inadequate transparency in hydrological modelling

- Hydrological modelling was the primary analytical tool used to determine impacts of reductions in water recovery but there is good scientific evidence that there was a mismatch between outputs of hydrological modelling and environmental assessment which relied on modelled scenarios of 320a, 320b and 320c, representing a reduction to 320GL per year. Recommendations for reduced water recovery were based on one of modelled scenarios 320i, 320j or 320k but with no accompanying environmental assessments.
- Hydrological modelling does not adequately measure impacts of a reduction in the water recovery on dependent plants, animals, other organisms and ecological processes.
- There was no hydrological data for floodplain systems to allow for adequate environmental assessment, with all assessment based on river flows in the main channel, the least sensitive part of the river.
- There was little transparency about the assumptions and quality of input data into the hydrological models, critical for a complex mechanistic hydrological model used to assess changes to flows.
- There was a lack of transparency about the derivation or use of 'cap factors'.
- The technical hydrological report was only released late in the consultation period,

providing limited time for adequate assessment.

8. Limited socio-economic cost benefit analyses

- Socio-economic analyses had limited scope, not adequately assessing direct and indirect non-use environmental values, including ecosystem services (salinity levels, erosion, acid sulfate soils), tourism, floodplain grazing and other passive uses.
- Such assessments were part of the development of the Murray-Darling Basin Plan but were not done for the Northern Basin Review.
- Real costs of water resource development and impacts on environmental degradation were not considered (e.g. dredging of Murray Mouth, acid sulfate soils, impacts on waterbird breeding).
- There was limited discussion of industry changes within the irrigation industry which may have contributed to impacts on communities (e.g. loss of employment for cotton chippers and harvesters with modern equipment and practices.
- There was no incorporation of the values and concerns of Traditional Owners, despite the commissioning of a survey to assess their views which mostly concerned the poor state of the river system.

9. Toolkit measures – lack of transparency and implementation risk

- The toolkit offers some promise to achieve environmental outcomes, without further recovery of water.
- There was a general lack of transparency in its use in the model runs.
- It is important to rigorously analyse the environmental and economic costs and benefits of different toolkit measures to ensure that there are not perverse outcomes. There was no transparency that this has occurred.
- Implementation of toolkit measures is highly reliant on operators and regulators in each of the States adequately developing these protection and water recovery measures.

10. Increased groundwater availability for diversion

- Current understanding of groundwater sustainability considerably lags understanding of surface waters.
- There was limited environmental assessment of potential impacts of increased groundwater access or how this would be regulated to ensure sustainable yields are maintained.

Background

I am the Director of the Centre for Ecosystem Science (CES), UNSW Australia, with a strong track record in the science of river and wetland management and their dependent organisms. In particular, I have more than 20 years of scientific investigation into the impacts of water resource development effects (dams, diversions and floodplain development) on the environment. I have also advised governments of the Murray-Darling Basin on environmental flow management and river management. I have also has done research on Ramsar-listed wetlands and waterbirds throughout the Murray-Darling Basin and in particular the northern basin. Also, researchers in the Centre of Ecosystem Science which was commissioned by the Murray-Darling Basin Authority to investigate potential effects of different water recovery on the breeding of waterbirds in Narran Lakes.

This submission focuses on 10 key issues which support the rejection of the Murray-Darling Basin Authority's recommendation to reduce the water recovery for the environment target from 390GL per year to 320 GL per year in the Northern Basin.

1. Poor condition of environmental assets in the Northern Basin of the Murray-Darling Basin

There is overwhelming evidence in the scientific peer reviewed literature that the status of environmental assets (floodplains, wetlands, channels, waterhole, riparian areas and their dependent organisms) of the rivers of the Northern Basin in the Murray-Darling Basin continue to decline. This is based on peer reviewed studies of the Northern Basin's environmental assets or the same species or ecological processes elsewhere (see Appendices 1 and 2).

Insufficient time has passed since the implementation of environmental flows and inadequate achievement of the 2,750 GL year target in the Basin Plan to provide confidence that the rate of decline of ecosystems and organisms. Further, reduction of the Northern Basin Plan environmental flow target from 390 GL per year to 320 GL per year only meets about half of the 22 of the 43 environmental indicators, as a best case scenario, specified under the Basin Plan. Using the IUCN Red Listing criteria for ecosystems, there was an assessment that the floodplains of the Murray-Darling Basin, driven primarily by data in the Northern Basin, provided enough evidence for a risk assessment status of critically endangered (Keith *et al.*, 2013).

The Northern Basin Review took a primary approach of linking hydrological models and their outputs to ecological sustainability. This remains highly uncertain, particularly when much of the ecological analysis and assessment has indicated considerable declines in environmental sustainability (Appendices 1 and 2). The hydrological models only measure flows in the main part of the river, not on the floodplain. The models used by the Murray-Darling Basin Authority might be considered to be 'fit for purpose' (Podger *et al.*, 2010) but they clearly do not adequately measure alteration of flow and flooding regimes on the floodplain. Our peer reviewed assessment of the Integrated Quality and Quantity Model (IQQM), used throughout the Northern Basin, compared to a statistical model using actual data showed underestimation of impact on floodplain flows (Ren and Kingsford, 2011). With no flow gauges on the floodplain, it is essential to determine changes in flooding regimes (Thomas *et al.*, 2011). By relying solely on modelled changes to flow regimes in the main gauges of the

rivers, the Murray-Darling Basin Authority has considerably underestimated environmental impacts of water resource development and, as a corollary, underestimated the benefits of environmental flows (see modelling section).

