Australian Government

MURRAY–DARLING
BASIN AUTHORITY

Assessment of environmental water requirements for the proposed Basin Plan:

Narran Lakes

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MDBA Publication No: 27/12

ISBN: 978-1-922068-35-4 (online)

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Condamine-Balonne Region

Assessment of Narran Lakes environmental water requirements

1. Introduction

The Water Act 2007 (Cwlth) established the Murray—Darling Basin Authority (MDBA) and tasked it with the preparation of a Basin Plan to provide for the integrated management of the Basin's water resources. One of the key requirements of the Basin Plan is to establish environmentally sustainable limits on the quantities of surface water that may be taken for consumptive use, termed Sustainable Diversion Limits (SDLs). SDLs are the maximum long-term annual average volumes of water that can be taken from the Basin and they must represent an Environmentally Sustainable Level of Take (ESLT).

The method used to determine the ESLT is described in detail within *'The proposed "environmentally sustainable level of take" for surface water of the Murray-Darling Basin: Method and Outcomes,'* (MDBA 2011). A summary of the main steps undertaken to determine the ESLT is presented in Figure 1. The assessment of environmental water requirements including specification of site-specific flow indicators at a subset of hydrologic indicator sites (Step 3 of the overall ESLT method) is the focus of this document.

The work described herein is the MDBA's current understanding of the environmental water requirements of the Narran Lakes system. It is not expected that the assessed environmental water requirements assessments will remain static, rather it is intended that they will evolve over time in response to new knowledge gained through additional scientific research or implementation of environmental watering actions. Within this context, feedback is sought on the material presented within this document whether that is as part of the formal draft Basin Plan consultation phase or during the environmental watering implementation phase within the framework of the Environmental Watering Plan.

1.1. Method to determine site-specific flow indicators

Assessment of environmental water requirements for different elements of the flow regime using the hydrologic indicator site approach is one of the key lines of evidence that has informed the proposed SDLs. Effort focussed on regions and parts of the flow regime with greatest sensitivity to the scale of reduction in diversions necessary to achieve environmental objectives, an ESLT and a healthy working Basin.

Within the overall framework of the ESLT method (Figure 1) the MDBA used an iterative process to assess environmental water requirements and develop site-specific flow indicators.

The hydrologic indicator site approach uses detailed eco-hydrological assessment of environmental water requirements for a subset of the key environmental assets and key ecosystem functions across the Basin. The Narran Lakes system is one of the key environmental assets where a detailed assessment of environmental water requirements was undertaken.

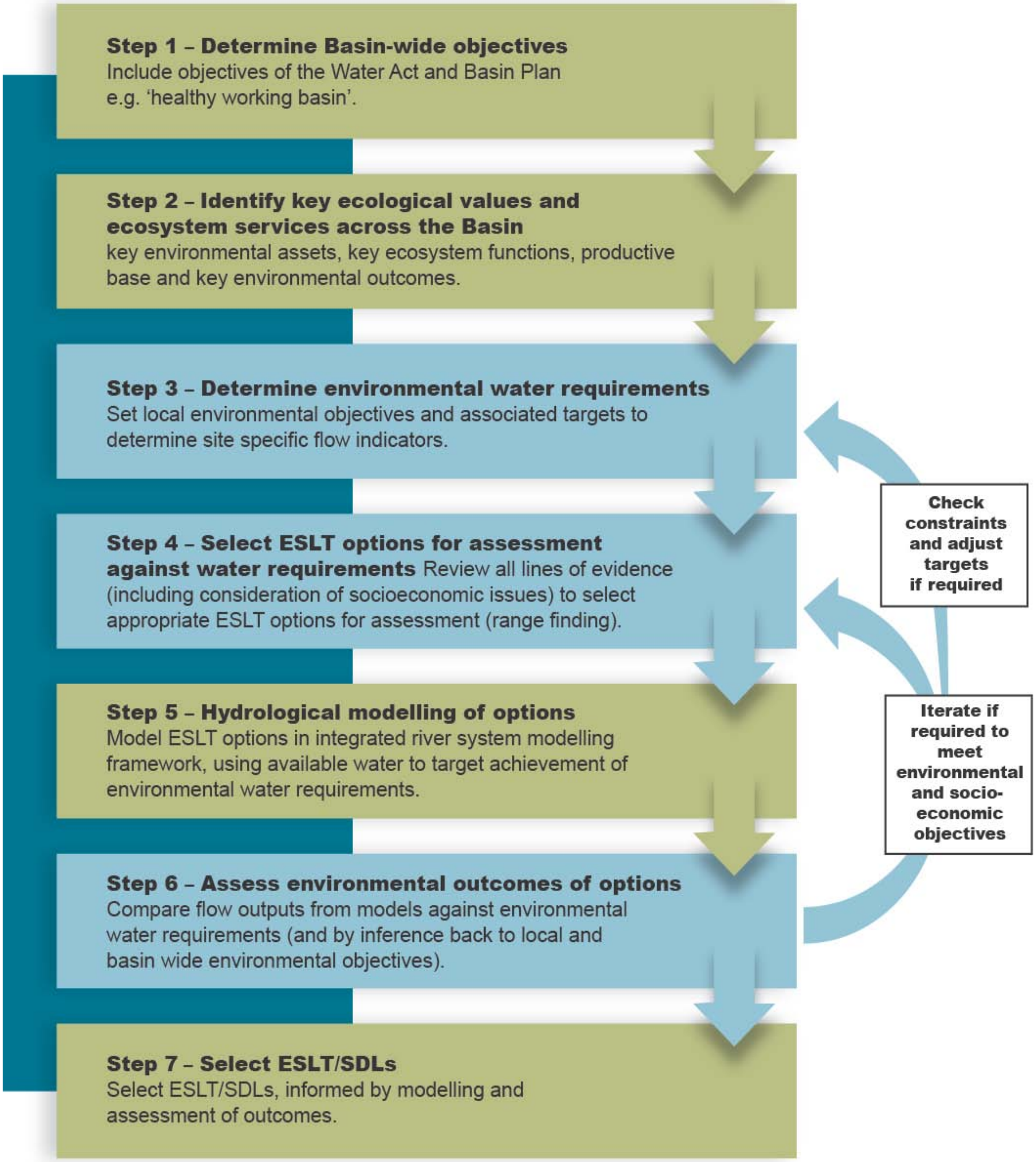

Figure 1: Outline of method used to determine an Environmentally Sustainable Level of Take. (Source: MDBA 2011).

Detailed environmental water requirement assessments lead to the specification of site-specific flow indicators to achieve site-specific ecological targets. Flow indicators were expressed at a hydrologic indicator site or sites. Environmental water requirements specified at hydrologic indicator sites are intended to represent the broader environmental flow needs of river valleys or reaches and thus the needs of a broader suite of assets and functions.

This report provides a description of the detailed eco-hydrological assessment of environmental water requirements for the Narran Lakes system including information supporting the development of site-specific flow indicators for the site (with reference to flows gauged on the Narran River at Wilby Wilby). More information on how the site-specific flow indicators for the Narran Lakes system were used within the Basin-wide modelling process to inform the ESLT (i.e. Step 5 and 6 in Figure 1) can be found in the report *'Hydrologic modelling to inform the proposed Basin Plan: Methods and results'* (MDBA 2012).

A description of the detailed eco-hydrological assessments of environmental water requirements for other indicator sites are described in other documents in the series '*Assessment of environmental water requirements for the proposed Basin Plan*'.

1.2. Scope and purpose for setting site-specific flow indicators

The MDBA's assessment of environmental water requirements and associated site-specific flow indicators at hydrologic indicator sites has been used to inform the development of SDLs. This enables the MDBA to estimate the amount of water that will be required by the environment over the long-term to achieve a healthy working Basin through the use of hydrological models. Accordingly, site-specific flow indicators are not intended to stipulate future use of environmental water. MDBA expects that the body of work undertaken to establish these site-specific flow indicators will provide valuable input to environmental watering but this watering will be a flexible and adaptive process guided by the framework of the Environmental Watering Plan and natural eco-hydrological cues. It will be up to the managers of environmental water, such as the Commonwealth Environmental Water Holder, State Government agencies, and local communities to decide how best to use the available environmental water during any one year to achieve environmental outcomes.

2. Site location and extent

The Narran Lakes system is a large terminal wetland on the lower reaches of the Narran River between Brewarrina and Walgett in New South Wales (Figure 2). The Narran River is the eastern-most tributary of the Lower Balonne system.

