INDEPENDENT SCIENTIFIC REVIEW OF THE REVISED CONDAMINE-BALONNE AND BARWON-DARLING ENVIRONMENTAL WATER REQUIREMENTS REPORTS

Dr Andrew J. Boulton
Adjunct Professor, Ecosystem Management,
School of Environmental and Rural Science, University of New England, Armidale, NSW

Professor Ross M. Thompson
Director, Chair of Water Science and ARC Future Fellow
Institute for Applied Ecology, University of Canberra, ACT, Australia.

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EXECUTIVE SUMMARY

This independent scientific review assesses two draft reports prepared by the Murray–Darling Basin Authority (MDBA) on the environmental water requirements (EWRs) of the Lower Balonne River Floodplain and the Narran Lakes, and the Barwon-Darling River system as part of the MDBA's review of Basin Plan settings for the Northern Murray-Darling Basin. The two reports describe the scientific basis for the selection of a set of site-specific flow indicators (SFIs) that are subsequently used in hydrological modelling to help inform decisions on long-term Sustainable Diversion Limits (SDLs). The SFIs are used to derive the SDLs and are not intended to be managed separately.

The Terms of Reference were to:

1. assess the references used to compile the EWR reports to identify strengths and weaknesses of the evidence base, and whether there is other science that is best available regarding these ecological assets that also should be considered,
2. assess both reports for consistency of methodology applied with respect to the Environmentally Sustainable Level of Take method, and,
3. assess whether the two reports adequately present the scientific evidence and how well this evidence has been applied in the selection of SFIs.

1. The evidence base supporting the two EWR reports is generally sound and is the best available science currently applicable to the ESLT method.

Strengths of the evidence base are:

- the inclusion of new commissioned research (including relevant site-specific field data) on eco-hydrological relationships in the Lower Balonne River Floodplain, the Narran Lakes and the Barwon-Darling River,
- integration of the requirements of multiple taxa (waterbirds, fish and floodplain vegetation) in target-setting and hypothesised ecological responses by different life-history stages to environmental watering, and,
- the use of the eco-hydrological driver of longitudinal and lateral connectivity from the reports' conceptual models to organise discussion of evidence supporting related suites of SFIs.

Weaknesses of the evidence base include:

- limited explanation of how logistic constraints on spatial and temporal extents of the regional field data translate into uncertainty in SFI relationships to flow,
- gaps in coverage of some relevant literature (e.g. refugia, potential effects of longitudinal and lateral hydrological connectivity on biogeochemical cycling of nutrients),
- limited use of relevant international peer-reviewed literature from equivalent ecosystems overseas,
- limited justification for the restricted suite of taxa (waterbirds, fish and floodplain vegetation) used for the lines of evidence about eco-hydrological relationships in the Northern Basin, and,
- the lack of a consistent assessment of specific sources of uncertainty in evaluating the evidence base to predict eco-hydrological responses that could then be used to inform judgement of uncertainty associated with the SFIs.

2. The ESLT method has been applied appropriately in both EWR reports. Where variations have been proposed (e.g. the increased focus on specifically linking SFIs to the eco-hydrological significance of longitudinal and lateral connectivity), these are adequately justified and take advantage of the recent advances in knowledge of the systems. The ESLT method assumes that the selected UEAs represent the water needs more broadly across the system of interest, and this crucial assumption deserves more detailed justification.

3. Scientific evidence supporting selection of SFIs is robust but several improvements could be made in its presentation. The narrative relating the technical information to the final flow recommendations and describing the inter-relationships and trade-offs between SFIs could be articulated better. Descriptions of the complex relationships between flows and SFIs need to explicitly acknowledge contingencies of responses, lags and overall uncertainty, and capture these in a robust conceptual model directly applicable to the Northern Basin.

Ways to improve the presentation of scientific evidence include:

- Adding a new table to each report that explicitly contrasts the scientific evidence used to support each of the previous SFIs in each UEA with the evidence used to select the current SFIs, and that includes references to relevant literature and empirical data. In particular, these tables need to emphasise data not available in the previous assessment.
- Supplementing the current tables summarising the evidence supporting estimated magnitude, duration, timing and frequency with explicit reference to the primary sources of information for each criterion.
- Explicitly acknowledging the extent of uncertainty around each flow-SFI relationship, potentially by using an 'uncertainty ranking' system such as that employed by the Inter-governmental Panel on Climate Change.
- Enhancing presentation of the scientific evidence by an improved explanation of the flow of logic leading from ecological targets and hydrological modelling to the detailed recommendations for watering.
- Developing a clear conceptual representation of the system that shows the relationships between flow, primary productivity and biogeochemical processes (e.g. nutrient release and

transport) and the other SFIs. This should be a robust conceptual eco-hydrological model at the scale of the Northern Basin that extends the current conceptual models to include multi-scale temporal components.

- Clearly describing the potential for antecedent environmental conditions to affect ecological responses to flow in the context of the SFIs for each UEA.
- Clear and consistent use of terminology, in particular the distinction between ecosystem (and ecological) functions and processes, and how these terms are used in the reports to describe hydrological connectivity.
- Adding a specific section to each report that lists remaining gaps in knowledge and data, identifying where these gaps constrain confidence in setting SFIs in each UEA.
- Adding a glossary to define technical terms, where possible using definitions consistent with use of these terms in the published literature.

