A review of the relationships between flow and waterbird ecology in the Condamine-Balonne and Barwon-Darling River Systems

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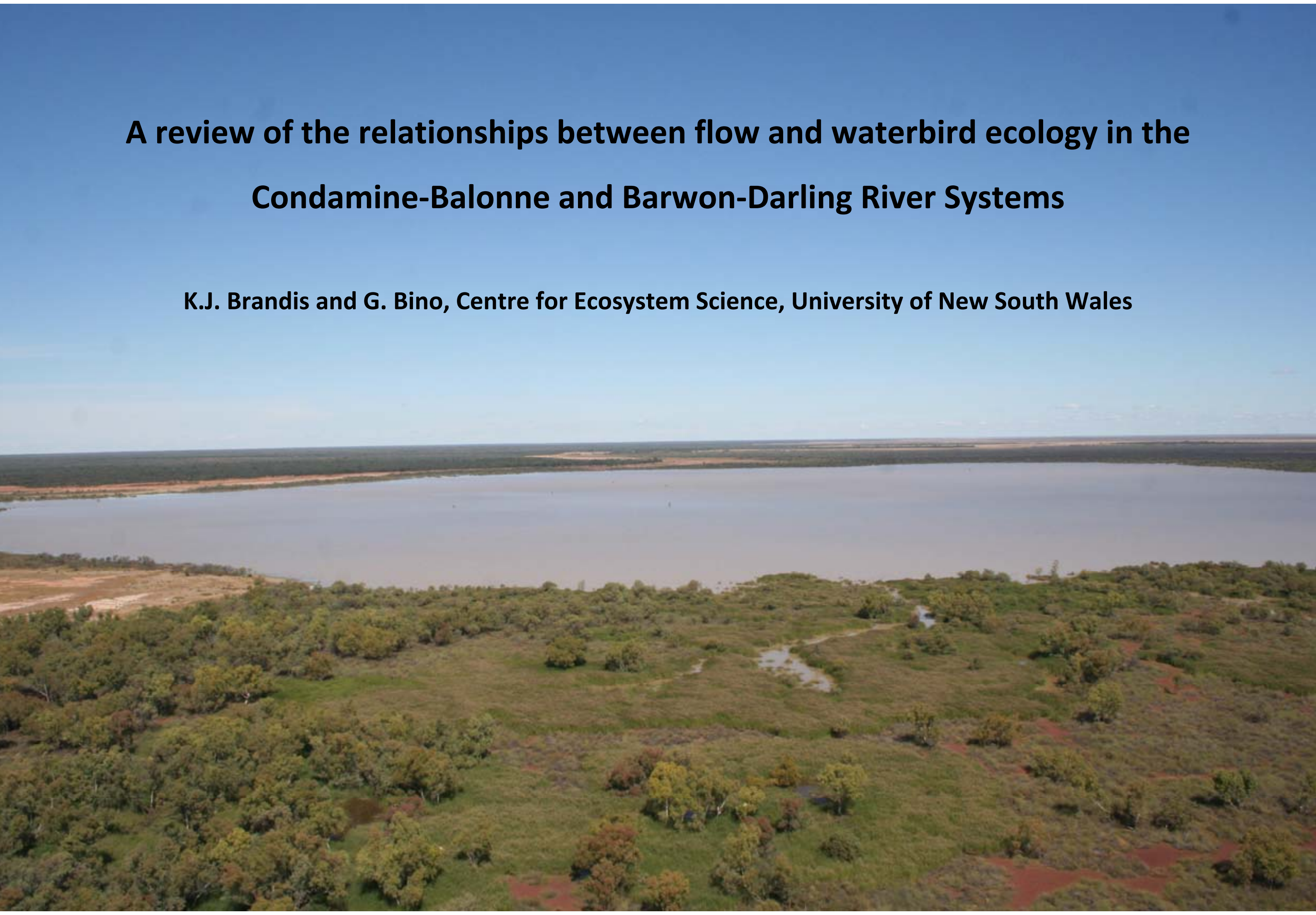

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Cover image: [Clear Lake, Narran Lakes Nature Reserve (K. Brandis)]

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Executive Summary

One of the key requirements of the Basin Plan is to establish Sustainable Diversion Limits (SDLs), which are the maximum long–term annual average volumes of water that can be taken from the Basin that represents an Environmentally Sustainable Level of Take (ESLT) (MDBA 2012). When finalising the Basin Plan in 2012 the Murray-Darling Basin Authority committed to conducting research and investigations into aspects of the Basin Plan in the Northern Basin, including the basis for the SDLS. This new research comprises an environmental science program, social economic assessments and water recovery modelling, which is referred to as the Northern Basin Review. The aim of the environmental science program is to implement a series of research projects and review other information to ensure the best available scientific knowledge can be used to review the environmental water requirements for the Condamine-Balonne and Barwon-Darling River systems.

This project carried out a knowledge review of the relationships between flow and waterbird ecology to inform the review of environmental watering requirements in the Condamine-Balonne and Barwon-Darling River systems. The objectives of the project were:

1) Develop conceptual models of the causal relationships between flow and waterbird ecology for the Condamine-Balonne and Barwon-Darling River systems that test the two key MDBA assumptions that informed the assessment of the ESLT.
2) Identify locally and regionally important waterbird breeding locations within the Condamine-Balonne and Barwon-Darling River systems.
3) Synthesize current knowledge of the relationships between flow and waterbird ecology relevant to locally and regionally important waterbird locations within Condamine-Balonne and Barwon-Darling River systems.

The two key MDBA assumptions are: the environmental water requirements for colonial nesting waterbird breeding (which have longer duration breeding water requirements) would satisfy the breeding requirements of other waterbirds; and environmental water requirements for native riparian, floodplain and wetland vegetation would also have beneficial effects on life-cycle and habitat requirements for waterbirds.

The project was carried out in three stages. First, a literature review and discussion paper was prepared, which tested the MDBA assumptions. Second, an expert panel workshop was held to discuss the information collated as part of stage 1 and to identify other relevant knowledge to help refine the conceptual models.

Finally, we synthesized the information generated from the first two stages, which forms the basis for this report.

Key findings

Records were identified for 110 waterbird species in the Condamine-Balonne and Barwon-Darling River systems. There are 25 locations across the two river systems where 54 waterbird species have been recorded breeding. Of these, locations with the greatest frequency of breeding, species diversity and size of breeding events are a priority for determining environmental water requirements as it is these sites that will have the greatest impact on waterbird populations and species viability. In particular, the Narran Lakes, which has supported the largest and most diverse waterbird breeding events.

There is evidence to show that non-colonial waterbirds also breed during the same flooding conditions that initiate colonial waterbird breeding. Therefore, the assumption is valid that the hydrological conditions required by colonial waterbirds for breeding initiation also meet those of non-colonial species. However, there is no evidence to support the assumption that colonial waterbirds have a longer duration breeding water requirement. Data is variable, showing that colonial waterbirds have some of the shortest breeding duration times across all waterbird species, but also some of the longer times. In general, while the same inundation requirements meet the needs of many waterbird species for breeding initiation, the required duration of inundation is longer for some non-colonial waterbird species.

This review has shown that the majority (11 of 15) of straw-necked ibis (the most numerous colonial species at Narran Lakes Nature Reserve) breeding events were associated with flow volumes in the first 90 days greater than 154,000 ML with an average duration of 218 days (~8 months). Analyses also indicated that when events did not reach the first 154,000 ML threshold, a second threshold of 20,000 ML in the first 10 days was important for straw-necked ibis (3 of 7). Importantly, the second, 10 day, threshold should be used while maintaining the natural hydrological associations with flow volumes at larger time spans (i.e., 90 days). Explicitly, historical breeding occurring during flow events that exceeded a flow volume of 20,000 ML in the first 10 days manifested in an average flow volume of 270,750 ML ± 178,441SD (min: 46,565 ML – max: 532,612 ML) in the first 90 days. The 10 day threshold may be used as a useful management indicator but is likely an important ecological indicator for waterbirds. Furthermore, increases in flow duration increased the probability of straw-necked ibis breeding and the probability of breeding by other waterbird species.

The Talyawalka Anabranch and Teryaweynya Creek system are important wetlands, supporting high waterbird species diversity (29 – 56 species) and high abundances. However, this review did not find, using the available data and expert knowledge, that these wetlands were important colonial waterbird breeding sites.

Environmental water requirements that maintain the distribution, structure and health of native riparian, floodplain and wetland vegetation will ensure that habitat is available for roosting, nesting and foraging when required by waterbirds. However, opportunities for foraging and nesting will depend upon the hydrological characteristics of the flow event, seasonal timing and requirements of the individual waterbird species. Targets for regeneration of floodplain vegetation, impacts would generally be expected to be positive for waterbirds, although there could be some negative effects such as infilling of lignum channels at colony sites in Narran Lakes Nature Reserve.

Recommendations

Recommendations regarding the environmental water requirements for the Condamine-Balonne and Barwon-Darling River systems based on the findings of this review are:

1. The 100,000 ML over 12 month site specific flow indicator for Narran Lakes is altered to 154,000 ML over 3 months and 20,000 ML delivered in the first 10 days of flows. This will provide the greatest opportunity for successful colonial and non-colonial waterbird breeding. This duration will allow for completion of breeding from egg laying to independence of chicks, maximizing chances of survival for juvenile birds.
2. We recommend that there be two opportunities for breeding every eight years at Narran Lakes. This recommendation is based upon life-history traits of the straw-necked ibis, and the assumption that opportunities for breeding are provided elsewhere in the Basin.
3. Amend the waterbird ecological target for the Talyawalka and Teryaweynya system to reflect the importance of these wetland sites for supporting high waterbird diversity and abundance. The site specific flow indicators should be maintained for these wetlands based on their ability to support high waterbird species diversity and abundance but not as a colonial waterbird breeding sites.
4. Maintain the ecological targets for vegetation on the basis that they will generally have beneficial effects on life-cycle and habitat requirements for waterbirds by providing habitat for roosting, nesting and foraging when required by waterbirds.

This review identifies a range of knowledge gaps related to wetland and waterbird ecology, waterbird movements and floodplain vegetation. We have outlined a research program to fill these knowledge gaps to inform the implementation and evaluations of the Basin Plan.

BACKGROUND

An undertaking was included in the Basin Plan to conduct research and investigations into aspects of the Basin Plan in the Northern Basin, including the basis for the long-term average sustainable diversion limits (SDL) for surface and groundwater SDL resource units. The Northern Basin Review comprises three components:

1) Environmental science;
2) water recovery modelling; and
3) social and economic assessments.

The aim of the environmental science component was to implement a series of research projects and review other information to ensure the best available scientific knowledge can be used to review the environmental water requirements for the Condamine-Balonne and Barwon-Darling River systems.

In finalising the Basin Plan, the Murray Darling Basin Authority decided to carry out further research and investigations on the settings in the Northern Basin to see if there is a case for changing them. This is because the information base used for the settings in the Northern Basin wasn't as well developed as that used for the Southern Basin. This particularly applies to our understanding of the environmental needs of the Barwon Darling and Condamine-Balonne River systems, and the challenges of providing additional environmental water in these unregulated systems. The Northern Basin Review, which is supported by Basin water ministers, is expected to be finalised by mid-2016.

This project carried out a knowledge review of the relationships between flow and waterbird ecology to inform the review of environmental watering requirements in the Condamine-Balonne and Barwon-Darling River systems.

The objectives of the project were:

1) Develop conceptual models of the causal relationships between flow and waterbird ecology for the Condamine-Balonne and Barwon-Darling River systems that test the two key MDBA assumptions that informed the assessment of the Environmentally Sustainable Level of Take.
2) Identify locally and regionally important waterbird breeding locations within the Condamine-Balonne and Barwon-Darling River systems.
3) Synthesize current knowledge of the relationships between flow and waterbird ecology relevant to locally and regionally important waterbird locations within Condamine-Balonne and Barwon-Darling River systems.

The project was structured into three parts:

- A literature review and preparation of a discussion paper.
- Expert panel workshop to discuss assumptions and discussion paper.
- Final report incorporating literature review and expert opinions.

In July 2015 the Murray Darling Basin Authority (MDBA) commissioned a review of the relationships between flow and waterbird ecology in the Condamine-Balonne and Barwon-Darling River Systems (Figure 1). This review paper tested two key MDBA assumptions that were used to determine environmental water requirements, which subsequently informed an assessment of the Environmentally Sustainable Level of Take. These two assumptions were:

Assumption 1: That environmental water requirements for colonial waterbird breeding (which have longer duration breeding water requirements) satisfy the breeding requirements of other waterbirds.

Assumption 2: That environmental water requirements for native riparian, floodplain and wetland vegetation have beneficial effects on life-cycle and habitat requirements for waterbirds.

The review process was undertaken is three stages:

1) Draft discussion paper (21st August 2015) with an initial review of data and literature distributed and discussed at an expert opinion workshop.
2) Expert opinion workshop held on the 28th August 2015 at UNSW brought together practitioners, managers and scientists to discuss the assumptions and the management of environmental flows for waterbirds (Appendix A).
3) A final report (this document) that collated the findings and recommendations of the expert workshop and the original data presented in the discussion paper.

The synthesis of current knowledge was based upon the structural (waterbird abundance and species richness) and functional themes (provision of breeding opportunities, diversity of habitats, protection of drought refuges) with consideration of waterbird functional groups (e.g. large waders, colonial nesters, migratory shorebirds, ducks and piscivores), and their life-cycle and habitat requirements (e.g. feeding, roosting and breeding).

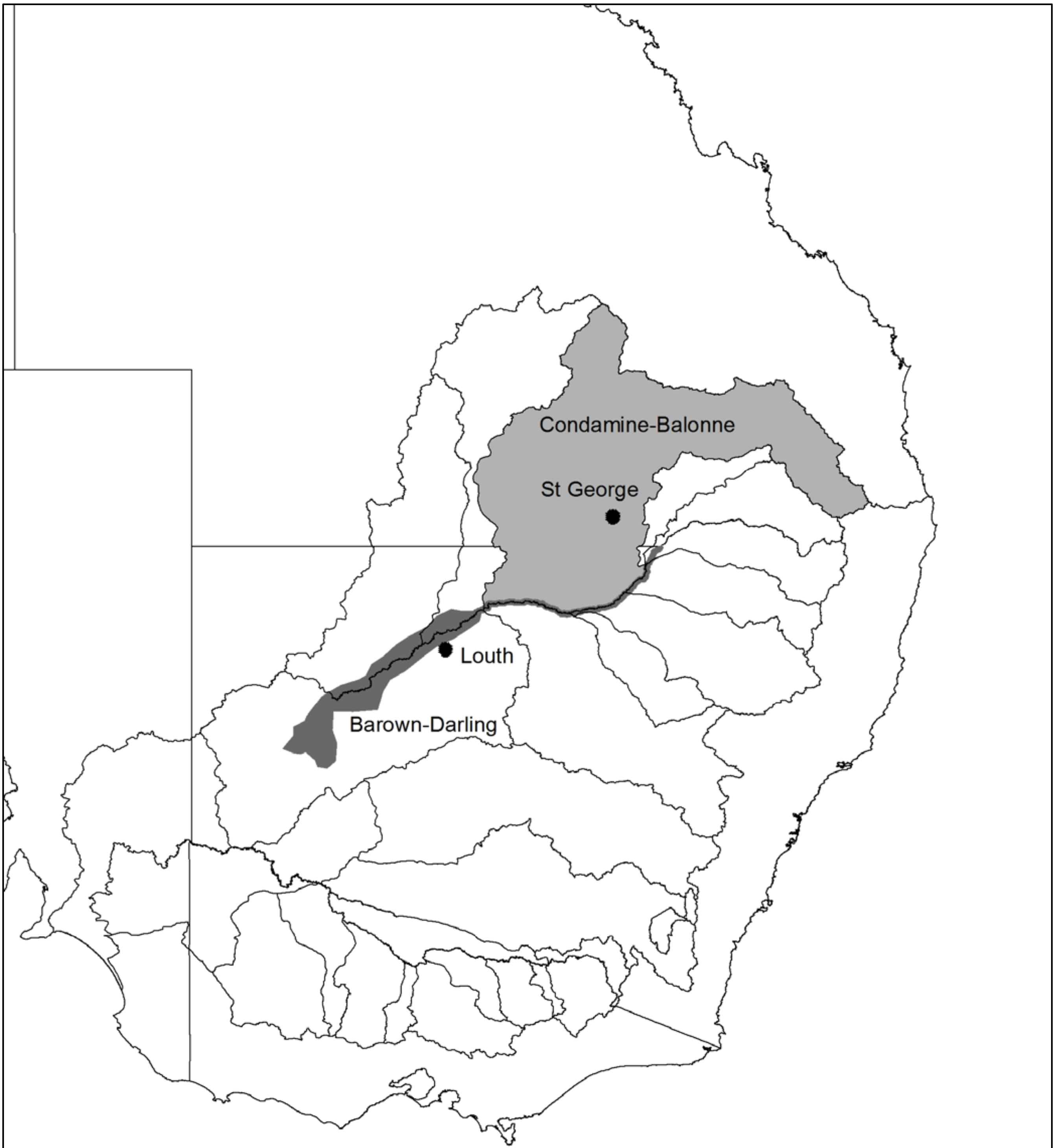


Figure 1 Condamine-Balonne and Barwon-Darling River Systems defined for this review. Note: The Condamine-Balonne boundary is the catchment boundary whereas the Barwon-Darling boundary has been defined for the purposes of this review.

REVIEW OF EXISTING LITERATURE AND DATASETS

Waterbirds in Australia

Colonially breeding waterbirds rely upon wetlands for critical stages in their life history. They commonly breed in large aggregations, feeding or nesting in wetlands, often stimulated by high river flows which produce extensive flooding (Kingsford and Johnson 1998; Leslie 2001; Brandis *et al.* 2011). This group of waterbirds have been a prominent casualty of the impacts of water resource development, habitat loss, and climatic extremes (drought) with reductions in breeding numbers, frequency and reproductive success (Kingsford and Thomas 1995; Kingsford *et al.* 2004; Kingsford and Thomas 2004; Nebel *et al.* 2008). Water resource developments have considerably reduced temporal variability, frequency and volume of river flows, significantly impacting on freshwater waterbirds (Maheshwari *et al.* 1995; Dudgeon *et al.* 2006; Nilsson *et al.* 2005, Lemly *et al.* 2000).

There are seventeen species of colonial waterbirds in Australia that are relevant for environmental flow management (Table 1) (Brandis and Kingsford in prep). These are species that typically rely upon flood events in wetland systems to provide suitable breeding habitat. Some species have the ability to breed in small groups or pairs (e.g. Little pied cormorant, White faced heron, Yellow-billed spoonbill), and some species may breed seasonally in locations where the availability of suitable habitat is more reliable, for example coastal areas and the tropics. However, most species are reliant upon the provision of suitable breeding habitat either from natural flood events or the delivery of water to wetlands via environmental flows.

In addition to colonially breeding species there are a range of other species of non-colonially breeding waterbirds that also respond to flooding and environmental flows including Black swan (*Cygnus atratus*), members of the Anatidae (ducks), Podicicpedidae (grebes), and Ardeidae (bitterns) families and shorebirds (Order: Charadriiformes).

Straw-necked ibis (*Threskiornis spinicollis)* are a species of colonially breeding waterbird commonly used as a target for environmental flow management because they have such specific flow and habitat condition requirements that need to be met before breeding is initiated. Straw-necked ibis are nomadic and do not typically breed seasonally but in response to suitable flooding conditions. Flood volume, duration, timing and availability of nesting habitat are all important factors in determining successful breeding by straw-necked ibis (Brandis *et al.* 2011; Merritt *et al.* 2016).

Table 1 Breeding information for seventeen species of colonial waterbirds in Australia that are relevant for environmental flow management (Brandis and Kingsford in prep.). Total time (days) required for completion of chick raising is the sum of incubation, fledging age and adult feeding post fledgling.