The MDBA has used data from *A directory of important wetlands in Australia* (Department of the Environment, Water, Heritage and the Arts 2001) to determine the extent of the indicator site. This data was also used to define the extent of the Ramsar-listed portion of the Narran Lakes asset. Spatial data used to define the extent of this site is listed in Appendix A.

The system is a floodplain wetland complex which consists of four lakes: Clear Lake, Back Lake and Long Arm (which form the northern lakes) and Narran Lake; and a complex network of river channels that dissect the floodplain (ANU Enterprise 2011).

Currently the main land use in the region is grazing with Narran Lake itself being used for dryland cropping (McGann et al. 2001).

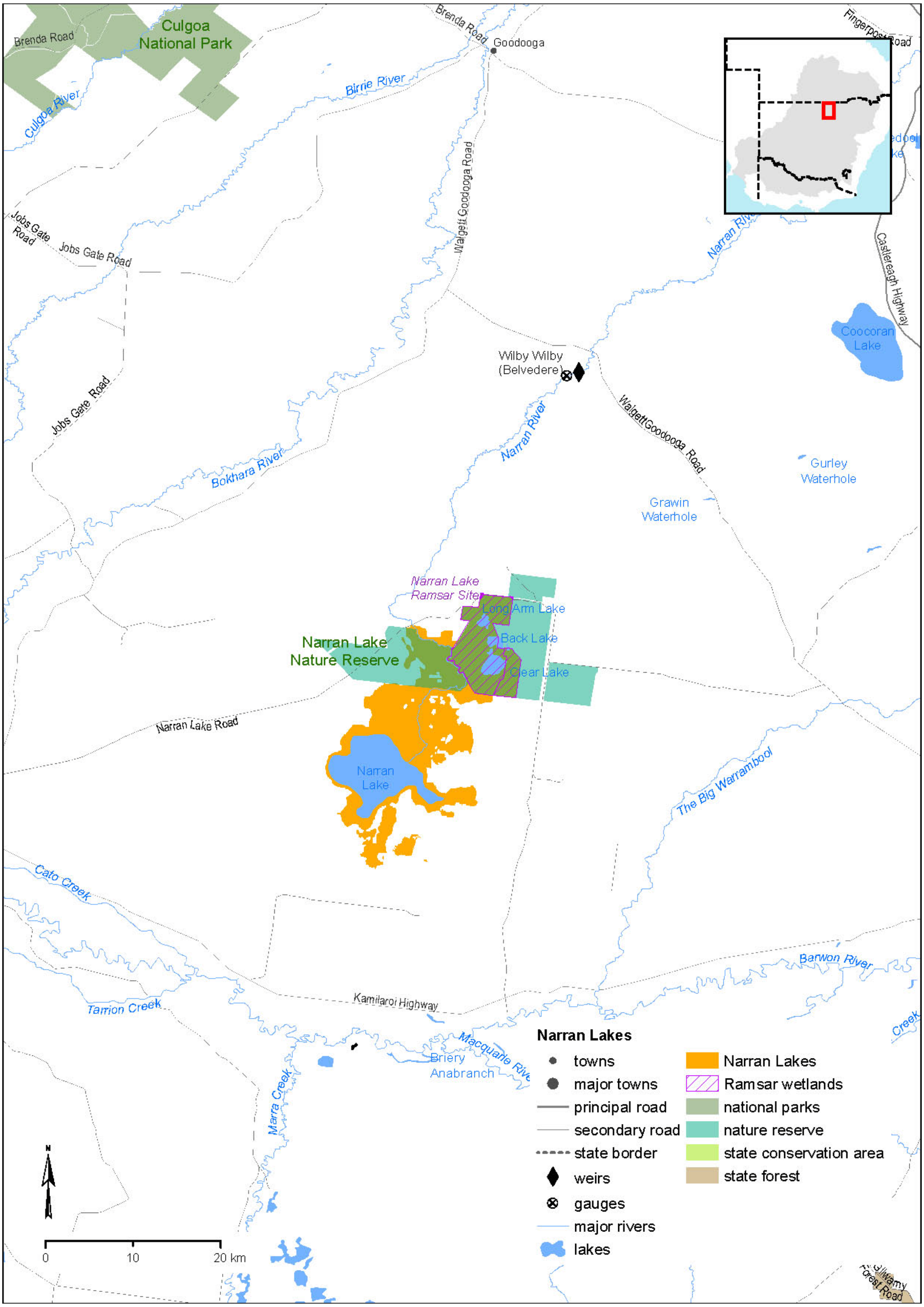

Figure 2 Location and extent of Narran Lakes hydrologic indicator site

3. Ecological Values

The Narran Lakes system includes portions of the Narran Lake Nature Reserve, a Ramsar-listed site. The Narran Lake Nature Reserve meets several of the Ramsar criteria as:

- It is particularly valuable as a habitat for plants or animals at critical stages of their life cycles;
- The wetlands are among the highest ranked sites in NSW for species richness, number of breeding species and total number of birds.
- large numbers of Black-winged Stilts, Red-necked Avocets, Marsh Sandpiper, Straw-necked Ibis and Red-kneed Dotterel recorded in the Narran Lake wetlands. This suggests that it is nationally and internationally important for these waterbird species.

The Narran Lake Nature Reserve has areas of extensive, frequently available breeding and feeding habitat for numerous waterbird species. Ibis, spoonbills, cormorants, pelicans and several waterfowl species breed in fringing lignum with river cooba used for nesting and roosting by egrets, herons, spoonbills, cormorants and darters. In addition many swan and duck species also breed on the main Narran Lake and associated channels (NSW National Parks and Wildlife Service 2000).

Wetland and floodplain vegetation in the Narran Lakes system can be broadly classified into three major community types (ANU Enterprise 2011, NSW National Parks and Wildlife Service 2000).

1. Riparian open forest and floodplain woodlands

Patches of mature open forest and woodland are relatively rare across the Narran Lakes system. Riparian open forests with canopies dominated by river red gum and coolibah are mostly limited to the banks of the Narran River and along the deeper channels towards Clear Lake where they occupy approximately 87 hectares of the Nature Reserve (McGann et al. 2001).

Areas of open forest and woodland also occur on the floodplain and fringe some of the major water bodies, especially the western side of Clear Lake and the eastern edge of Back Lake (ANU Enterprise 2011). In addition to river red gum and coolibah, river cooba dominates the canopies of several areas to the west of Clear Lake (ANU Enterprise 2011) and black box is found in some areas. Understorey species include lignum *(Muehlenbeckia florulenta)*, *Alstonia constricta*, *Acacia brachystachya* and *Paspalidium jubiflorum.*

2. Lignum Shrublands

As part of a survey of the Narran Lake Nature Reserve, McGann et. al. (2001) found that the floodplains of the northern lakes were dominated by lignum shrubby thickets which covered almost 3,000 hectares of the Reserve. Lignum shrublands occupy the areas fringing Clear Lake and most of Back Lake and Long Arm (NSW National Parks and Wildlife Service 2000; McGann et. al. 2001; ANU Enterprise 2011). Lignum shrublands are also common along both major and minor drainage channels that dissect the systems floodplains as well as the delta area where the Narran River enters Narran Lake (ANU Enterprise 2011).

The lignum shrublands fringing Clear Lake and the floodplain to the west of Clear Lake, as well as the eastern edge of Clear and Back Lakes, contain scattered river cooba and river red gum (ANU Enterprise 2011).

3. Ephemeral Herb Fields

McGann et. al. (2001) found that the floodplains of the Narran Lake Nature Reserve contained 1000 hectares of ephemeral herb fields. In addition to these areas sedges, grasses and ephemeral herbs develop on the main lake beds once flood waters recede (NSW National Parks and Wildlife Service 2000).

These ecosystems support important species that are listed in international agreements such as the Ramsar Convention, and include vulnerable and endangered species. Appendix B provides a summary of the conservationally significant species recorded at Narran Lakes.

The ecological values of the Narran Lakes system are reflected in MDBA's assessment against the criteria used to identify key environmental assets within the Basin. The MDBA established five criteria to identify important environmental assets in the Basin. The criteria broadly align with the National Framework and Guidance for Describing the Ecological Character of Australian Ramsar Wetlands (Department of the Environment, Water, Heritage and the Arts 2008) and the draft criteria for identifying High Conservation Value Aquatic Ecosystems (SKM 2007).

Based on the ecological values identified at Narran Lakes, the site meets all five key environmental asset criteria (Table 1).

Table 1 Assessment of Narran Lakes against MDBA key environmental asset criteria.