The review concludes by reiterating our main recommendations for improving the scientific validity and clarity of presentation of the scientific evidence base in the two reports.

CONTEXT

The Murray–Darling Basin Authority (MDBA) is reviewing the Basin Plan settings for the Northern Murray-Darling Basin. The Northern Basin review includes research in social and economic analysis, hydrological modelling, and environmental science, supported by stakeholder engagement. This work will inform re-consideration of policy settings for long-term average Sustainable Diversion Limits (SDLs). Before the Basin Plan was devised, environmental water requirements (EWRs) of 24 ecological assets across the Murray-Darling Basin were assessed by the MDBA. These assets included the Lower Balonne River Floodplain and the Narran Lakes, and the Barwon-Darling River system. Data from these sites were used to establish the SDLs for the Northern Basin.

As part of the Northern Basin SDL review, the water requirements of these three assets are currently being re-assessed using the Environmentally Sustainable Level of Take (ESLT) method (Swirepik et al. 2015). This re-assessment has involved commissioning several scientific investigations to improve the scientific evidence base, in particular the eco-hydrological relationships for these assets.

Two draft reports have been prepared (MDBA 2016a, 2016b) on the EWRs of the Lower Balonne River Floodplain and the Narran Lakes, and the Barwon-Darling River system. These reports are described in the Terms of Reference for the present review as aimed at "linking ecological values to broad ecological targets to ecological functions to site-specific flow indicators. The site-specific flow indicators (SFIs) are subsequently used in hydrological modelling to provide environmental information used in decisions on the long-term average Sustainable Diversion Limits."

As a pair of independent environmental scientists, we have been commissioned by the MDBA to review these two draft reports according to the following Terms of Reference:

"1. Assess the references used to compile the EWR reports in order to identify strengths and weaknesses of the evidence base, and whether there is other science that is best available regarding these ecological assets that also should be considered.
2. Assess the Condamine-Balonne and Barwon-Darling EWR reports for consistency of methodology applied with respect to the ESLT method.
3. Assess whether the Condamine-Balonne and Barwon-Darling EWR reports adequately present the scientific evidence and how well this evidence has been applied in the selection of SFIs."

The following were specified as outside our scope: (1) review of the ESLT method (already done by Young et al. 2011), (2) review of scientific technical reports that underpin the EWR reports, and (3) review of any environmental outcomes reports that will be prepared following the modelling of selected site-specific flow indicators. As we are ecologists and not professional hydrologists, assessment of the adequacy of the hydrological analysis was also deemed to be out of our scope because we are not qualified to advise on this topic.

We acknowledge valuable discussions with members of the Environmental Science Technical Advisory Group (12th May, 2016) and the Lower Balonne Working Group, the Environmental Science Working Group, and Smartrivers consultants Owen Droop and Dr Lee Benson (7th June, 2016). We intend our broad review to complement the region-specific comments made by these groups in separate submissions to the MDBA.

1. STRENGTHS AND WEAKNESSES OF THE EVIDENCE BASE, INCLUDING USE OF BEST AVAILABLE SCIENCE ON THESE ECOLOGICAL ASSETS

The evidence base on which the two EWR reports is founded is generally sound and reflects the best available science applicable to the ESLT method.

Strengths of the evidence base used to compile these two EWR reports are:

1. The inclusion of new commissioned research (including some field data) on eco-hydrological relationships in the two UEAs to complement inferences drawn from research and peer-reviewed literature from the southern Murray Darling Basin. Involvement of numerous experts in this commissioned research helped ensure inclusion of the best available science about the ecological assets.
2. An effort to integrate requirements of multiple taxa (waterbirds, fish and floodplain vegetation) in target-setting and hypothesised ecological responses by different life-history stages to flows.
3. The explicit use of the eco-hydrological driver of longitudinal and lateral connectivity from the reports' conceptual models to organise discussion of evidence supporting related suites of SFIs.

Weaknesses of the evidence base include:

1. Inevitably, there are logistic constraints on spatial (e.g. limited number of sites) and temporal (e.g. short time series) extents of the field data, as well as gaps in the information that further constrains the evidence base. A fuller explanation is needed of how these constraints translate into uncertainty in the assessments of the EWRs.
2. Gaps in coverage of some relevant literature (e.g. refugia, potential effects of hydrological longitudinal and lateral connectivity on biogeochemical cycling of nutrients).
3. Limited use of relevant international peer-reviewed literature on equivalent ecosystems overseas as a further source of evidence to support EWR assessment as well as demonstrating that the current studies are at the international forefront of tackling environmental watering in entire river basins in regions with high climatic variability.
4. Despite the pragmatic focus on a limited suite of taxa (waterbirds, fish and floodplain vegetation) for the lines of evidence about eco-hydrological relationships, stronger justification is needed that these choices provide the best evidence base, including explanation of why other taxa (e.g. algae, aquatic invertebrates) were not selected.
5. The lack of an assessment of specific sources of uncertainty in evaluating the evidence base to predict eco-hydrological responses that would then assist independent judgement of uncertainty associated with the SFIs. Related to this, it was not clear why more formal systematic approaches were not considered to evaluate the literature, expert opinion and other components of the evidence base.