Species		Nesting habitat	Breeding stimulus	Wetland characteristics	Incubation (days)	Fledging age (days)	Adult feeding post fledging (days)	Total time (days)
Australian pelican[a]	Pelecanus conspicillatus	On ground usually on sparsely vegetated low secluded sandy islands and shores	Flooding, seasonal	Waterbodies with large areas of open water, free of dense aquatic vegetation; sandy islands	32-35	~84	105[d]	221-224
Great cormorant[ac]	Phalacrocorax carbo	Trees or woody shrubs close to or flooded by surface water	Flooding, seasonal	Large areas of deep open water	27-31	~49	~28	104-108
Pied cormorant[a]	P. varius	Trees or woody shrubs close to or flooded by surface water	Flooding, seasonal	Large areas of deep open water	25-33	47-60	80	152-173
Little black cormorant[a]	P. sulcirostris	Trees or woody shrubs close to or flooded by surface water	Flooding, seasonal	Vegetated swamps and lakes; flooded trees	No data	No data	No data	
Little pied cormorant[a*]	P. melanoleucos	Trees or woody shrubs close to or flooded by surface water	Flooding, seasonal	Vegetated wetlands and sheltered waters; open water	~20	~28	No data	>48
Pacific heron[a]	Ardea pacifica	Trees or shrubs close to or flooded by surface water	Flooding, opportunistic	Shallow sparsely vegetated swamps wetlands with fringing or flooded trees	28-30	42-49	No data	70-79
Great egret[a]	A. alba	Flooded trees or other tall vegetation	Flooding, seasonal	Wet grasslands; still freshwater with emergent vegetation	No data	~42	~21	>63
Intermediate egret[a]	Mesophoyx (Ardea) intermedia	Trees close to or flooded by surface water	Flooding, seasonal	Still, shallow water, dense aquatic and emergent	24-27	37-53	21	82-101

				vegetation. Deep water with matted surface vegetation.				
Little egret[ab]	A. garzetta	Trees close to or flooded by surface water	Flooding, seasonal	Shallow open areas of freshwater swamps with emergent vegetation	20-25	32-46	No data	52-71
White-faced heron[a*]	A. novaehollandiae	Trees or woody shrubs close to or flooded by surface water	Flooding, seasonal	Shallow wetlands with open water areas, emergent vegetation, abundant aquatic vegetation	24-26	43	18	85-87
Cattle egret[a]	Bubulcus ibis	Dense woodland in or beside swamps, rivers or pools	Flooding, seasonal	Grasslands, wooded lands, terrestrial wetlands; moist, low-lying, poorly drained pasture	23-26	~42	14	79-82
Rufous night heron[ab]	Nycticorax caledonicus	Dense cover of trees or shrubs, near or inundated by surface water	Flooding, seasonal	Still or slow-moving shallow water, with exposed shores, banks and flats in wetlands, swampy vegetation	21-22	40-49	No data	61-71
Glossy ibis[a]	Plegadis falcinellus	Inundated trees, lignum or reeds	Flooding, seasonal	Floodplain waterbodies, shallow swamps with abundant aquatic flora	21	~25	~21	67
Australian white ibis[a]	Threskiornis. molucca	Trees or shrubs close to or flooded by surface water	Flooding, seasonal	Shallow swamps with abundant aquatic flora and open fresh water, tall emergent vegetation	20-23	30 - 48	~21	71-92
Straw-necked ibis[a]	T. spinicollis	Inundated trees, lignum or reeds	Flooding	Shallow swamps with abundant aquatic and tall emergent vegetation	~21	~28	14	~63
Royal spoonbill[a]	Platalea regia	Trees, lignum or reeds at inundated wetlands	Flooding, seasonal	Large areas of water, freshwater wetlands with tall emergent vegetation	20-25	~28	No data	48-53
Yellow-billed spoonbill[a*]	P. flavipes	Trees, lignum or reeds at inundated wetlands	Flooding	Shallow swamps with abundant aquatic flora	26-31	~35	~21	82-87

[*]Can breed in single pairs; [a]Marchant and Higgins 1990; [b]Fasola 2010; [c]Grieco 1999; [d]Vestjens 1977

Waterbird data

A review of available waterbird breeding and abundance/presence data was undertaken searching a range of databases including the Colonial Waterbird Breeding Database (CWBD), Australian Waterbird Survey (AWS) (http://aws.ecosystem.unsw.edu.au), and the Atlas of Living Australia (ALA) (www.ala.org.au). The Colonial Waterbird Breeding Database is held by UNSW and is a collation of recorded colonial waterbird breeding events across Australia. It consists of >1000 records from 1899 – 2014 (Brandis 2010). The Australian Waterbird Survey database is a publicly available database of data collected from aerial surveys of wetlands in eastern Australia 1983-2014 (https://aws.ecosystem.unsw.edu.au/). The Atlas of Living Australia is part of the Australian Governments National Research Infrastructure for Australia project; it is a database of 55.6 million records from a range of different independent sources focusing on Australia's biodiversity. The Atlas of Living Australia does not contain records of breeding, only presence data. Records of breeding were sourced from the Colonial Waterbird Breeding Database and the Australian Waterbird Survey.

Searches of these databases found records for 102 waterbird species (including waders, ducks, grebes, shorebirds, piscivores) in the Condamine-Balonne and 74 species in the Barwon-Darling River Systems (Atlas of Living Australia, 2015). Fifty-four waterbird species, including 17 colonially nesting species, of waterbird have been recorded breeding in the Condamine-Balonne River system at 18 wetlands (Table 2; Figure 2). Seven species, including two colonial species recorded breeding in the Barwon-Darling River system at 7 wetland sites (Table 2; Figure 2).

Waterbird breeding in the Condamine-Balonne and Barwon-Darling River system

Table 2 provides information regarding the years in which breeding occurred and the number of nests/broods observed in the Condamine-Balonne and Barwon-Darling River systems (1971-2014). Data was sourced from the Australian Waterbird Survey database (https://aws.ecosystem.unsw.edu.au/ and the Colonial Waterbird Breeding Database). Narran Lakes Nature Reserve had the highest number of recorded breeding events (n=22 of which 18 were confirmed as successful), however the Nature Reserve also has the longest record of surveys (1971-2014) (Appendix B). Other key sites included Narran Lake (n=8), Darling River 1 (n=6), Dry Lake (n=5) and Darling River 3 (n=4) all other wetlands had ≤3 breeding events (1983 -2014). Narran Lakes Nature Reserve supported the greatest species diversity of both colonial and non-colonial waterbirds. Narran Lake supported a high diversity of colonial waterbirds while the Darling River 1 wetland supported a high diversity of non-colonial waterbirds. Darling River wetlands 1 -3 are palustrine (floodplain) wetlands with no definitive mapped boundary, they are areas subject to inundation when the Darling River receives overbank flows inundating the floodplain. Darling River 1 is a floodplain wetland on the northern side of the Darling River near the town of Louth. Darling River 2 and 3 are floodplain wetlands on the confluence of the Warrego and Darling River systems.

This information can be used to inform the environmental water requirement assessments in identifying key wetland sites for waterbird breeding, the frequency of breeding, the species diversity and abundance at these key wetlands. Many of the wetlands identified here are ephemeral, only providing habitat when flooding or flow conditions are suitable e.g. Talyawalka Creek, Dry Lake, and Pelican Lake. Wetlands with the greatest frequency of breeding, species diversity and size of breeding events (Table 2), such as Narran Lakes should be prioritized for flow delivery as it is these sites that will have the greatest impact on waterbird populations and species viability in addition to beneficial impacts on other wetland biota and vegetation.

Table 2 A list of important wetlands for waterbird breeding, and breeding records in the Condamine-Balonne (CB) and Barwon-Darling (BD) River systems. See Figure 2 for location of wetlands identified using (a-x). Breeding records for Narran Lakes Nature Reserve have been restricted to colonially nesting species for this table, see Appendix B for full set of breeding records.

River System	Wetland Name	Wetland Type	Year of breeding	Common Name	Scientific Name	Count of birds	Count nests/broods
CB	Armidillo Station Tank (a)	Human-made	2010	Black swan	Cygnus atratus	3	1
CB	Balonne River (b)	Riverine	1983	Eurasian coot	Fulica atra	36	18
CB	Bungil Creek Lagoon (c)	Palustrine	1984	Wood (Maned) duck	Chenonetta jubata	52	1
CB	Charleys Creek Dam (d)	Human-made	1983	Wood (Maned) duck	Chenonetta jubata	2	6
CB	Charleys Creek Dam (d)	Human-made	1997	Black swan	Cygnus atratus	1	1
BD	Darling River 1 (e)	Riverine	1983	Grey teal	Anas gracilis	3505	157
BD	Darling River 1 (e)	Riverine	1983	Wood (Maned) duck	Chenonetta jubata	10438	157
BD	Darling River 1 (e)	Riverine	1984	Black swan	Cygnus atratus	194	97
BD	Darling River 1 (e)	Riverine	1984	Grey teal	Anas gracilis	40921	486
BD	Darling River 1 (e)	Riverine	1984	Pacific black duck	Anas superciliosa	777	97
BD	Darling River 1 (e)	Riverine	1984	Yellow-billed spoonbill[#]	Platalea flavipes	2430	194
BD	Darling River 1 (e)	Riverine	1987	Wood (Maned) duck	Chenonetta jubata	1180	20
BD	Darling River 1 (e)	Riverine	1988	Pink-eared duck	Malacorhynchus membranaceus	62	3
BD	Darling River 1 (e)	Riverine	1990	Wood (Maned) duck	Chenonetta jubata	1236	31
BD	Darling River 1 (e)	Riverine	1998	Grey teal	Anas gracilis	360	80
BD	Darling River 1 (e)	Riverine	1998	Pacific black duck	Anas superciliosa	220	40
BD	Darling River 1 (e)	Riverine	1998	Pink-eared duck	Malacorhynchus membranaceus	280	40
BD	Darling River 1 (e)	Riverine	1998	Wood (Maned) duck	Chenonetta jubata	320	60
BD	Darling River 2 (f)	Riverine	1987	Pied cormorant	Phalacrocorax varius	7	5

River System	Wetland Name	Wetland Type	Year of breeding	Common Name	Scientific Name	Count of birds	Count nests/broods
BD	Darling River 3 (g)	Riverine	1984	Grey teal	Anas gracilis	646	2
BD	Darling River 3 (g)	Riverine	1984	Pacific black duck	Anas superciliosa	147	8
BD	Darling River 3 (g)	Riverine	1984	Yellow-billed spoonbill[#]	Platalea flavipes	14	2
BD	Darling River 3 (g)	Riverine	1991	Yellow-billed spoonbill[#]	Platalea flavipes	63	1
BD	Darling River 3 (g)	Riverine	1995	Black swan	Cygnus atratus	22	2
BD	Darling River 3 (g)	Riverine	2000	Yellow-billed spoonbill[#]	Platalea flavipes	120	10
BD	Dry Corner Swamp (x)	Palustrine	1983	Grey teal	Anas gracilis	120	2
CB	Dry Lake (h)	Lacustrine	1983	White-necked heron[#]	Ardea pacifica	4	*
CB	Dry Lake (h)	Lacustrine	1984	White-necked heron[#]	Ardea pacifica	8	*
CB	Dry Lake (h)	Lacustrine	1988	White-necked heron[#]	Ardea pacifica		1
CB	Dry Lake (h)	Lacustrine	1990	Great cormorant[#]	Phalacrocorax carbo		2
CB	Dry Lake (h)	Lacustrine	2008	Great cormorant[#]	Phalacrocorax carbo	312	312
CB	Kanowna West Swamp (i)	Palustrine	1983	Grey teal	Anas gracilis	18	6
CB	Narran Lake (j)	Lacustrine	1978	Australian pelican[#]	Pelecanus conspicillatus	13245	6623
CB	Narran Lake (j)	Lacustrine	1978	Glossy ibis[#]	Plegadis falcinellus	100	50
CB	Narran Lake (j)	Lacustrine	1978	Great cormorant[#]	Phalacrocorax carbo	56	28
CB	Narran Lake (j)	Lacustrine	1978	White-necked heron[#]	Ardea pacifica	23	12
CB	Narran Lake (j)	Lacustrine	1978	Straw-necked Ibis[#]	Threskiornis spinicollis	520	260
CB	Narran Lake (j)	Lacustrine	1979	Glossy ibis[#]	Plegadis falcinellus	1323	662
CB	Narran Lake (j)	Lacustrine	1983	Straw-necked Ibis[#]	Threskiornis spinicollis	400000	200000
CB	Narran Lake (j)	Lacustrine	1996	Australian pelican[#]	Pelecanus conspicillatus	1000	500
CB	Narran Lake (j)	Lacustrine	1996	Royal spoonbill[#]	Platalea regia		
CB	Narran Lake (j)	Lacustrine	1996	Straw-necked Ibis[#]	Threskiornis spinicollis		500
CB	Narran Lake (j)	Lacustrine	1998	Royal spoonbill[#]	Platalea regia	450	225

River System	Wetland Name	Wetland Type	Year of breeding	Common Name	Scientific Name	Count of birds	Count nests/broods
CB	Narran Lake (j)	Lacustrine	1999	Australian pelican#	Pelecanus conspicillatus	2300	1150
CB	Narran Lake (j)	Lacustrine	1999	Pied cormorant#	Phalacrocorax varius	350	175
CB	Narran Lake (j)	Lacustrine	2010	Straw-necked Ibis#	Threskiornis spinicollis		6029
CB	Narran Lake (j)	Lacustrine	2012	Australian white ibis#	Threskiornis molucca		236
CB	Narran Lake (j)	Lacustrine	2012	Cormorants#	Phalacrocorax spp.		10045
CB	Narran Lake (j)	Lacustrine	2012	Royal spoonbill#	Platalea regia		1635
CB	Narran Lake (j)	Lacustrine	2012	Straw-necked Ibis#	Threskiornis spinicollis		21410
CB	Narran Lakes Nature Reserve (k)	Palustrine	1971	Australian pelican#	Pelecanus conspicillatus	200	100
CB	Narran Lakes Nature Reserve (k)	Palustrine	1971	Glossy ibis#	Plegadis falcinellus	400	200
CB	Narran Lakes Nature Reserve (k)	Palustrine	1971	Great cormorant#	Phalacrocorax carbo	400	200
CB	Narran Lakes Nature Reserve (k)	Palustrine	1971	Intermediate egret#	Ardea intermedia	600	300
CB	Narran Lakes Nature Reserve (k)	Palustrine	1971	Pied cormorant#	Phalacrocorax varius	400	200
CB	Narran Lakes Nature Reserve (k)	Palustrine	1971	Royal spoonbill#	Platalea regia		
CB	Narran Lakes Nature Reserve (k)	Palustrine	1971	Straw-necked Ibis#	Threskiornis spinicollis	20000	10000
CB	Narran Lakes Nature Reserve (k)	Palustrine	1972	Straw-necked Ibis#	Threskiornis spinicollis		
CB	Narran Lakes Nature Reserve (k)	Palustrine	1974	Glossy ibis#	Plegadis falcinellus		
CB	Narran Lakes Nature Reserve (k)	Palustrine	1974	Straw-necked Ibis#	Threskiornis spinicollis		
CB	Narran Lakes Nature Reserve (k)	Palustrine	1976	Glossy ibis#	Plegadis falcinellus		
CB	Narran Lakes Nature Reserve (k)	Palustrine	1976	Straw-necked Ibis#	Threskiornis spinicollis		

River System	Wetland Name	Wetland Type	Year of breeding	Common Name	Scientific Name	Count of birds	Count nests/broods
CB	Narran Lakes Nature Reserve (k)	Palustrine	1978	Glossy ibis[#]	Plegadis falcinellus	100	50
CB	Narran Lakes Nature Reserve (k)	Palustrine	1981	Australian pelican[#]	Pelecanus conspicillatus	30	15
CB	Narran Lakes Nature Reserve (k)	Palustrine	1981	Glossy ibis[#]	Plegadis falcinellus	10	5
CB	Narran Lakes Nature Reserve (k)	Palustrine	1981	Great cormorant[#]	Phalacrocorax carbo	20	10
CB	Narran Lakes Nature Reserve (k)	Palustrine	1981	White-necked heron[#]	Ardea pacifica	150	75
CB	Narran Lakes Nature Reserve (k)	Palustrine	1981	Pied cormorant[#]	Phalacrocorax varius	50	25
CB	Narran Lakes Nature Reserve (k)	Palustrine	1981	Royal spoonbill[#]	Platalea regia	100	50
CB	Narran Lakes Nature Reserve (k)	Palustrine	1981	Straw-necked Ibis[#]	Threskiornis spinicollis	100	50
CB	Narran Lakes Nature Reserve (k)	Palustrine	1984	Australian pelican[#]	Pelecanus conspicillatus		
CB	Narran Lakes Nature Reserve (k)	Palustrine	1984	Glossy ibis[#]	Plegadis falcinellus		
CB	Narran Lakes Nature Reserve (k)	Palustrine	1984	Great cormorant[#]	Phalacrocorax carbo		
CB	Narran Lakes Nature Reserve (k)	Palustrine	1984	Pied cormorant[#]	Phalacrocorax varius		
CB	Narran Lakes Nature Reserve (k)	Palustrine	1984	Royal spoonbill[#]	Platalea regia		
CB	Narran Lakes Nature Reserve (k)	Palustrine	1984	Straw-necked Ibis[#]	Threskiornis spinicollis		
CB	Narran Lakes Nature Reserve (k)	Palustrine	1988	Australian pelican[#]	Pelecanus conspicillatus	600	300
CB	Narran Lakes Nature Reserve (k)	Palustrine	1988	Royal spoonbill[#]	Platalea regia	600	300

River System	Wetland Name	Wetland Type	Year of breeding	Common Name	Scientific Name	Count of birds	Count nests/broods
CB	Narran Lakes Nature Reserve (k)	Palustrine	1988	Straw-necked Ibis[#]	Threskiornis spinicollis	>3000	
CB	Narran Lakes Nature Reserve (k)	Palustrine	1989	Glossy ibis[#]	Plegadis falcinellus	720	360
CB	Narran Lakes Nature Reserve (k)	Palustrine	1989	Intermediate egret[#]	Ardea intermedia	20	10
CB	Narran Lakes Nature Reserve (k)	Palustrine	1989	Straw-necked Ibis[#]	Threskiornis spinicollis	18000	9000
CB	Narran Lakes Nature Reserve (k)	Palustrine	1990	Australian pelican[#]	Pelecanus conspicillatus	200	100
CB	Narran Lakes Nature Reserve (k)	Palustrine	1990	Great cormorant[#]	Phalacrocorax carbo	100	50
CB	Narran Lakes Nature Reserve (k)	Palustrine	1990	Intermediate egret[#]	Ardea intermedia	10	5
CB	Narran Lakes Nature Reserve (k)	Palustrine	1990	Royal spoonbill[#]	Platalea regia	400	200
CB	Narran Lakes Nature Reserve (k)	Palustrine	1990	Straw-necked Ibis[#]	Threskiornis spinicollis	100000	50000
CB	Narran Lakes Nature Reserve (k)	Palustrine	1991	Australian pelican[#]	Pelecanus conspicillatus	5000	2500
CB	Narran Lakes Nature Reserve (k)	Palustrine	1991	Straw-necked Ibis[#]	Threskiornis spinicollis	500	250
CB	Narran Lakes Nature Reserve (k)	Palustrine	1996	Great cormorant[#]	Phalacrocorax carbo	800	400
CB	Narran Lakes Nature Reserve (k)	Palustrine	1996	Pied cormorant[#]	Phalacrocorax varius	150	75
CB	Narran Lakes Nature Reserve (k)	Palustrine	1996	Royal spoonbill[#]	Platalea regia	300	150
CB	Narran Lakes Nature Reserve (k)	Palustrine	1996	Straw-necked Ibis[#]	Threskiornis spinicollis		102000
CB	Narran Lakes Nature Reserve (k)	Palustrine	1997	Great cormorant[#]	Phalacrocorax carbo	100	50

River System	Wetland Name	Wetland Type	Year of breeding	Common Name	Scientific Name	Count of birds	Count nests/broods
CB	Narran Lakes Nature Reserve (k)	Palustrine	1997	Pied cormorant[#]	Phalacrocorax varius	80	40
CB	Narran Lakes Nature Reserve (k)	Palustrine	1997	Royal spoonbill[#]	Platalea regia	100	50
CB	Narran Lakes Nature Reserve (k)	Palustrine	1997	Straw-necked Ibis[#]	Threskiornis spinicollis	2500	1250
CB	Narran Lakes Nature Reserve (k)	Palustrine	1998	Great cormorant[#]	Phalacrocorax carbo	100	50
CB	Narran Lakes Nature Reserve (k)	Palustrine	1998	Pied cormorant[#]	Phalacrocorax varius	80	40
CB	Narran Lakes Nature Reserve (k)	Palustrine	1998	Royal spoonbill[#]	Platalea regia	3000	1500
CB	Narran Lakes Nature Reserve (k)	Palustrine	1998	Royal spoonbill[#]	Platalea regia	40	20
CB	Narran Lakes Nature Reserve (k)	Palustrine	1998	Straw-necked Ibis[#]	Threskiornis spinicollis	100000	50000
CB	Narran Lakes Nature Reserve (k)	Palustrine	1999	Australian pelican[#]	Pelecanus conspicillatus	3020	1510
CB	Narran Lakes Nature Reserve (k)	Palustrine	1999	Great cormorant[#]	Phalacrocorax carbo	100	50
CB	Narran Lakes Nature Reserve (k)	Palustrine	1999	Pied cormorant[#]	Phalacrocorax varius	150	75
CB	Narran Lakes Nature Reserve (k)	Palustrine	2001	Royal spoonbill[#]	Platalea regia	383	191
CB	Narran Lakes Nature Reserve (k)	Palustrine	2001	Straw-necked Ibis[#]	Threskiornis spinicollis		
CB	Narran Lakes Nature Reserve (k)	Palustrine	2008	Australian white ibis[#]	Threskiornis molucca		
CB	Narran Lakes Nature Reserve (k)	Palustrine	2008	Glossy ibis[#]	Plegadis falcinellus		
CB	Narran Lakes Nature Reserve (k)	Palustrine	2008	Royal spoonbill[#]	Platalea regia		