Criterion	Ecological values that support the criterion
1. The water-dependent ecosystem is formally recognised in international agreements or, with environmental watering, is capable of supporting species listed in those agreements	The Narran Lakes system is formally recognised in, or is capable of supporting species listed in the Japan–Australia Migratory Bird Agreement, the China–Australia Migratory Bird Agreement or the Republic of Korea–Australia Migratory Bird Agreement. The Narran Lakes indicator site includes portions of the Ramsar-listed Narran Lake Nature Reserve. Species listed in international agreements that have been recorded at the Narran Lakes indicator site are in Appendix B.
2. The water-dependent ecosystem is natural or near-natural, rare or unique	The Narran Lakes system is an example of a unique water-dependent ecosystem. It contains a considerable diversity of habitats, including some of the largest expanses of lignum (*Muehlenbeckia florulenta*) in New South Wales and is considered as vital for ibis breeding (Aldis 1987; NSW National Parks and Wildlife Service 2000). The ecosystem's geomorphology is significant as an excellent example of a relatively undisturbed terminal (or closed) lake system in New South Wales (Thoms et al. 2002; NSW National Parks and Wildlife Service 2000).
3. The water-dependent	The Narran Lakes are recognised as one of the most important waterbird habitats in eastern

Criterion	Ecological values that support the criterion
ecosystem provides vital habitat	Australia. The Lakes have national significance as a major breeding site for a large number of waterbird species and are on the Register of the National Estate (NSW National Parks and Wildlife Service 2000). The Narran wetlands flood more frequently than most other wetlands in northwestern NSW and therefore provide important habitat for waterbirds (NSW National Parks and Wildlife Service 2000). Waterfowl considered to have a restricted breeding distribution in western New South Wales that breed in the Narran Lake Nature Reserve include the Australian pelican (*Pelecanus conspicillatus*), the great cormorant (*Phalacrocorax carbo*), the pied cormorant (*P. varius*), the darter (*Anhinga melanogaster*), the rufous night heron (*Nycticorax caledonicus*), the little egret (*Ardea gazetta*), the intermediate egret (*A. intermedia*), the great crested grebe (*Podiceps cristatus*), and the gull-billed tern (*Sterna nilotica*) (Smith 1993).
4. Water-dependent ecosystems that support Commonwealth, State or Territory listed threatened species or communities	Species and communities listed as threatened under both Commonwealth and state legislation that have been recorded at the site are in Appendix B.
5 The water-dependent ecosystem supports, or with environmental watering is capable of supporting, significant biodiversity	The large numbers of black-winged stilts (*Himantopus himantopus*), red-necked avocets (*Recurvirostra novaehollandiae*), marsh sandpiper (*Tringa stagnatilis*), straw-necked ibis (*Threskiornis spinicollis*) and red-kneed dotterel (*Erythrogonys cinctus*) recorded in the Narran Lakes suggest that these wetlands may be of international importance for these species (NSW National Parks and Wildlife Service 1999). The system of four major lakes interspersed with an extensive network of channels supports large numbers of breeding waterbirds; it hosted the country's largest recorded ibis breeding event in 1983. The lakes are one of the twelve most significant ibis breeding sites in Australia. Australia's three species of ibis use the wetlands: the abundant Australian white ibis (*Threskiornis molucca)*, the straw-necked ibis, and the glossy ibis (*Plegadis falcinellus*) (Thoms et al. 2007). Thoms et al. (2007) documented that 65 species of waterbirds have been recorded in the Narran Lakes. Of these species, 46 breed in the system, 5 are listed under the *Threatened Species Conservation Act 1995* (NSW) and a further 8 are of conservation concern (Cullen, Marchant & Mein 2003).

4. Hydrology

Downstream from St George, the Condamine–Balonne River divides into five separate channels. The Culgoa and Narran Rivers are the main channels, conveying 35% and 28% of the long-term mean annual flow at St George respectively; while the Ballandool and Bokhara Rivers and Birrie Creek flow only during higher discharge periods (Thoms et al. 2007).

The Narran Lakes system comprises four distinct structural features — a complex network of river channels (channelised floodplain), floodplain lakes, ephemeral wetlands and a broader floodplain surface.

There are four main lakes or water bodies, which are surrounded by a large floodplain area: Clear Lake, Back Lake, Long Arm (the northern lakes) and Narran Lake (to the south). The lakes fill sequentially — first Clear Lake, then Back Lake and Long Arm, and then, if the event is sufficiently large, Narran Lake (Thoms et al. 2007).

When full, the main Narran Lake is about 2 m deep and Clear Lake approximately 1.5 m deep. The Narran Lakes system is about 278 km^2 in area and holds some 146 GL of water when full (see Table 2). About half its area comprises the lakes while the rest (136 km^2) is associated floodplain (Thoms et al. 2007).

Table 2 Surface area and volume of water features for Narran Lakes

Feature	Surface area (km^2)	Storage volume (ML)
Narran Lake	122.9	122,876
Intervening storages	11.3	4,035
Clear Lake	5.4	4,476
Back Lake	1.3	861
Long Arm	1.5	0.6
Narran floodplains	135.7	13,573
Total	**278.1**	**145,822**

Thoms et al. (2007) suggest that the floodplains hold water for less than 1 month, while the lakes hold water for 2–15 months. If no top-up events occur as the floodwaters recede, Long Arm could typically expect to retain water for 2 months; Back Lake for 3 months; Clear Lake for 6 -12 months and Narran Lake for 15 – 24 months (Thoms et al. 2007; NSW National Parks and Wildlife Service 2000).

Being a terminal lake system, outflows from the northern lakes in the Nature Reserve occur only through drainage into Narran Lake and by evaporation and seepage (NSW National Parks and Wildlife Service 1999). The lakes within the Narran Lakes system have an average inundation frequency of one in two years and, as such, provide a more frequent waterbird habitat than other inland wetlands in New South Wales (Magrath 1991).

While flooding is also recorded in winter and spring, 85% of the flooding in Narran Lakes occurs in summer and autumn (Smith 1993). Annual inflows to the Narran wetlands are highly variable and multiple flood events have occurred in a quarter of the years in which flood data have been recorded (NSW National Parks and Wildlife Service 1999).

The Lower Balonne floodplain has been grazed since the 1840s (Sims et al. 1999), predominantly by cattle and sheep. The change to irrigated agriculture since the 1990s represents a significant shift in land-use practice and use of water resources (Thoms et al. 2002). The major irrigated crop is cotton, with cropped area increasing significantly since 1988. Associated with this expansion in the cotton industry has been the expansion of private water storages on the floodplain over the same period.

As part of an analysis of surface and ground water hydrology of the Darling Basin, Webb McKeown and Associates (2007) found that average annual modelled inflows for the Narran Lakes system were 52 % less under current development than those occurring under without development conditions.

5. Determining the site-specific flow indicators for Narran Lakes

5.1. Setting site-specific ecological targets

The objective setting framework used to determine the ESLT is outlined in the report '*The proposed "environmentally sustainable level of take" for surface water of the Murray-Darling Basin: Method and Outcomes*' (MDBA 2011). In summary, the MDBA developed a set of Basin-wide environmental objectives and ecological targets, which were then applied at a finer scale to develop site-specific objectives for individual key environmental assets. Using these site-specific objectives, ecological targets that relate specifically to the Narran Lakes system were developed (Table 3). Information underpinning site-specific ecological targets is shown in Table 3.

Table 3 Site-specific ecological targets for Narran Lakes

Site-specific ecological targets	Justification of targets
• Provide a flow regime which ensures the current extent of native vegetation of the riparian, floodplain and wetland communities is sustained in a healthy, dynamic and resilient condition • Provide a flow regime which supports the habitat requirements of waterbirds and is conducive to successful breeding of colonial nesting waterbirds • Provide a flow regime which supports recruitment opportunities for a range of native aquatic species (e.g. fish, frogs, turtles, invertebrates). • Provide a flow regime which supports key ecosystem functions, particularly those related to connectivity between the river and the floodplain	The site includes portions of the Ramsar-listed Narran Lake Nature Reserve and supports a number of different flood dependent vegetation types which are important habitats for a range of biota. The Narran Lakes system contains a considerable diversity of habitats, including some of the largest expanses of lignum (*Muehlenbeckia florulenta*) in New South Wales and is considered vital habitat for ibis breeding (Aldis 1987; NSW National Parks and Wildlife Service 2000). This site contains an extensive network of channels supporting large numbers of breeding waterbirds; it hosted the country's largest recorded ibis breeding event in 1983. The lakes are one of the twelve most significant ibis breeding sites in Australia. Australia's three species of ibis use the wetlands: the abundant Australian white ibis (*Threskiornis molucca)*, the straw-necked ibis, and the glossy ibis (*Plegadis falcinellus*) (Thoms et al. 2007). Achieving the targets for floodplain wetlands and waterbirds will ensure inundation of breeding and feeding habitats considered key for a range of fish, amphibian and water-dependent reptile and invertebrate species. Key ecosystem functions support fish, birds and invertebrates through habitat maintenance, energy transfer and facilitating connections between rivers and floodplains. Overbank flows supply the floodplains with nutrients and sediments from the river, accelerate the breakdown of organic matter and supply water to

	disconnected wetlands, billabongs and oxbow lakes. As the floodwaters recede, the floodplains provide the main river channel with organic matter. The hydrological connection between lakes, channels, watercourses and their associated floodplain provides for the exchange of carbon and nutrients (Thoms 2003). These connections are considered essential for the functioning and integrity of floodplain-river ecosystems.

