

REVIEWING THE SCIENTIFIC BASIS OF ENVIRONMENTAL WATER REQUIREMENTS IN THE CONDAMINE-BALONNE AND BARWON-DARLING: A SYNTHESIS

SYNTHESIS JUNE 2014

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Context and objectives

The Murray-Darling Basin Authority (MDBA) has a responsibility to manage water resources in the Murray Darling Basin (the Basin) in an integrated and sustainable way. One of the mechanisms to achieving this is the establishment of long-term average sustainable diversion limits (SDLs). These SDLs are based on an environmentally sustainable level of take (ESLT), which is the amount of water that can be taken for consumptive uses, while ensuring there is enough water to achieve healthy aquatic ecosystems (MDBA 2011). SDLs have been developed for the southern and the northern Basin. It is acknowledged that for a variety of reasons, there is comparatively less information on aquatic ecosystems in the northern Basin to inform the SDL process. The Basin Plan commits the MDBA to conduct research and investigations into the basis for SDLs in the northern Basin by 2015 (Basin Plan 2012). This will include environmental science, social and economic impact assessment, and water recovery modelling (Figure 1). The MDBA will review outcomes of this further research and investigation in 2016 and advise if and where SDLs should change as a result.



Figure 1: The MDBA Northern Basin work Program, including this science review.

To inform on priorities for research and investigation in the northern Basin, the MDBA appointed a scientific panel to review the environmental water requirements within two regions:

- 1. The Condamine Balonne catchment represented by the Lower Balonne Floodplain and Narran Lakes; and
- 2. The Barwon-Darling River from Mungindi to Wilcannia represented by the main stem of the Barwon-Darling River.

This document summarises the findings and recommendations of the review by the science panel. The detailed findings are documented in the full technical report.

Approach and methods

The review of the scientific basis of environmental water requirements in the Condamine-Balonne and Barwon Darling River systems was undertaken in a consultative manner, with attempts made to provide a wide range of stakeholders an opportunity to contribute to the project. Specific consultation activities included:

- Meetings with regional community representatives in Bourke, Walgett and St George;
- A workshop with State agency ecologists;
- A forum of researcher's with expertise and experience in the northern Basin; and
- Input from the steering committee comprising a mix of stakeholders representing different interests in the northern Basin.

The scientific review was conducted in a systematic manner, incorporating the outputs of the stakeholder engagement activities as well as a development of conceptual models and a comprehensive review of the existing literature relevant to flow ecology relationships in the northern Basin. The science panel have framed the review around key steps in the ESLT process with a series of questions nested into each of these steps (Table 1).

Step in SDL/ESLT process	Key questions for science review
1. Identify key environmental	1a. Did the approach of the MDBA in identifying key environmental assets represent
assets within the review regions	best practice?
(Condamine-Balonne, Barwon and	1b. What additional information is available for identification of key environmental
Darling Rivers)	assets, and what knowledge gaps exist?
2. Select indicator environmental	2a. Do the selected indicator environmental assets represent the water
assets that can represent the	requirements of the key environmental assets of each of the regions (i.e. the
water requirements of the	Condamine-Balonne, and Barwon-Darling Rivers)?
identified key environmental	2b. What additional information is available for identification of indicator
assets in the review regions	environmental assets, and what knowledge gaps exist?
3. Specify objectives and targets	3a. Are the ecological objectives and targets for indicator environmental assets
for the indicator environmental	consistent with Basin Plan objectives?
assets, in the context of the Water	3b. How could the development of ecological objectives and targets be improved?
Act requirements and Basin Plan	
objectives	
4. Select hydrologic indicator sites	4a. Do the selected indicator sites (i.e. flow gauge locations) adequately represent
(i.e. flow gauge locations) to	flows across the indicator environmental assets?
represent flows across the	
indicator environmental assets to	
achieve objectives and targets	
5. Determine flows required to	5a. What knowledge needs are desirable to determine required flows?
achieve the objectives and targets	5b. How relevant was the knowledge used in determining flow requirements?
at the indicator sites	5c. What other knowledge is available to determine flow requirements?
	5d. What are the key knowledge gaps that might be addressed by further research?

Table 1: Key questions for the science review.

Identification of ecological assets

The following provides a summary of the findings with respect to each of the five questions of the review (see Table 1 above). A more comprehensive understanding of the review findings and recommendations can be found in the main body of this report.

1a. Did the approach of the MDBA in identifying assets represent best practice?

The MDBA developed a process for identifying key environmental assets that was consistent with the more recently developed Australian National Framework for identifying High Ecological Value Aquatic Ecosystems (HEVAE) (Aquatic Ecosystem Task Group 2012). The MDBA observed that the process identified thousands of key environmental assets, and that the information base was not available to enable environmental water requirements to be identified for each of these assets. Recognising that many of these assets are hydrologically connected – at a reach or catchment scale many key environmental assets are watered by the same flow events - the MDBA developed the 'hydrologic indicator site' approach. This approach uses relatively well studied sites to describe the pattern of flows for those sites. These flows are seen to provide outcomes for a number of key environmental assets within the same section of river.