River System	Wetland Name	Wetland Type	Year of breeding	Common Name	Scientific Name	Count of birds	Count nests/broods
CB	Narran Lakes Nature Reserve (k)	Palustrine	2008	Straw-necked Ibis[#]	Threskiornis spinicollis	140000	74000
CB	Narran Lakes Nature Reserve (k)	Palustrine	2010	Australian white ibis[#]	Threskiornis molucca		
CB	Narran Lakes Nature Reserve (k)	Palustrine	2010	Cormorants[#]	Phalacrocorax spp.		3000
CB	Narran Lakes Nature Reserve (k)	Palustrine	2010	Egrets[#]	Ardea spp.		
CB	Narran Lakes Nature Reserve (k)	Palustrine	2010	Royal spoonbill[#]	Platalea regia		
CB	Narran Lakes Nature Reserve (k)	Palustrine	2010	Straw-necked Ibis[#]	Threskiornis spinicollis		10681
CB	Narran Lakes Nature Reserve (k)	Palustrine	2010	Straw-necked Ibis[#]	Threskiornis spinicollis		13303
CB	Narran Lakes Nature Reserve (k)	Palustrine	2010	Straw-necked Ibis[#]	Threskiornis spinicollis		6651
CB	Narran Lakes Nature Reserve (k)	Palustrine	2010	Yellow-billed spoonbill[#]	Platalea flavipes		
CB	Narran Lakes Nature Reserve (k)	Palustrine	2011	Australian white ibis[#]	Threskiornis molucca		308
CB	Narran Lakes Nature Reserve (k)	Palustrine	2011	Egrets[#]	Ardea spp.		227
CB	Narran Lakes Nature Reserve (k)	Palustrine	2011	Royal spoonbill[#]	Platalea regia		1
CB	Narran Lakes Nature Reserve (k)	Palustrine	2011	Straw-necked Ibis[#]	Threskiornis spinicollis		14367
CB	Narran Lakes Nature Reserve (k)	Palustrine	2012	Australian white ibis[#]	Threskiornis molucca		631
CB	Narran Lakes Nature Reserve (k)	Palustrine	2012	Cormorants[#]	Phalacrocorax spp.		1174
CB	Narran Lakes Nature Reserve (k)	Palustrine	2012	Egrets[#]	Ardea spp.		2905

River System	Wetland Name	Wetland Type	Year of breeding	Common Name	Scientific Name	Count of birds	Count nests/broods
CB	Narran Lakes Nature Reserve (k)	Palustrine	2012	Straw-necked Ibis[#]	Threskiornis spinicollis		131442
BD	Pelican Lake (w)	Lacustrine	1984	Black swan	Cygnus atratus	14	2
BD	Pelican Lake (w)	Lacustrine	1984	Wood (Maned) duck	Chenonetta jubata	539	4
CB	Ready Creek Dam (l)	Human-made	1994	Wood (Maned) duck	Chenonetta jubata	6	1
CB	Roma Golf course Lagoon East (m)	Human-made	1988	Black swan	Cygnus atratus	3	1
CB	Ross Creek Dam (n)	Human-made	1989	Black swan	Cygnus atratus	2	1
CB	Ross Creek Dam (n)	Human-made	1990	Black swan	Cygnus atratus	2	1
CB	Ross Creek Dam (n)	Human-made	2000	Brolga	Grus rubicunda	108	1
BD	Talywalka Creek (v)	Riverine	1983	Black swan	Cygnus atratus	42	2
BD	Talywalka Creek (v)	Riverine	1983	Grey teal	Anas gracilis	1263	263
BD	Talywalka Creek (v)	Riverine	1983	Pink-eared duck	Malacorhynchus membranaceus	222	41
BD	Talywalka Creek (v)	Riverine	1984	Grey teal	Anas gracilis	113	2
BD	Talywalka Creek (v)	Riverine	1989	Grey teal	Anas gracilis	140	4
CB	Unnamed Wetland 1 (o)	Riverine	1988	Royal spoonbill[#]	Platalea regia	3	1
CB	Unnamed Wetland 2 (p)	Riverine	1988	Grey teal	Anas gracilis	42	1
CB	Unnamed Wetland 3 (q)	Riverine	2003	Black swan	Cygnus atratus	6	1
CB	Warrambah Creek Claypan (r)	Palustrine	1990	Black swan	Cygnus atratus	60	10
CB	Warrambah Creek Lagoon (s)	Palustrine	1998	Black swan	Cygnus atratus	3	2
CB	Warrambah Creek Lagoon (s)	Palustrine	1998	Grey teal	Anas gracilis	10	1
CB	Warrambah East Claypan No.C (t)	Palustrine	1998	Pacific black duck	Anas superciliosa	1	1

River System	Wetland Name	Wetland Type	Year of breeding	Common Name	Scientific Name	Count of birds	Count nests/broods
BD	Waterloo Lake (y)	Lacustrine	1984	Wood (Maned) duck	Chenonetta jubata	2	1
CB	Yuleba Creek Waterholes (u)	Riverine	1988	Grey teal	Anas gracilis	2	2
CB	Yuleba Creek Waterholes (u)	Riverine	1998	Black swan	Cygnus atratus	1	1

*These wetlands are unnamed floodplain wetlands; [#]Colonial nesting species

[a]Cowardin *et al.* 1979 wetland classification system

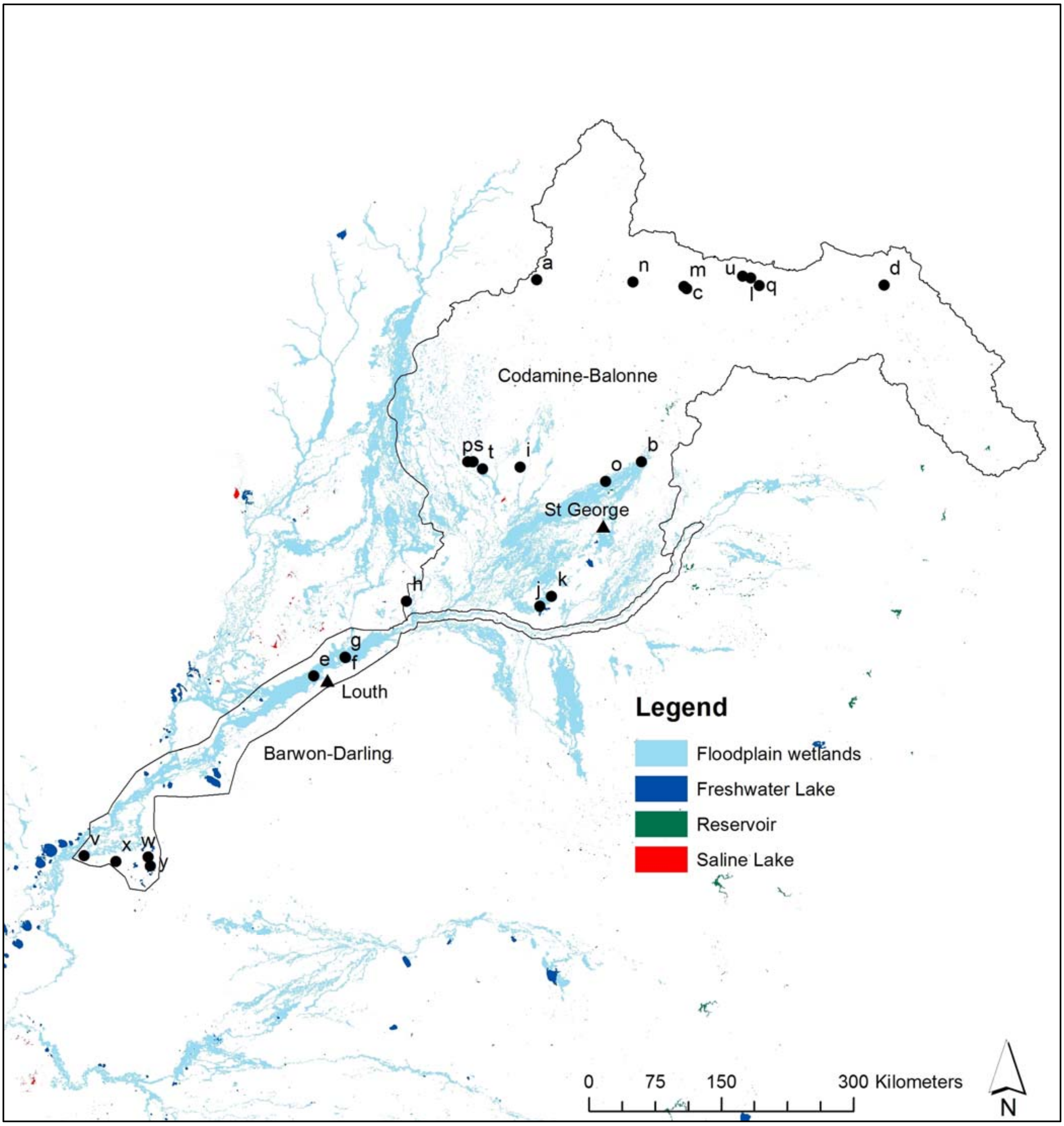


Figure 2. Location of wetlands with breeding records in the Condamine-Balonne and Barwon-Darling River systems. See Table 2 for wetland names. Wetlands mapping from Kingsford *et al.* 1999.

The distribution and species diversity of waterbirds in the Condamine-Balonne and Barwon-Darling River systems

A total of 102 waterbird species have been recorded in the Condamine-Balonne and Barwon-Darling River systems (Atlas of Living Australia) (Table 3). The most commonly recorded species included the Australian wood (maned) duck (*Chenonetta jubata)* and Pacific black duck (*Anas superciliosa)* with >4000 records.

For further analyses, waterbirds were divided into broad functional groups, corresponding to different food preferences (Barker and Vestjens 1989) and where the birds usually forage (Kingsford and Porter 1994) (Table 3). The six groups included duck species (all duck species, except herbivorous species, including small grebes), herbivorous waterbirds (e.g swans), waders (e.g bitterns), large wading birds (e.g. ibis, spoonbills), piscivorous birds (e.g., cormorants, Australian pelican), and shorebirds (plovers, sandpipers) (Kingsford *et al.* 2004). Figure 3 shows the distribution of waterbirds in the Condamine-Balonne and Barwon-Darling River systems classified by functional feeding group.

Shorebirds were the most diverse functional group of waterbirds with 31 species recorded, the next most diverse groups were Piscivores with 19 species, Ducks 15 species, Large waders 14 species, Herbivores 12 species, and Waders with eleven species.

Table 3 Functional feeding groups of waterbird species recorded in the Condamine-Balonne and Barwon-Darling River systems (Atlas of Living Australia 2015)

Functional group	Common name	Scientific name
Wader	Australasian Bittern	Botaurus poiciloptilus
	Australian Little Bittern	Ixobrychus dubius
	Black Bittern	Ixobrychus flavicollis
	Bush Stone-curlew	Burhinus (Burhinus) grallarius
	Cattle Egret	Ardea (Bubulcus) ibis
	Cocoi Heron	Ardea cocoi
	Comb-crested Jacana	Irediparra gallinacean
	Little Bittern	Ixobrychus minutus
	Little Egret	Egretta garzetta
	Pied Heron	Egretta picata
	Plains-wanderer	Pedionomus torquatus
Shorebird	Australian Painted Snipe	Rostratula australis
	Australian Pied Oystercatcher	Haematopus longirostris
	Australian Pratincole	Stiltia Isabella
	Banded Lapwing	Vanellus (Lobivanellus) tricolor
	Banded Stilt	Cladorhynchus leucocephalus

	Bar-tailed Godwit	Limosa lapponica
	Black-fronted Dotterel	Elseyornis melanops
	Black-tailed Godwit	Limosa limosa
	Black-winged Stilt	Himantopus himantopus
	Common Greenshank	Tringa (Glottis) nebularia
	Common Pratincole	Glareola pratincola
	Common Sandpiper	Actitis hypoleucos
	Curlew Sandpiper	Calidris (Erolia) ferruginea
	Double-banded Plover	Charadrius (Charadrius) bicinctus bicinctus
	Eastern Curlew	Numenius (Numenius) madagascariensis
	Grey Plover	Pluvialis squatarola
	Inland Dotterel	Charadrius (Eupoda) australis
	Latham's Snipe	Gallinago (Gallinago) hardwickii
	Little Curlew	Numenius (Mesoscolopax) minutus
	Marsh Sandpiper	Tringa (Rhyacophilus) stagnatilis
	Masked Lapwing	Vanellus (Lobipluvia) miles
	Oriental Pratincole	Glareola (Glareola) maldivarum
	Pacific Golden Plover	Pluvialis fulva
	Pectoral Sandpiper	Calidris (Erolia) melanotos
	Red-capped Plover	Charadrius (Charadrius) ruficapillus
	Red-kneed Dotterel	Erythrogonys cinctus
	Red-necked Avocet	Recurvirostra novaehollandiae
	Red-necked Stint	Calidris (Ereunetes) ruficollis
	Sharp-tailed Sandpiper	Calidris (Erolia) acuminata
	Terek Sandpiper	Xenus cinereus
	Wood Sandpiper	Tringa (Rhyacophilus) glareola
Piscivore	African Darter	Anhinga melanogaster
	Australasian Darter	Anhinga novaehollandiae
	Australian Pelican	Pelecanus conspicillatus
	Black-faced Cormorant	Phalacrocorax (Anacarbo) fuscescens
	Caspian Tern	Hydroprogne caspia
	Crested Tern	Thalasseus bergii
	Great Cormorant	Phalacrocorax (Phalacrocorax) carbo
	Gull-billed Tern	Gelochelidon nilotica
	Lesser Frigatebird	Fregata ariel
	Little Black Cormorant	Phalacrocorax (Phalacrocorax) sulcirostris
	Little Pied Cormorant	Microcarbo melanoleucos
	Pacific Gull	Larus (Larus) pacificus pacificus
	Pied Cormorant	Phalacrocorax (Phalacrocorax) varius
	Red-tailed Tropicbird	Phaethon rubricauda
	Silver Gull	Chroicocephalus novaehollandiae
	Sooty Tern	Onychoprion fuscata
	Whiskered Tern	Chlidonias (Pelodes) hybrida

	White-tailed Tropicbird	Phaethon lepturus
	White-winged Black Tern	Chlidonias (Chlidonias) leucopterus
Large Wader	Australian White Ibis	Threskiornis Molucca
	Black-necked Stork	Ephippiorhynchus (Ephippiorhynchus) asiaticus
	Eastern Great Egret	Ardea (Casmerodius) modesta
	Glossy Ibis	Plegadis falcinellus
	Great-billed Heron	Ardea (Typhon) sumatrana
	Intermediate Egret	Ardea (Mesophoyx) intermedia
	Nankeen Night-heron	Nycticorax caledonicus
	Nankeen Night Heron	Nycticorax caledonicus australasiae
	Royal Spoonbill	Platalea (Platalea) regia
	Straw-necked Ibis	Threskiornis spinicollis
	White-faced Heron	Egretta novaehollandiae
	White-necked Heron	Ardea (Ardea) pacifica
	Yellow-billed Egret	Mesophoyx intermedia
	Yellow-billed Spoonbill	Platalea (Platibis) flavipes
Herbivore	Australian Shelduck	Tadorna (Casarca) tadornoides
	Australian Wood Duck	Chenonetta jubata
	Black Swan	Cygnus (Chenopis) atratus
	Cape Barren Goose	Cereopsis novaehollandiae novaehollandiae
	Cotton Pygmy-goose	Nettapus (Cheniscus) coromandelianus
	Domestic Goose	Anser anser
	Garganey	Anas (Querquedula) querquedula
	Green Pygmy-goose	Nettapus (Cheniscus) pulchellus
	Magpie Goose	Anseranas semipalmata
	Northern Mallard	Anas (Anas) platyrhynchos
	Plumed Whistling-duck	Dendrocygna (Leptotarsis) eytoni
	Radjah Shelduck	Tadorna (Radjah) radjah
Duck	Australasian grebe	Tachybaptus novaehollandiae novaehollandiae
	Australasian Grebe	Tachybaptus novaehollandiae
	Australian Shoveler	Anas (Spatula) rhynchotis rhynchotis
	Blue-billed Duck	Oxyura australis
	Chestnut Teal	Anas (Nettion) castanea
	Freckled Duck	Stictonetta naevosa
	Great Crested Grebe	Podiceps cristatus
	Grey Teal	Anas (Nettion) gracilis
	Hardhead	Aythya (Nyroca) australis
	Hoary-headed Grebe	Poliocephalus poliocephalus
	Musk Duck	Biziura lobate
	Northern Shoveler	Anas (Spatula) clypeata
	Pacific Black Duck	Anas (Anas) superciliosa
	Pink-eared Duck	Malacorhynchus membranaceus
	Wandering Whistling-duck	Dendrocygna (Dendrocygna) arcuata

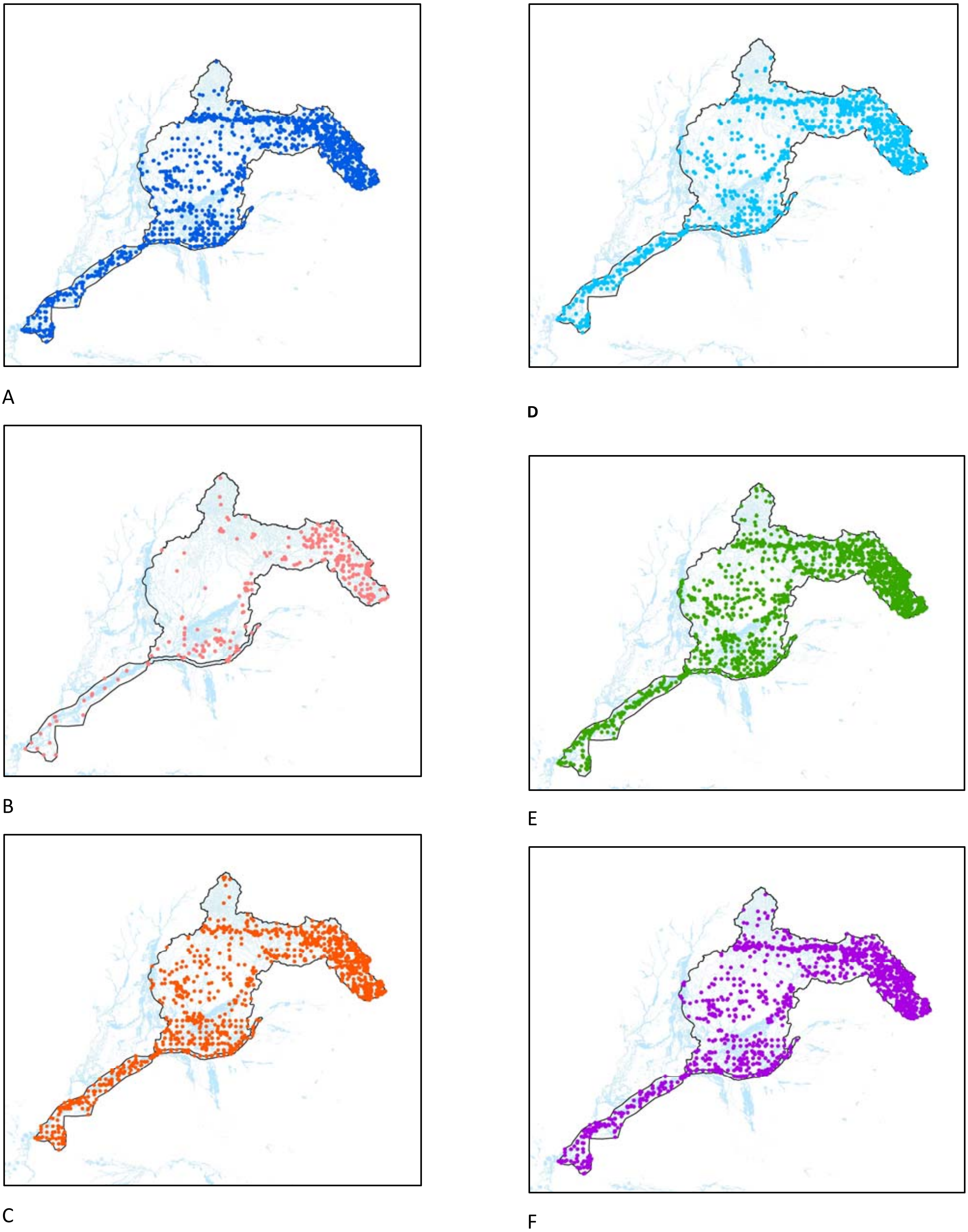


Figure 3 Records of sightings of waterbirds belonging to: A-Ducks, B-Waders, C-Shorebirds, D-Piscivores, E-Large waders, F-Herbivore functional groups in the Condamine-Balonne and Barwon-Darling River system. Data source: Atlas of Living Australia. Wetland data source: Kingsford *et al.* 1999.