Site-specific ecological targets formed the basis of an assessment of environmental water requirements and the subsequent determination of site-specific flow indicators for the Narran Lakes system, as described below.

5.2. Information used to determine site-specific flow indicators

The site-specific flow indicators have been determined through a synthesis of current literature and MDBA's analysis of modelled flow data, in addition to consultation with state government staff and research providers.

Similar to those of other rivers in the lower Condamine–Balonne system, flows down the Narran River are highly variable (Sheldon et al. 2000) with relatively high magnitudes and short durations, interspersed by periods of little to no flow (Figure 3). The occurrence of multiple flow events of a similar threshold in close proximity are important for extending the duration of floodplain and lake inundation, something to which the flora and fauna of these systems has become adapted (Roberts & Marston 2000).

The complex geomorphic nature of the Narran Lakes ecosystem means that the pattern of inundation is also complex, and may differ over time (Thoms et al. 2007). This is a result of different areas of the ecosystem holding water for different lengths of time. Therefore, the total area of the ecosystem which becomes inundated is not just a result of the amount of water in a single flow event, but of the volume of flows entering within the past several years (Sims & Thoms 2003). Similarly, the duration over which a flow volume occurs is important to ensure flood events are ecologically significant. Therefore, site-specific flow indicators were not directly linked to individual vegetation communities, but focused on wetting each major component of the ecosystem and are based on an inflow volume to ensure a period of inundation.

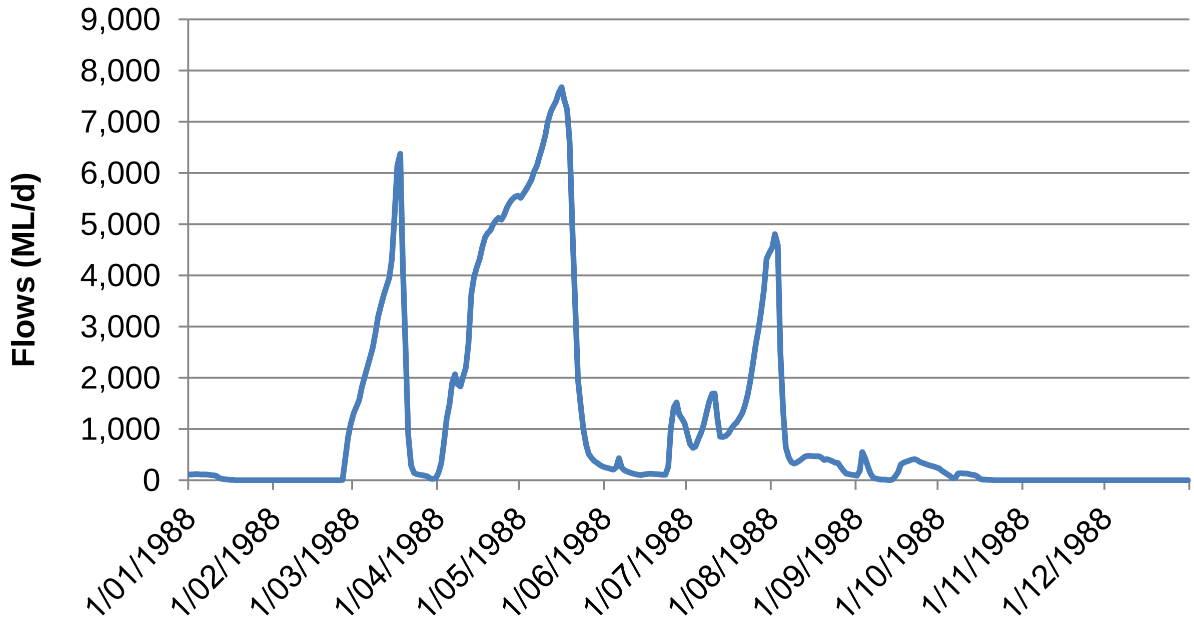

Figure 3 Highly variable flows past Wilby Wilby gauge Narran River

5.2.1. Vegetation

Sims and Thoms (2003) analysed 11 satellite images captured between 1990 and 2002 and linked the hydrologic conditions before image capture to the amount of inundation within each image. Inundation of different sections of the Narran Lakes could be linked to the flow regime at Wilby Wilby gauge on the Narran River. Findings from this report, in conjunction with results from the Narran Lakes hydrodynamic model described in Rayburg and Thoms (2009), were used as a basis for selecting inflow volumes for the vegetation communities of the Narran Lakes.

The MDBA has compared available information on the specified water regime for these flood dependent key vegetation communities occurring within the Narran Lakes Indicator site (Table 4). This comparison informs the frequency and duration of suggested inflow volumes.

Table 4 Current knowledge relating to water dependent species

River Red Gum (*Eucalyptus camaldulensis*) For large basins (such as those that occur in the Narran Lakes system) the most important water regime components for the maintenance of river red gums are filling frequency and how long the wetland stays dry between flood events (Roberts & Marston 2011). Frequency of inundation – About every one to three years for forests and about every two to four years for woodlands (Roberts & Marston 2011). Critical Interval between inundations – Do not form a seed bank, hence it is important to maintain trees in good condition so that a good supply of seed is available (Roberts & Marston 2011). Inundation required after about 3 years for forests and five to seven years for woodlands. Longer intervals may be tolerated periodically, but if these become routine then tree

condition is likely to deteriorate in the long term (Roberts & Marston 2011).

Current understanding of river red gum within the Narran Lakes System

ANU Enterprise (2011) found that the abundance of river red rums within the Narran Lakes system was more likely to be related to localised conditions such as elevation rather than a large scale flood regime.

Lignum (*Muehlenbeckia florentula*)

Water regime is a very strong influence on lignum growth and reproduction. Frequency and duration of inundation are the most important components for maintaining adult lignum in good condition (Roberts & Marston 2011). Estimates of the average flooding frequency expected to maintain lignum vigour are very similar across the Murray-Darling Basin (Roberts & Marston 2011).

Based on an assessment of current literature, the Gwydir Wetlands Adaptive Environmental Management Plan recommends that lignum shrublands (association with river cooba or coolibah) need to be inundated for at least 3 months between September and March at least 5 years in 10 (NSW Department of Environment, Climate Change and Water 2011).

Frequency of inundation – About every one to three years for large shrubs with vigorous canopy; every three to five years for healthy shrubs (Roberts & Marston 2011). For maintenance of small shrubs less frequent inundation of every seven to 10 years is tolerable however these will not be suitable as nesting platforms (Roberts & Marston 2011).

Duration of inundation - About three to seven months for vigorous canopy (Roberts & Marston 2011).

Critical Interval between inundations – inundation required after five to seven years to maintain vigour (Roberts & Marston 2011).

Current understanding of lignum within the Narran Lakes System

ANU Enterprise (2011) found that flood frequency was critical in explaining the cover and number of clumps as well as the mean height and mean perimeter of each clump. ANU Enterprise (2011) found that where the flood or inundation frequency was less than 1.33 years the cover of lignum as well as the height and perimeter of each clump was significantly higher. Areas that are frequently flooded (where the inundation frequency is less than 1.33 years) have an average of 60 % lignum cover but less clumps, while areas less frequently inundated have only 20 % lignum cover but more clumps (ANU Enterprise 2011).

Coolibah (*Eucalyptus coolabah)*

In their review of literature for selected wetland and floodplain species, Roberts & Marston (2011) found that the importance of flooding for adult coolibah had not been established. Roberts & Marston (2011), found that inundation is probably important for seedling establishment, and a sequence of floods, or flood and wet years, may be necessary to ensure seedlings are well established.