The Authority invited CSIRO to lead a review on how the hydrologic indicator site method was applied to determine the environmentally sustainable level of diversion in the Basin. The review looked at the scientific information, models and modelling that the Authority used in developing the Basin Plan. The CSIRO led review (Young et al. 2011) concluded that the indicator site method was "an appropriately pragmatic approach". Given the data availability at the time of development of the Basin Plan, particularly for the review regions in the northern Basin we feel this method was appropriate. However, in future assessments and revisions of the ESLT in the northern Basin more recently developed methods should be applied.

1b. What additional information is available for identification of key environmental assets, and what knowledge gaps exist?

Since the finalisation of the Basin Plan and the determination of SDLs in the Basin there have been developments in the methods used to identify environmental assets and areas considered of high conservation value. A number of steps in the process of identifying high value assets are currently accepted practice (and within the national framework) that were unable to be implemented by the MDBA in the identification of key ecological assets as the ESLT process was occurring in parallel with the development of the national HEVAE framework. One of these steps is in the application of the criteria. The MDBA applied the criteria for identifying high value assets in an absolute manner, that is, if an asset (aquatic ecosystem) met any criterion to any degree (e.g. there is a single listed threatened species recorded at the site) this was then considered to be a key ecological asset. Thus, a very large number of key environmental assets were identified across the Basin, and within the two regions that are the focus of this review. While this is consistent with some international processes for identifying high value ecosystems (e.g. the Ramsar Convention) the science in this field has progressed and a more commonly accepted practice is to apply a scoring and prioritisation system for each criterion so that a ranked, prioritised list of aquatic ecosystems is identified (Hale 2010, Aquatic Ecosystem Task Group 2012, Butcher et al. 2013). This then allows for the objective identification of the highest value aquatic ecosystems, or filtering of the list to meet desired requirements specific to the objectives of the process (e.g. representativeness of ecosystem type or flow, water requirements or current condition).

In addition, for the northern region of the MDB the geographic scale of application of criteria appears to be inconsistent across aquatic ecosystems, ranging from entire river systems (e.g. the Paroo and Macquarie Rivers in the Barwon-Darling region) to smaller individual wetlands (e.g. Horseshoe Lagoon and Ross Billabong in the Barwon-Darling region). It is currently accepted practice that a consistent spatial unit of application be applied, be that at the scale of individual wetlands or larger segments of the landscape (Hale 2010, Aquatic Ecosystem Task Group 2012). This provides a more consistent and even application of the criteria within a region.

Finally, in areas with significant knowledge gaps or uneven spatial distribution of knowledge (such as the northern Basin) a top down approach may be more efficient than the bottom-up approach adopted by the MDBA. A top-down approach involves the attributing of criteria to assessment units (hydrologically, physically or geomorphically derived) rather than individual wetlands, waterholes or river reaches. Criteria can then be applied on the basis of available data (e.g. Hale 2010) or from predictive modelling of aquatic species and communities distributions (e.g. Kennard et al. 2010).

One of the fundamental requirements in the identification of high value aquatic ecosystems is a complete wetland inventory and mapping layer (Hale et al. 2010). At the time the MDBA was undertaking the task of identifying key environmental assets, there was no consistent mapping and classification of aquatic ecosystems in the Basin. Since that time, a number of new products have been developed which could be used in any further assessments, for instance the Australian National Aquatic Ecosystem (ANAE) interim classification has been applied across the Basin and a mapping layer integrating all available aquatic ecosystem mapping products has been compiled (Brooks et al. 2013). While there are still inconsistencies with the detail of this new wetland mapping, particularly in NSW, it represents a product that could inform a robust identification of key environmental assets.

It terms of identifying HEVAEs in the Basin, the Queensland EPA's Aquatic Conservation Assessments (ACAs) using AquaBAMM (rapid) methodology was applied to the northern Basin, both in Queensland (Fielder et al. 2011) and the entire northern Basin (NSW Department of Primary Industries 2008). The AquaBAMM method has been developed for the identification of high value aquatic ecosystems and uses a series of criteria and a prioritisation process that is consistent with the national framework for the identification of HEVAE.

2a. Do the selected indicator environmental assets represent the water requirements of the key environmental assets of each of the regions (i.e. the Condamine-Balonne, and Barwon-Darling Rivers)?

The MDBA selected three indicator environmental assets in the two regions relevant to this review; i.e. . the Lower Balonne floodplain and Narran Lakes in the Condamine-Balonne catchment (Figure 2) and the main stem of the Barwon-Darling Rivers in the Barwon-Darling system (Figure 3). While these undoubtedly meet the criteria for identifying key environmental assets, whether they adequately represent the flow requirements of all of the key environmental assets in these two regions is less certain. The Condamine-Balonne catchment is currently represented by environmental assets and associated hydrological indicator sites located solely in the lower end of the system and some consideration for water requirements of environmental assets upstream is also needed. This may just be an analysis of how well the hydrological indicator site in the lower catchment represents flows at key points in the upper catchment. It is recognised, however, that for flows to have an environmental response in the region of the environmental asset at the end of the Condamine-Balonne Balonne floodplain) they are likely to originate in the catchment above the floodplain and therefore have positive ecological responses in the upper catchment. The environmental asset of the Barwon-Darling is representative of this portion of that river system.



Figure 2: Schematic of the Condamine-Balonne region illustrating the indicator environmental assets (in green) and hydrologic indicator sites (red stars) (MDBA).



Figure 3: Schematic of the Barwon-Darling region illustrating the indicator environmental asset (in green) and hydrologic indicator sites (red stars) (MDBA).