The distribution of species in the Condamine-Balonne and Barwon-Darling River systems represents recorded observations sourced from the Atlas of Living Australia. Some of these data are from scientific surveys, such as the East Australian Waterbird Survey (EAWS), while others are ad hoc or targeted – for example bird watchers searching for particular species, specifically shorebirds or uncommon species. This can result in a bias in the data towards uncommon species, and a greater number of records closer to population centres. These data are presence only and do not record abundance.

Waterbird abundance data available for the Condamine-Balonne and Barwon-Darling River systems includes the EAWS and targeted breeding waterbird surveys (CWBD). However, there is likely a strong confounding effect of uneven sampling intensity, particularly driven by the existence of a survey band of EAWS along the Brigalow Belt South bioregion.

Using the Atlas of Living Australia records we analysed total species diversity and within functional group species diversity for each of the Biogeographic Regions in the Condamine-Balonne and Barwon-Darling River systems (Table 4).

Table 4 Species diversity within each waterbird functional group within each of the Biogeographic regions in the Condamine-Balonne (CB) and Barwon-Darling (BD).

River system	IBRA	Ducks	Herbivores	Large waders	Piscivores	Shorebirds	Waders	Total
CB	Brigalow Belt South	14	11	14	17	27	10	93
CB	Darling Riverine Plains	13	4	12	12	18	6	65
CB	Mulga Lands	13	4	12	12	16	3	60
CB	Nandewar	9	3	12	10	13	4	51
CB	New England Tablelands	4	1	5	4	2	0	16
CB	South Eastern Queensland	9	3	8	6	12	5	43
BD	Broken Hill Complex	9	3	5	10	8	0	35
BD	Cobar Peneplain	5	3	7	6	5	0	26
BD	Darling Riverine Plains	14	6	13	12	20	7	72
BD	Mulga Lands	11	3	10	11	16	1	52
BD	Murray Darling Depression	11	4	10	11	14	4	54

The Condamine-Balonne encompasses seven Biogeographic Regions (IBRA http://www.environment.gov.au/land/nrs/science/ibra), dominated by the Brigalow Belt South, Mulga Lands, and the Darling Riverine Plains (Figure 4). In the Barwon-Darling, the dominant bioregion is the Darling Riverine Plains (Figure 4).

Figure 4 Biogeographic Regions (IBRA) found in the Condamine-Balonne and Barwon-Darling. Wetlands mapping from Kingsford *et al.* 1999.

Summary of Atlas of Living Australia records indicate the highest species diversity within each of the functional groups was in the Brigalow Belt South bioregion (encompassing the Narran Lakes) followed by the Darling Riverine Plains (

Figure 5 and Figure 6). Within the Mulga Lands bioregion large numbers of ducks and large waders (and to some extent piscivores and shorebirds) were recorded.

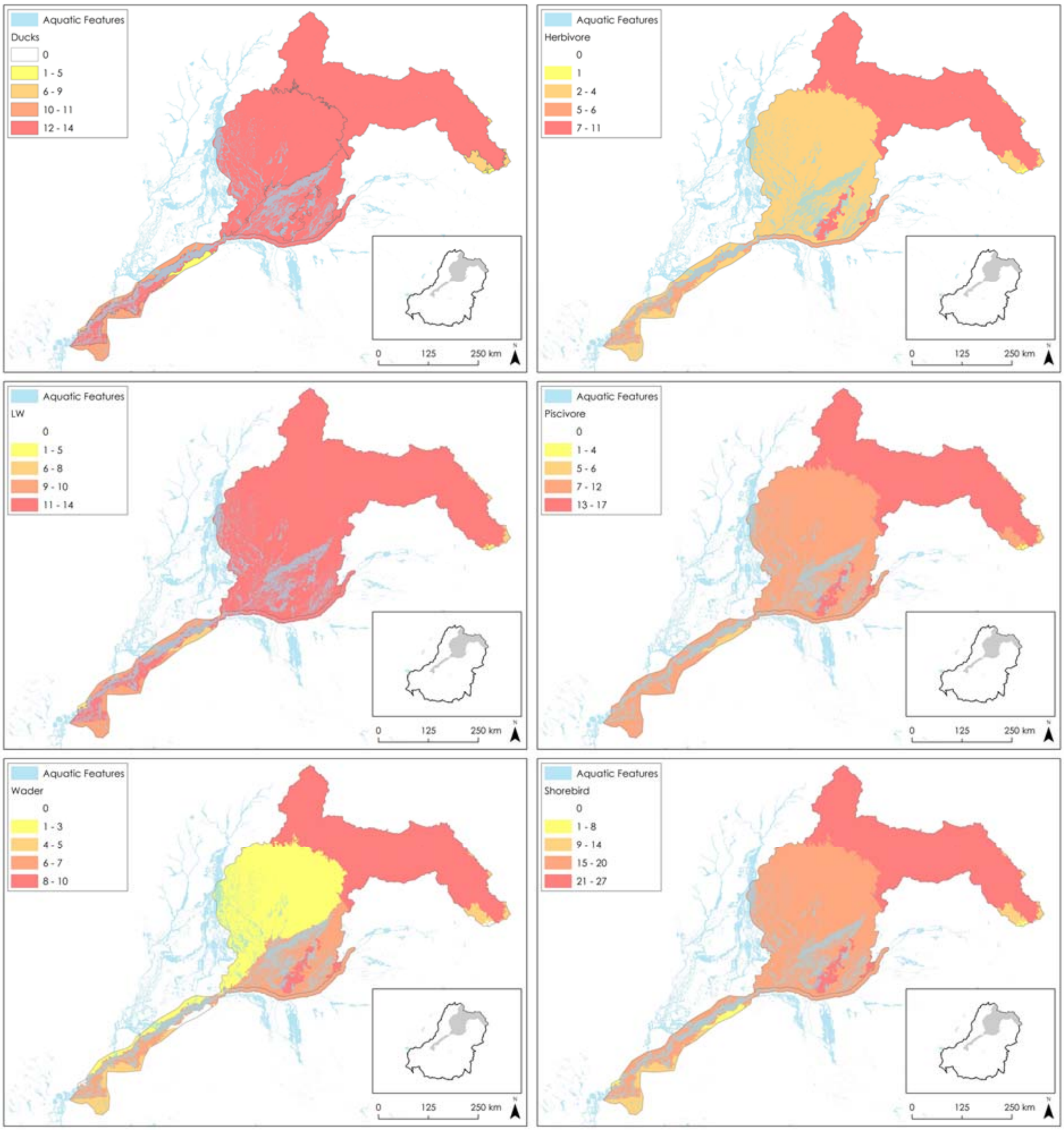


Figure 5 Species diversity within each waterbird functional group for each of the Biogeographic regions (see Table 4).

Figure 6 Waterbird species diversity within each of the Biogeographic regions (see Table 4).

Stratifying the Condamine-Balonne and Barwon-Darling to cells of 30km x 30km indicated large numbers of Atlas of Living Australia waterbird records in the north-east of the Condamine-Balonne, within the Narran Lakes, and along the Darling River (Figure 7). In the Barwon-Darling, considerable number of records were located along the Darling River in the Bourke area, Walgett (meeting of the Barwon and Namoi Rivers), and the Teryaweynya system.

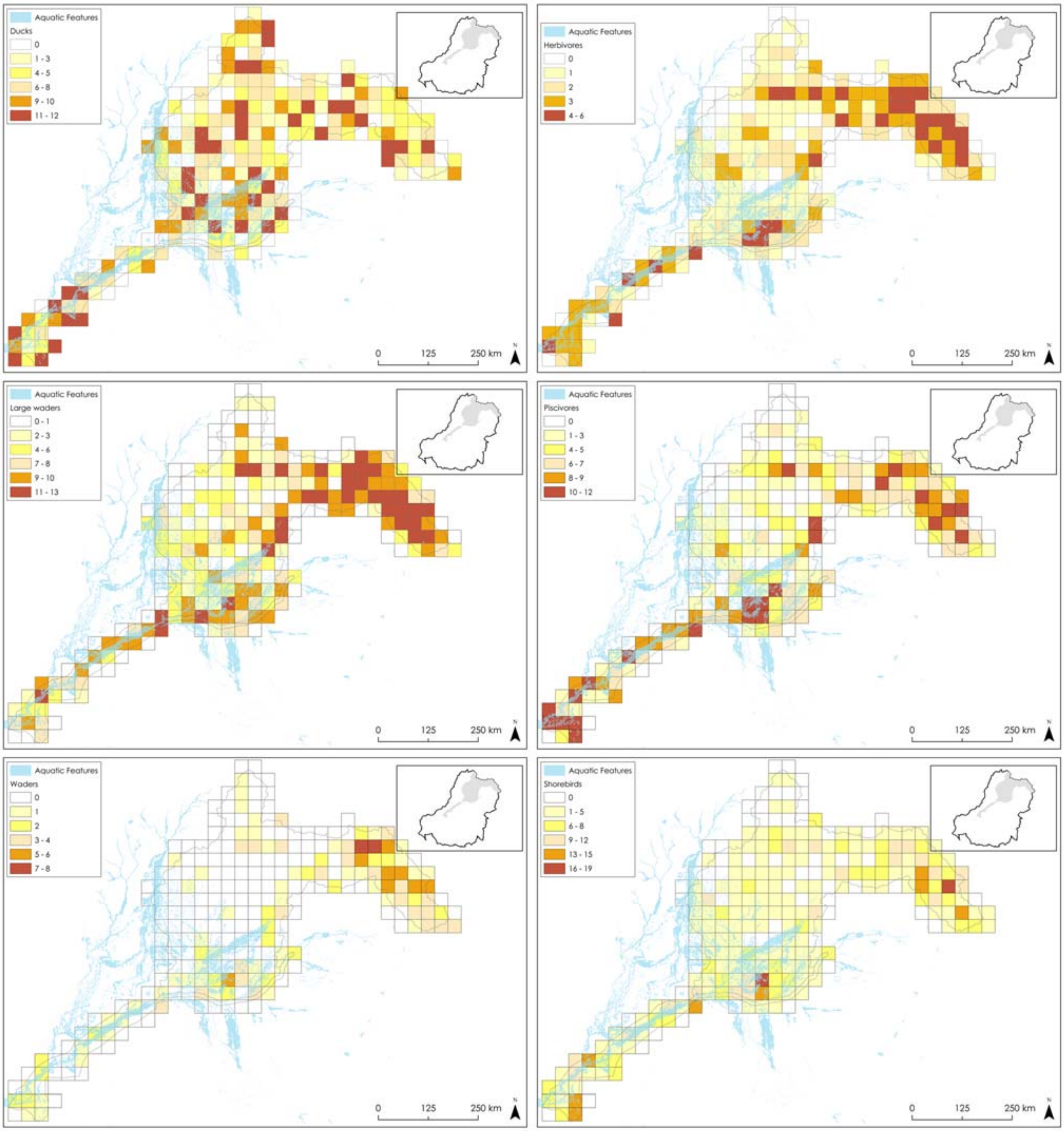


Figure 7 Species diversity within each waterbird functional group within each 30km X 30km cell across the Condamine-Balonne and Barwon-Darling River systems.

Figure 8 Species diversity within each 30km X 30km cell across the Condamine-Balonne and Barwon-Darling River systems.

These data (Figure 8) identify which wetlands of the Condamine-Balonne and Barwon-Darling River systems have the greatest waterbird species diversity. Key areas that support high (36-56) species diversity included the upper reaches of the Condamine and Balonne Rivers, the Narran Lakes area, the confluence of the Warrego and Darling Rivers, the confluence of the Paroo and Darling Rivers, and the Taylawalka Anabranch and Teryaweynya Creek system. The upper reaches of the Condamine and Balonne Rivers have large numbers of dams and storages, while the Narran Lakes, Warrego-Darling, Paroo-Darling confluences, and the Talyawalka Anabranch and Teryaweynya Creek system and predominantly floodplain wetland systems. These wetlands, while not necessarily providing breeding habitat are providing high value habitat which is reflected in the high species diversity. The provision of water to these wetland sites will be important to maintain the characteristics of these wetlands that make them high value habitats for waterbirds.

Talyawalka Anabranch and Teryaweynya Creek system

Kingsford et.al (1997) identified Poopelloe Lake, Talyawalka Creek and Pelican Lake within the Teryaweynya creek system as areas known or predicted to support 20,000 or more waterbirds (Figure 9 & Figure 10).

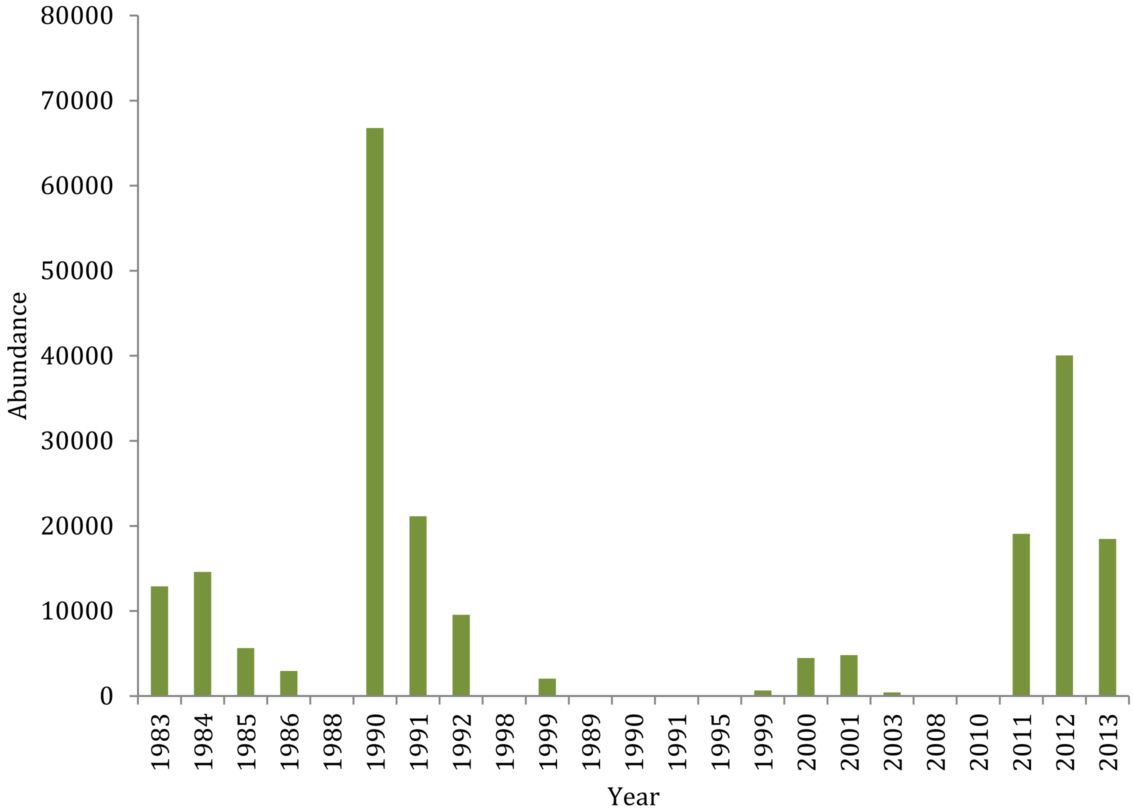


Figure 9 Total abundance of waterbirds recorded in the Talyawalka Ananbranch and Teryaweynya Creek system 1983 -2013 (source: Australian Waterbird Survey).

Eucalyptus Lake, Pelican Lake and Victoria Lake have all recorded >20,000 waterbirds in a single survey (Appendix D).

The assessment of environmental water requirements for the proposed Basin Plan: Barwon-Darling River upstream of Menindee Lakes (MDBA, 2012) identifies the following ecological targets for the Talyawalka Anabranch and Teryawynya Creek system:

“Kingsford et.al (1997) identified Poopelloe Lake, Talyawalka Creek and Pelican Lake within the Teryaweynya system as well as the Darling River floodplain near Louth are known or predicted to support 20,000 or more waterbirds. On this basis, a target has been identified that centres on flows to support moderate to large breeding events by colonial nesting waterbirds.”

The data analysed as part of this review found that the Talyawalka Anabranch and Teryawynya Creek system (including Pelican Lake) were not key colonial waterbird breeding sites, but did support breeding by non-colonial species, Black swans and ducks (Table 2). This review found that these wetlands (Figure 10) provided important habitat for waterbirds. Since 1983 records show (Figure 9) that these wetlands regularly support large numbers of waterbirds with high species diversity (Figure 8). Based on this data, and expert knowledge, it is recommended that the ecological target be modified to provide flows that ensure maintenance of these wetlands so that they continue to provide high quality habitat for large numbers of waterbirds.

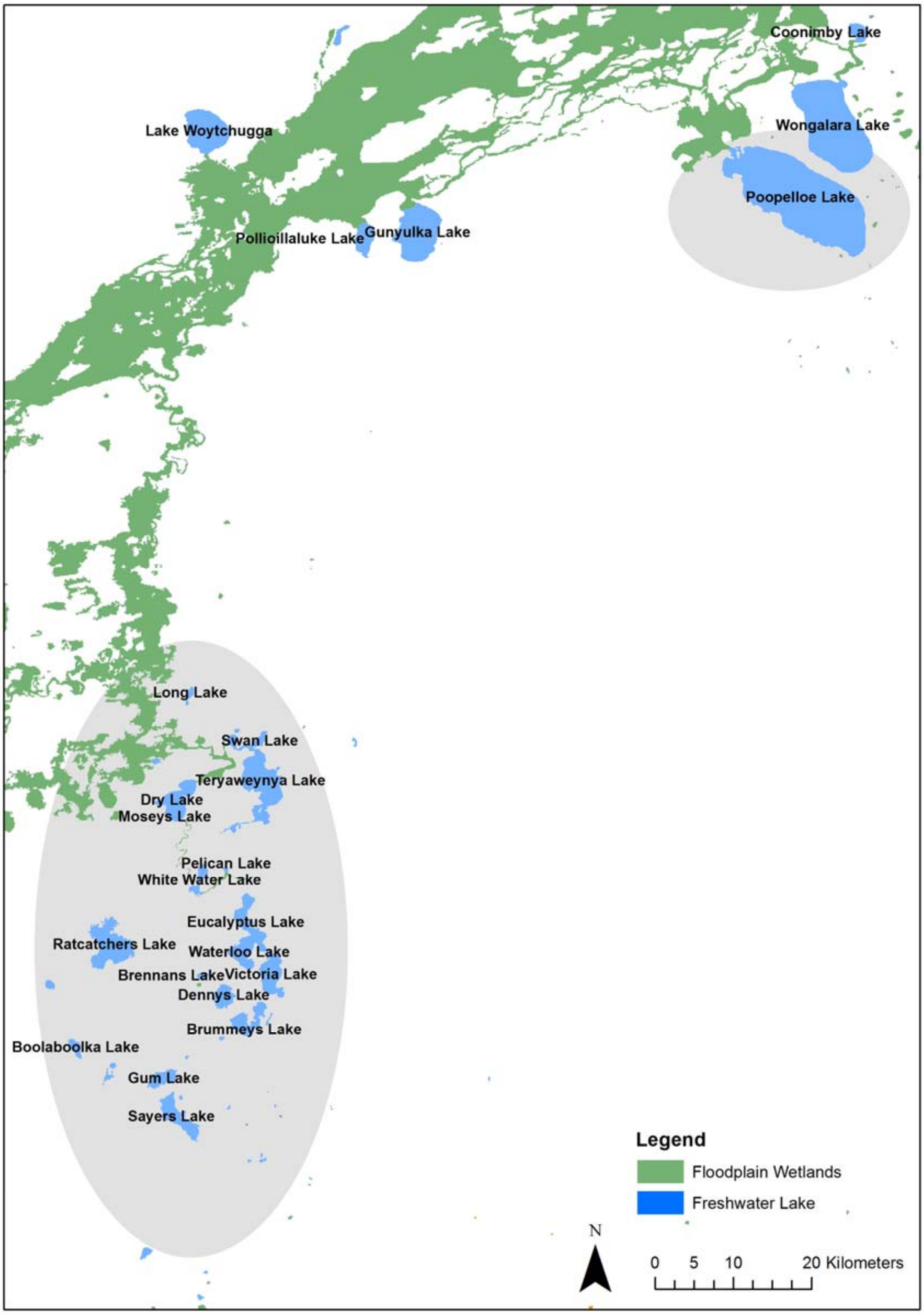


Figure 10 Talywalka Ananbranch and Teryaweynya Creek system including Pelican Lake and Poopelloe Lake. Wetlands mapping from Kingsford *et al.* 1999.