Roberts & Marston (2011) found that although tolerant of hot dry conditions and infrequent flooding, Coolibah is unlikely to persist if flow regime or regional hydrology becomes substantially drier.

Frequency of inundation – About every 10 to 20 years (Roberts & Marston 2011).

Duration of inundation – Not known.

Critical Interval between inundations – Uncertain. Can maintain fair to good condition for possibly as long as 10 – 20 years (Roberts & Marston 2011).

River cooba (*Acacia stenophylla*)

In their review of literature for selected wetland and floodplain species Roberts & Marston (2011), found that flooding was important in determining the vigour of river cooba and implicated in germination and establishment of the species.

Frequency of inundation – About every three to seven years for large shrubs with vigorous canopy (Roberts & Marston 2011)

Duration of inundation - About two to three months (Roberts & Marston 2011)

Critical Interval between inundations – Not known, possible maintains vigour up to five years without flooding, with trees near creeks and waterholes able to maintain vigour for much longer periods (Roberts & Marston 2011).

Current understanding of river cooba within the Narran Lakes System

ANU Enterprise (2011) found that the abundance of river cooba within the Narran Lakes System was likely to be associated with frequently flooded zones. In particular, a significantly high proportion of river cooba is found in areas that have been flooded at least once every 2 years.

Northern Lakes and surrounding floodplain

The Narran Lake Nature Reserve Plan of Management (NSW National Parks and Wildlife Service 2000) and the Final Report on the Decision Support System for the Narran Lakes (ANU Enterprise 2011) describes the complicated array of vegetation associations which exists in the northern lakes (Back and Clear Lakes) and associated floodplains contained within the Narran system. These include:

- sedges, grasses and ephemeral herbs on the beds of the northern lakes following receding flood waters;
- extensive areas of lignum, forming dense shrubland in the littoral zone of Clear and Back Lake;
- small areas of cumbungi - *Phragmites australis* among the lignum;
- stands of river red gum, coolibah, black box and river cooba fringing the river and wetland channels on the floodplains contained within the Narran Lake Nature Reserve;
- extensive areas of river cooba with lignum to the south and a relatively large area of river red gum to the north east of Clear Lake; and
- lignum shrublands are also common along both major and minor drainage channels that dissect the systems floodplains as well as the delta area where the Narran River enters Narran Lake.

25,000 ML delivered over two months

A volume of around 25,000 ML delivered over two months would inundate the northern lakes, filling Back Lake, and bringing Clear Lake up to about 80% capacity (Sims & Thoms 2003). Thoms et al. (2007) suggest that if no top-up events occur as the floodwaters recede, Back Lake will retain water for 3 months.

Based on the distribution of vegetation communities described in The Narran Lake Nature Reserve Plan of Management (NSW National Parks and Wildlife Service 2000) and the Final Report on the Decision Support System for the Narran Lakes (ANU Enterprise 2011), the MDBA concluded that this flow would inundate lignum shrublands in the littoral zone of Back Lake, riparian open forest fringing river and wetland channels between Narran River and Clear Lake as well as between Clear and Back Lakes. Drawing upon Roberts & Marston (2011) and ANU Enterprise (2011), the MDBA has concluded that lignum shrublands need to be inundated for a period of at least 3 months to maintain healthy shrubs and that the average period between events should be at least 1.33 years.

<u>50,000 ML delivered over three months</u>

A volume of 50,000 ML delivered over three months would significantly inundate the northern lakes and areas of the channelised floodplain covered in lignum south of Clear Lake (S Rayburg 2010, pers. comm., 30 June). A flow of this magnitude would also push water down the length of the system and into Narran Lake (Sims & Thoms 2003). Water levels in Clear Lake would reach 1 m in depth and would remain for up to 12 months (Thoms et al. 2007).

Drawing upon Roberts & Marston (2011) and ANU Enterprise (2011), the MDBA has concluded that an event of this magnitude and duration with an average period between events of 1.33 years is sufficient to ensure that lignum communities around Clear Lake will be dominated by large shrubs with a vigorous canopy. It is also likely that this frequency will maintain areas of river cooba located to the south of Clear Lake in good condition.

Thoms et al. (2007) suggest that the floodplains of the Narran Lakes system hold water for less than 1 month. Based on this and known water requirements of lignum (Table 4), the MDBA has concluded that closely spaced multiple events will be required to ensure stands of lignum located on the broader floodplain will be inundated for a sufficient period (i.e. 3 months) to ensure shrubs maintain a healthy condition. This conclusion is based on a review of existing knowledge and information related to lignum communities including work by Roberts & Marston (2011) who found that to maintain plant vigour the maximum period between inundation events was between five and seven years. Roberts & Marston (2011) also found that small shrubs are able to tolerate less frequent inundation and recommended that areas dominated by smaller lignum shrubs be inundated once every seven to 10 years.

Given previous assumptions and analysis, the MDBA has specified that the maximum period between years containing two or more events is seven to 10 years (Table 6).

Narran Lake and surrounding floodplain

A volume of 250,000 ML delivered over six months would inundate most of the Narran Lakes ecosystem. A flow of this volume would inundate the broader floodplain (Sims & Thoms 2003) and also fill Narran Lake to about 60% capacity, depending on prevailing water levels before the event (S Rayburg 2010, pers. comm., 30 June). Water may then stay in Narran Lake for up to 18 months (Thoms et al. 2007).

Based on the distribution of vegetation communities described in The Narran Lake Nature Reserve Plan of Management (NSW National Parks and Wildlife Service 2000) and the Final Report on the

Decision Support System for the Narran Lakes (ANU Enterprise 2011), the MDBA concluded that this flow would inundate lignum shrublands throughout the broader floodplain. Key areas inundated would include the major and minor drainage channels that dissect the systems floodplains as well as the area where the Narran River enters Narran Lake. The MDBA has assumed that lignum occurring in these areas is likely to be dominated by small shrubs. Drawing upon Roberts & Marston (2011), the MDBA has concluded that lignum shrublands in the broader floodplain would need to have an average inundation frequency of at least once every 10 years.

5.2.2. Waterbirds

The relationship between inflows measured at Wilby Wilby flow gauge and the number of nests in the Narran Lakes System has been estimated based on historical observed data. Between 1965 and 2004, 16 recorded waterbird breeding events occurred in the Narran Lakes ecosystem, equating to roughly one breeding event every 2.5 years (Rayburg & Thoms 2008). Most of these breeding events occurred in clusters, with several years of consecutive breeding events followed by several years without breeding (Figure 4). All breeding events occurred when all gauges along the Narran River — Dirrinbandi, New Angledool and Wilby Wilby — recorded annual flows in excess of 100,000 ML.