All the scientific evidence currently available indicates that Australia is failing to meet its international obligations for the management of internationally important wetlands: Ramsar listed wetlands. This was one of the major reasons the Australian Government, under its international responsibilities (see also migratory birds) was able to establish new water legislation, the *Water Act 2007*, to try and avoid the mismanagement of the Murray-Darling Basin by the States. Australia's three internationally listed wetlands under the Ramsar Convention in the Northern Basin (Gwydir wetlands, Macquarie Marshes, Narran Lakes) will continue to change their ecological character, mainly as a result of reductions in flow. Further, Narran Lakes will join the other two wetlands in the future when the Australian Government will need to similarly admit to the international community that the ecological character of the Narran Lakes Ramsar site has changed, as a result of human impacts (water resource development predominantly) upstream.

There is also a key responsibility of the States in relation to protected areas, including National Parks and National Parks. The responsibilities of the States in this area are not well recognized or implemented. There is incorporation of some of protected areas in the environmental assets but this is generally inadequate. For example the environmental values of Kinchega National Park on the Darling River at Menindee Lakes fail to receive any recognition, despite 28% of their area identified as wetland. More specifically Lake Cawndilla is identified as an area that could be permanently dried, no longer serving any ecological value as a wetland. This decision is not adequately discussed or considered. Similarly, the national parks in Queensland and New South Wales on the Culgoa River have many of their environmental values dependent on the dependent plants and animals that require natural flooding regimes. The decision by the Murray-Darling Basin Authority to reduce environmental flow targets in the Condamine-Balonne appear to ignore this important responsibility of two of the key states of the Murray-Darling Basin.

Finally, it is important to remember the considerable scientific assessment and work which has gone before the current recommendation to reduce the environmental flow component of the Northern Basin from 390 GL to 320 GL per year. Initially a scientific assessment by the Murray-Darling Basin Authority identified that 6,000-7,000 GL per year would be required to return the environmental assets of the Murray-Darling Basin to sustainable environmental condition. This was considered too much of an impact on current socio-economic values and was reduced by almost half to 3,000-4,000 GL per year in the Basin Guide. Eventually, the Australian Government considered 2,800 GL, even lower than the minimum proposed, was a reasonable target. This was further reduced to 2,750 GL before the Queensland Government agreed to sign up to the Basin Plan, a reduction from the Northern Basin. Reduction of the target by another 70 GL represents a further significant reduction in environmental flows which will further exacerbate environmental decline.

Socio-economic considerations have continued to drive down water to be provided to the environment and other ecosystem services. Further these socio-economic considerations have continued to narrow towards only one sector of society, largely ignoring the benefits to other sectors of society (e.g. river towns, Aboriginal communities, passive users, urban

communities, floodplain graziers), as well as the environmental benefits.

2. Downstream impacts on communities, the River Murray and the Coorong, Lower Lakes and Murray Mouth Ramsar site

The final assessment of the impact downstream of the Northern Basin was to reduce flows to Menindee Lakes by 7GL per year, 4GL a year to South Australia and 3 GL per year to the barrages or the Coorong, Lower Lakes and Murray Mouth Ramsar site (Murray-Darling Basin Authority, 2016a).

Reductions in flow into Menindee Lakes as a result of upstream development of water resources have reduced Broken Hill's water supply to such an extent that the New South Wales Government now plans to build a 270km pipeline from the River Murray to supply the town at the cost of $500 million to taxpayers. Further reductions in flow will affect the ecology and the amenity value of Menindee Lakes.

A clear objective of the Murray-Darling Basin plan is to provide equitable access of water throughout the basin. Reductions of flows to South Australia and also to the Coorong, Lower Lakes and Murray Mouth site will have further impacts on communities and ecological sustainability of these systems which will need to be met from sources in the River Murray. Changes to these flows affect the environmental flow targets in the lower Murray and yet these were not modelled.

3. Inadequate use of environmental science

a. Inadequate focus on current understanding

The summary of the Northern Basin Review (Murray-Darling Basin Authority, 2016c) generally poorly represented current understanding of environmental science and the impacts of water resource development on the environmental assets of the northern basin. There was insufficient emphasis provided on the considerable investment in environmental science and understanding of the links between river flows and inundation patterns and the health of populations of plants, animals, other organisms and ecological processes. Inevitably much of understanding is scattered about likely effects of water resource development on riverine ecosystems and their organisms but many of the same organisms are affected in different river systems. For example, effects of reductions in flow on river red gums in the River Murray are similar to those recently identified in the Macquarie Marshes (Catelotti *et al.*, 2015).