We also advocate adding further background material to enable the reports to 'stand alone'. This needs to include clear explanation of the role of the EWR reports and the SFIs in the process used to determine the SDLs. There were several cases of apparent misinterpretation of cited literature; two are described here and others are identified on the annotated copies of both reports. Other minor points are detailed below or on annotated versions of both EWR reports that have been provided to the MDBA.

Strengths of the evidence base

Overall, we consider the evidence base to be sound and fit-for-purpose in application within the ESLT method for these two sets of umbrella environmental assets (UEAs). While there remain some uncertainties about several of the eco-hydrological relationships, the EWR reports represent a clear step forward in terms of the research provided and application of that evidence base.

The main strength of the evidence base compared with the previous assessments (MDBA 2012a, 2012b) of EWRs for these two sets of UEAs is the capacity to draw on recent MDBA-commissioned literature assessments and research data collected from the region explicitly to support EWRs. This considerably strengthens inferences about likely ecological responses to flows of particular magnitudes, durations and annual frequency. It also helps address concerns about the validity of extrapolating results from the better-known Southern Basin to Northern Basin ecosystems.

A second strength of the evidence base is the attempt to integrate flow requirements of diverse multiple taxa (primarily waterbirds, fish and floodplain vegetation) when selecting SFIs in the two UEAs. Rather than focus solely on eco-hydrological requirements of several species of fish, for example, there has been a concerted effort to address the likely flow-regime requirements of a diverse suite of biota, particularly those for which region-specific data are available or whose biology is reasonably well-known. Even where reference is made to the requirements of a specific taxon when explaining the choice for parameters of a given flow (e.g. straw-necked ibis), the decision is justified by assertion that this taxon's requirements is likely to reflect those of other taxa (p80, MDBA 2016b) and that the intention is not to solely favour one or a few species. Biological responses to all types of flow management involve trade-offs and, ecologically, there will be 'winners' and 'losers' under any prescribed flow as would also occur naturally under without-development flows.

Related to the strength above is the targeting of some SFIs to support different life history stages of the various taxa rather than all SFIs focusing on requirements for adults only. This recognises the importance of suitable environmental conditions for recruitment, juvenile growth and other potential 'life-history bottlenecks' to persistence of particular taxa. We see this broader flow-management perspective as one of the strengths of the evidence base because it includes relevant information on, for example, eco-hydrological requirements for nesting waterbirds or germinating floodplain vegetation to inform selection of SFIs to support particular life-stages at critical times.

A third strength of the evidence base is the use of the eco-hydrological driver of longitudinal and lateral connectivity to organise the lines of evidence supporting selection of related suites of SFIs. Contemporary conceptual models of river ecosystems acknowledge the primacy of hydrological connectivity (*sensu* Pringle 2003) in all three spatial dimensions (longitudinal, lateral and vertical) as well as the temporal dimension that describes how these spatial vectors of connectivity vary over time (reviews in Boulton et al. 2014, Costigan et al. 2015). Restoration and conservation strategies routinely emphasise the ecological significance of connectivity (Beger et al. 2010, Palmer and McDonough 2013), especially in river-floodplain ecosystems (e.g. Paillex et al. 2009, Jacobson and Faust 2014). In both reports, hydrological connectivity underpins the conceptual models (Figures 3 and 11 in MDBA 2016a; Figures 4 and 19 in MDBA 2016b) used to portray mechanisms by which SFIs respond to flow. Recent work in this region, but outside of the UEAs considered here (e.g. Holloway et al. 2013), suggests that lateral connectivity may be particularly important in driving ecological responses in the Northern Basin. Preserving this theme in organising the lines of evidence supporting selection of related suites of SFIs helps readers grasp the fundamental importance of longitudinal and lateral hydrological connectivity in these river-floodplain ecosystems.

Weaknesses of the evidence base

Although we applaud the collection of data from relevant areas of the Northern Basin to support the current selection of SFIs, there are inevitable logistic constraints on the spatial and temporal extents of these field data. In dryland river systems such as the two UEAs, the problem is especially severe because the inherent natural variability typical of dryland rivers (Gordon et al. 2004, Leigh et al. 2010) necessitates long-term data sets to adequately capture the range of ecological responses to different flows and their antecedent conditions. Spatially, extrapolating inferences from one part of a dryland river basin to another is perilous, again because of the substantial inherent hydrological and ecological variability in these ecosystems. Many of these constraints are acknowledged in the supporting reports and we accept that these logistic weaknesses in the evidence base are inevitable and can best be addressed by additional empirical data.

However, we consider that both EWR reports would benefit greatly from including a specific section for each UEA that lists each of these constraints in the supporting data and assesses the potential severity of their impact on the reliability of particular SFIs. For example, the research on waterholes (DSITI 2015) identified constraints in the evidence base about the depths at which habitat and water quality decline in persistent waterholes across the Lower Balonne. These constraints are relevant to the choice of 0.5m as a threshold depth below which the refuge quality of a persistent waterhole is considered at significant risk (e.g. Section 5.1.1 in MDBA 2016b). Expert assessment is needed about the potential consequences uncertainty about this threshold (e.g. what if the true threshold is 0.75m for particularly important aquatic taxa?) for the reliability of SFIs associated with drought refuges in the Lower Balonne River Floodplain UEA (Table 2 in MDBA 2016b). Another source of uncertainty relates to the adoption of flow indicators recommended by different researchers who are likely to have different perceptions and interpretations of uncertainty. A consistent approach is needed to clearly describe where there is uncertainty, what type of uncertainty this is (discussed by Tartakovsky 2013) and how this uncertainty may affect the application of the SFIs.