2b. What additional information is available for identification of indicator environmental assets, and what knowledge gaps exist?

As stated above, there is now an interim classification and inventory of aquatic ecosystems across the Basin (Brooks et al. 2013). However, as recognised by MDBA (2012) the lack of an inundation model for the two regions (Condamine-Balonne and Barwon-Darling) hampers the identification of the water regime requirements and hydrological connectivity of key environmental assets. Without this information, there is no surety that the indicator environmental assets adequately represent the water regime requirements of key environmental assets in the review regions.

It is widely acknowledged that there are significant knowledge gaps with respect to background information on aquatic ecosystems in the review regions of the northern Basin. In particular, although there is a wetland classification and mapping layer for the Basin, its resolution is not consistent at a sufficiently fine scale to adequately inform the outcomes of the ESLT process. Mapping and inventory of wetland systems in Queensland has been undertaken (click here to visit the Queensland Government WetlandMaps web page) and the river network is well defined across Australia (Bureau of Meteorology 2011). However wetland mapping within the NSW section of the two focus regions is of a courser resolution which limits its ability to accurately identify key environmental assets and this lack of detail represents a significant knowledge gap (Saintilan et al. 2010, Cottingham et al. 2012). Comprehensive knowledge of the ecological values of wetlands across the NSW portion of the two regions is another knowledge gap which limits the ability to accurately identify key environmental assets.

Development of environmental objectives and targets

3a. Are the ecological objectives and targets consistent with Basin Plan objectives?

3b. How could the development of ecological objectives and targets be improved?

The Basin Plan identifies four broad environmental objectives for water-dependent ecosystems in the Murray-Darling Basin (see Chapter 5, Section 5.03 of the Basin Plan):

- **Biodiversity**: "To protect and restore water-dependent ecosystems of the Murray-Darling Basin"
- Function: 'To protect and restore the ecosystem functions of water-dependent ecosystems'
- **Resilience**: 'To ensure that water-dependent ecosystems are resilient to climate change and other risks and threats'
- Water quality: 'To ensure water quality is sufficient to achieve the above objectives for waterdependent ecosystems; and for Ramsar wetlands, sufficient to maintain ecological character'

The indicator sites and ecological targets for the northern Basin broadly reflect the Basin Plan objectives, with specific mention of biodiversity, function, resilience and implied targets for water quality related to maintaining habitat and condition for aquatic species such as fish. Indicator sites also support Ramsar wetlands (Narran Lakes) and listed migratory and threatened species and ecological communities. The ecological targets used are very broad and as such it will be difficult to determine if the ecological targets have been met without the development of more specific targets and a recognition that restoring parts of the flow regime may not result in the complete protection or restoration of diversity, function and resilience and that other co-variates may need to be considered (landuse, invasive species).

The generation of background information that would allow the development of more specific ecological targets is one of the key knowledge gaps to be filled within the review regions. More specific information on ecological targets will improve their ability to inform against Basin Plan objectives, and a useful approach may be to follow the accepted standard for objective writing, the ubiquitous SMART acronym representing the following five criteria: Specific, Measureable, Achievable, Relevant, Time-bound. The more specific information for the review regions to underpin ecological targets represents a longer term activity.

4. Do the selected indicator sites (i.e. flow gauge locations) adequately represent flows across the indicator environmental assets?

The MDBA selected hydrologic indicator sites (i.e. flow gauge locations) at which site-specific flow indicators are established to meet environmental objectives and targets for each of the indicator environmental assets. The hydrologic indicator sites for the three assets that are the subject of this review are as follows:

- The Lower-Balonne Floodplain is represented by a single hydrologic indicator site, the gauging station on the Culgoa River at Brenda (Figure 2);
- The Narran Lakes is represented by a single hydrologic indicator site, the gauging station on the Narran River at Wilby Wilby (Figure 2); and
- The Barwon-Darling River is represented by three hydrologic indicator sites on the Darling River at Bourke, Louth and Wilcannia (Figure 3).

While a full analysis of the data from gauging stations relevant to the indicator environmental assets is beyond the scope of this science review, the science panel concluded that the hydrologic indicator sites were selected based on a robust process and relevant information. There are two clarifying points (i) there is some doubt about the adequacy of the single hydrological indicator site on the Culgoa River to capture all the water requirements of the Lower Balonne Floodplain and further work potentially needs to be focussed here; and (ii) the three hydrological indicator sites on the Darling River are downstream of the beginning of the environmental asset and it is unclear how they represent the water requirements of upstream locations on the Barwon River.

For the Barwon-Darling, although the review was restricted to looking at the hydrological indicators sites used within the environmental asset region, in the broader northern Basin some of the uncertainty of how well the indicator sites represented flows within this asset were mitigated by the use of other hydrologic indicators sites either at the top of the Barwon River (Mungindi on the Barwon) or other sites located in the lower section tributaries (Bugilbone on the Namoi). For the Lower Balonne floodplain there remains uncertainty how well the single hydrological indicator site represents the flow variability across the floodplain asset.

Flows required to meet ecological objectives and targets

Once indicator environmental assets and hydrologic indicator sites were selected, the next step in the ESLT process was deriving flow requirements for each hydrologic indicator site. The following questions were used to review this step in the process with respect to the Condamine-Balonne and Barwon-Darling systems.