Flow and waterbird breeding responses in the Condamine-Balonne and Barwon-Darling River systems

To better understand the flow characteristics that are associated with colonial waterbird breeding events in the Condamine-Balonne and Barwon-Darling River systems we analysed the flow events that were associated with recorded breeding at wetland sites (Table 2 and Appendix E). Flow gauge data was not available for all wetland sites (Appendix E). For waterbird breeding records from the Australian Waterbird Survey which were carried out in annually in October, we calculated the total flow volume in October and total cumulative flows over the months of August, September, and October. For breeding records originating from other sources, we matched the survey month with total cumulative flows during that month and the previous two months (total of three months). We also provided historic perspectives to those particular flow volumes by deriving the percentile of the recorded flow volumes against long-term monthly flow volumes and against long-term monthly flow volumes of that particular month. For example, when a breeding record was recorded in October, we calculated what percentile the total flow volume during that month and year was with respect to the long-term record (Table 5 and Appendix E).

At wetland such as Narran Lakes Nature Reserve, Narran Lake, Darling River 1 and Dry Lake, the majority of flows that were associated with waterbird breeding were large flows in the 90th percentile of all flow events (Table 5). Conversely, at wetland Darling River 2, the majority of flows associated with waterbird breeding were smaller flows in the lower 50th percentile of all flows at that site. This data provides an indication of the relative size of flows for each wetland that are associated with waterbird breeding. However, more detailed hydrological analyses are required to determine flow volumes for each wetland known to support waterbird breeding.

Table 5 Summary of sizes of flow events associated with breeding at key wetland sites in the Condamine-Balonne and Barwon-Darling River systems (Figure 2). Percentile ranks were calculated for the total flows recorded during the month that breeding occurred with respect to the long-term total monthly flow volumes recorded in that gauge (see Appendix E).

Wetland	No. breeding records	Relative size and number of flows associated with breeding			
		>90th percentile	75th - 90th percentile	50th - 75th percentile	<50th percentile
Armidillo Station Tank	1		1		
Balonne River	1			1	
Bungil Creek Lagoon	1			1	
Charleys Creek Dam	2			2	
Darling River 1	6	4	1		1
Darling River 2 & 3	5	1			4
Dry Lake	5	3			2
Kanowna West Swamp	1		1		
Narran Lake	6	3	1	1	
Narran Lake Nature Reserve	22	12	8	2	
Reedy Creek Dam	1	no gauge data			
Roma Golf Course Lagoon	1			1	
Ross Creek Dam	2				2
Unnamed wetland 1	1		1		
Unnamed wetland 2	1		1		
Unnamed wetland 3	1			1	
Warrambah Creek Claypan	1			1	
Warrambah Creek Lagoon	1	1			
Warrambah East Claypan	1	1			
Yuleba Creek Waterholes	1			1	
Talywalka Creek	3	2		1	
Talyawalka Anabranch incl. Pelican Lake, Dry Corner Swamp, Waterloo Lake	1	1			

ASSUMPTION 1: THAT ENVIRONMENTAL WATER REQUIREMENTS FOR COLONIAL WATERBIRD BREEDING (WHICH HAVE LONGER DURATION BREEDING WATER REQUIREMENTS) SATISFY THE BREEDING REQUIREMENTS OF OTHER WATERBIRDS.

Conceptual models can provide a useful method of qualitatively and/or quantitatively illustrating links between ecological components, including triggers and responses (Gentile *et al.* 2001). Figure 11 is a conceptual model that illustrates waterbird responses to flow. It includes the hydrological characteristics; area of inundation, water depth, volume and duration, which are required for colonial waterbird breeding to be initiated once the required hydrological thresholds have been met. This conceptual model also incorporates the average breeding duration (egg laying to independence) for the six functional feeding groups of waterbirds (herbivores, shorebirds, ducks, piscivores, waders and large waders), it also incorporates the average breeding (egg laying to independence) duration required for species grouped by similar breeding requirements (ibis and spoonbills, cormorants and darter, egrets and herons, and the Masked lapwing with the longest breeding duration in this selection of species).

It should be noted that the response of waterbirds to flow is not necessarily cause and effect. Responses of waterbirds at a wetland will be influenced by other factors occurring at the region and landscape scale. Influences such as availability of habitat in the region or past opportunities for breeding will influence the response of birds. For example if suitable breeding habitat is available elsewhere in the region prior to the 'flow managed wetland' becoming suitable/available then birds may not respond as anticipated in the ways identified in this conceptual model.

Colonial waterbird breeding requirements

For colonial wading birds to reproduce successfully, flooding is required for a minimum of five to six months (140-168 days) (Leslie 2001; Briggs and Thornton 1998, Brandis *et al.* 2011, Figure 11). Breeding habitat suitability is determined by a number of factors including; flow volume, duration of inundation, seasonal timing of flows, nesting habitat availability, and sufficient food resources. Area of inundation and water depth at wetlands where colonial waterbirds breed is primarily determined by total flow volume (Kingsford and Thomas 1995; Ren *et al.* 2009). For many species of colonial wading birds (e.g. ibis, spoonbills, egrets, herons), nests need to be surrounded by water (Carrick 1962; Bancroft 2002). If flow volumes are not sufficiently large to provide long term nesting habitat, breeding may be initiated but reproductive success compromised (Leslie 2001; Frederick 2009). Reductions in flow can drop water levels, reducing the duration of flooding and triggering desertion by adult birds with high chick mortality, particularly in ibis (McCosker

1996; Scott 1997; Kingsford 1998; Brandis *et al.* 2011).

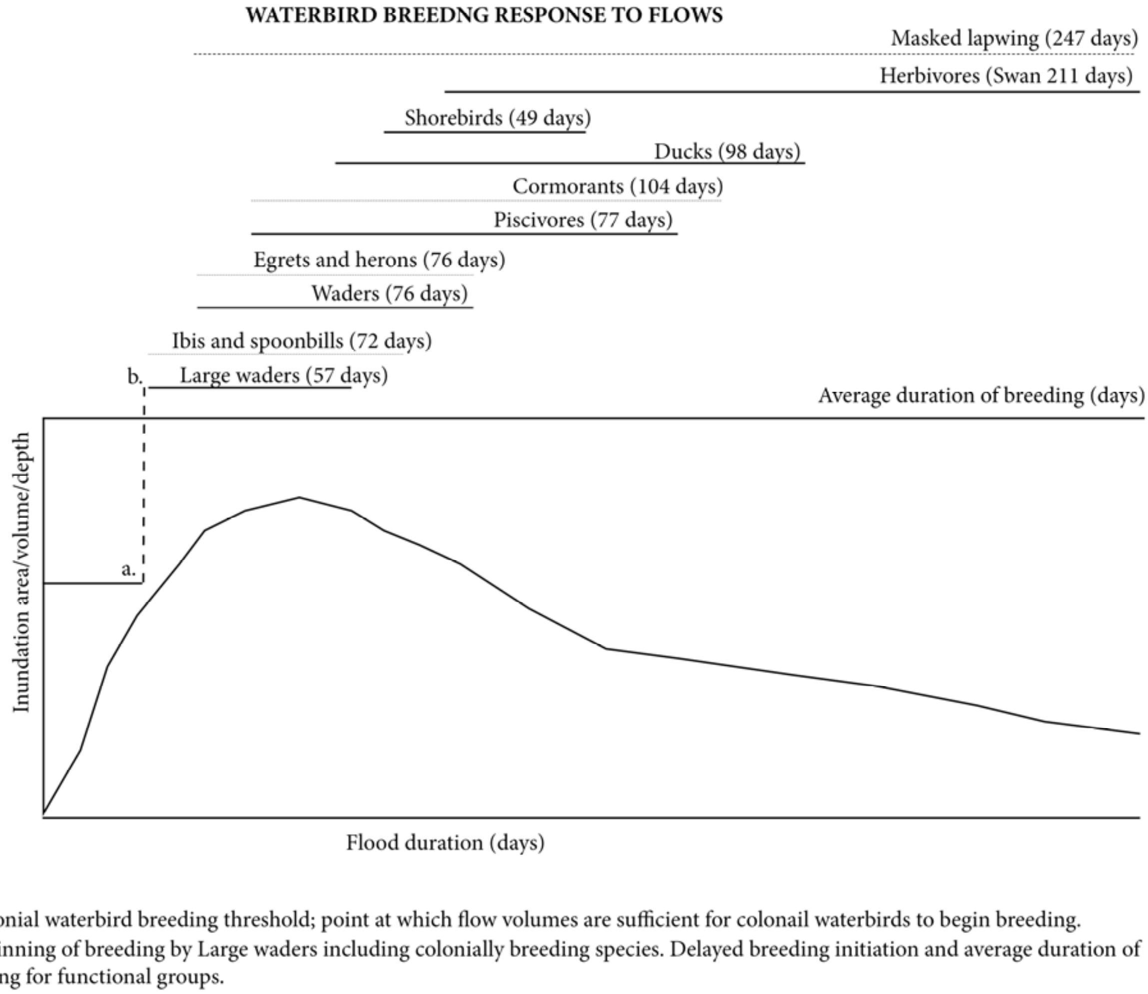


Figure 11. Conceptual model for waterbird breeding response to flows.

Duration of inundation is critical for breeding success and is closely tied to duration of breeding. There are well recognised stages of breeding that determine duration of breeding: build-up of body condition (Briggs *et al.* 1991), courtship, nesting and egg laying, incubation, chick provisioning, fledging and post fledging. Time periods spent at each stage vary among colonial waterbird species (Table 1). Once breeding is initiated, there needs to be sufficient ongoing resources to allow for successful completion of breeding. This translates into duration of breeding which extends over several months of suitable nesting and foraging habitat for successful raising of young for most colonially breeding waterbird species (Table 1).

Following body preparation, courtship and nesting, eggs are laid. Incubation periods differ between species ranging from the shortest incubation period of 20 days for the little egret to the longest period of 35 days for the Australian pelican (Marchant and Higgins 1990; Table 1). During the incubation period the eggs are constantly tended by one or both parents.

Following hatching, chicks progress through two phases until they are fully independent from their parents. The first phase extends from hatching to fledging. This period of time varies between species but is shortest for glossy ibis at just 25 days until fledging and longest at 84 days for the Australian pelican (Marchant and Higgins 1990; Table 1). For many species there is a second phase of chick reliance where chicks are still fed by parents post fledging. This period of time can be as short as 14 days for straw-necked ibis and cattle egrets or as long as 80 days for the pied cormorant (Marchant and Higgins 1990; Table 1).

Post fledging and independence from their parents' juvenile birds are able to leave the natal wetland. If wetland conditions such as water levels and/or food availability change to an extent where they are no longer suitable for waterbirds then adults and juveniles may disperse in small groups across the landscape.

Overall, from egg laying to fledging takes 3-6 months for the 17 species of colonially breeding waterbirds (Marchant and Higgins 1990, Table 1), the only exception being the Australian pelican which takes around 7-8 months.

The seasonal timing of flows can also impact on the establishment of colonies. Data from Narran Lakes shows that the majority of breeding events occur during October – March (73%) (Merritt *et al.* 2016) during warmer weather and longer day length.

The availability of nesting habitat is also critical for the establishment of colonies. Straw-necked ibis repeatedly use areas of lignum at Narran Lakes, while areas of inundated river cooba, and river red gums are used by cormorants, darters, egrets and nankeen night herons (Brandis *et al.* 2011, OEH, 2015).

The provision of food resources during a breeding event is poorly understood, Jenkins *et al.*, 2008 undertook a limited study that recorded prey items and availability for straw-necked ibis towards the end of the 2008 breeding event, and Brandis *et al.* (in prep) analysed straw-necked ibis diets and temporal shifts throughout a large breeding event in the Lowbidgee wetlands (2010-2011). Results of these studies found that ibis are predominantly terrestrial foraging birds, they feed on the floodplain and agricultural land surrounding the wetland. They consume a wide range of prey items and have the ability to switch prey items based on its relative abundance in the landscape (Brandis *et al.* in prep). It is acknowledged (expert advice) that a sufficient supply of food is required for the duration of the breeding event to support both adults and chicks.

Non-colonial waterbird breeding requirements

To determine whether the assumed duration of breeding and therefore water requirements for colonial waterbirds were also sufficient for non-colonial waterbirds breeding duration of incubation (time spent on eggs), chick rearing (hatching to fledging) and post fledging parental care stages were collated for a selection of species, for which data were available, that were recorded breeding in the Condamine-Balonne and Barwon-Darling River systems. Post-parental care data were not available for all species. Species included colonial and non-colonial waterbirds (Figure 12). These data do not include the time taken for species to prepare for breeding, including improving body condition, pairing and nest building, as this data is currently not available in the scientific literature.

Straw-necked ibis, which are often the target for environmental flows (Brandis *et al.* 2011), were the fourth fastest breeding species (63 days; 49 days laying to fledging plus 14 days post-fledging parental care) of the 27 species considered (Figure 12). Straw-necked ibis are often used as a target species due to their specific habitat requirements for breeding. Straw-necked ibis are opportunistic breeders, breeding in large colonies when conditions are suitable. Suitable conditions are usually comprised of a combination of hydrological factors (volume, duration, timing, water depth) and habitat conditions e.g. suitable nesting vegetation (Figure 11, Merritt *et al*. 2016). It is assumed that if conditions can be met for straw-necked ibis breeding then other species will also breed.

The majority of the 27 waterbird species considered, both colonial and non-colonial nesters, took greater than 63 days to complete breeding. Of the colonially breeding species the Glossy ibis had the shortest laying to fledging duration (46 days) but a longer post parental care period (21 days) than the straw-necked ibis. The Australian pelican had the longest duration of breeding with post fledging parental care finishing 224 days after egg laying (119 days laying to fledging). Of the non-colonially breeding species Whiskered tern had the shortest breeding period (45 days from egg laying to independence) (recorded breeding twice at Narran Lakes Nature Reserve), the Black swan had the longest period from laying to fledging (211 days)(5 recorded breeding events at NLNR) with no data available regarding post-fledging parental care while the Masked lapwing (4 recorded breeding events at NLNR) had the longest total breeding period 247days (laying to independence) (Figure 12).

Many species had similar incubation periods with a median of 25.5 days (range 20-41). While the chick rearing stage had a large range of time periods from 18 to 170 days (median 47 days). Post-fledging parental care was similarly variable (7-105 days; median 21 days) and data for many species were not available.

Table 1 and Figure 12 shows the current understanding of duration of breeding from egg laying and incubation to post fledging parental care for a selection of waterbirds in Australia. With regards to water management there are possibly two components to the breeding time requirements as shown in Table 1 and Figure 12. The first, being from egg laying and incubation through to fledging. The second is the continued parental feeding of the young. During the first component of breeding the provision of water and maintenance of water levels has been shown to be important for reproductive success (Brandis *et al.* 2011). However, there were no data available regarding the water requirements during component 2, the ongoing parental care of young post fledging. It is not known whether the ongoing care takes place at the colony site or elsewhere, or a combination of both. The availability of food resources during this period will be critical for the survival of young and the body condition required to move away from the colony site. Expert opinion was that the longer duration flood events will provide the greatest opportunity for waterbird species to successfully raise young to independence. It is assumed that if chicks can reach independence prior to dispersing from the colony site this will increase their chances of survival post dispersal.

These data show that breeding times are variable amongst colonial and non-colonially breeding waterbirds. Based on the breeding duration data five to six months (140-168 days) (Figure 12) of flooding (Leslie 2001; Briggs and Thornton 1998) would be sufficient for the majority of non-colonially breeding waterbirds (excluding Pied cormorant (173 days), Black swan (211 days) and Masked lapwing (247 days) to complete their breeding cycles and raise chicks to independence (Table 1).

However, the assumption states 'That environmental water requirements for colonial waterbird breeding (which have longer duration breeding water requirements) satisfy the breeding requirements of other waterbirds.' This Assumption is underpinned by the perception that colonial waterbirds have a longer duration breeding water requirement. This is not supported by the scientific literature nor was it supported during discussions at the expert workshop. Non colonial species such as the Masked lapwing and Black swan had the longest breeding duration of 247 and 211 days respectively (incubation to independence). The duck species represented in Figure 12 have a breeding duration range from 83 – 108 days (average = 98 days) including post-fledging parental care (post-fledging parental care data for 3 species) (Marchant and Higgins 1990). This is in comparison to the colonially breeding species; ibis and spoonbills 53-92 days laying to independence (average = 72 days), cormorants (including Australasian darter) 48-173 days laying to independence (average = 104 days) (no post-fledging care available for 2 species), and egrets and herons 71-101 days (average = 76 days) (no post-fledging data available for 3 species).

The general assumption that colonially breeding waterbirds have a longer duration breeding water requirement is not applicable to all species of colonial waterbirds. The variability within the group is quite large 48-173 days with a median of 83 days. The longest duration for a colonially breeding species represented here, for which post-fledging parental care data is available is the Australian pelican (224 days) while the shortest is straw-necked ibis (63 days).

Succession of breeding

From the initial inundation of a wetland there is a succession of species breeding that relates to both time required for preparation for breeding, and the availability of food resources (see Figure 28). Waterbirds require a period of time prior to laying eggs that includes body preparation, pairing, and nest building. This period of time varies between species with some, such as the straw-necked ibis, able to respond quickly to suitable flow/breeding conditions, whereas observational and anecdotal evidence suggests that this period of pre-breeding preparation is longer for waterfowl species.
Similarly the food web response varies over time, with invertebrates hatching and recolonizing areas following the initial inundation, providing food for fish and higher trophic level organisms (See Figure 28).

Interbreeding periods

The period of time between opportunities for breeding is critical in determining the number of reproductive opportunities a bird has in its lifetime and its contribution to the larger population. For example, straw-necked ibis have a life-span of 10-16 years (expert advice; comparison with other species of a similar body size), and sexual maturity is reached at 3-4 years (based on age at which adult plumage is achieved Marchant and Higgins 1999). Assuming that one chick per clutch reaches adulthood (Brandis *et al.*, 2011, McKilligan 2005), a pair of ibis require at least two breeding opportunities in their lives to replace themselves and maintain population size. However long term trends in populations of waterbirds in the Murray Darling Basin (Kingsford *et al*., 2013) have shown that waterbird populations are declining putting more importance on the provision of breeding opportunities to slow population declines.

The risk associated with long average intervals between breeding events include potentially significant declines in waterbirds populations and reduced opportunities for breeding during the life span of an individual. This will be critical if any waterbird species exhibit natal site fidelity. Whether any species do exhibit natal site is currently unknown but has been shown in other waterbird species (Hazllit and Butler, 2001; Atwood and Massey 1988; Gratto 1988). If natal site fidelity is exhibited by some species then the frequency of breeding opportunities is critical. Longer inter-breeding intervals will result in fewer opportunities for breeding and potential further declines in populations.

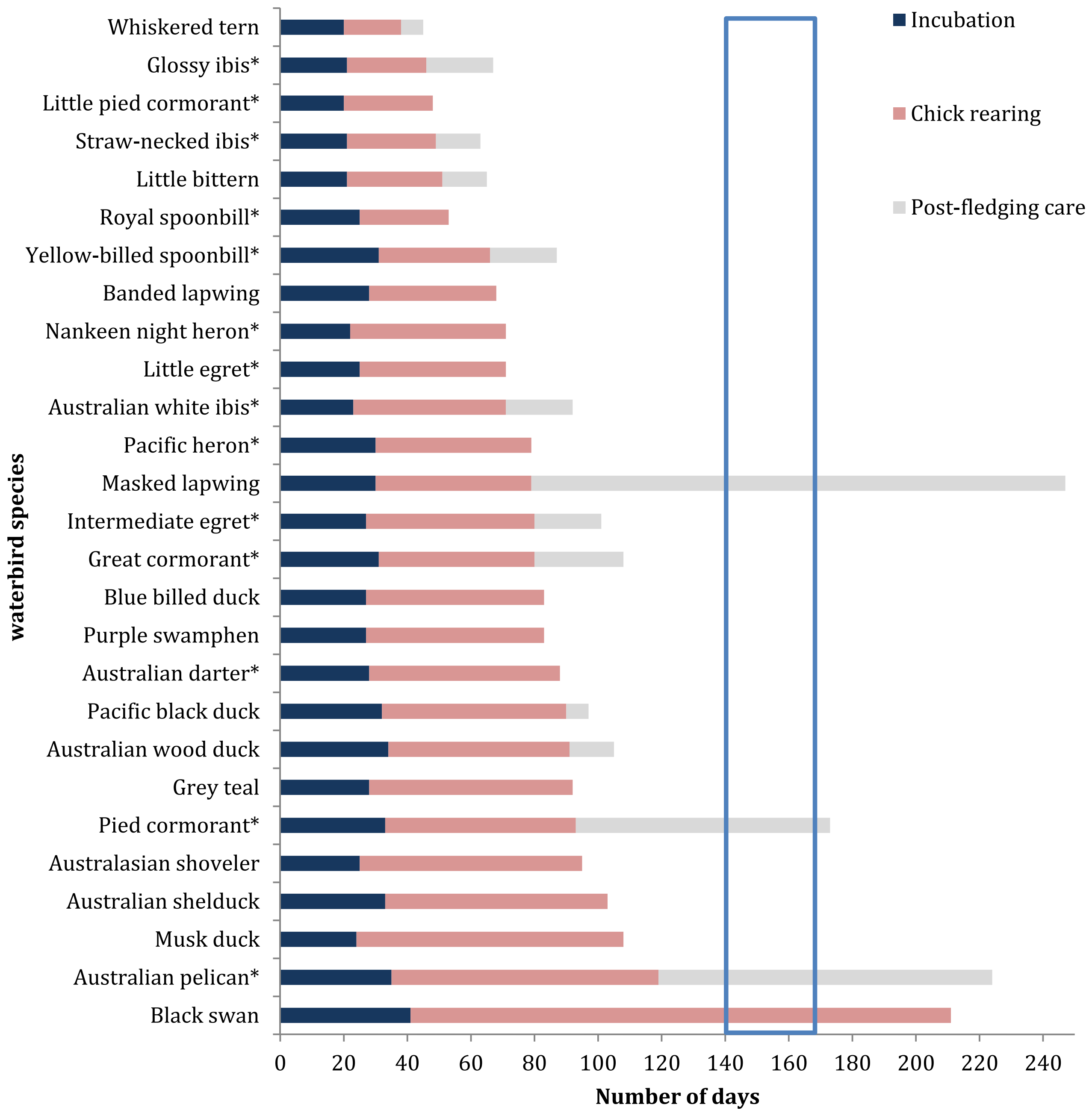


Figure 12 Breeding stage durations (days) for a subset of waterbird species that breed in the Condamine-Balonne and Barwon-Darling River systems. Species sorted by total duration of incubation and chick-rearing stages, post-fledging parental care data is not available for 13 species. *denotes colonially breeding species. Blue rectangle represents the recommended flow duration (140-168 days) required for successful colonial waterbird breeding (Leslie 2001; Briggs and Thornton 1998) (Data source; Table 1, and Marchant and Higgins 1990).