We recommend adding a section in each report dedicated to assessing the constraints in the evidence base and providing a more transparent explanation of how these constraints impact on the reliability of particular SFIs. This section should also address how these constraints translate into uncertainty that may contribute to the overall uncertainty about the eco-hydrological relationships. Currently, there is acknowledgement of uncertainty in Appendix A in both reports but this does not explain how the evidence base was interpreted to acknowledge these uncertainties, especially where flow indicators were adopted based on recommendations from different sources. Similar constraints apply to evidence gathered from literature and expert opinion, and later in this section we describe a potential approach (Webb et al. 2015) that attempts to address this in determining environmental flows in Victoria. If desired, a formal risk assessment (e.g. Pollino et al. 2007; Poff et al. 2010) could be conducted, but we do not consider this essential.

We acknowledge that both reports strive to be succinct and are not intended as comprehensive reviews of published literature. Nonetheless, we did identify several areas in both reports where we considered there were major gaps in coverage of relevant literature. One of these was in the discussion of refugia, which would benefit from considering the conceptual framework provided by

Davis et al. (2013) and McNeil (2011 and the arising peer-reviewed papers). This work clearly identifies the critical role of refugia in maintaining persistence of species. Modelling precisely the drying of waterholes is challenging, and justifies a conservative approach to ensuring that water is available for these habitats under dry conditions. The interaction between floodplain flooding and recharging of shallow groundwater aquifers is poorly understood in these systems (and elsewhere) but is likely to be important for sustaining refugial pools and supporting floodplain vegetation. Actual efficacy of refugia can only be assessed using insights from molecular tools such as evidence for genetic bottlenecks or gene flows from the refugia into rewetted neighbouring habitat (e.g. Razeng et al. 2016) or long-term studies of species range and persistence (e.g. McNeil et al. 2011). While we accept that studies of this type have not been a priority in these systems to date, detailed mapping coupled with information on efficacy of refugia through time would benefit management.

A second gap is the discussion of the potential effects of longitudinal and lateral hydrological connectivity on biogeochemical cycling of nutrients in dryland river ecosystems. Although the importance of nutrient dynamics in the UEAs is explicitly acknowledged in both reports, explanation of some of the processes and underlying mechanisms is unclear. For example, in the conceptual model (Figure 3 in MDBA 2016a), periods of baseflow and no flow are proposed to 'dilute' nutrients following floods. Although floodplain sediments do release nitrogen and phosphorus on rewetting (Baldwin and Mitchell 2000) resulting in transient increases in nutrient concentrations, it is likely that rapid microbial uptake occurs, even after long dry periods (review in Sabater et al. 2016). Post-flood, some dissolved and particulate nutrients may be carried downstream by baseflow but this is not really 'dilution' and when flow ceases, available nutrients are more likely to be taken up biologically than 'diluted' (see Boulton et al. 2014 for diagrams of nutrient cycling and spiralling that illustrate these processes). There are several other examples of unclear explanations about predicted flow-related nutrient dynamics in the two UEAs (e.g. p37, p39, MDBA 2016a; p68, MDBA 2016b) and we provide further comments on our editorial annotations of the two reports.

We recommend that both reports substantially revise their explanations of how longitudinal and lateral hydrological connectivity influence dynamics of macronutrients (N, P and C) so that the conceptual models are more accurate (discussed further in Section 3 below). Explanations must adequately capture the mechanisms of uptake and release of macronutrients by microbes (including bacterioplankton and Cyanobacteria – 'blue-green algae') and algae in these types of dryland river-floodplain ecosystems under different conditions of longitudinal and lateral hydrological connectivity. The effects of different periods of wetting and drying of the floodplain is especially relevant given the SFIs for inner, mid-, and outer floodplain of the Lower Balonne River Floodplain. Addressing this gap will clarify key links in the current conceptualisation of the two UEAs (e.g. the mechanism by which 'small in-channel freshes' are proposed to increase in-stream primary production (p39, MDBA 2016a). Input from experts such as Dr Darren Baldwin (MDFRC) is recommended.

There is surprisingly little reference in either report to relevant international literature on environmental watering in dryland river ecosystems. We accept that this may partly reflect efforts to constrain the length of the reports. However, we urge more inclusion of international literature in these reports for three reasons. The first is to highlight that choosing appropriate environmental watering strategies in dryland river ecosystems is also a challenge outside Australia; globally, managers are facing similar difficulties to those described in the present pair of studies (e.g. Arizona: Mott LaCroix et al. 2016; South Africa: King and Pienaar 2011; Israel: Chen and Weisbrod 2016). The second is to identify differences and parallels in the diverse approaches being used overseas so that the advantages of the current approach can be better demonstrated (cf. Swirepik et al. 2015). The third and perhaps most significant benefit is to widen the evidence base for predicting likely eco-hydrological responses, especially those less likely to be region-specific (e.g. nutrient dynamics during wetting and drying, Sabater et al. 2016). Inclusion of additional international literature in these two reports will counter criticisms of parochialism and exemplify how the current work is at the global forefront of tacking EWRs of entire river basins in regions of high climatic variability.