The Northern Basin Review focused on seven core projects, one of which (waterbirds) was completed by researchers in the Centre for Ecosystem Science. This approach was laudable but not sufficient. In addition to this work, there should have been a thorough analyses of current understanding of widespread impacts of reductions in flow on the different organisms, hydrology, inundation patterns, relationships and ecosystem processes in the Northern Basin. This information could come from systems throughout the Northern Basin and across the Southern Basin.

There is widespread evidence for significant changes to ecosystems and their dependent organisms, as a result of alterations to flow, principally reductions (Appendices 1 and 2). These did not receive sufficient weight in the decision by the Murray-Darling Basin Authority

to recommend a reduction of 70 GL per year in flows to the environment and other users (Murray-Darling Basin Authority, 2016a). This evidence shows that there are widespread changes and associated degradation of the environment, when river flows and flooding declines, affecting many different organisms and their supporting ecological processes. It is critical to use multiple lines of evidence.

b. Best available science – not rigorously applied

There was no evidence of an assessment of the current state of scientific knowledge for each of the main river basins, supported by current rigorous science, principally peer reviewed scientific papers. For example, there are now a series of applied analyses that can link river flows to flooding regimes (Thomas *et al.*, 2011; Thomas *et al.*, 2015), condition of vegetation (Bino *et al.*, 2015) and breeding of waterbirds (Bino *et al.*, 2014) in the Macquarie Marshes, supplied by the Macquarie River. These peer reviewed papers show ecosystem assets in decline. There is also a peer reviewed paper showing the current inadequacy of the current modelling framework, underestimating impacts of water resource developments (Ren and Kingsford, 2011). Little of this scientific information was used in the Murray-Darling Basin Authority's assessment of changes to flow and effects on environmental assets in the Macquarie Marshes and Macquarie River.

There is clear scientific evidence that many of the organisms that depend on natural flooding regimes in Ramsar-listed sites are in decline. Much of this evidence was largely ignored by the Northern Basin Review, which focused all of its decision-making on output of hydrological models, with considerable uncertainty, rather than considering multiple lines of evidence or rigorous scientific studies.

At the very least, there should have been an assessment of what the latest science indicates the status of these core environmental assets for the State of the Basin. It is important to use multiple lines of evidence in an assessment of this magnitude, not just rely on hydrological assessments to drive policy decisions. Omission of this information was critical in terms of both informing the community as well as providing a background for the current decisions on water recovery.

A rigorous process of reviewing the science would have summarized the current scientific literature for each catchment, organism and ecosystem and identified relevant findings, tools and understanding that were catchment specific but also transferable across different river catchments. This could have further informed whether the river flow scenarios delivered adequately on the environmental indicators in each river catchment.

c. Independent scientific review - not adequately incorporated

The Northern Basin Review commissioned an independent scientific review of current understanding of the environmental science underpinning decision-making in the Northern Basin (Hale *et al.*, 2014). There are two key issues of concern about use of results of this report.

i. Focus inadequate

The independent scientific review only focused on the Barwon-Darling and the Condamine-

Balonne, leaving out the Macquarie, Paroo, Warrego, Border Rivers, Namoi and Gwydir catchments. If this was meant to provide an independent review of the state of the current understanding across the Northern Basin, it was clearly inadequate in terms of coverage for the decision-making involving all the northern basin catchments. It should be clearly marked as it is in the title of this report that it only applied to the Barwon-Darling and the Condamine-Balonne catchments.

ii. Poor incorporation into decision-making

The independent scientific review provided some excellent evidence for ecologically based decision-making that would have potentially ensured that the environmental assets of the Basin Plan were adequately met or could at least be measured and appropriately assessed. However much of this information did not appear to be considered or adequately integrated into either the summary report of the environmental science (Murray-Darling Basin Authority, 2016c) or the hydrological modelling (Murray-Darling Basin Authority, 2017).

d. Commissioned Research

There were seven commissioned scientific reports. These analyses were not well integrated into the decision-making. It was not clear how their outcomes were incorporated into the hydrological analyses linked to environmental assets. For example, scientists in the Centre for Ecosystem Science, UNSW Australia, completed a comprehensive series of reports on the effects of different scenarios on waterbird breeding in Narran Lakes. These studies provided some rigorous recommendations to ensure the sustainability of the Ramsar-listed Narran Lakes for which Australia and the Australian Government has international obligations. Three key reports, commissioned by the Murray-Darling Basin Authority identified the role Narran Lakes plays in providing critical waterbird breeding habitat and quantifying the water requirements to ensure it remains a viable breeding site (Brandis and Bino, 2016b; Brandis and Bino, 2016a; Merritt *et al.*, 2016). The decision was made not to provide sufficient water to ensure breeding of waterbirds, a key environmental outcome of the Murray-Darling Basin Plan.

Other commissioned science projects were useful but often limited to parts of the Northern Basin and so difficult to integrate their results for decision-making across the entire river basin. So they were poorly integrated into the decision-making. This problem was exacerbated because it was not clear which modelled outputs were used and the mismatch with the environmental outcomes. Specifically, model runs 320a, 320b, 320c appear in the environmental outcomes report but the final model run for the decision appears to be one of 320i, 320j or 320k which appear in the most recent summary tables. There is a clear lack of transparency with no information on what was included or excluded in the final models, compared to the models which provide information for the environmental outcomes.

e. Absence of climate change modelling

There is overwhelming evidence for climate change affecting Australia and the Murray-Darling Basin, including increasing temperatures (Reisinger *et al.*, 2014). The CSIRO sustainable yields studies clearly identified that this would have significant impacts on ecosystems and current users (CSIRO, 2008; Leblanc *et al.*, 2012). The effects of climate change will also fall disproportionately on the environment, compared to other users.