Waterbird responses to flow

As an example of the breeding responses of other waterbird bird species during colonial waterbird breeding events, species lists were collated from detailed ground surveys at Narran Lakes Nature Reserve and Narran Lake in 1988 (Maher, pers comm.), 1990 (Maher, pers comm.), 1996 (Ley, 1998a), 1997 (Ley, 1999b), 1998 (Henderson, 1999) and 2008 (Brandis, 2010) (Table 6). These data illustrate the responses of other groups of waterbirds to wetland conditions when suitable for colonial waterbird breeding. This type of analyses was possible only for the Narran Lakes in the Condamine-Balonne and Barwon-Darling River systems due to the availability of records, but also the high species diversity of both colonial and non-colonial waterbirds supported by this wetland when in flood.

A total of 54 species of waterbirds have been recorded breeding at Narran Lake and Narran Lakes Nature Reserves since 1971. Many of these species have been recorded multiple times including colonially breeding, waterfowl and shorebird species (Table 6). These data indicate that when wetland conditions are suitable for colonial waterbird breeding that there is a strong response from other waterbird species. Large numbers of non-colonial waterbird species take advantage of the wetland condition and many can also breed in response to the same conditions as colonial waterbirds.

Table 6. Waterbird species observed breeding during colonial waterbird breeding events at Narran Lakes Nature Reserve and Narran Lake. * denotes colonially breeding species.

Common Name	Scientific Name	1988	1990	1996	1997	1998	2008
Australasian black bittern	*Botaurus poiciloptilus*						y
Australasian darter*	Arhinga melanogaster	Y	Y	Y	Y	Y	y
Australasian grebe	*Tachybaptus novaehollandiae*					Y	
Australasian shoveller	*Anas rhynchotis*		Y			Y	
Australian pelican*	Pelicanus conspicillatus	Y	Y	Y		Y	y
Australian white ibis*	Threskiornis molucca	Y	Y	Y		Y	y
Australian wood duck	Chenonetta jubata	Y	Y	Y		Y	Y
Banded lapwing	*Vanellus tricolor*			Y	Y	Y	
Black cormorant*	*Phalacrocorax sulcirostris*						Y
Black fronted dotterel	Elseyornis (Charadrius) melanops	Y	Y	Y			Y
Black fronted plover	Elseyornis melanops		Y				
Black swan	Cygnus atratus	Y	Y	Y		Y	Y
Black-tailed native hen	*Tribonyx ventralis*	Y	Y				

Black-winged stilt	Himantopus himantopus			Y			Y
Blue-billed duck	Oxyura australis	Y					Y
Brolga	*Grus rubicunda*				Y		
Dusky moorhen	*Gallinula tenebrosa*	Y					
Eurasian coot	*Fulica atra*	Y	Y				
Freckled duck	Stictonetta naevosa	Y		Y			Y
Glossy ibis*	Plegadis falcinellus	Y		Y		Y	Y
Great cormorant*	*Phalacrocorax carbo*		Y	Y	Y	Y	
Great crested grebe	Podiceps cristatus			Y			Y
Great egret*	Ardea alba	Y	Y	Y			Y
Grey teal	Anas gracilis	Y	Y				Y
Gull billed tern	Sterna nilotica						Y
Hardhead	Aythya australis	Y	Y				Y
Hoary headed grebe	*Poliocephalus poliocephalus*			Y	Y		
Intermediate egret	Ardea intermedia		Y				Y
Little black cormorant*	Phalacrocorax sulcirostris	Y	Y	Y		Y	
Little egret*	Egretta (Ardea) garzetta						
Little pied cormorant*	Phalacrocorax melanoleucos	Y	Y			Y	Y
Marsh sandpiper	*Tringa stagnatilis*			Y			
Masked lapwing	Vanellus miles		Y	Y			
Musk duck	Biziuria lobata	Y					Y
Nankeen night heron*	Nycticorax caledonicus	Y	Y				Y
Pacific black duck	Anas superciliosa	Y	Y				Y
Pacific heron*	Ardea pacifica						Y
Pied cormorant*	*Phalacrocorax varius*			Y	Y	Y	Y
Pied stilt	Himantopus himantopus	Y					
Pink-eared duck	Malacorhynchus membranaceus	Y	Y	Y		Y	Y
Plumed whistling duck	Dendrocygna eytoni					Y	Y
Purple swamphen	*Porphyrio porphyrio*	Y					
Red capped plover	*Charadrius ruficapillus*			Y			
Red necked avocet	Recurvirostra novaehollandiae			Y		Y	
Red-Kneed dotterel	*Erythrogonys cinctus*	Y	Y	Y		Y	Y
Red-necked avocet	*Recurvirostra novaehollandiae*						Y
Royal spoonbill*	Platalea regia	Y	Y	Y	Y	Y	Y

Sharp-tailed sandpiper	*Calidris acuminata*			Y			
Silver gull	Larus novaehollandiae						Y
Spur winged lapwing	*Vanellus spinosus*						Y
Straw-necked Ibis*	Threskionis spinicollis	Y	Y	Y	Y	Y	Y
Whiskered tern	Childonias hybridus					Y	Y
Yellow-billed spoonbill*	Platalea flavipes		Y	Y	Y	Y	Y

Flow characteristics and waterbird responses at Narran Lakes

Developing quantitative response models for waterbirds was only possible for the Narran Lakes Nature Reserve given the existence of long-term breeding records (Brandis 2010). As part of a recent assessment into the hydrological and climatic triggers for straw-necked ibis breeding in the Narran Lakes (Merritt *et al. 2016*), several flow event definitions were tested as best matched historical breeding events of straw-necked ibis since 1971. Evaluation was carried out by examining the performance of classification and regression tree models using each flow event definition as a predictor of successful breeding events (n=18). The model with the best fit defined a flow event as starting an event when flow volumes were over 100ML/day at Wilby Wilby gauge on the Narran River and continued until water levels (mAHD) at Back Lake gauge were below 120.746mAHD. Based on this flow event definition, since 1970 there were 33 flow events with an average total flow event volume measured at Wilby Wilby gauge of 202.5 GL ± 217.0 SD and lasting on average 165.4 days±106.4SD. Based on this flow event definition, there were 15 flow events that resulted in successful breeding events, meaning three flow events encompassed 2 breeding events each (15/07/1983 and 15/03/1984, 15/03/1988 and 1/06/1988, 30/04/1990 and 15/08/1990). Classification and regression tree analysis identified a breeding threshold when total flow volumes in the first 90 days were greater than 154GL with a probability of straw-necked ibis breeding of P=1.00 (11 breeding events of 11 flow events), vs a breeding probability of P=0.18 (4/22) when total flow volumes in the first 90 days were less than 154GL (Figure 13). Historic breeding records that occurred during flow events exceeding the 154 GL, 90 days threshold had an average flow volume of 20.5GL±12.0GL (min:1.2GL – max:43.5GL) in the first 10 days. Concurrently, the CART analyses indicated a second breeding threshold (contingent that flows in first 90 days were less than 154GL) when flow volumes in the first 10 days since beginning of flow event was greater than 20GL, with a breeding probability of P=0.43 (3 breeding events of 7 flow events). If both thresholds were not reached, breeding probability was low (P=0.067) (1 breeding event of 15 flow events) (Figure 13). Importantly, the second, 10 day, threshold should be used while maintaining the natural hydrological associations with flow volumes at larger time spans (i.e., 90 days). Explicitly, historical breeding occurring during flow events that exceeded a flow volume of 20GL in the first 10 days manifested in an average flow volume of 270.75GL ± 178.44SD (min: 46.57GL – max: 532.61GL) in the first 90 days (Figure 14).

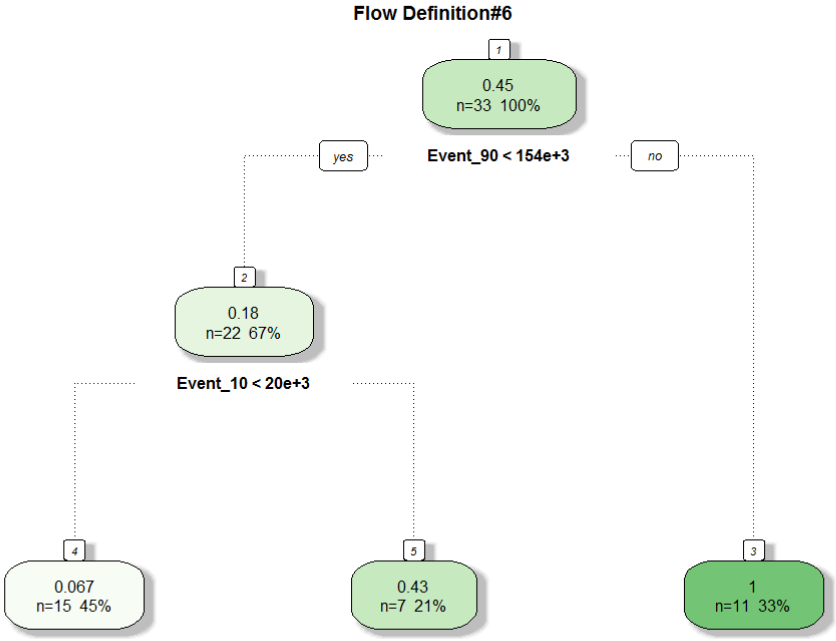


Figure 13 Classification and regression tree of straw-necked ibis breeding (from Merritt et al., 2016).

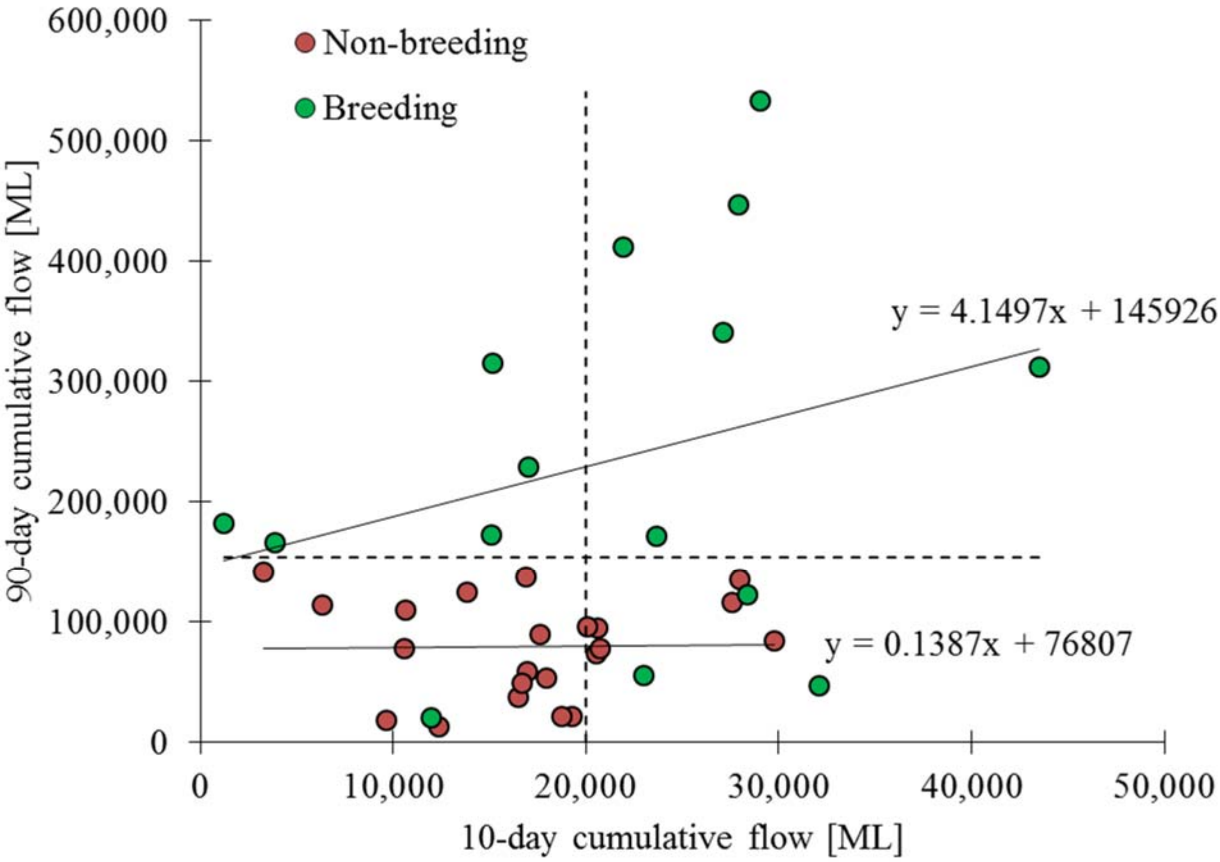


Figure 14: Historic relationship between 10-day and 90-day cumulative flow volumes (linear trends shown). Breeding events are represented with green and non-breeding events with red. Dashed lines represent the 90-day 154,000 ML and 10-day 20,000 ML thresholds.

To provide more details with regards to flow thresholds under the flow event definition, we included additional Classification and Regression Tree analyses constraining particular cumulative flow durations (Table 7). We also calculated a correlation matrix between cumulative flow durations to emphasize the important relationships between the various cumulative flow durations (Table 8).

Table 7 Thresholds and breeding probabilities (P) under flow event formulations #6 when constraining particular predictors in the CART analysis which identified the best explanatory variable (first flow threshold) and then next best variable (second flow threshold).[1] Re-substitution error rate identifies the best fit model .

Flow metric	First threshold	P(breeding)	rt.error[1]
Annual cumulative flow	157GL	0.92	0.90
90-day cumulative flow	154GL	1.00	0.91
50-day cumulative flow	140GL	1.00	0.85
30-day cumulative flow	99GL	0.86	0.80
10-day cumulative flow	21GL	0.75	0.82

Table 8 Linear relationship and correlation between varying cumulative flow duration under hydrological event formulations #6

	D30	D60	D90	CF
D10	D30=3.25*D10+2336, R^2=0.38,p=0.0001	D60=4.26*D10+32450, R^2=0.18,p=0.147	D90=4.753*D10+61764 R^2=0.11,p=0.056	CF=3.07*D10+144800, R^2=0.07,p=0.465
D30		D60=1.70*D30+5053, R^2=0.77,p<0.0001	D90=2.13*D30+16110, R^2=0.62,p<0.0001	CF=2.75*D30+28220, R^2=0.38,p=0.0001
D60			D90=1.33*D60+1968, R^2=0.90,p<0.0001	CF=1.77*D60+3885, R^2=0.59,p<0.0001
D90				CF=1.42*D90-11260, R^2=0.74,p<0.0001

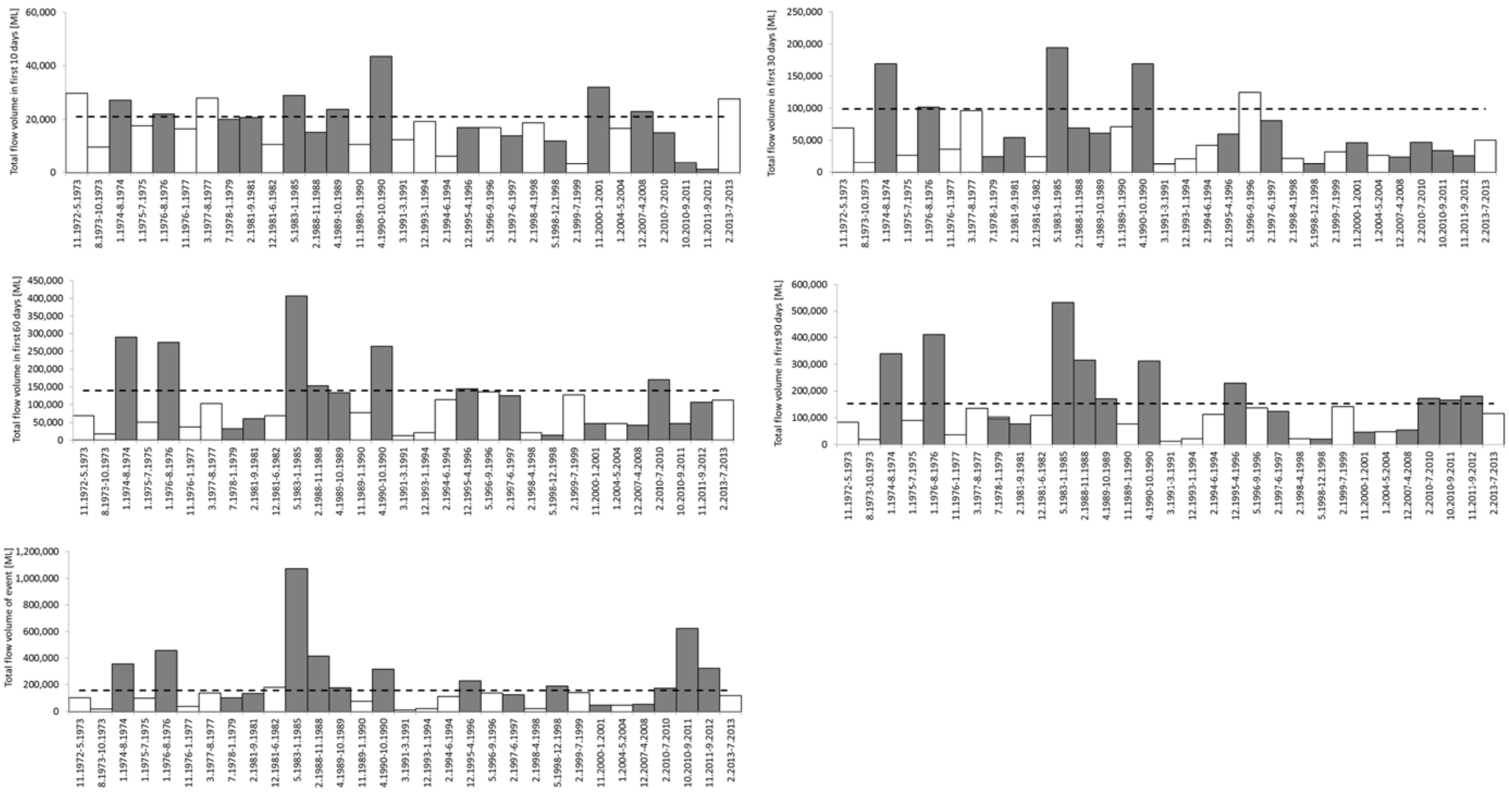


Figure 15: Flow events since 1971 and breeding events (grey shaded) along with identified single threshold as per Table 7 (dashed line).