Choosing EWRs of a limited suite of taxa (waterbirds, fish and floodplain vegetation) is understandably pragmatic. However, because this suite is only a subset of those possible, we consider that stronger justification is needed for these particular choices. This has been partly done in Sections 4.1 and 4.2 of both reports but these sections lack explanation of why other groups (e.g. algae, aquatic invertebrates) were not used even though some of these groups are stated as ecological targets (e.g. invertebrates on p3, p6, MDBA 2016b). We consider that the case for choosing the present limited suite would be strengthened by identifying the problems of using other taxa that, for example, might be harder to monitor or have less well-known eco-hydrological responses. This weakness can be readily addressed (perhaps as a box in Section 4.1) and, during the process, might either reveal potential candidates for future assessments or confirm ecological redundancies where satisfying the needs of one group of the currently chosen taxa will address the needs of another group that has not been assessed.

The complexity and importance of effective integration of information gleaned from field data, published literature and expert opinion on likely ecological responses to flow have prompted some researchers to advocate the use of formal approaches for assessing the quality (including uncertainty) of these different sources of information in a transparent, consistent and repeatable way. One promising formal approach used in Victoria for predicting the effects of environmental flows is that described by Webb et al. (2015). In brief, the method uses a systematic review of the literature to develop evidence-based conceptual models, formal expert elicitation to quantify links in the models, and data derived from purpose-designed monitoring programs over large spatial scales. These three elements are combined in a Bayesian hierarchical model that quantifies the relationship between flow variation and ecological response that can then be used to predict ecological responses to flow restoration.

To strengthen analysis of the evidence base used in the two reports, there could be a systematic review of the literature, using techniques such as the freely available 'Eco Evidence' software (Norris et al. 2012) exemplified by the analysis by Webb et al. (2012) of published evidence linking wetland plants to water regime components. This approach and others like it (e.g. Woodcock et al. 2014) are transparent, logical and consistent (Webb et al. 2013), as well as capable of being integrated into the broader framework described in Webb et al. (2015). Approaches such as 'Eco Evidence' are best used to complement the more traditional narrative literature review currently used in the two reports that, although lacking rigour (Slavin 1995), allows more detailed examination of individual studies. Numerical techniques like 'Eco Evidence' maximize the transparency and repeatability of literature reviews and uses systematic search-and-evaluation techniques to avoid bias in the conclusions. Use of these formal frameworks and various 'multiple lines of evidence' approaches in ecological restoration are being increasingly advocated in the scientific literature (e.g. Diefenderfer et al. 2016). None of the commissioned reviews supporting the two EWRs appeared to use a systematic approach to analyse the inferential strength of their cited literature, particularly where this information was being used to predict eco-hydrological responses.

In several instances, literature cited in the two reports appears to have been misinterpreted. For example in MDBA (2016a, p40), the paper by Boys and Thoms (2006) is used to support the statement that Murray cod access to snag habitat is a key requirement to initiate breeding. This study certainly found that Murray cod were strongly associated with wood but the authors do not present evidence that snag access initiates breeding (indeed, they do not discuss breeding biology of Murray cod at all). In another part of the same report (p37), it is claimed that "Jenkins and Boulton (2003) showed that recruitment of macroinvertebrates into floodplain lakes on the Darling had a large influence on the composition of the community" when in fact this study by these two authors was entirely on microinvertebrates. Other examples where literature appears to have been inadvertently misinterpreted are identified on the annotated copies of both reports.

Instead of using italics to denote references from the Barwon-Darling and Condamine-Balonne catchments produced since the making of the Basin Plan in 2012, we suggest including a short section in each report that specifically identifies all the new knowledge, fully cited, that has contributed to changes in the current EWRs compared to the previous version. These changes and associated references also need to be specified and highlighted in the summary tables, as suggested in Section 3 below.

The commissioned research supporting these two reports has captured the best available science for the region, especially where expert opinion and reviews were sought. In various places in this review, we draw attention to some of the broader international literature on assessing EWRs in dryland river ecosystems overseas but acknowledge that our report lacks space to provide a comprehensive review of all this material. The MDBA is aware of ongoing ecological research in nearby Australian dryland river ecosystems (including by members of the Environmental Science Technical Advisory Group) and this work, although not from the UEAs themselves, is likely to be relevant for future iterations of SFIs.

2. CONSISTENCY OF METHODOLOGY APPLIED WITH RESPECT TO THE ESLT METHOD

The ESLT method, used to ensure a standard approach across the MDB, is appropriately applied in the reports provided. Where variations from the initial EWR reports (MDBA 2012a, 2012b) have been proposed (e.g. the increased focus on specifically linking site-specific flow indicators to the eco-hydrological significance of longitudinal and lateral connectivity), these are adequately justified and take advantage of the recent advances in knowledge and understanding of the systems.

However, two issues deserve some attention:

1. The ESLT method relies upon an assumption that the selected UEAs are representative of the water needs more broadly across the system of interest. Although the importance of spatial representativeness is acknowledged (Section 2.2.1 in both reports), a short section should be added to each report that robustly justifies the choice of these UEAs and makes the case for their representativeness.
2. In the Condamine-Balonne EWR report (MDBA 2016b), reference is made to emerging data on the Condamine River upstream of Beardmore Dam in the vicinity of Chinchilla. However, there is no assessment of whether this data is consistent with patterns seen in the UEA.