Increasing temperatures increase evaporation of surface flows, affecting water security for the environment and other current users. Given the significant environmental impacts of current water resource development, exacerbated by increased temperatures and potentially more variable rainfall, the critically important policy decisions to restore the Murray-Darling Basin to sustainability will increasingly fail because of the impacts of climate change.

It was critically important to include the effects of this climate change on river flows and environmental assets. It is not clear why such analyses were conducted by the Murray-Darling Basin Authority before the Murray-Darling Basin Plan to inform decision-makers but these analyses were not carried out for equally major decisions to reduce environmental flows in the Northern Basin. The recommended water recovery targets of the Northern Basin Review will further drive failure of Australian Governments to meet their conservation or environmental obligations, including international responsibilities.

4. Failing the Ramsar wetlands – a state, national and international responsibility

There are 16 Ramsar sites in the Murray-Darling Basin, with many highly reliant on river flows (Pittock and Finlayson, 2011). Three of these sites are the focus of Article 3.2 notifications of the Ramsar Convention (Australia is a signatory), to the international community that their ecological character has changed as a result of human impacts: Coorong, Lower Lake and Murray Mouth; Gwydir wetlands; and Macquarie Marshes. The latter two are in the Northern Basin. Narran Lakes Nature Reserve is also a key Ramsar site in the Northern Basin, with one of the main criteria for inclusion being its outstanding value for the breeding of colonial waterbirds (RIS (Information sheet on Ramsar Wetlands) - Narran Lakes, 2011).

The Murray-Darling Basin commissioned research into the requirements for breeding (Brandis and Bino, 2016b; Brandis and Bino, 2016a; Merritt *et al.*, 2016), given the value of this site for breeding of waterbirds. These studies identified a threshold when breeding occurred but the current recommendation to reduce cost recovery does not meeting this threshold. It fails to meet obligations of the Australian Government or New South Wales Government in the management of Ramsar-listed site. It is likely that there will be a future requirement for an Article 3.2 notification of the Ramsar Convention for this site. Further, there is a potential danger that there may not be sufficient water to complete a breeding event because of upstream extraction of water, requiring considerable cost expenditure by tax payers and risking considerable mortality of chicks, as occurred relatively recently (Brandis *et al.*, 2011b). In 2008, 74,095 pairs of ibis bred for the first time in seven years, establishing two contiguous colonies at Narran Lakes, a month apart. Most (97%) of the colony consisted of the straw-necked ibis (*Threskiornis spinicollis*) with the remainder consisting of glossy ibis (2%, *Plegadis falcinellus*) and Australian white ibis (1%, *T. molucca*). Following cessation of river flows, water levels fell rapidly in the colony site, resulting in a crisis management decision by governments to purchase and deliver water (10,423 ML) to avert mass desertion of the colonies. There were significant impacts on the reproductive success with only 17% of chicks fledging in late breeding birds as a result of falling water levels (Brandis *et al.*, 2011a).

Further, the Murray-Darling Basin Authority has assessed Macquarie Marshes and Gwydir

wetland systems as over recovered, solely on the basis of hydrological modelling (see commentary on hydrological modelling). For the Gwydir, the assessment concludes that there should be a reduction of environmental flows of 14,000 ML a year and for the Macquarie, it is 12,000 ML a year, based on shared and local recovery (Murray-Darling Basin Authority, 2016a). This decision exposes the Australian and State Governments to criticism about not meeting their international obligations for these wetlands, given their current state of decline.

In addition, the ability of the environmental flow targets to adequately measure ecological impacts is uncertain. For example for the Macquarie Marshes, the four targets are relatively simple and do not adequately reflect the complexity of the system. There are also concerns that their specification does not adequately represent their variability, combined with the uncertainties of the hydrological modelling (see below). Further the application of 'cap factors' lacks transparency.

Current water recovery is not sufficiently providing for the ecological character of the three internationally listed wetlands which are in ecological decline. For example, considerable rigorous research has been done in the Ramsar-listed Macquarie Marshes to support decision-making (Ren *et al.*, 2010; Ren and Kingsford, 2011; Thomas *et al.*, 2011; Steinfeld and Kingsford, 2013; Bino *et al.*, 2014; Ocock *et al.*, 2014; Bino *et al.*, 2015; Catelotti *et al.*, 2015; Steinfeld *et al.*, 2015; Thomas *et al.*, 2015). Most of this research was not mentioned in the Northern Basin Review, despite its rigor and relevance.

The sustainable management of Ramsar sites was a major rationale for a federal role in the management of the rivers of the Murray-Darling Basin, through the *Water Act 2007*, taking over responsibilities of the states under the Constitution. It will reflect a failure in the *Water Act 2007* and the Basin Plan if the Australian Government does not adequately manage the sustainability of Ramsar sites. The recommendations of the Northern Basin Review will clearly reduce the ability of the Australian Government and the New South Wales Government to meet their state, national and international responsibilties.