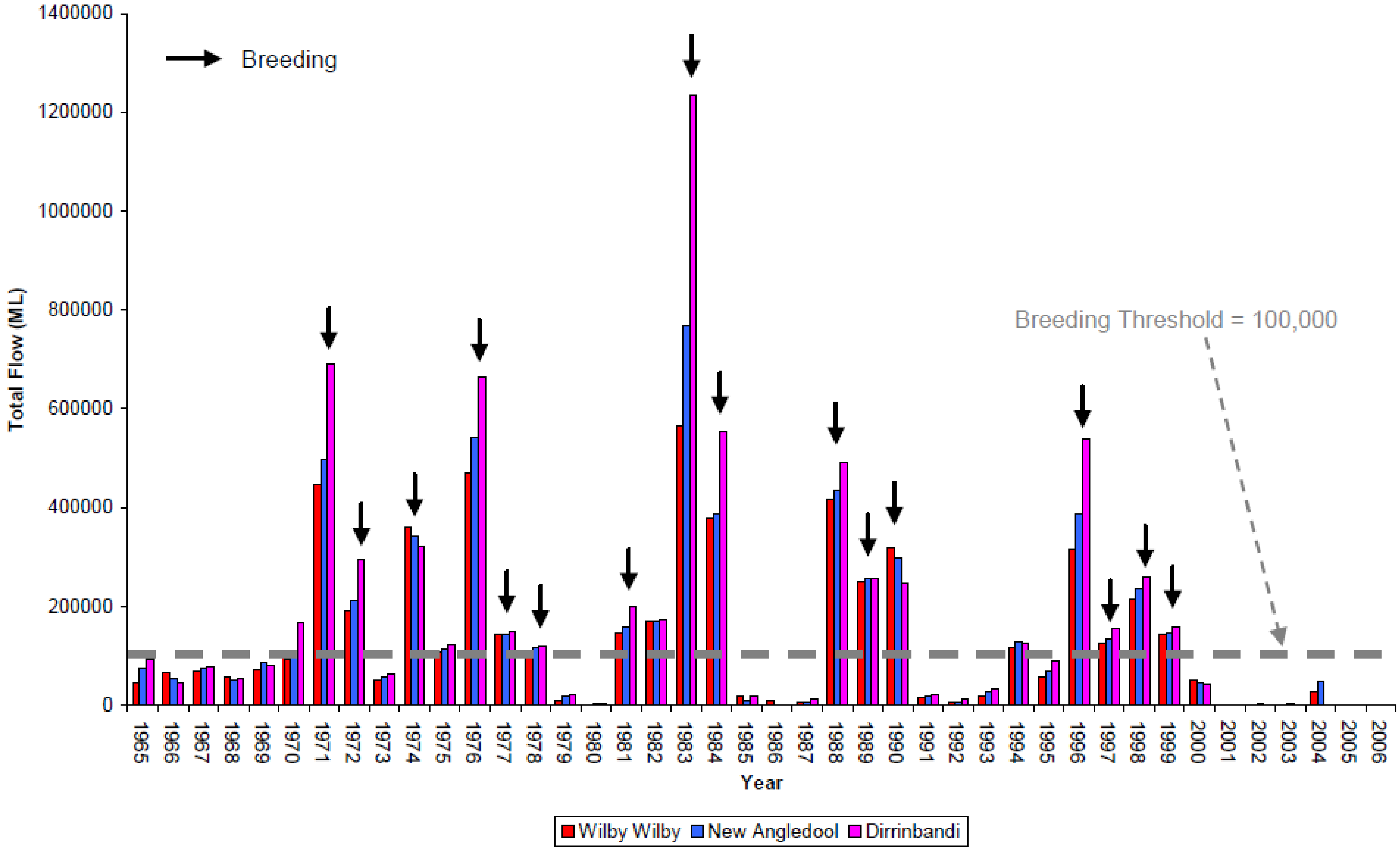

Figure 4 Annual flow volumes for the three principal Narran River flow gauges and associated waterbird breeding events. (Source: Rayburg & Thoms 2008).

As part of the Rivers Environmental Restoration Program (RERP) the NSW Department of Environment Climate Change and Water funded the development of tools to support environmental managers to manage the duration, timing and quantity of flows. As part of RERP a Decision Support System for the Narran Lakes was developed by the Integrated Catchment Assessment and Management (iCAM) centre at the Australian National University.

The adoption of an annual inflow of 100,000 ML (gauged at Wilby Wilby) as a key threshold for waterbird breeding in the system is supported by analysis undertaken as part of a report prepared by ANU Enterprise (2011) on the Decision Support System for the Narran Lakes. ANU Enterprise (2011) reported that there was a 95% probability that ibis nesting would occur when annual inflows at Wilby Wilby were greater than 100,000 ML (Table 5). Large Ibis nesting events where the total numbers of nests are likely to exceed 50,000 generally require annual inflows totalling at least 300,000 ML.

Table 5 Relationship between the number of nests and annual inflow (figures are % probability). (Source: ANU Enterprise 2011).

Annual Inflow (ML)	Likely number of nests				
	0	<1000	1,000 – 50,000	50,000 – 100,000	>100,000
0 – 100,000	95	5	0	0	0
100,000 – 150,000	2.5	95	2.5	0	0
150,000 – 200,000	0	80	20	0	0
200,000 – 300,000	0	70	26	3	1
300,000 – 400,000	0.1	4.9	10	50	35
400,000 – 500,000	0.01	5	30	40	25
> 500,000	0.01	1	3	6	90

All breeding events in the Narran Lakes wetlands occurred above the 100,000 ML annual inflow threshold, with only three instances of flows above this threshold where breeding events failed to occur (Rayburg and Thoms 2008). An exception to this occurred in 2008, when waterbird breeding occurred with a flow volume of less than 50,000 ML. This was thought to have occurred because the waterbirds were an ageing population, the event was preceded by a lengthy period of extreme drought (1999 to 2008), and because there was exceptional local rainfall which provided favourable floodplain conditions for foraging. The MDBA has assumed that the eight period between 1999 and 2008 represents the maximum number of years between nesting opportunities for key waterbird species.

Given the above relationship between flow and breeding of colonial waterbirds, a flow of at least 100,000 ML over 12 months is stipulated to provide conditions conducive for successful breeding of colonial nesting waterbirds in the Narran Lakes with a maximum period between events of six to eight years (Table 6).

5.2.3. Other biota

The MDBA is confident that the site-specific flow indicators determined to achieve the ecological targets relating to the current extent of native vegetation communities and the habitat requirements for waterbirds in the Narran lakes system will also have valuable beneficial effects on the life-cycle and habitat requirements of native fish, amphibians, and water-dependent reptiles and invertebrates (see below for further discussion on native fish). In addition the site-specific flow indicators specified for the Lower Balonne River Floodplain System (see separate report) are likely to also provide connectivity both between the Narran River and other channels in the Lower Balonne floodplain and along the Narran River itself. Maintaining longitudinal connectivity throughout the broader Lower Balonne system is also likely to have benefits for a range of aquatic fauna.

There is still debate in the scientific literature as to the relative role of flooding to fish community dynamics, and an understanding of the nature of 'fish ecology'-'river flow' interactions is by no means clear (Humphries et al. 1999, Mallen-Cooper and Stuart 2003, Graham and Harris 2004; King et al. 2009). For example, it has been suggested that some fish species, such as golden perch (*Macquaria ambigua ambigua*), which has been recorded along the Narran River, require flow pulses or floods for spawning i.e. flood recruitment hypothesis (Humphries et al. 1999). Other factors such water temperature and day length, or the interaction of a range of environmental variables including flow, are suggested to also be important for native fish recruitment (King et al. 2009).

Despite the ongoing debate regarding the link between hydrology and fish ecology, available evidence supports that provision of flows that connect the river channel to the floodplain as well as in-channel flow variability are important to sustaining key ecological features such as native fish populations. Flow indicators described herein for high flow elements of the flow regime primarily based on the water requirements of flood dependent vegetation communities and waterbirds are expected to be sufficient to support life-cycle and habitat requirements of native fish including provision of cues for spawning, migration and access to food sources.

5.3. Proposed flow indicators

Based on the hydrology described in Section 4 and the environmental water requirements described in Sections 5.1 and 5.2, the MDBA has proposed five flow indicators for the Narran Lakes system (Table 6). The site-specific flow indicators for the Narran Lakes system represent an amalgam of information from existing literature and hydrologic modelling data, checked against an analysis of modelled without development and baseline flow data. Site-specific flow indicators are expressed at the Wilby Wilby gauge on the Narran River.

Flow indicators as specified for high flow elements of the flow regime attempt to strike a balance between desirable frequency (e.g. as described in Table 4) and desirable magnitude, duration and timing using the modelled "without development" hydrology of the site as a guide. Where a discrepancy exists between the literature and inundation / hydrology modelling, an analysis of modelled without development flows has been used to guide the determination of site-specific flow indicators, particularly to ensure that the recommended flows are achievable and not greater than without development flows.

The site-specific flow indicators needed to achieve ecological targets for the Narran Lakes system should be read in their entirety to understand the environmental water requirements, as multiple flow indicators will contribute to achieving each ecological target. This approach has been used because it is not possible to define a single flow threshold for each vegetation community. The flood dependent vegetation communities cover a wide range of flows (Figure 3) and a single indicator would be misleading.

Generally, the flow indicator component with the greatest level of uncertainty across the Basin is the definition of the desirable frequency of inundation, expressed as the proportion of years an event is required. This uncertainty is due to a number of reasons. Firstly, it is likely that there are thresholds for many plants and animals beyond which their survival or ability to reproduce is lost, but the precise details of those thresholds are mostly unknown or where there is information our knowledge is evolving. Secondly, vegetation communities are located across the floodplain and would have experienced significant variability in their inundation frequency under pre-development conditions which subsequently makes specification of a single frequency metric deceptively certain. For many species and ecological communities the relationship between water provisions and environmental outcomes may not be threshold based, rather there could be a linear relationship between flow and the extent of environmental outcomes or the condition of a particular ecological species/community.