- 5a. What knowledge needs are desirable to determine required flows?
- 5b. How relevant was the knowledge used in determining flow requirements?
- 5c. What other knowledge is available to determine flow requirements?
- 5d. What are the key knowledge gaps that might be addressed by further research?

This review was completed using available literature relevant to these questions and this step in the ESLT process in the northern Basin.

5a. What knowledge needs are desirable to determine required flows?

Based on current ecological understanding, a suite of desirable knowledge needs to determine the water requirements of the three focus indicator asset sites and their key components can be identified. These can be broadly categorised as:

- 1. Baseline ecological data needed to identify the character, components and processes as well as the condition of the three focus indicator environmental assets;
- 2. Ecohydrological relationships in order to determine environmental water requirements for the focus indicator environmental assets, a knowledge of the flow-ecology relationships of the biota, processes and physical habitat of each asset is required;
- 3. Flow attributes in order to adequately determine the flows required to meet objectives and targets set for each of the focus indicator environmental assets, knowledge of the flow attributes (cease to flow, overbank flow, etc.) is required; and
- 4. Significant covariates Knowledge of how the covariates may influence the response of ecosystem components will be critical in understanding spatial and temporal differences in ecological responses to similar flow conditions. For instance, there may be differential fish spawning response to a flow pulse based on local habitat conditions or the condition of floodplain trees may differ between locations that receive similar flooding due to the presence of absence of groundwater.

These four categories have been used to structure the review with respect to the flows required to meet ecological objectives and targets set for indicator environmental assets in the Condamine-Balonne and Barwon-Darling River systems.

5b. How relevant was the knowledge used in determining flow requirements?

Baseline ecological data

- For the most part, the MDBA used the best available information for the key ecological components at each of the indicator environmental asset sites.
- Broadly for the review regions, relevant baseline ecological data was lacking during the ESLT development process and is still lacking for many of the key ecological components, although important waterbirds sites are considered relatively well known.
- The physical habitat structure of systems within the review regions has been well described but there is limited understanding of the flows required for the maintenance of physical habitat.
- At the time of the ESLT process the best available spatial information documenting the composition, structure and condition of riparian and floodplain vegetation species was used by the MDBA. However, the available data was lacking in resolution and detail to adequately develop specific flow requirements for the indicator environmental asset sites.
- Very little information about aquatic species or communities was available for use by the MDBA in the ESLT process.

In summary, the MDBA used the best information available at the time, but much of this lacked the detailed resolution.

Ecohydrological relationships

- Much of the available knowledge concerning ecohydrological relationships is drawn from work conducted in the southern Basin or from general ecological theory on floodplain rivers. The relevance of this knowledge to the review regions is poorly understood.
- For vegetation, knowledge of flow relationships used to date is mostly drawn from the recent review by Roberts and Marston (2011) which represents the best available information. However, for some key asset species, particularly coolabah, knowledge of the differences in water requirements and responses of different cohorts (e.g. adults vs. seedlings) of key species is also mostly lacking or based on very limited observations.

- Similarly, the knowledge available to the MDBA during the ESLT process to develop flow indicators for aquatic biota were largely based on studies from the southern Basin (e.g. King et al. 2009; Beesley et al. 2011) or inferred from ecological concepts derived from general ecological studies of floodplain rivers (e.g. Poff et al. 2010). Most of the literature that was relevant either directly (within the review regions) or indirectly (in a nearby location (e.g. Warrego River) was cited within the EWR reports, however, again much of this information tends to be broad, with little species specific information making it difficult to use to generate specific ecological targets for each environmental asset.
- In part this difficulty in generating specific ecological targets from broad information, or information generated from other systems, occurs because there is significant doubt about the relevance of transferring ecological responses of fauna among rivers geographically located close by (see Balcombe and Arthington. 2009; Balcombe and Sternberg 2012), and hence, a greater doubt if comparing ecological response in systems that are significantly separated geographically.

Flow attributes

- The flow indicators calculated for flows at each hydrological indicator site are predominantly associated with flow magnitude (or volume), duration and frequency which are all appropriate flow indicators which have been linked directly to different aspects of river ecosystem function (Bunn and Arthington 2002).
- The spatial and temporal complexity (e.g. seasonal timing) of flows across the northern Basin has been considered with guidelines provided on the ideal frequency of events in different seasons, however, seasonality is largely assumed to be accounted for by the unconstrained nature of flow events in the unregulated systems of the northern Basin review regions.
- It is recognised that the seasonal timing of individual flow events is important, equally important is the antecedent conditions, or timing of multiple flow events over a period of a number of years.
- While timing of flows either seasonally or within recent flow history cannot feasibly be managed in unregulated systems, the amount of take in response to flows could be managed to take into account the timing of these flows and/or the antecedent conditions prior to specific flow events.

Significant covariates

• Due to a lack of information, covariates were not explicitly included by the MDBA in the development of the flow indicators as part of the ESLT process to date and this lack of information has limited the ability of the MDBA to consider the role of covariates in influencing flow requirements.

5c. What other knowledge is available to determine flow requirements?