5. Environmental targets not met

The best case scenario for the recommendations on water recovery by the Murray-Darling Basin Authority is that only 22 of the 43 targets of the current Murray-Darling Basin Plan in the Northern Basin are met. The major goal of the Basin Plan, supported by the *Water Act 2007*, was to restore the sustainability of the Murray-Darling Basin, including its wetlands, rivers and dependent organisms, ecological processes and ecosystem services. A substantial body of rigorous work underpins this analysis, setting targets for each of these river systems and for only about half to be achieved in the best case scenario is a serious concern.

Although the environmental targets are an important index, they only measure a fraction of the variability and complexity of river systems. They do not adequately measure impacts or restoration as they are theoretically met when water reaches a threshold but the Basin plan does not adequately also measure duration, sequencing or behaviour of flooding regimes, essential for sustainability. Environmental targets represent only a minimum.

Even some targets which were modelled to be met (Murray-Darling Basin Authority, 2016c),

such as in the Macquarie Marshes, do not adequately represent the complexity and reliance on flooding for maintenance of the environmental values of the Macquarie Marshes. Specifically there are four targets which were supposedly met, using hydrological modelling, under a 320 GL target, resulting in the recommendation to reduce the amount of environmental water to reach the Macquarie Marshes by 12,000 ML per year. Importantly, this process of decision-making neglected to take account of the multiple lines of evidence for the poor health of the Macquarie Marshes. These targets were thresholds of at least one event of a certain volume of flow, measured at Marebone Break (100GL and 250GL over five months and 400 GL and 700GL over seven months, June to April). There are seven reasons why these thresholds did not adequately represent targets that reflected the environmental sustainability of the Macquarie Marshes.

- There was no analysis provided of frequencies of when more than one flood occurred at the different thresholds. So, some flow volumes may deliver more than one flood (e.g. 390GL vs 320GL) but there was no measure of this difference in the assessment in the Northern Basin Review.

- Measurement of these indicators at Marebone Break, as opposed to Marebone Gauge is critical because of the different flow patterns. It is not clear what impact this could have on the assessments.

- The sequencing of floods is important. There was some spells analysis in the assessment but sequencing of different sized floods remains critically important for ecologically complex wetlands and this was inadequate to determine potential effects of different water recovery options.

- There is an assumption that different thresholds translate to flooding regimes on a linear basis. This may not be true. In addition, there will be complex hydraulic features that will be highly variable on the floodplain and affected in different ways by flow volume.

- Measurement of flooding at Marebone Break does not adequately measure the behaviour of creeks which contribute to the overall health of the Macquarie Marshes, including Gunningbar Creek and Marthaguy Creek.

- There is no measure of duration of flooding; this is a key indicator of the value of different types of floods.

- There is no transparency or connection between the scenarios modelled for the environmental outcomes (320a, 320b, 320c) and the final recommendation based on different models (most likely 320j but could also be 320i and 320k). It is not possible to know how the final models affected flow targets because these were not reported (only 320a, 320b, 320c results reported in the environmental outcomes report).

- The definition of the ‘cap factor’ was not transparent and the implications for water recovery.

6. Fails migratory shorebirds – a state, national and international responsibility

There is increasing evidence that migratory species for which Australia has an international responsibility are declining (Gosbell and Clemens, 2006; Clemens *et al.*, 2016), across the continent. Inland survey data are also showing that migratory shorebirds are declining and some of this decline is due to the development of water resources on the rivers of the Murray-Darling Basin (Nebel *et al.*, 2008). Reduction in water recovery will further decrease habitats for migratory shorebirds species, particularly on floodplains.

Migratory shorebirds rely on wetlands such as the Macquarie Marshes, Narran Lakes, Gwydir wetlands, Menindee Lakes, Tallywalka lakes and Darling Anabranch lakes to provide resources while overwintering in Australia. All of these major wetlands are affected severely by reductions in flows from water resource developments. Further reductions in flow recovery as recommended by the Murray-Darling Basin Authority will further impact on shorebird populations.

The Australian Government has international responsibilities for migratory shorebirds which was another major rationale for a federal role in the management of the rivers of the Murray-Darling Basin, through the *Water Act 2007*, taking over responsibilities of the states under the Constitution. It will expose the Australian Government to criticism in terms of not only not meeting the objectives of the Murray-Darling Basin Plan but also not meeting its international obligations, which were a major driver for the Australian Government taking control of the management of the Murray-Darling Basin.