It is outside the scope of the current review to assess the ESLT method, which has been independently reviewed in the past (Young et al. 2011). We are aware that alternative methods and alternative UEAs have been proposed for the Northern Basin, but it is not clear that their application or inclusion would substantively alter the outcomes of the EWRs. The 'industry standard' approaches to determining water needs (e.g. ELOHA; Poff et al. 2010) require detailed and spatially comprehensive data which are not available for these catchments. The high variability of the system is well represented in Figures 11 and 12 from the Condamine-Balonne EWR report (MDBA 2016b), and makes the development of empirical flow-ecology relationships throughout the system impractical. We consider the ESLT approach as applied as appropriate for determining the water needs of the river system.

Because the Narran UEA is at the downstream end of the system, it is assumed that supplying water to meet the ecological needs of the UEAs is also likely to provide water for the remainder of the system. The process whereby the UEAs were chosen is well described in previous work, and make clear that there is a critical assumption that the UEAs are representative. Where feasible, multiple lines of evidence should be gathered to support this crucial assumption, especially given the spatial and temporal variability inherent to the river-floodplain systems of the Northern Basin. This should also take advantage of information collected outside of the UEAs, for example in the Condamine-Balonne EWR report (MDBA 2016b), reference is made to emerging data on the Condamine River upstream of Beardmore Dam in the vicinity of Chinchilla.

3. ADEQUACY OF PRESENTATION OF THE SCIENTIFIC EVIDENCE AND ITS APPLICATION TO SELECTION OF SITE-SPECIFIC FLOW INDICATORS

Scientific evidence supporting selection of SFIs is appropriately applied; however, several improvements could be made in its presentation. The narrative relating the technical information to the final flow recommendations is not always clear, and the inter-relationships and trade-offs between SFIs could be articulated better. Although we recognise that SFIs function collectively in this approach, this needs to be made clear to prevent the impression that all SFIs are being managed separately. Finally the complex nature of the relationships between flows and SFIs must be clarified through explicit acknowledgement of contingencies of responses, lags and overall uncertainty. These complex relationships need to be captured by a robust conceptual eco-hydrological model at the scale of the Northern Basin that extends the current spatial conceptual models to include temporal aspects.

We propose some ways to address our concerns about presentation of scientific evidence:

1. Add a new table to each report that explicitly contrasts the scientific evidence used to support each of the previous SFIs in each UEA with the evidence used to select the current SFIs. This table should include references to relevant literature and empirical data, and will illustrate the substantial advances in understanding that have accrued from recent work, including that commissioned by the MDBA.
2. Although the tables summarising the evidence supporting estimated magnitude, duration, timing and frequency are highly effective presentations, they also need to list the primary sources of information for each criterion so that interested readers can readily check the evidence. Judicious use of superscripts denoting references in the tables is recommended.
3. Explicit acknowledgement of the uncertainty around each flow-SFI relationship would greatly improve the clarity of this crucial aspect. One potential approach is the 'uncertainty ranking' system used by the Inter-governmental Panel on Climate Change. This could be combined with a preliminary attempt to identify sources, types and magnitudes of uncertainty at all steps in the chain of logic used to derive each SFI.
4. Presentation of the scientific evidence would be helped by improved explanations of: (1) the flow of logic leading to the conclusions about specific flow dependencies for each SFI, (2) the relationships between flow, primary productivity and biogeochemical processes (e.g. nutrient release and transport), (3) the influence of antecedent environmental conditions on ecological responses to flow, and (4) the distinction between ecosystem (and ecological) functions and processes, and how these are applied to describe hydrological connectivity. These should then be incorporated into a robust conceptual eco-hydrological model at the scale of the Northern Basin that extends the current conceptual models by incorporating multi-scale temporal components.
5. Many gaps in knowledge have been addressed by the commissioned research but some gaps remain. Each report should include a specific section (perhaps inserted just before the final summary) that lists current gaps in knowledge and data, identifying where these gaps constrain confidence in setting SFIs in each UEA. Although each report currently identifies these gaps, this information is scattered through the text.
6. Include a glossary because, in places, some technical terms are used inconsistently, detracting from the clarity of the presentation of the scientific evidence.

The scientific evidence, especially recent information commissioned by the MDBA, has been applied appropriately to the selection of SFIs, and the summary tables (e.g. Tables 2, 3 and 7 in MDBA 2016a) that specify the evidence supporting magnitude, duration, timing and frequency estimates are especially powerful presentations. These tables would, however, benefit from specifically referencing primary sources of information for each criterion so that interested readers can readily check the evidence and follow particular lines of evidence. To keep the tables from growing unwieldy, superscripts could be judiciously used to denote each relevant reference.

In general, the SFIs are representative of likely flow-dependent ecological processes in these systems although we recommend clearer justification for their choice (discussed in Section 1). The SFIs in the EWRs are intended to be treated as a 'suite' of responses which collectively contribute to deriving an SDL. However, this is not well articulated in the reports, and might lead the reader to concentrate on a single SFI (e.g. the emphasis on fish in SFIs for longitudinal connectivity in the Barwon-Darling river system UEA in Section 5.1 of MDBA 2016a), or interpreting that management seeks to optimise all SFIs. For example, maximising in-stream primary productivity (ISPP) is likely to be represented by an algal bloom, which would not always be a desirable state. Both reports would benefit from a clearer discussion of specific trade-offs between different SFIs (perhaps a text-box that includes a relevant example) so that readers better appreciate the complexity of the management strategy and the difficulties in catering for the diversity of ecological requirements of multiple taxa.