Baseline ecological data

- There are some additional or recently available data and information that could inform key elements of the indicator environmental assets in the Condamine-Balonne and Barwon-Darling systems; these are mostly broad landscape data sets from satellite imagery or aerial photography that would require additional work to develop useable products.
- An inundation model was developed by CSIRO (Chen et al. 2012) to document the inundation patterns associated with different flow events across the Murray-Darling Basin (Murray-Darling Basin Floodplain Inundation Model (Basin-FIM1 and Basin-FIM2) and build a model that allows prediction of changes to flood extent. Outputs to date have not been of sufficient reliability and / or resolution to allow for characterisation of the water regimes of floodplain wetland systems (Brooks et al. 2013) although future iterations of the model at a finer level of detail may provide information to derive water requirements of indicator sites and assets. The development of a reliable floodplain inundation model is a key recommendation of this review.

- The large body of satellite imagery, aerial photography and other remote sensed products provides a substantial record from which baseline ecological data could be extracted for the three environmental assets. Since the remote sensing studies used by the MDBA in the ESLT process (e.g. Sims 2004), the availability, cost and accessibility of image archives has been greatly improved as has the capacity to conduct image analyses.
- Spatial maps of vegetation and aquatic habitat linked to a flood inundation model would provide a good mechanism for exploring changes in inundation, and therefore predicted ecosystem response, associated with the ESLT process.
- While studies such as the Sustainable Rivers Audit (Davies et al. 2008, MDBA 2012) provide condition monitoring for both macroinvertebrates and fish at specific sites across the different river valleys, and similarly the Smart Rivers sampling across various sites and times in the lower Balonne (click here to visit the Smart Rivers website), these programmes do not provide a context for ecological response to wetting or drying events by the in-stream fauna. As such there is a lack of quantitative data on aquatic fauna in general across the three environmental asset sites.

Ecohydrological relationships

- There is a small amount of additional information and data that could be used (with additional analysis or interpretation) to inform ecohydrological relationships and associated flow attributes of the key ecological components of relevance to the development of flow indicators, these include:
- vegetation monitoring conducted by Roberts and Hale (2013), which provides some information about how asset plant species and vegetation communities within the three indicator sites have responded to rewetting following drought and;
- site-specific studies from the Barwon Darling (Balcombe et al. 2010), Lower Balonne (Webb et al. 2011) and Narran Lakes (Rolls and Wilson 2010) which could be a useful starting point for understanding the role of flow regulation on recruitment response by native fish species in response to different aspects of the flow regime in the presence of environmental stressors (e.g. Land-use change).

Apart from this information there is very little additional information available and no known studies of ecohydrological response by aquatic fauna other than fish that are directly relevant to the review regions.

Significant covariates

• Currently there is limited knowledge concerning the relationships of significant covariates such as weather, groundwater and land use, with flow and their quantitative effects on ecological responses to flow.

5d. What are the key knowledge gaps that might be addressed by further research?

Baseline ecological data

In terms of baseline ecological data, identified knowledge gaps of relevance to the ESLT process at the three indicator sites are mostly related to the distribution and condition of flora and fauna. Gaps in knowledge are not evenly distributed across the three sites, with a greater degree of knowledge available for the Ramsar site, the Narran Lakes and the Lower-Balonne Floodplain than for the Barwon-Darling system. In addition, while data is available on original physical landscape structure (see Thoms et al. 2004a) and current landscape structure, including existing river channels, anabranches and billabongs (SKM 2009), baseline knowledge on processes maintaining these physical structures is lacking. In particular, data is needed on erosion rates in both natural and altered areas to model soil entrainment, movement and deposition. The major knowledge gaps related to baseline ecological data are:

- Knowledge of historical patterns of in-channel, persistent refugia, hydrologic connectivity and inundation extents in relation to flow events in the Condamine-Balonne and Barwon- Darling environmental assets;
- Knowledge of erosion and deposition rates across all three environmental assets;
- Consistent vegetation maps with information on population structure, vegetation composition (especially understoreys) and condition all three environmental assets;
- Inventories of aquatic communities in key in-stream habitats and the importance of these habitats to dispersal and population maintenance all three environmental assets;
- Knowledge of waterbird habitat use and movement between habitats, particularly the Barwon-Darling and Lower Balonne environmental asset, relatively good data exists for the Narran Lakes environmental asset.

Ecohydrological relationships and flow attributes

- There is poor understanding of the links between flow and physical form in the three environmental assets and, more specifically, the impacts of changes in flow on habitat availability and physical form.
- Responses of biota to flow in the three environmental assets are a significant knowledge gap for plant and animal species as well as communities at different spatial and temporal scales. For example, at the species scale, there may be good knowledge on the likely response of individual species to a single flow event, but less is known about the longer term water requirements of these species within the three environmental assets, and the entire northern Basin.
- Very little information exists concerning interactions between key plant species, their importance in structuring vegetation communities and vegscapes, and the effects of these on flow regimes over broad spatial and temporal scales.

Significant covariates

- While broad scale geomorphological processes within the northern Basin are relatively well understood (Thoms et al. 2004b, SKM 2009) there is a paucity of information on small-scale processes and the relationship between altered land-use and its impact on physical habitat.
- Similarly, while information concerning the extent and nature of most significant covariates identified as important is widely available (e.g. from national datasets or the satellite record), understanding of their relationships with flow and ecological responses to flow in the review regions is mostly lacking.
- Knowledge concerning the influence of weather, grazing and groundwater is desirable to understand riparian and floodplain vegetation responses to flow as are the effects of vegetation fragmentation due to land use change and in-stream barriers.
- With respect to aquatic communities, knowledge of the influence of land use disturbances and in-stream barriers on the aquatic species, including exotic species (e.g. carp) is desirable to understand flow responses.
- For waterbirds, knowledge of habitat requirements for breeding and feeding beyond flow conditions, e.g. vegetation structure, is a major knowledge gap.