7. Inadequate transparency in hydrological modelling

Hydrological modelling was the primary analytical tool used to determine impacts of reductions in water recovery on environmental assets and communities. There were six issues of concern in relation to the presentation and output from the hydrological modelling, the main surrogate used for assessment of environmental and socio-economic impacts.

i. Mismatch modelling to environmental assessment

Most serious of all, environmental flow assessments for the final 320 GL per year threshold of water recovery were based on modelling scenarios 320a, 320b and 320c (Murray-Darling Basin Authority, 2016c). The final model scenarios on which decisions were made by the Murray-Darling Basin Authority to reduce water recovery from 390GL to 320GL was one of the following model scenarios 320i, 320j or 320k. This begs the question why was an environmental assessment not done on these three model scenarios. It is not possible for an objective assessment of the environmental or other consequences of these different scenarios on the environment. This process lacks transparency. It is also safe to assume there were another five model scenarios (320d-320h) for which there was no output presented. It is not clear what has differed among all these different modelled scenarios. Most importantly, there is no prospect of a transparent assessment of the environmental effects of the final decision by the Murray-Darling Basin Authority on the water recovery. It is also not clear what role the “Toolkit” has played and what guarantee that the options for water recovery in the toolkit will be implemented.

ii. Inadequacy of IQQM for measuring environmental impacts

There is good scientific evidence that current hydrological modelling does not adequately test effects of reductions to flow on inundation patterns of wetlands. A comparative analysis of IQQM (Integrated Quantity and Quality Modelling) modelling, used in the

Northern Basin analysis, and a statistical analysis using actual flow data and rainfall for the Macquarie Marshes showed that IQQM underestimated impacts to wetlands significantly (Ren and Kingsford, 2011).

Specifically IQQM overestimated flows after development and underestimated flows before development in the Macquarie River and Macquarie Marshes. The result was an underestimation of hydrological impact of about 10% to one of the gauges (Oxley) in the Macquarie Marshes. These analyses, published in a peer reviewed international scientific journal, received no reference in any documentation of the Northern Basin Review despite their relevance to decision-making and interpretation.

iii. No hydrological data for floodplains

Compounding this problem of underestimation, hydrological models used for the Northern Basin Assessments only have data for the main channels of rivers. There are no data to test the effects on the floodplain. So there is insensitivity to the importance of large flows on the floodplain which are critical for ecosystems because these are not adequately captured by the gauges in the main stem of the rivers. Consequently, the impacts of water resource development are underestimated as are the ecological importance of increased flows for recovery. Hydrological modelling does not adequately measure impacts of a reduction in the water recovery on dependent plants, animals, other organisms and ecological processes.

iv. Uncertainty of input data to hydrological models

There was little transparency about the assumptions of the hydrological models and poor state of input data, critical for a complex mechanistic hydrological model used to assess changes to flows in the Barwon-Darling and its tributaries. Such complex hydrological models rely on many different variables, often with unspecified assumptions (Ren and Kingsford, 2011). In particular, there is poor understanding of actual patterns of water use in the northern river valleys of the Northern Basin, a key input into the hydrological modelling.

v. Lack of transparency of interpretation of cap factors

Finally, the application of different 'cap factors' to final estimates, particularly for the Macquarie and Gwydir lacks transparency or specification.

vi. Inadequate review time for hydrological report

The technical hydrological report (Murray-Darling Basin Authority, 2017) was only released in January 2017, making it difficult to make a thorough analysis of how the different scenarios and modelled output was interpreted in the final decision-making process.

8. Limited socio-economic cost-benefit analysis

Socio-economic analyses were particularly narrow, primarily focusing on effects on irrigation communities. These analyses did not adequately incorporate structural changes in the industry. For example, transitioning from using cotton pickers for weeds and round bales in harvesting in the northern basin reduced labour by 75% (Chandler, 2016). This differed considerably to the development of the Murray-Darling Basin Plan where there was a much more holistic analysis of socio-economic impacts. There are economic values to the environment which were largely ignored, including use and non-use values (Morrison and Hatton-Macdonald, 2010). These were not assessed. Many of these environmental values

provide ecosystems services, critical to economic pursuits and quality of life.

Socio-economic analyses did not estimate the costs of ecosystem services provided by water recovery. These specifically relate to water quality, flooding for floodplain grazing communities, water source for Broken Hill, impacts of blue-green algal bloom. There was an analysis of potential effects on floodplain grazing (Murray-Darling Basin Authority, 2016b), but this was not adequately incorporated into the final decision-making. Perhaps as a reflection, the final report available is only marked as a draft report.

Socio-economic analysis was biased towards the irrigation industry with no analysis of positive benefits to downstream wetlands (tourism) or grazing. This is despite detailed analyses conducted as part of the Basin plan for the Coorong, Lower Lakes and Murray Mouth by CSIRO and other research institutions. These analyses which did not take into account the potential economic benefits to the entire Murray-Darling Basin, estimated that there were positive economic benefits of $3.4-7.7 billion provided by the environment, based on the focus of different studies (Centre for International Economics, 2011 ; Prosser *et al.*, 2012) for an increased environmental flow of 2,800 GL per year. This was because a range of ecosystem services were improved including reductions in salinity for agriculture and households, acid sulfate soils, tourism, reductions in dredging of Murray Mouth, carbon sequestration, erosion prevention. In relation to reductions in water recovery, there are real values which were not taking into account in the Northern Basin Review. This is not transparent economic analyses which were used to primarily justify the decision.