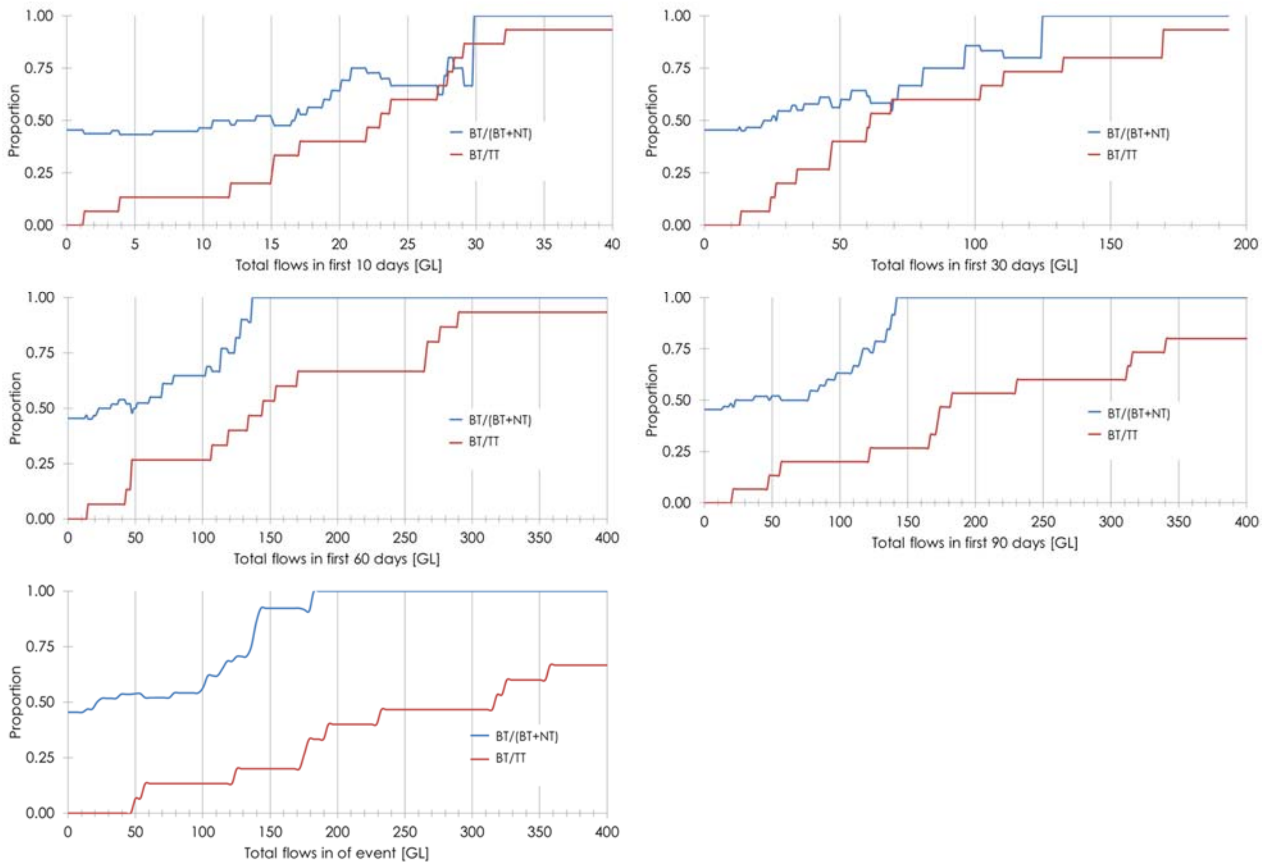


Figure 16 Proportion of breeding events of total hydrological events (breeding and non-breeding) that have occurred with flow the metric above a particular threshold (X-axis), (blue line) and proportion of breeding events of total breeding events (n=18) that occurred below that particular threshold (X-axis), (red line).

To compare breeding probabilities of other waterbird species in the Narran Lakes Nature Reserve in relation to water requirements of straw-necked ibis, we modelled waterbird responses using a generalized linear model (GLM) with a binomial distribution and logistic link function. A GLM approach provided a more continuous examination of responses to hydrological conditions and enabled us to compare variation between species and functional groups. We modelled waterbird responses to both total flow volume in the first 90 days and first 10 days as identified as the main instigators of straw-necked ibis breeding. We excluded species and functional groups with less than four breeding records since 1971 (Figure 17).

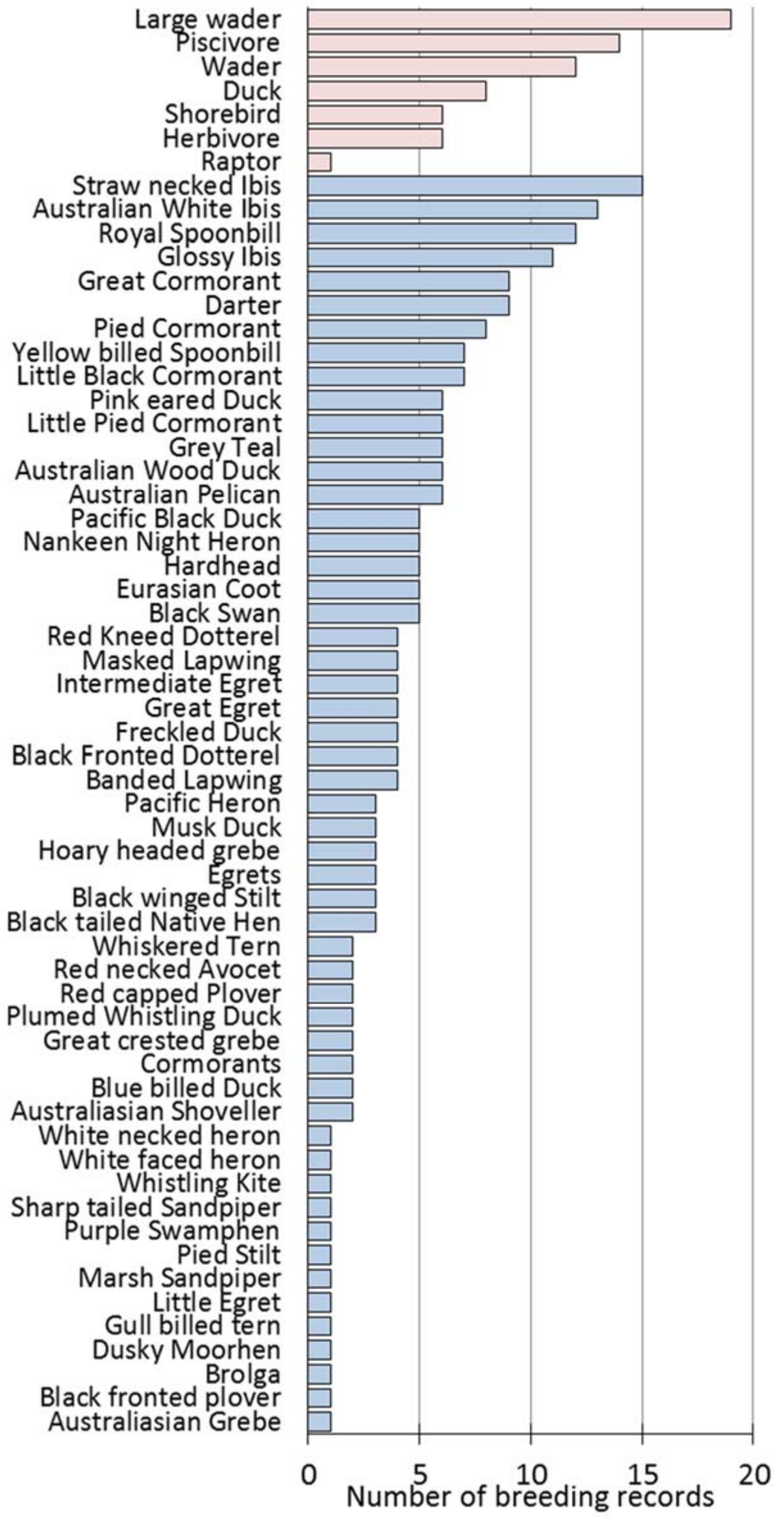


Figure 17 Number of waterbird breeding records since 1971 for the Narran Lakes Nature Reserve

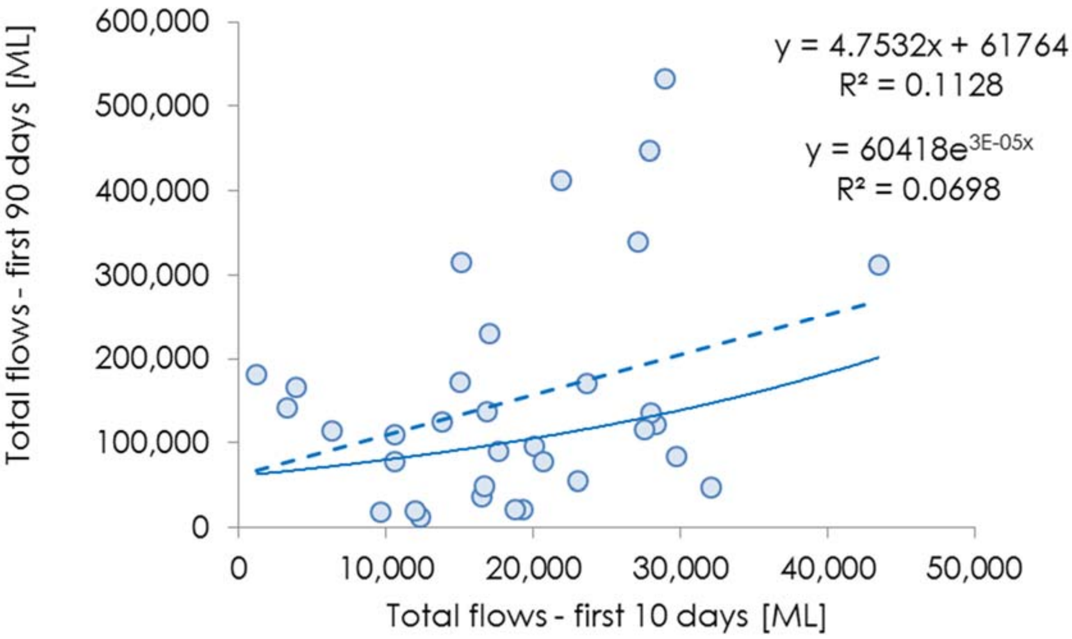


Figure 18 Relationship between cumulative flows (ML) in first 10 days and first 90 days.

Straw-necked ibis consistently had the highest probability of breeding in response to flow volumes followed by Australian white ibis, and royal spoonbill (Figure 20). With regards to functional groups, we found that large waders had the lowest requirements of total cumulative flow volumes followed by waders and piscivores (Figure 20 and Figure 19).

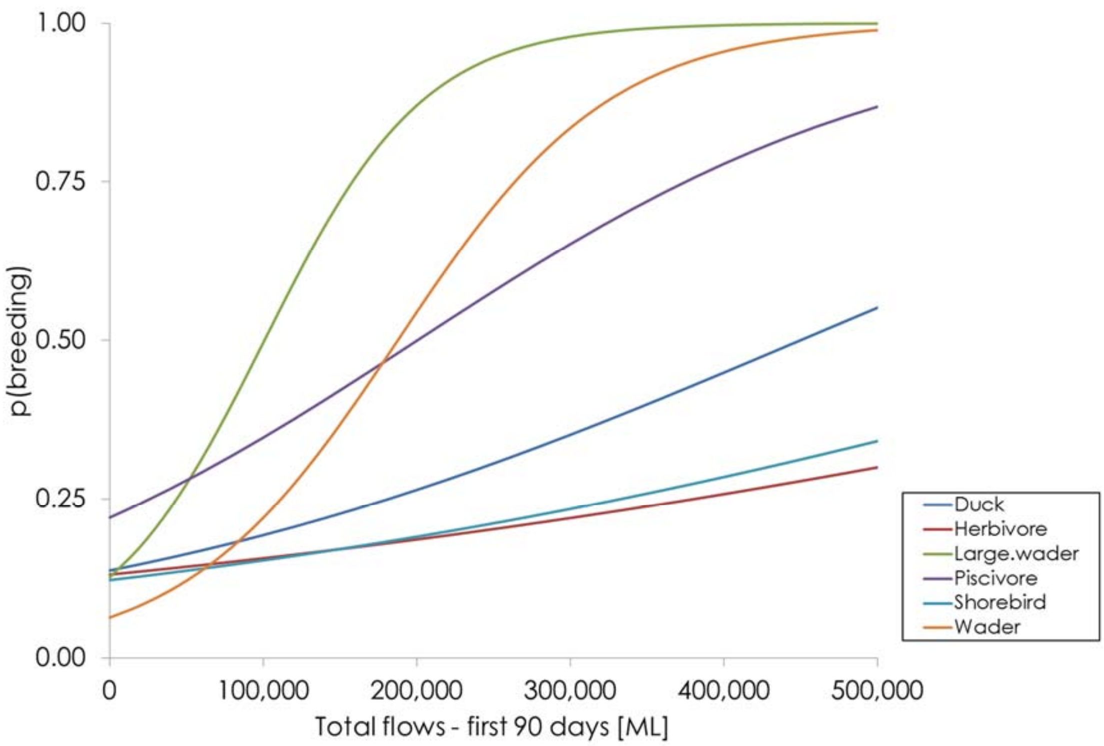


Figure 19 Predicted breeding responses by waterbird feeding guilds in relation to total flow volume in the first 90 days (assuming a linear relationship between flow volumes in the first 90 days and 10 days - see Figure 18).

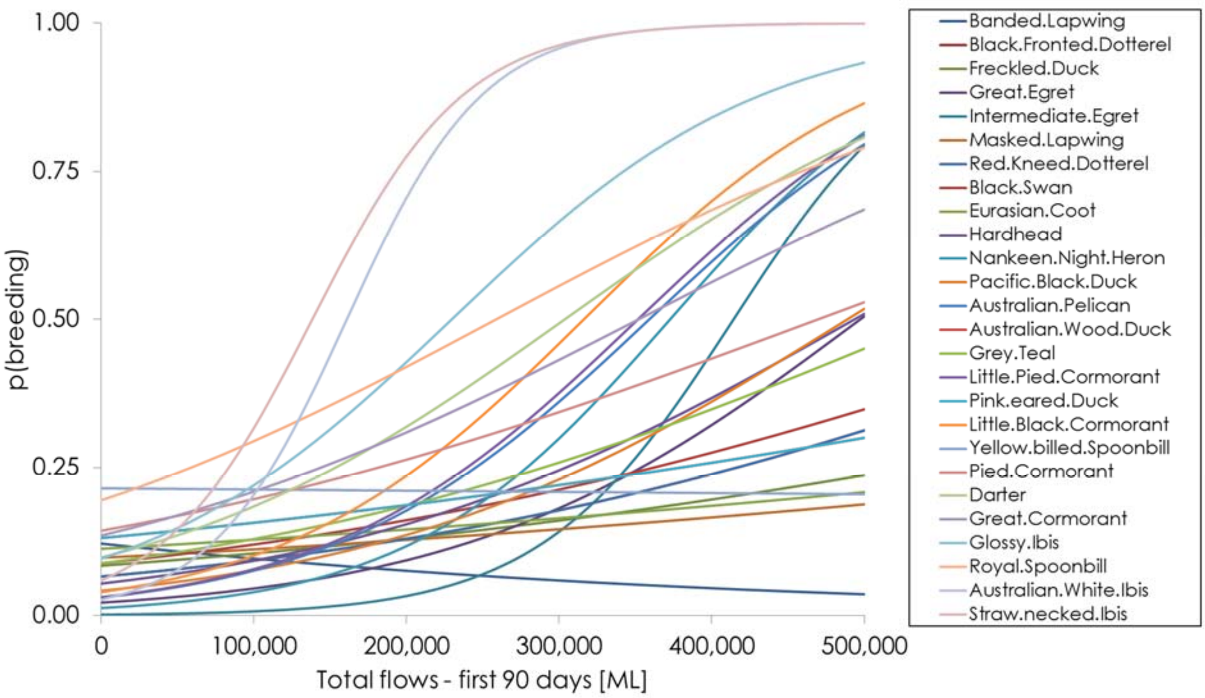


Figure 20 Predicted breeding responses of waterbird species in relation to total flow volume in the first 90 days (assuming a linear relationship between flow volumes in the first 90 days and 10 days - see Figure 18).

For straw-necked ibis, the predicted probability of breeding from the Generalized Linear Model when total flow volumes in the first 90 days was 154GL (and total flow volumes in the first 10 days was 18GL) (given observed linear association – see Figure 18) was P=0.58. We examined a range of breeding probabilities from 0.2 to 0.9 to quantify the number of possible breeding species in the Narran Lakes Nature Reserve in response to the volume of flow events. When total flow volumes in the first 90 days of the event were 154GL, (and 10-day total flow was 19GL) there was one species with a chance of breeding greater than 40% (straw necked ibis), two species with a breeding chance greater than 40% (addition of Australian white ibis), four species greater than 30% (addition of glossy ibis and royal spoonbill), and eight species greater than 20% (addition of great cormorant, yellow billed spoonbill, pied cormorant, darter) (Figure 21).

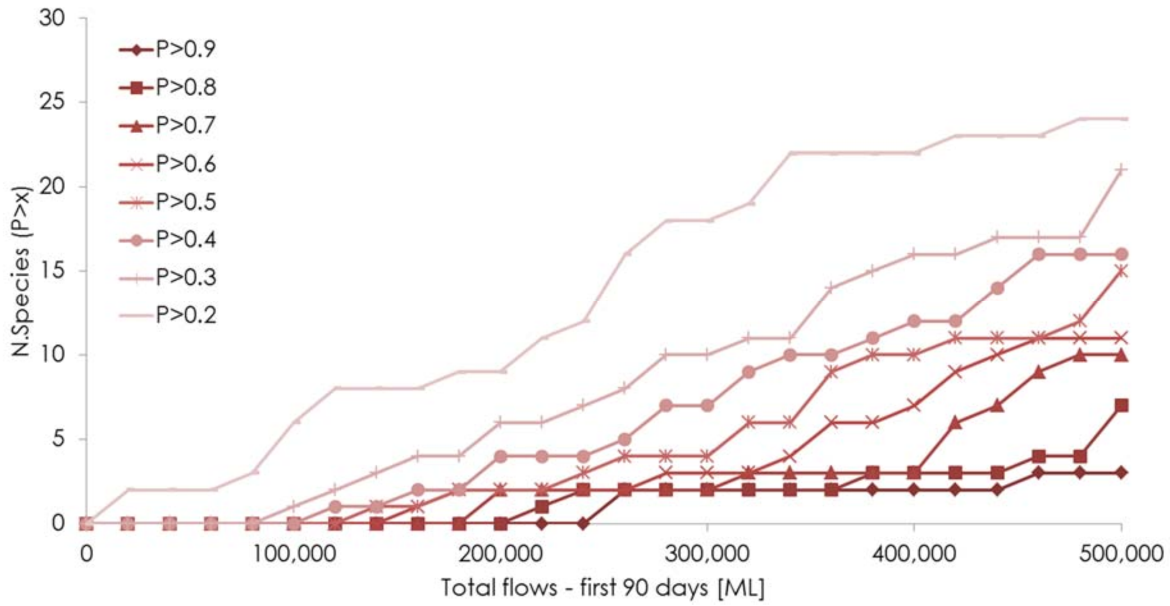


Figure 21 Number of species with probability of breeding P>0.2 – 0.9 against total flow volumes in first 90 days (ML).

We were also particularly interested in understanding the relationship between the duration of flooding and straw-necked ibis breeding. Duration of flow and inundation of the wetland and colony site is critical for successful breeding (Brandis *et al.* 2011). If the duration of flow and/or inundation is too short then ibis will desert nests and young. The reasons for this may be due to risk of predation (access to ground predators as water recedes) or limited food resources as water levels fall. A recognized limitation of historical straw-necked ibis records is uncertainty with regards to success of straw-necked ibis breeding, as opposed to instigation of breeding. Duration of flow event was strongly correlated with total flow volume in first 90 days (R^2=0.58, Figure 22) but not with total flow volume in the first 10 days (R^2=0.01, Figure 23).

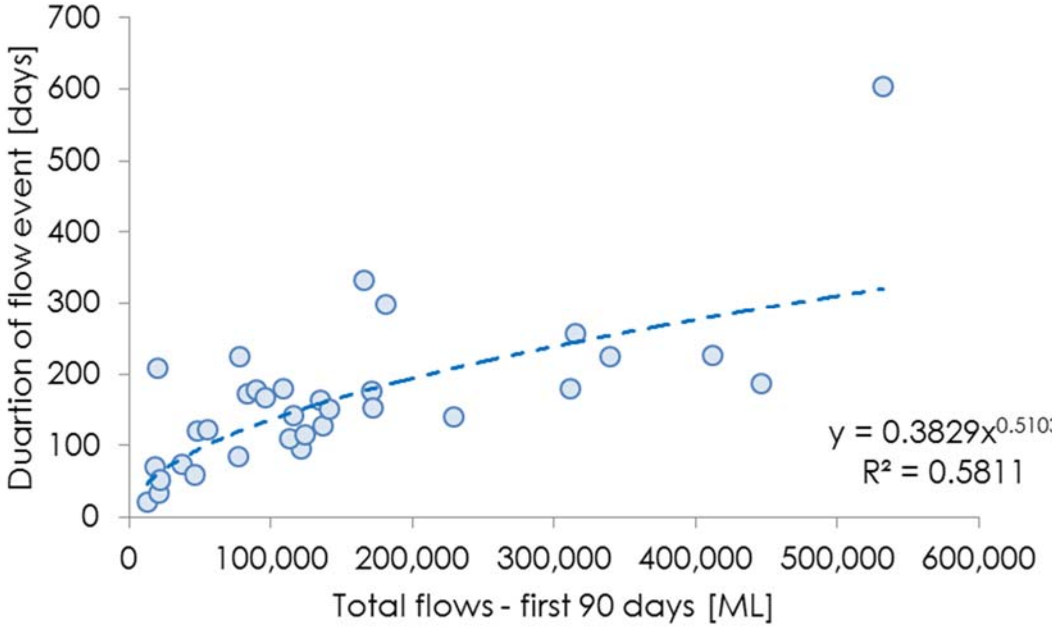


Figure 22 Relationship between total flow volume in first 90 days (ML) and the duration of flow (days).