Research priorities and recommendations

The knowledge gaps identified in through this review process were assessed by the science review team according to six criteria as follows:

- 1. Their relevance to the ESLT process:
 - **High**: knowledge would be directly relevant to development of quantitative, spatially explicit flow indicators;
 - **Moderate**: knowledge could be directly relevant to development of flow indicators, especially if combined with other knowledge;

- **Low**: knowledge of indirect relevance to development of flow indicators, i.e. provides greater conceptual understand.
- 2. Levels of existing knowledge:
 - **High**: knowledge gap could be addressed through synthesis or analyses of existing datasets and is supported by strong ecological understanding in general or for other regions;
 - **Moderate**: knowledge gap could be partially addressed through synthesis or analyses of existing datasets or is supported by good ecological understanding in general or for other regions;
 - Low: knowledge gap unlikely to be addressed through synthesis or analyses of existing datasets or is supported only by limited ecological understanding in general or for other regions.
- 3. The likely ecological value of the knowledge:
 - **High**: knowledge critical for understanding current ecological character and condition across multiple ecological components;
 - **Moderate**: knowledge moderately important for understanding current ecological character and condition across some ecological components;
 - **Low**: knowledge important for understanding limited aspects of current ecological character and condition across a few ecological components.
- 4. The likely socio-economic value of the knowledge:
 - **High**: knowledge relates to high socio-economic value across the region;
 - Moderate: knowledge relates to moderate socio-economic value at multiple sites;
 - Low: knowledge only has limited relevance to socio-economic values.
- 5. The likelihood of research generating new and useful knowledge:
 - **High**: research addressing knowledge gap associated with few risks and a high probability of success, e.g. uses well-established methods;
 - **Moderate**: research addressing knowledge gap associated with some risks and a moderate probability of success, e.g. may be dependent on particular field conditions (i.e. floods);
 - Low: research addressing knowledge gap associated with a high degree of risk and an uncertain probability of success, e.g. may use novel methods.
- 6. The timeframe to complete the research.
 - **High** research addressing knowledge gap likely to be completed in < 2 years;
 - Moderate: research addressing knowledge gap likely to be completed in 2-5 years;
 - Low: research addressing knowledge gap likely to be completed in >5 years.

Criteria were populated by the project team based on literature reviews, stakeholder engagement and expert opinion and were used to generate a broad ranking of overall priority. Based on this assessment, research priorities were identified for each of the identified categories: baseline ecological data; ecohydrological relationships and associated flow attributes; and significant covariates. These are briefly described in below. The science panel recognises that the projects designed to address research priorities are connected, with some projects relying on outputs of others. The relationship between projects and research priorities is illustrated in Figure 4.



Figure 4: Relationship between research projects.

Research Area 1: Understanding the hydrologic and ecologic setting of the northern Basin

Summary and ESLT relevance:

This group of projects will provide a consistent digital inventory and classification of wetlands across the northern Basin (Project 1) and use this information, combined with hydrological data and inundation maps, to model persistence, connectivity and inundation frequency of key aquatic habitats (Project 2) with the potential in the longer-term to use these models to understand historical patterns (Project 3a) and/or future changes (Project 3b). To supplement the physical and hydrological maps, Project 4 would provide a spatial inventory of the key ecological components. This suite of projects could be undertaken within the two year timeframe and provide the background for understanding and modelling (through conceptual models) changes in the key ecological components associated with changes to the hydrological targets associated with the ESLT process.

Project 1

Title: Aquatic ecosystem classification across the northern Basin *Priority*: High *Knowledge gaps addressed (Appendix 3)*: Consistent aquatic ecosystem classification across the northern Basin *Timeline*: 12 months

Relevance to the ESLT process: Understanding the diversity, distribution and extent of aquatic ecosystems across the northern Basin is a vital first step in being able to measure the ecosystem responses to flow changes.

It is also essential for informing the selection of indicator environmental assets that represent the flow requirements of key environmental assets within the Condamine-Balonne and Barwon-Darling systems. *Project Description*: This project would use existing spatial data (e.g. satellite imagery, LiDAR, air photos etc.) and the current interim ANAE map of the Basin (Brooks et al. 2013) to map and classify aquatic ecosystems in the target systems, but more usefully across the northern Basin.

Project 2

Title: Mapping and modelling patterns of hydrological connection and inundation on the Lower Balonne floodplain and Barwon-Darling River systems

Priority: High

Knowledge gaps addressed: Baseline information of hydrology and water regimes

Timeline: 2 years

Relevance to the ESLT process: This project will provide a visual tool for understanding and quantifying the inundation patterns and requirements of ecosystem components to support the determination of flow requirements as part of the ESLT process. This will be crucial for understanding the magnitude of any specific ecosystem response within the review regions that may be associated with changes to inundation patterns and frequency of aquatic habitats.

Project Description: This project will use mapping of permanent aquatic habitats (i.e. refugia) along with hydrological data (flow attributes including magnitude, duration, timing and frequency) to determine the current patterns of persistence of in-stream refugia, the connectivity of in-stream and floodplain wetland habitats, and inundation extent.