Recognising the degree of confidence in specifying a desirable frequency, 'low-uncertainty' and 'high-uncertainty' frequency of flow events have been specified (Table 6). For the low-uncertainty frequency, there is a high likelihood that the environmental objectives and targets will be achieved. The lower boundary of the desired range is referred to here as the high uncertainty frequency which is effectively the best estimate of the threshold, based on current scientific understanding, which, if not met, may lead to the loss of health or resilience of ecological communities, or the inability of species to reproduce frequently enough to sustain populations. The high certainty frequencies attempt to define critical ecological thresholds. The high uncertainty frequency is considered to indicate a level beyond which the ecological targets may not be achieved.

For the Narran Lakes system a number of key sources of information (as presented in Table 4) were used to inform the high and low uncertainty frequencies. These documents express the desired frequency as a range and the high and low uncertainty frequency flow indicator metrics attempt to encapsulate the broad water requirements represented by this range. Modelled flow data was used to verify if recommended frequencies were achievable and not greater than without development flows.

It is recognised that periods between inundation events are an important consideration when trying to determine ecosystem resilience or thresholds of irreversible change. When investigating the environmental water requirements for the Narran Lakes system consideration was given to specifying a maximum period between events or metrics related to maximum dry. However, the literature regarding the tolerance of various floodplain ecosystems to dry periods is limited and the use of this metric has only been applied where appropriate.

Table 6 Site-specific ecological targets and associated flow Indicators for Narran Lakes

Site-Specific Ecological Targets	Site-Specific Flow Indicators					Without development and baseline event frequencies	
	Event			Average period between events (years) except where labelled		Average period between events (except where labelled) under modelled without development conditions (years)	Average period between events (except where labelled) under modelled baseline conditions (years)
	Inflow Volume (measured at Wilby Wilby - ML)	Maximum period over which flows can occur (months)	Timing	Low uncertainty (years)	High uncertainty (years)		
Provide a flow regime which ensures the current extent of native vegetation of the riparian, floodplain and wetland communities is sustained in a healthy, dynamic and resilient condition Provide a flow regime which supports the habitat requirements of waterbirds and is conducive to successful breeding of colonial nesting waterbirds	25,000	2	Preferably summer /autumn but timing not constrained to reflect that high flows depend on occurrence of heavy rainfall and will be largely unregulated events	1	1.1	0.7	1.4
	50,000	3		1	1.33	0.9	2.0
	250,000	6		8	10	7.2	15.9
Provide a flow regime which supports recruitment opportunities for a range of native aquatic species (e.g. fish, frogs, turtles, invertebrates).	100,000	12	N/A	6 (maximum period between events)	8 (maximum period between events)	3.1 (maximum period between events)	16 (maximum period between events)
Provide a flow regime which supports key ecosystem functions, particularly those related to connectivity between the river and the floodplain	50,000	3	Minimum of 2 events in a year preferably one summer/autumn	7 (maximum period between events)	10 (maximum period between events)	6 (maximum period between events)	18 (maximum period between events)

Note: Multiplication of the flow rate by the duration and frequency does not translate into the additional volume of water the site needs to be environmentally sustainable. This is because part of the required flow is already provided under the current water management arrangements (i.e. baseline conditions) and that the additional environmental water required is the amount over and above the baseline flows.

6. Summary and conclusion

The Narran Lakes system is a key environmental asset within the Basin and is an important site for the determination of the environmental water requirements of the Basin. The MDBA has undertaken a detailed eco-hydrological assessment of the environmental water requirements of the Narran Lakes system. Specified flow indicators are indicative of a long-term flow regime required to enable the achievement of site-specific ecological targets at the Narran Lakes system and for the broader river valley and reach. Along with other site-specific flow indicators developed across the Basin at other hydrologic indicator sites, these environmental flow requirements were integrated within hydrological models to inform the ESLT. This process is described in further detail within the companion report on the modelling process '*Hydrologic modelling to inform the proposed Basin Plan: Methods and results*' (MDBA 2012).

The flow indicators in this report are used to assess potential Basin Plan scenarios. MDBA (2012) summarises how the proposed draft Basin Plan released in November 2011 performs against flow indicators for the Narran Lakes system.

References

Aldis, RJ 1987, '*A biological description of the lower Narran catchment, Western Division of NSW, as a basis for the identification of optimal land management strategies*', in prep thesis, University of New England, Armidale, New South Wales.

ANU Enterprise 2011, Decision Support System for the Narran Lakes, Final Report to the NSW Department of Environment, Climate Change and Water, Sydney.

Cullen P, Marchant, R & Mein, R 2003, *Review of science underpinning the assessment of the ecological condition of the Lower Balonne system*, report to the Queensland Government Independent Scientific Review Panel, Brisbane.

Department of the Environment, Water, Heritage and the Arts 2001, *A directory of important wetlands in Australia*, Australian wetlands database — spatial data, viewed November 2008, <asdd.ga.gov.au/asdd>.

Department of the Environment, Water, Heritage and the Arts 2008, National framework and guidance for describing the ecological character of Australian Ramsar wetlands, module 2 of the national guidelines for Ramsar wetlands — implementing the Ramsar Convention in Australia, viewed 5 January 2010, www.environment.gov.au/water/publications/environmental/wetlands/module-2-framework.html

Graham, R & Harris, JH 2004, *Floodplain inundation and fish dynamics in the Murray-Darling Basin. Current concepts and future research: a scoping study*. CRC for Freshwater Ecology, Canberra.

Humphries, P, King, AJ and Koehn, JD 1999, 'Fish, flows and floodplains: links between freshwater fishes and their environment in the Murray-Darling River system, Australia'. *Environmental Biology of Fishes* 56, 129-151.

King, AJ, Ramsey, D, Baumgartner, L, Humphries, P, Jones, M, Koehn, J, Lyon, J, Mallen-Cooper, M, Meredith, S, Vilizzi, L, Ye, Q & Zampatti, B 2009, *Environmental requirements for managing successful fish recruitment in the Murray River Valley – Review of existing knowledge*, Arthur Rylah Institute for Environmental Research Technical Report Series No. 197, Department of Sustainability and Environment, Heidelberg.

Mallen-Cooper, M & Stuart, IG 2003, 'Age, growth and non-flood recruitment of two potamodromous fishes in a large semi-arid/temperate river system'. *River research and applications* 19: 697-719.

Magrath, M 1991, *Waterbird breeding in the Narran Wetlands*, New South Wales Department of Water Resources, Technical Services Division, Sydney.

McGann, TD, Kingsford, RT, Bell, D 2001 Vegetation of Narran Lake Nature Reserve, North Western Plains, New South Wales, Cunninghamia 7(1): 43-64.

MDBA (Murray-Darling Basin Authority) 2011*, The proposed "environmentally sustainable level of take" for surface water of the Murray-Darling Basin: Method and Outcomes.* Murray-Darling Basin Authority, Canberra.

MDBA (Murray-Darling Basin Authority) 2012*, Hydrological modelling to inform the Basin Plan.* MDBA , Canberra.

NSW Department of Environment, Climate Change and Water 2009, *Atlas of NSW wildlife*, viewed October 2009, <www.wildlifeatlas.nationalparks.nsw.gov.au/wildlifeatlas/watlas.jsp>.

NSW Department of Environment, Climate Change and Water 2011, 'Gwydir Wetlands: Adaptive Environmental Management Plan – synthesis of information projects and actions'. NSW Department of Environment, Climate Change and Water, Sydney.

NSW National Parks and Wildlife Service 1999, Information sheet on Ramsar Wetlands(RIS) – Narran Lakes Nature Reserve, viewed 17 December 2009, <http://www.environment.gov.au/water/topics/wetlands/database/pubs/53-ris.pdf>

NSW National Parks and Wildlife Service 2000, Narran Lake Nature Reserve Plan of Management, viewed 19 August 2011, http://www.environment.nsw.gov.au/resources/parks/pomfinalnarran.pdf

Rayburg, S & Thoms, M 2008*, A real time hydrological model for the Narran Lakes Floodplain Wetland Ecosystem*, Murray–Darling Basin Commission, Canberra.

Rayburg, S & Thoms, M 2009, A coupled hydraulic-hydrologic modelling approach to deriving a water balance model for a complex floodplain wetland system, Hydrology Research, vol. 40, pp. 364-379.

Roberts, J & Marston, F 2000, *Water regime of wetland and floodplain plants in the Murray–Darling Basin – a source book of ecological knowledge*, technical report 30/00, CSIRO Land and Water, Canberra.

Roberts, J & Marston, F 2011, *Water regime of wetland and floodplain plants. A source book for the Murray-Darling Basin*, National Water Commission, Canberra.