Presentation and explanation of the ecosystem process components in both reports are relatively weak. For example, the ecosystem processes of nutrient spiralling and ISPP are not well explained, perhaps because of the lack of focused work on these components. The relationships between flow, productivity and biogeochemical processes (e.g. nutrient release and transport) are poorly established and although some inferences are drawn from cited literature, these are not presented sufficiently precisely to demonstrate how changes in longitudinal and lateral connectivity resulting from different-sized hydrologic metrics might influence biogeochemical processes in the channel (especially in persistent waterholes) and on the floodplain before and after inundation.

Furthermore, the relationships between ISPP and other SFIs are poorly explained. For example, it is inferred that inundation of snags and shallow benches is likely to generate significant ISPP whose trophic products can then flow to higher-order consumers such as birds and fish via invertebrate food chains. However, without a clear explanation of this link it is possible that a reader could interpret the reports as suggesting that the ISPP SFI is being managed for its own sake. Similarly, the failure to explain this important role for snags and benches leads to an impression that their inundation is largely targeted to provision of fish habitat, when in fact the dual roles of habitat and substrate for primary productivity are both important. The same applies to the detrital food pathway and the role of microbial communities (e.g. biofilms on snags). Care also needs to be taken in claiming that ecosystems can 'adapt' to a given hydrological regime (p25 in MDBA 2016a); biota with traits that favour their persistence under a given hydrological regime may be more abundant than those biota that lack such traits but ecosystems are seldom considered as units capable of active adaptation to environmental conditions.

While we appreciate the desire for brevity in both reports, it is critical that the derivation of the bounds on the hydrologic metrics (magnitude, duration, timing, frequency) of each SFI is very transparent. For example, how the recommendations for plant water requirements were generalised from the technical information is not always clear. Given the pivotal importance of this aspect of both reports, we would propose relaxing constraints on length so that each step in the chain of logic can be fully justified. There are several places where claims in the reports must be supported by specific reference to relevant literature and/or empirical data (e.g. the claim that provision of more frequent inundation in wetter times will often increase the resilience of communities, increasing the likelihood of survival during dry times [p. 20 of MDBA 2016a]). Other examples where specific references are needed to support key claims are listed on the two annotated reports submitted to the MDBA with this review.

The nature of the relationships between flow and SFIs are presented in a highly simplified fashion. Although this lends itself to communicating the overall purpose of using a suite of SFIs to contribute to derivation of the SDL, the reports should explain the factors that complicate these relationships. Flow-SFI relationships may be highly non-linear or include thresholds, meaning that provision of a proportional component of the required flows will not always generate a proportional response in the SFIs. For example, if a fish species requires a certain stage height in the river to trigger spawning (e.g. King et al. 2009), then providing half that flow will not provide half the ecological response.

Particular suites of antecedent conditions may increase or reduce the potential of some SFIs to respond to a given flow event. For example, long dry periods may reduce condition of floodplain vegetation such that an initial watering event may trigger re-growth rather than flowering (e.g. Wen et al. 2009). Life history constraints can also affect flow responses, with longer-lived species often requiring multiple flow events before they exhibit a response. This can be due to trophic relationships; provision of flow may allow increased primary production and proliferation of invertebrates and small-bodied fish, but large-bodied fish may not be able to respond until these prey items have reached a necessary biomass. One of the major sources of uncertainty in inferring the relationships between flow and SFIs arises from a lack of knowledge about the influence of antecedent conditions, and this constraint needs more discussion in the two reports.

We fully support the use of longitudinal and lateral connectivity as themes for grouping the SFIs and hypothesised ecological responses; this eco-hydrological approach is well-grounded and appropriate, and its use here is a major step forward from the initial EWR assessment (MDBA 2012). However, the description of longitudinal and lateral connectivity as ‘ecological functions’ (e.g. top of p4 in MDBA 2016a and MDBA 2016b) is inconsistent with the general usage of the term, and potentially causes confusion because of the frequent interchangeable use of ‘ecological function’ and ‘ecosystem function’ in the published literature (e.g. Nichols et al. 2008; Braga et al. 2013) as well as in both reports. In the context used here, longitudinal and lateral connectivity are hydrological processes that have been selected because changes in flow management are hypothesised to alter hydrological connectivity that in turn cause different ecological responses (including altered rates of ecological processes such as photosynthesis and fish recruitment). Therefore, in these reports, longitudinal and lateral connectivity are perhaps better described as 'eco-hydrological drivers'.

Furthermore, the reports need to clarify whether the use of ‘connectivity’ in this context is solely hydrological (and not functional, *sensu* Pe’er et al. 2011) and, if so, whether it is only the surface expression of water (as appears to be the case, e.g. Figure 11 in MDBA 2016a) and intentionally omits consideration of groundwater flowpaths and hydrological gradients, especially laterally. Earlier in this section, we highlighted the need to further explain the importance of longitudinal connectivity to in-stream primary productivity (ISPP), claimed as an ecological target (p 32, MDBA 2016a) because although longitudinal connectivity is certainly important for nutrient spiralling, ISPP probably also occurs when longitudinal connectivity is limited or absent. The relevance of longitudinal and lateral hydrological connectivity to processes such as sediment transport and deposition also needs more explanation as this geomorphic aspect has major ecological repercussions (e.g. habitat structure, soil matrix properties for floodplain vegetation, bank stability, etc.); the annotated copies of the reports indicate some places where this aspect could be better presented.