Project 3a and 3b

Title: Modelling changes in hydrological setting: modelling current changes compared with past conditions (Project 3a) and modelling future projected changes associated with climate change (Project 3b) for the Lower Balonne floodplain and Barwon-Darling River systems.

Priority: Moderate

Knowledge gaps addressed: Baseline information of hydrology and water regimes *Timeline*: 2 years

Relevance to the ESLT process: This project would enable a comparison of conditions under a range of scenarios (Project 3a). The project would also provide an additional resource for future management through understanding future climate scenarios in relation to the ESLT process. While this is not urgent in the short term, once a spatial inundation model is constructed, the capacity to test changes in inundation associated with different discharge regimes would be a useful management tool. *Project Description:* This project will use the inundation models generated in Project 2 to undertake scenario testing. Two different aspects of scenario testing include understanding current changes compared with historical patterns (Project 3a) and understanding future changes under different climate change projections (Project 3b).

Project 4

Title: Baseline inventory of environmental assets

Priority: High (Desktop Study); Moderate (Ground Truthing)

Knowledge gaps addressed: Baseline information about the distribution and condition of vegetation communities and key plant species; Baseline ecological information about aquatic fauna (fish, invertebrates, frogs, turtles)

Timeline: less than 2 years for desktop study, ground truthing will take significantly longer (> 2 years) but could be aligned with other field based projects.

Relevance to ESLT Process: An understanding of the ecosystem response to flows regained through the ESLT process is vital for assessing the success, or otherwise, of the process. A key step in understanding ecosystem response is to understand the spatial distribution of different ecosystem components and how they relate to the spatial changes in expected inundation (Project 2).

Project Description: This project would initially produce consistent digital inventories of fauna and flora across the northern Basin using existing information and in the long-term verify this data through ground truthing. These flora and fauna 'maps' could underpin a HEVAE process for the northern Basin. This project has been divided into three sub-projects as they could each be undertaken individually:

- Project 4a: Vegetation mapping
- Project 4b: Aquatic community inventories
- Project 4c: Waterbirds

Research Area 2: Determining ecohydrological relationships for key ecological components

Summary and ESLT relevance:

This group of projects will use the classification (Project 1), hydrological understanding (Project 2 and 3) and digital inventories of ecological component distribution (Project 4) combined with some focussed field based studies to develop ecohydrological relationships for key ecological components; vegetation (Project 5), aquatic communities (Project 6) and waterbirds (Project 7). Initial broad relationships for vegetation and waterbirds could be undertaken as desktop studies within the two year timeframe and provide the background for targeted longer-term studies to understanding population and community changes associated with changes to the hydrological targets associated with the ESLT process. For the aquatic species initial field based sampling at targeted sites would provide initial information which could be supplemented in the longer term by further field based sampling.

Project 5

Title: Vegetation ecohydrology

Priority: High (Desktop Study); Moderate (Ground Truthing)

Knowledge gaps addressed: Responses of vegetation communities and key plant species to flows in the northern Basin, relationships between the distribution and condition of vegetation communities and water regimes.

Timeline: This project would initially combine the hydrological understanding obtained in Project 2 with the vegetation maps generated in Project 4a to provide initial information on the ecohydrological response of vegetation across the review regions, this would be a desktop study and develop ecohydrological relationships at community / landscape scale (<2 years). A second larger

component would be field based and validate detailed relationships and use these findings to develop stronger species based ecohydrological models (<5 years).

Relevance to ESLT Process: The targeted hydrological components in each of the indicator asset areas have been chosen to fulfil the hydrological requirements of key ecological components, of which vegetation is one. An understanding of the response of the ecological components to specific flows will be important in interpreting the success or otherwise of hydrological changes associated with the ESLT process.

Project Description: This project would contain two components, a desktop component that would use the hydrological information from Project 2 and the vegetation inventory from Project 4a to provide an initial understanding of the ecology (including tolerances to different flow events) of specific species including specific ecohydrological relationships across the northern Basin (with a priority for coolabah).

Project 6

Title: Ecohydrological relationships of aquatic fauna within the two review regions

Priority: High

Knowledge gaps addressed: Water requirements of key aquatic fauna species and their responses to flows.

Timeline: This would need to be a field based project focussed on sites within the environmental asset areas of the Lower Balonne and the Barwon-Darling. This could initially be undertaken at a few key locations within the environmental assets reflecting high value areas and broadened over the longer term to include the full suite of wetland types identified by Project 1. Initial information for key species at selected sites could be completed in less than two years. The outcomes would then be used to incorporate more medium term (<5 years) findings to develop stronger species based ecohydrological models for particular species. Given the high variability of flows within these systems any sampling program would need to be mindful of not receiving a required range of flows during the project funding cycle, so contingency plans to include sampling locations outside the three review regions should be included in the design.

Relevance to ESLT Process: The targeted hydrological components in each of the indicator asset areas have been chosen to fulfil the hydrological requirements of key ecological components, of which instream aquatic species are included. An understanding of the response of the ecological components to specific flows will be important in interpreting the success or otherwise of hydrological changes associated with the ESLT process.