Rolls, R & Wilson, G 2008, *Responses of fish assemblages to flooding of the Narran Lakes ecosystem, 2008*, final report to the NSW Department of Environment and Climate Change, University of New England, Armidale, New South Wales.

Sheldon, F, Thoms, M, Berry & Puckridge, J 2000, 'Using disaster to prevent catastrophe: referencing the impacts of flow changes in large dryland rivers'*, Regulated Rivers: Research & Management,* vol. 16, pp. 403–420.

Sims, N, Thoms, MC, Levings, PF, McGinness, HM 1999, *Large scale vegetation response to wetting on the Lower Balonne floodplain,* report to the Lower Balonne Floodplain Advisory Committee, Cooperative Research Centre for Freshwater Ecology, Canberra.

Sims, N & Thoms, M 2003, *Water requirements of the Narran Lakes ecosystem*, Cooperative Research Centre for Freshwater Ecology, Canberra.

SKM 2007, High Conservation Value Aquatic Ecosystems project - identifying, categorising and managing HCVAE, Final report, Department of the Environment and Water Resources, 16 March 2007. www.environment.gov.au/water/publications/environmental/ecosystems/hcvae.html

Smith, J 1993, *A report on the vertebrate fauna of the Narran River Floodplain in NSW*, NSW National Parks and Wildlife Service, Hurstville, New South Wales.

Thoms, M 2003 *Floodplain-river ecosystems: lateral connections and the implications of human interference*. Geomorphology 56: pp. 335–349.

Thoms, M, Quinn, G, Butcher, R, Phillips, B, Wilson, G, Brock, M, & Gawne, B 2002, *Scoping study for the Narran Lakes and Lower Balonne floodplain management study* (R2011), Cooperative Research Centre for Freshwater Ecology, Canberra.

Thoms, M, Capon, S, James, C Padgham, M & Rayburg, S 2007, *Narran Ecosystem Project: the response of a terminal wetland system to variable wetting and drying*, Murray–Darling Basin Commission, Canberra.

Webb, McKeown and Associates (2007), State of the Darling. Interim Hydrology Report to the Murray-Darling Basin Commission. ISBN 1 921 257 17 2.

Whittington, J, Bunn, S, Cullen, P, Jones, G, Thoms, M, Quinn, G & Walker, K 2002, *Ecological assessment of flow management scenarios for the Lower Balonne*, report to the Queensland Department of Natural Resources and Mines, Cooperative Research Centre for Freshwater Ecology, Canberra.

Appendix A

Data used in producing hydrologic indicator site maps

Data	Dataset name	Source[a]
Basin Plan regions	Draft Basin Plan Areas 25 May 2010	Murray–Darling Basin Authority (2010)
Dam walls/barrages	GEODATA TOPO 250K Series 3 Topographic Data	Geoscience Australia 2006
Gauges	100120 Master AWRC Gauges	
Icon sites	Living Murray Indicative Icon Site Boundaries	Murray–Darling Basin Commission (2007)
Irrigation areas	Combined Irrigation Areas of Australia Dataset	Bureau of Rural Sciences (2008)
Lakes	GEODATA TOPO 250K Series 3 Topographic Data	Geoscience Australia (2006)
Maximum wetland extents	Wetlands GIS of the Murray–Darling Basin Series 2.0 (Kingsford)	Murray–Darling Basin Commission (1993)
National parks/nature reserves	Digital Cadastral Database	New South Wales Department of Lands (2007)
National parks/nature reserves	Collaborative Australian Protected Areas Database — CAPAD 2004	Department of the Environment, Water, Heritage and the Arts (2004)
Nationally important wetlands	Directory of Important Wetlands in Australia Spatial Database	Department of the Environment, Water, Heritage and the Arts (2001)
Ocean and landmass	GEODATA TOPO 250K Series 3 Topographic Data	Geoscience Australia (2006)
Ramsar sites	Ramsar wetlands in Australia	Department of the Environment, Water, Heritage and the Arts (2009)
Rivers	Surface Hydrology (AUSHYDRO version 1-6)	Geoscience Australia (2010)
Roads	GEODATA TOPO 250K Series 3 Topographic Data	Geoscience Australia (2006)
State border	GEODATA TOPO 250K Series 3 Topographic Data	Geoscience Australia (2006)
State forests	Digital Cadastral Database	New South Wales Department of Lands (2007)
Towns	GEODATA TOPO 250K Series 3 Topographic Data	Geoscience Australia (2006)
Weirs	Murray–Darling Basin Weir Information System	Murray–Darling Basin Commission (2001)
Weirs 2	River Murray Water Main Structures	Murray–Darling Basin Authority (2008)

[a] Agency listed is custodian of relevant dataset; year reflects currency of the data layer.

Appendix B

Species relevant to criteria 1 and 4: Narran Lakes

Species	Recognised in international agreement(s)[1]	*Environmental Protection and Biodiversity Conservation Act 1999* (Cwlth)	*Fisheries Management Act 2004* (NSW)	*Threatened Species Conservation Act 1995* (NSW)
Birds				
Australasian bittern (*Botaurus poiciloptilus*)[2]				V
Australian bustard (*Ardeotis australis*)[2, 3,]				E
Barking owl (*Ninox connivens*)[5]				V
Bar-tailed godwit (*Limosa lapponica*)[2, 3]	✔			
Black-breasted buzzard (*Hamirostra melanosternon*)[5]				V
Black-necked stork (*Ephippiorhynchus asiaticus*)[5]				E
Black-tailed godwit (*Limosa limosa*)[3, 2]	✔			E
Blue-billed duck (*Oxyura australis*)[3, 2]				V
Brolga (*Grus rubicundus*)[3, 2]				V
Brown treecreeper (*Climacteris picumnus*)[5]				V
Bush thick-knee (stone-curlew) (*Burhinus grallarius*)[3]				E
Caspian tern (*Sterna caspia*)[3]	✔			
Cattle egret (*Ardea ibis*)[3]	✔			
Curlew sandpiper (*Calidrus ferruginea*)[2, 3]	✔			
Diamond firetail (*Stagonopleura guttata*)[5]				V
Eastern great egret (*Ardea modesta* var. *Ardea alba*, *Egretta alba*)[3]	✔			
Freckled duck (*Stictonetta naevosa*)[3, 2]				V
Glossy ibis (*Plegadis falcinellus*)[3]	✔			
Greenshank (*Tringa nebularia*)[3]	✔			
Grey falcon (*Falco hypoleucos*)[2, 3]				V
Grey-crowned babbler (eastern subspecies) (*Pomatostomus temporalis temporalis*)[5]				V
Hooded robin (*Melanodryas cucullata*)[5]				V
Latham's snipe (*Gallinago hardwickii*)[3]	✔			

Species	Recognised in international agreement(s)[1]	*Environmental Protection and Biodiversity Conservation Act 1999* (Cwlth)	*Fisheries Management Act 2004* (NSW)	*Threatened Species Conservation Act 1995* (NSW)
Magpie goose (*Anseranas semipalmata*)[2, 3]				V
Major Mitchell's cockatoo or pink cockatoo (*Cacatua leadbeateri*)[2, 5]				V
Marsh sandpiper (*Tringa stagnatilis*)[3]	✔			
Masked owl (*Tyto novaehollandiae*)[2]				V
Painted honeyeater (*Grantiella picta*)[2, 3]				V
Red-tailed black-cockatoo (*Calyptorhynchus banksii*)[2, 3]				V
Sharp-tailed sandpiper (*Calidrus acuminate*)[3]	✔			
White-bellied sea-eagle (*Haliaeetus leucogaster*)[3]	✔			
Fish				
Silver perch (*Bidyanus bidyanus*)[4, 2]			V	
Mammals				
Koala (*Phascolarctos cinereus*)[2, 3]				V
Kultarr (*Antechinomys laniger*)[3]				E
Little pied bat (*Chalinolobus picatus*)[2]				V
Stripe-faced dunnart (*Sminthopsis macroura*)[2]				V
Yellow-bellied sheathtail-bat (*Saccolaimus flaviventris*)[5]				V
Plants				
Winged peppercress (*Lepidium monoplocoides*)[2, 5]		E		E

E = endangered   V= vulnerable

1 Japan–Australia Migratory Bird Agreement, China–Australia Migratory Bird Agreement, or Republic of Korea – Australia Migratory Bird Agreement

2 Thoms et al. (2002)

3 NSW National Parks and Wildlife Service (1999)

4 Rolls & Wilson (2008)

5 NSW Department of Environment, Climate Change and Water (2009)