Further, there are considerable costs in just treating the symptoms of ecological collapse. For example the impact of low flow primarily because of over development upstream on the Coorong, Lower Lakes and Murray Mouth cost Australian taxpayers more than two billion dollars (Kingsford *et al.*, 2011). This consisted of a desalination plant for Adelaide and measures such as providing water for communities and treatment of acid sulfate soils. In addition, dealing with lack of water for waterbird breeding for Narran Lakes cost more than $1,870,000 (Brandis *et al.*, 2011b). There are real costs, not projected estimates, to Australian taxpayers resulting from water resource developments and mitigating the impacts.

There was a survey of the importance of the rivers in the Northern Basin to Aboriginal communities, with strong convictions of the importance of a river in good condition (Murray-Darling Basin Authority, 2016d). This input appeared to be largely ignored in terms of reduced recovery target of environmental water from the Northern Basin.

9. Toolkit measures – lack of transparency and implementation risk

The toolkit is considered integral to achieving cost recovery in the Northern Basin. There is a general lack of transparency about how this will be implemented across the Northern Basin and what audit or compliance issues can be put in place to ensure this occurs. There is also a general lack of transparency about how such savings measures actually provide additional environmental water.

The final models used for analyzing effects of different cost recovery lacked specification about what dependencies there were on different toolkit measures. It was therefore not possible to assess likely effects.

There seems little guarantee that different toolkit measures will necessarily be implemented as they are reliant on State process and would not be part of enforceable legislation.

Some water savings measures may not be positive in their current state for the environment. For example, current options of saving water in the Menindee Lakes may be costly to the environment. For example, the drying up of Lake Cawndilla will affect the environmental values of the wetland system and also the values and responsibilities of the NSW State Government for Kinchega National Park.

10. Increased groundwater availability for diversion

The Murray-Darling Basin Authority has recommended an increase in groundwater access from the Murray-Darling Basin. Two key issues need to be considered and are not adequately canvassed in the decision-making at this point: environmental assessment of the impact and regulation to ensure that sustainable yields are not exceeded.

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Appendix 2 references numbered separately below the table

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Appendix 1.Indicators and a brief summary (not an exhaustive list) of the scientific evidence for their degradation or decline in the Murray–Darling Basin due to river regulation and water resource development.

References were included when authors use primary data to link an indicator response with effects of water resource development – note that they may have also linked other factors also.

Indicator	Response due to river regulation	References
Hydrology	Hydrological change after dam and weir construction; alteration of seasonality of flows and flow regimes. Barriers to movements of organisms (e.g. native fish) and nutrients. Increases in flow volume in some rivers and decreases in flow volume in downstream parts of other rivers. Changes to temperature regimes, with colder regimes downstream of some dams. Increased low flows.	Baker and Wright (1978), Frazier et al (2005), Maheshwari et al (1995), Schreider et al (2002), Page et al (2005), Souter (2005), Mosely et al. (2010), Ren and Kingsford (2011) Ren et al (2010), Thoms and Sheldon (2000), Wen et al (2011); Leblanc et al. (2012), Wedderburn et al. (2012), Reid et al. (2013), Ren and Kingsford (2014), Souter and Shultz (2014), ,
Floodplain inundation	Decreased frequency and extent of inundation, particularly overbank flows affecting major wetlands and floodplains along rivers.	Frazier and Page (2006), Mosley et al. (2010), Ren et al (2010), Ren and Kingsford (2011), Thomas et al. (2011), Ren and Kingsford (2014), Thomas et al. (2015)
Algae, Biofilms	Alteration of assemblages and population declines, with potential effects of food webs.	Burns and Walker (2000), Chester and Norris (2006) Gell et al. (2007), Gell and Little (2007), Yu et al (2015)
Flow-dependent vegetation	Limits to germination and recruitment; increased abundance, dispersal and impact of alien species; alteration of growth and biomass.	Chesterfield (1986), Dexter et al. (1986), Bren (1992), Walker et al. (1994), Blanch et al. (2000), Bren (2005), Armstrong et al. (2009), Cunningham et al. (2009), Horner et al. (2009), Catford and Downes (2010), Catford et al. (2011), Cunningham et al. (2011), MacNally et al. (2011), Greet et al. (2013), Catford et al. (2014), MacNally et al. (2014a), Bino et al. (2015), Catelotti et al. (2015),
Macroinvertebrates and zooplankton	Assemblage change and/or population declines.	Walker (1981), Sheldon and Walker (1997); Quinn et al (2000), Chessman et al (2010), Richardson and Humphries (2010), Brooks et al (2011), Ning et al (2013), Pardo et al (2013), Reeves et al (2015),
Native fish species	Assemblage change and/or population declines; increased abundance, dispersal and impact of alien species; decreased spawning and recruitment success of native species; decreased movement and dispersal of native species.	Cadwallader (1977), Humphries and Lake (2000), Humphries et al. (2002), Mallen-Cooper and Stuart (2003), Rowland (2004), Driver et al. (2005), Todd et al. (2005), Stuart and Jones (2006), Jones and Stuart (2008), Roberts et al. (2008), Tonkin et al. (2008), Zampatti et al. (2010), Bice and Zampatti (2011), Wedderburn and Suitor (2012), Wedderburn et al. (2012), Ferguson et al. (2013), Humphries et al. (2013), Koehn et al. (2013), Rolls et al. (2013), Wedderburn et al. (2014)
Frogs	Assemblage change and/or population declines; significant range reductions of summer-breeding floodplain specialists; altered dispersal patterns.	Wassens (2006); Wassens 2008; Wassens et al. (2008a,b); Wassens and Maher (2011); Mac Nally et al. (2014b)
Waterbirds	Assemblage change and/or population declines; decreased frequency and size of breeding attempts; reduced reproductive success.	Kingsford and Thomas (1995), Kingsford and Johnson (1998), Leslie (2001), Kingsford et al. (2004), Kingsford and Thomas (2004), Kingsford and Auld (2005), Nebel et al. (2008), Brandis et al. (2011), Arthur et al. (2012); Reid et al. (2013)
Other birds	Reduced abundances, occurrence and reproductive performance, assemblage change and/or population declines.	McGinness et al. (2013), MacNally et al. (2014a), Selwood et al. (2015)