Project Description: This project would initially develop a priority list of species to target for specific research needs in relation to ecohydrological response across the northern Basin. For fish, these priority species should include all threatened and endangered species (e.g. silver perch) and species that will represent greater groups (guilds – e.g. spangled perch could represent the flow responsive fish species). Other aquatic species of interest would include the freshwater mussels and the decapod crustaceans, which provide a significant food source for larger fauna. The project could use the classification of wetlands (Project 1) to select sites that cover the range of different aquatic habitat types within the northern Basin. The project would research (i) patterns of distribution and abundance (and population attributes including size structure) across appropriate spatial and temporal scale to develop ecohydrological models (for individual species and species guilds) and (ii) environmental cues (including various aspects of flow – timing, duration, magnitude) associated with movement for aquatic species. To gain a complete understanding of the relative importance of hydrological components in the ecological responses of key species analyses should also incorporate different covariates such as landuse and in- stream and floodplain barriers to movement.

Project 7

Title: Response of waterbirds to hydrological components.

Priority: High

Knowledge gaps addressed:Location of important waterbird sites (outside the Narran Lakes) and responses of waterbirds to patterns of flows.

Timeline: This could initially be undertaken as a desktop study in less than 2 years after completion of Project 2 with recommendations to develop site-based long-term studies.

Relevance to ESLT Process: The targeted hydrological components in each of the indicator environmental assets have been chosen to fulfil the hydrological requirements of key ecological components, of which waterbird persistence and breeding is one. An understanding of the response of the waterbirds, breeding and successful recruitment to specific flows will be important in interpreting the success or otherwise of hydrological changes associated with the ESLT process. *Project Description*: This project would use the map of waterbird distributions and waterbird breeding habitat distribution based on past surveys generated as part of Project 4c and relate these distributions to past hydrological records (Project 2). This would provide site-based assessments of important waterbird sites to determine flow thresholds for waterbird presence and reproduction; landscape-scale assessment of habitat use by waterbirds in relation to larger spatial and temporal patterns in water availability and flow conditions and an initial determination of habitat requirements (e.g. vegetation structure) for waterbird breeding and feeding at site and landscape scales (i.e. patch dynamics).

Research Area 3: Covariates that may override or diminish outcomes of the ESLT process

Within the Basin Plan, through the application of Sections 21 (1) & (2) and 22(9)-(12) of the Act, flow restoration through the improved use and management of water resources is the only lever that can be manipulated. Within the three review regions the ESLT process specifically identifies flow as the main stressor and provides a mechanism to restore aspects of the flow regime to wetlands (in- channel and off-channel) including significant floodplain inundation. Flow is not the only stressor acting on the aquatic ecosystem within the review regions and it does not act in isolation. These two projects focus on two significant stressors that may interact with changes in flow to significantly reduce the expected ecosystem response of any flow restoration measures.

Project 8

Title: Impacts of carp on aquatic fauna in the northern Basin.

Priority: Moderate

Knowledge gaps addressed: Distribution and effect of carp on the responses of aquatic fauna to flows.

Timeline: This project would involve both a desktop and field (experimental) component. The desktop component which would produce an inventory of carp hotspots and an initial summary of likely impacts to aquatic species based on current datasets could be completed in <1 year. The experimental/field aspect could be completed in < 2 years.

Relevance to ESLT Process: Carp are a known stressor for both individual species and aquatic ecosystems in general. Across the whole Basin they have a significant presence, particularly in lowland aquatic habitats, dominating fish biomass in many regions. They achieve large numbers through high reproductive output and growth rates and as such they represent a significant component of aquatic secondary production. They are highly responsive to flow (breeding and movement) and hence, any change to flow regimes as an outcome of the ESLT process may provide a significant advantage to these fish over other native aquatic fauna. As such, they could significantly reduce any expected outcomes of flow restoration for aquatic ecosystems. An understanding of both the nature of impacts on aquatic fauna (e.g. is it the same as found in the southern Basin?) and how to best manage such impacts will be important in interpreting the success or otherwise of hydrological changes associated with the ESLT process on aquatic fauna.

Project Description: This project would initially develop an inventory of carp hotspots (this could be achieved through interrogation of current datasets) to investigate likely areas to target for specific management. Further interrogation of these datasets could also elucidate species that are more impacted by carp than others (particularly threatened species). In order to understand how carp impact on native species an experimental programme should be undertaken to examine how carp at varying densities impact on both ecosystems (e.g. food-webs, nutrient and sediment dynamics) and directly on aquatic species themselves. Experimentation could be undertaken in both filed situations where carp are absent v present under varying density and additionally in mesocosms where carp densities can be controlled.

Project 9

Title: Impacts of land-use on floodplain vegetation condition and flood response. *Priority*: Low

Knowledge gaps addressed: Interactive effects of weather, grazing and groundwater availability on vegetation responses to flow.

Timeline: 2-5 years

Relevance to ESLT Process: Knowledge yielded by this project would inform an understanding of spatial and temporal differences in riparian and floodplain vegetation responses to flow in different locations as a result of other constraints.

Project Description: This project would involve desktop analyses of satellite imagery and other spatial data products (e.g. land use maps, LiDAR) in combination with products from project 4a and some ground-truthing. The aim would be to identify how important patterns of land use and vegetation fragmentation are in determining riparian and floodplain vegetation condition and responses to flooding. The project could be easily conducted in conjunction with Project 4a using compatible datasets and methods with the added consideration of vegetation condition (e.g. using NDVI or other indices of vegetation condition).

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