One of the most important aspects of presentation of the scientific evidence supporting selection of SFIs is the communication of the sources, relevance and magnitude of uncertainty (both epistemic and irreducible forms; for description of different types of uncertainty, see review by Tartakovsky 2013). Currently, both reports specify uncertainty associated with the frequency statistic of the SFIs, defining ‘low uncertainty’ as a high chance that the associated ecological targets will be achieved, and ‘high uncertainty’ as representing a boundary beyond which there is a high likelihood that the associated ecological targets will not be achieved (e.g. footnote of Table E1 in MDBA 2016b). However, ‘high chance’ and ‘high likelihood’ are not defined, nor are there estimates of uncertainty for the other hydrologic metrics of magnitude, duration and timing. We fully appreciate the complexity of assessing uncertainty and its different forms, acknowledging that assessment of this aspect of the reports is not in our Terms of Reference. However, presentation of these estimates of uncertainty may be improved by adopting formats such as the one used by the Inter-governmental Panel on Climate Change ‘uncertainty ranking’ system (e.g. Mastrandrea et al. 2010) where there is specific guidance on terminology and what particular phrases mean. In particular, this ranking system distinguishes confidence in the validity of a finding (based on the type, amount, quality and consistency of evidence) from quantified measures of uncertainty in a finding expressed probabilistically (based on statistical analysis of observations or model results, or expert judgment), and then combines these for an overall ranking of uncertainty.

One issue is more to do with general presentation of the reports than specifically presenting the scientific evidence supporting selection of site-specific flow indicators, and we consider it worth adding here. In many places, there are terms being used that have a specific meaning in the context of the two reports (e.g. ‘assets’, ‘watering event’, ‘connectivity’, ‘ecosystem function’). Sometimes these terms are defined in the text but often they are not. A Glossary for each report would greatly assist because some of the key terms are being used in a particular context and, at times, differ from conventional usage. In some cases, these definitions are associated with Schedules in the Basin Plan (e.g. p15, MDBA 2016a) and these associations should also be explained in the Glossary so that the sequence of usage is transparent across different reports, policies and other MDBA documents. On the two sets of annotated reports, we have indicated some of the potential candidates for such a Glossary. While on the topic of general presentation, the final Summary of both reports (Section 6 in MDBA 2016a, Section 7 in MDBA 2016b) reads more like a table of contents than a true summary of the main findings of the work and their implications, and the Reference sections in both reports need careful editing for consistency in style (see annotated reports for details and, in some cases, the full citations). Check that all references cited in the report also appear in the list of cited literature (e.g. Poff et al. 2009 mentioned in text on p69 is not in the references section in MDBA 2016a; Larned et al. 2010 mentioned in text on p28 is not in the references section in MDBA 2016b).

PRINCIPAL RECOMMENDATIONS

Throughout the text above, we have made numerous suggestions and recommendations. The list below reiterates the principal ones that we feel would substantially improve the scientific validity and clarity of presentation of the scientific evidence base in the two reports.

Principal recommendations include:

1. Development of a coherent conceptual eco-hydrological model that shows the relationships between flows, SFIs and inferred ecological responses for the Northern Basin, extending the current static spatial diagrams to include multi-scale temporal components. This will enhance communication of the complexity of these eco-hydrological relationships (e.g. lag effects, influence of antecedent conditions, nonlinear ecological responses to flows) and serve to reveal current gaps in knowledge.

2. Addition of more explicit discussion of the sources, types and magnitudes of uncertainty at all steps in the chain of logic used to derive each SFI, focussing on which aspects of uncertainty particularly influence confidence in inferences of eco-hydrological relationships for the Northern Basin. Useful approaches to address this recommendation include the 'uncertainty ranking' system used by the Inter-governmental Panel on Climate Change and potential application of consistent systematic methods in evaluating lines of evidence.

3. A broadening of the literature to include relevant international literature and recent Australian research from outside the MDB, especially in the presentations of aspects such as the association of longitudinal and lateral hydrological connectivity with biogeochemical processes such as nutrient spiralling. This broader literature coverage will partially address some of the current knowledge gaps, validate that the present ESLT approach is internationally significant, and reveal commonality of the Northern Basin with dryland systems elsewhere in Australia and overseas.

4. A clearer articulation of what research is new in these EWRs, specifying where this new information has led to an improved understanding of flow-SFI relationships and the derivation of particular values for the hydrological metrics of magnitude, duration, timing and frequency at a given gauge. This should be coupled with a more detailed explanation of how specific values for the hydrological metrics have been derived from the technical information, including references to specific data sets or primary literature where applicable.

5. Addition of a section to each report that identifies current knowledge gaps that still persist in the Northern Basin, explaining how addressing these gaps would enhance future assessment of EWRs in the region.

6. More precise and consistent use of technical terminology in the reports, supplemented with a Glossary in each report that defines each technical term.

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