Appendix 2. Timeline of documented historical changes of Murray–Darling River flow-dependent ecosystems

See below for numbers matching supporting references

Period	Pressures	Plants	Invertebrates	Fish	Frogs	Turtles	Waterbirds	Other
1820–1900		Decline in wetland aquatic plants[1–5]	Decline in plant-associated wetland invertebrates[2, 3, 5, 6]	Decline in Murray cod abundance and distribution.[7–10]			Hunting impacts on some waterbird species[11]	Changes in wetland diatom assemblages, and increased salinity, nutrients, sedimentation and turbidity[1, 3–5, 12–14]
	Catchment and riparian vegetation extensively cleared, contributing to high erosion[15]			European perch, tench, common carp, brown trout and rainbow trout become established[16]				
	Grazing livestock, rabbits and foxes introduced							
	Alien fish species introduced							
	Commercial fishing, hunting of waterbirds and water diversions began							

Period	Pressures	Plants	Invertebrates	Fish	Frogs	Turtles	Waterbirds	Other
1900–1950	Commercial fishing and hunting of waterbirds increased	Decline in wetland aquatic plants[17]	Decline in plant-associated wetland invertebrates[17]	Decline in populations of native fish species. Rise of alien species[9, 10, 18–20]			Hunting impacts on egret populations and some duck species	Reduced platypus populations[21]
	Dams and weirs constructed, flows regulated, and water diversions increased	Wetland plants invade margins of Lower Murray weir pools[22, 23]	Wetland species – freshwater mussel (*Velesunio ambiguus*); yabbie (*Cherax destructor*) – become common in Lower Murray weir pools[24]					
	Gambusia introduced							
1950–2000	Dam and weir construction and floodplain development continued; water diversions continued to grow and peaked	Changes in composition and condition of vegetation communities,alteration of structure, including favouring invasive species[25–31]	Loss or decline of aquatic snail species in the lower Murray River[32]	Reduced range, abundance and breeding of many native species[33–42]	Reduced range and abundance of several species[43–47]		Decline in populations and breeding[48–56]	Increasing salinity,[57]
								increasing fragmentation of floodplains[58]
	Boolarra strain of common carp introduced to Murray–Darling Basin and rapidly dispersed and became abundant	Decline of *Ruppia* spp. in Coorong	Decline in distribution and abundance of Murray crayfish (*Euastacus armatus*)[59]					

Period	Pressures	Plants	Invertebrates	Fish	Frogs	Turtles	Waterbirds	Other
	Chytrid fungus accidentally introduced		Change in composition of Murray River fauna after about 1970[60]					Increasing occurrence of planktonic algae and cyanobacterial blooms[13, 61]
			Artemia replaces *Parartemia* in Coorong, South Lagoon					
2000–2010	Millennium Drought	Widespread canopy loss and dieback of floodplain eucalypts[62–67]	Reduced occurrence of drought-sensitive species[68, 69]	Reduced populations of drought-sensitive species[44, 70–74]	Reduced populations and recruitment of many species. Severe decline of summer-breeding floodplain specialists due to loss of refuge habitats[53, 75, 76]	Reduced populations of long-necked turtles[77]	Decline in populations and breeding[37, 50, 78–80]	Decline in water levels, salinisation and acidification of Lower Lakes[81]
								Changes to bird fauna with declines and partial recovery[82–85]
	Increased salinities and major water level recessions in Lower Murray, Lower Lakes and Coorong; riverbank collapse.							

Period	Pressures	Plants	Invertebrates	Fish	Frogs	Turtles	Waterbirds	Other
			Saltwater species, including tubeworm (*Ficopomatus enigmaticus*), invade Lower Lakes. Loss of freshwater mussel (*Velesunio ambiguus*) population in Lake Alexandrina[81]	Several small native species approached extinction and became conservation-reliant[86, 87]		Salinity in Lower Lakes caused short-neck turtle (*Emydura macquarii*) deaths from tubeworm infestation[81]		
2010–2015	Continuing water diversions, persistent alien species, anthropogenic climate change	Floodplain eucalypts partly recovered[88]	Some species that declined during Millennium Drought recovered but others did not[9, 69, 89]	Some species that declined during Millennium Drought recovered, but most did not[90–94]	Some species that declined during Millennium Drought recovered but others did not[53]			

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