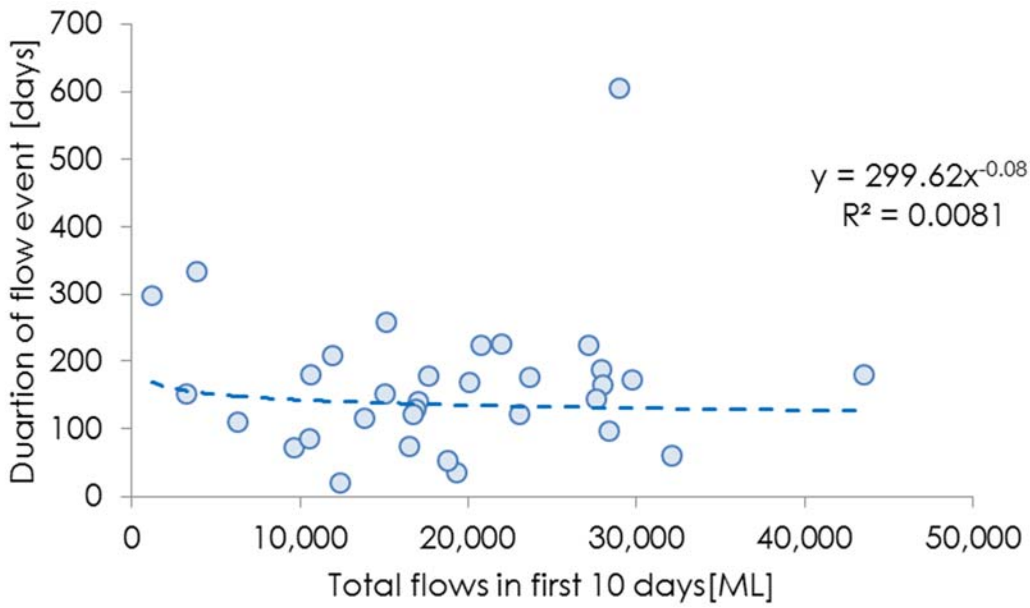


Figure 23 Relationship between total flow volume (ML) in the first 10 days of event and its duration (days).

Table 9 Average (and SD) of total flow volumes in the first 90 days, first 10 days, and duration.

Straw-necked ibis	Total flow 1st 90 days (ML)	Total flow 1st 10 days (ML)	Duration (days)
Non-breeding	79,169±40,933	17,030±6,636	122.7±54.8
Breeding	234,739±153,600	21,402±11,001	217.5±129.3
Overall	142,238±127,076	18,802±8,803	161.1±102.4

When combined in a GLM, total flow in the first 90 days had a significant and positive association with probability of straw-necked ibis breeding while duration did not (Table 10). When total flow in the first 10 days and duration of flow event were considered, both had a significant and positive association with probability of straw-necked ibis breeding (Table 10). When all three explanatory variables were considered within a single model, only cumulative flow in the first 90 days had a positive and significant association. For example, when total flow volume in the first 90 days was 142,000 ML (observed long term average – see Table 9), the predicted probability of straw-necked ibis breeding ranged between 0.25 to 0.84 depending on the duration of the flow event (100-400 days) (Figure 24). When total flow volume in the first 10 days was 19,000 ML (observed long term average – see Table 9), the predicted probability of straw-necked ibis breeding ranged between 0.05 to 0.99 depending on the duration of the flow event (100-400 days). When the flow event lasted 218 days and total flow volume in the first 90 days was 235,000 ML(the historical averages of flooding coinciding with straw-necked ibis breeding (Table 9), the probability of straw-necked ibis breeding was P=0.85.

Table 10. Coefficient estimates of explanatory variables (z-score scaled) from GLM model of probability of breeding of best fit model

Explanatory variable	Estimate	Std. Error	z value	p
Intercept	-3.29700	1.33100	-2.47700	0.01330
D90.Flow	0.00001	0.00001	1.91200	0.05590
Duration	0.00712	0.00825	0.86400	0.38780
Intercept	-4.9500	1.8690	-2.6480	0.0081
D10.Flow	0.0001	0.0001	1.6790	0.0932
Duration	0.0190	0.0073	2.6030	0.0092
Intercept	-4.90000	2.12400	-2.30700	0.02110
D90.Flow	0.00001	0.00001	1.65700	0.09750
D10.Flow	0.00007	0.00006	1.10200	0.27060
Duration	0.01031	0.00863	1.19500	0.23210

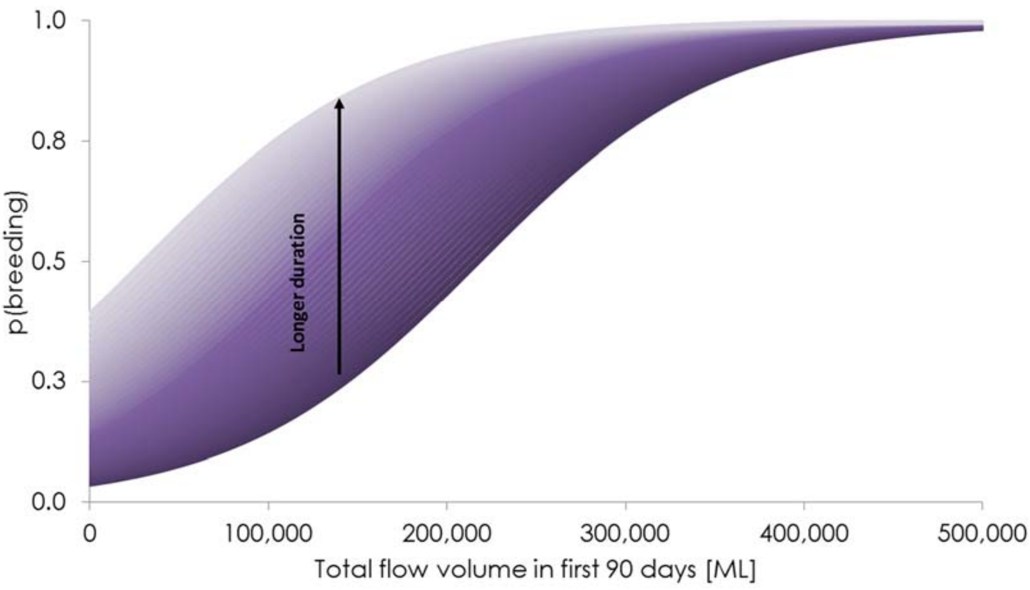


Figure 24 Changes in the probability of straw-necked ibis breeding in response to flow volume in the first 90 days and total duration of the flow event (10-400 days).

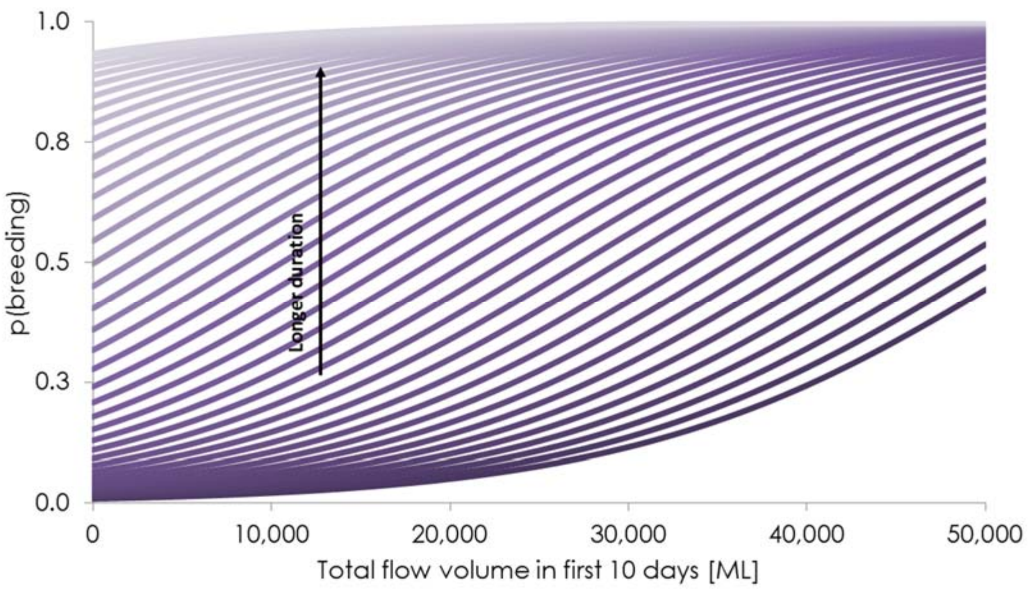


Figure 25 Changes in the probability of straw-necked ibis breeding in response to flow volume in the first 10 days and total duration of the flow event (10-400 days).

Given our understanding of the specific flow requirements for waterbirds breeding at Narran Lakes Nature Reserve and the life history traits of those species we estimated which species would have sufficient time to breed if water were provided for the purposes of straw-necked ibis breeding. Analyses have shown that the cumulative flow in the first 30 days of the flow event is the best indicator for ibis breeding response and the duration of flow needs to be at least 73 days (Merritt *et al.* 2016). This incorporates the know incubation, chick rearing and post parental care time of 63 days (Figure 12) with an allowance of 10 days prior to egg laying to allow for body conditioning and nest building (Merritt *et al.* 2016).

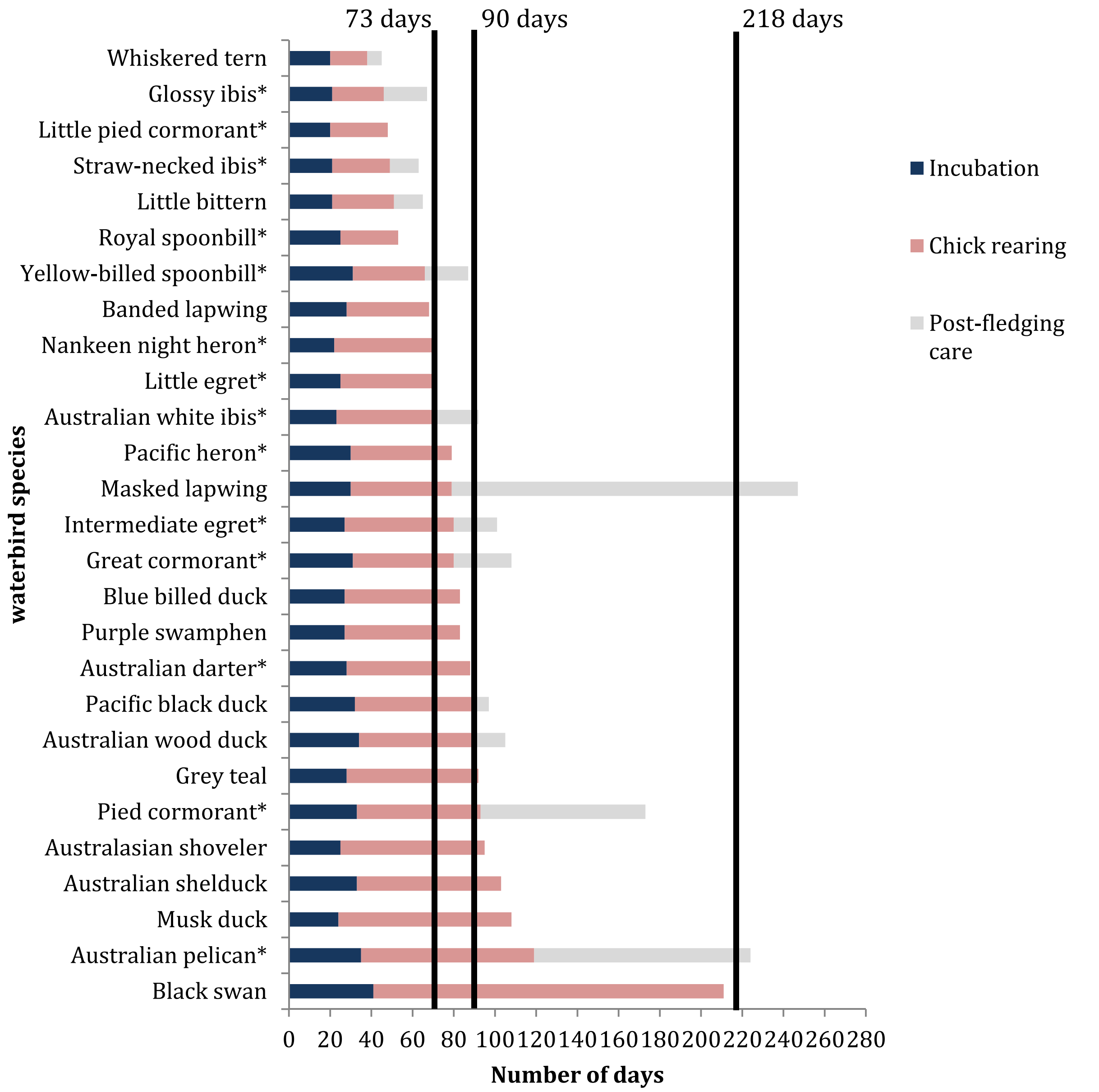


Figure 26 Plot showing which waterbird species would be able to complete breeding within the 73 days (inundation identified as optimal for straw-necked ibis breeding), 90 days (identified as first threshold of CART – see Figure 18) and 218 days (average flow duration). * denotes colonially breeding species. (Note this is not a complete list of all 54 species recorded breeding at Narran Lakes but is a subset based on available data).

Figure 26 demonstrates that providing flow conditions that are optimal for straw-necked ibis for duration of 73 days (Merritt *et al.* 2016) does not provide suitable breeding conditions for many other waterbird species. Many colonial species including; straw-necked ibis, Australian white ibis, glossy ibis, royal spoonbill, yellow-billed spoonbill and nankeen night heron will be able to complete breeding (egg laying to independence), but other colonial (cormorants, pelicans) and non-colonial species (duck spp., Black swan) would not have enough time to complete breeding including the rearing of chicks to independence. Ninety day flow duration would allow an additional eight species (Figure 26) to get chicks to fledging, assuming all breeding started at the same time and the beginning of flows.

However, the average duration of flow events at Narran Lakes Nature Reserve that have resulted in waterbird breeding was 218 days. If the flow duration were set to 218 days minimum then twenty-five of the twenty-seven the species shown in Figure 25 would be able to complete their breeding cycles. This duration also accounts for successional breeding; not all waterbird species start breeding at the beginning of flows (Figure 11).

Summary: Assumption 1

That environmental water requirements for colonial waterbird breeding (which have longer duration breeding water requirements) satisfy the breeding requirements of other waterbirds.

- There is evidence to show that non-colonial waterbirds also breed during the same flooding conditions that initiate colonial waterbird breeding. Therefore the assumption is valid that the hydrological conditions required by colonial waterbirds for breeding initiation also meet those of non-colonial species.
- There is no evidence to support the assumption that colonial waterbirds have a longer duration breeding water requirement. Data is variable, showing that colonial waterbirds have some of the shortest breeding duration times across all waterbird species, but also some of the longer times.
- In general, while the same inundation requirements meet the needs of many waterbird species for breeding initiation, the required duration of inundation is longer for non-colonial waterbird species.

Recommendations regarding flow requirements for waterbird ecological targets

The Murray-Darling Basin Authority undertook a series of assessments of environmental water requirements for the proposed Basin Plan (MDBA, 2012). As part of this process key ecological targets were identified (Appendix C). The following waterbird targets were identified for the three key regions relevant to this report:

Narran Lake

"Provide a flow regime which supports the habitat requirements of waterbirds and is conducive to successful breeding of colonial nesting waterbirds; Timing of flows: Preferably summer /autumn but timing not constrained to reflect that high flows depend on occurrence of heavy rainfall and will be largely unregulated events; Flow volume and duration: 250, 000 ML over 6 months, or 100,000 ML over 12 months."

This review has shown that the majority of straw-necked ibis (the most numerous colonial species at Narran Lakes Nature Reserve) breeding events were associated with total flow volumes in the first 90 days greater than 154,000 ML with an average duration of 218 days (~8 months). Our analyses also showed that flow volume in the first 10 days was also important for straw-necked ibis. 20,000 ML in the first 10 days was critical, and increases in flow duration increased the probability of straw-necked ibis breeding and increases in flow volume and duration increased the probability of breeding by other waterbird species.

We recommend that the 100,000 ML over 12 month indicator be altered to 154,000 ML over a period of 3 months (flow volume and duration are highly correlated, the larger the flow the longer the duration) with 20,000 ML delivered in the first 10 days of flows. This will provide the greatest opportunity for successful colonial, and non-colonial waterbird breeding. This duration will allow for completion of breeding from egg laying to independence of chicks, maximizing chances of survival for juvenile birds.

We recommend the Narran Lakes site-specific flow indicators (MDBA 2012) representing the opportunities for straw-necked ibis breeding in the Narran Lakes are revised from a maximum period between events of six to eight years to two opportunities in eight years (representing low uncertainty) and two opportunities in 10 years (representing high uncertainty where this would represent a risk for maintaining straw-necked ibis populations). These recommendations are based upon life-history traits of the straw-necked ibis, and the assumption that opportunities for breeding are provided elsewhere in the Basin. Life history information for Straw-necked Ibis is limited with only a small number of banding returns. Based on this data and on information for other ibis species they are thought to have a lifespan of 10-16 years and reach sexual maturity at around three to four years (based on age at which adult plumage is achieved; Marchant and Higgins 1990). The higher risk associated with the two in ten years or greater intervals between breeding events include potentially significant declines in straw-necked ibis populations and other waterbirds through reduced opportunities for breeding during the life span of an individual. This will be critical if any waterbird species exhibit natal site fidelity. Whether any species do exhibit natal site fidelity to Narran Lakes is currently unknown but has been shown in other waterbird species (Hazllit and Butler, 2001; Atwood and Massey 1988; Gratto 1988). If natal site fidelity is exhibited by some species then the frequency of breeding opportunities is critical. Longer inter-breeding intervals will result in fewer opportunities for breeding (both at Narran Lakes and Basin wide) and potentially declines in populations. Where suitable flows occur to support two opportunities for breeding within an eight year period this would allow for the increase in waterbird abundance (i.e. the restoration of populations).

Lower Balonne

"Provide a flow regime which supports the habitat requirements of waterbirds. The Lower Balonne has high ecological and hydrological connectivity to the Ramsar-listed Narran Lakes Nature Reserve which is as an important site for colonial waterbird breeding. The link between waterbird breeding and inundation of habitat which provides foraging and nesting opportunities is relatively well understood. The broader Lower Balonne floodplain is likely to provide foraging habitats and in doing so supports major bird breeding events in the Narran Lakes system."

This review has found that the Lower Balonne supports high waterbird species diversity for the duck, large wader and piscivore guilds (Figure 7). We do not recommend any change to this target.

Barwon-Darling upstream of Menindee Lakes

"Provide a flow regime which supports the habitat requirements of waterbirds and is conducive to successful breeding of colonial nesting waterbirds. Kingsford et.al (1997) identified Poopelloe Lake, Talyawalka Creek and Pelican Lake within the Teryaweynya system as well as the Darling River floodplain near Louth are known or predicted to support 20,000 or more waterbirds. On this basis, a target has been identified that centres on flows to support moderate to large breeding events by colonial nesting waterbirds."

- This review has found that the Talyawalka Anabranch and Teryaweynya Creek system are important wetlands, supporting high waterbird species diversity (29 – 56 species) (Figure 8) and high abundances (Figure 9). However, this review did not find, using the available data and expert opinion, that these wetlands were important colonial waterbird breeding sites. We recommend that this target be altered to reflect the importance of these wetland sites for supporting high waterbird diversity and abundance. These wetlands should remain an environmental flow target based on their ability to support high waterbird species diversity and abundance but not as a colonial waterbird breeding sites.

ASSUMPTION 2: THAT ENVIRONMENTAL WATER REQUIREMENTS FOR NATIVE RIPARIAN, FLOODPLAIN AND WETLAND VEGETATION HAVE BENEFICIAL EFFECTS ON LIFE-CYCLE AND HABITAT REQUIREMENTS FOR WATERBIRDS.

Figure 27 is a conceptual model illustrating the water requirements (duration of inundation in days) of floodplain vegetation (maintenance flow regime) compared with that of the duration of breeding for waterbirds (grouped by feeding guild). This figure shows that if environmental water was delivered to target lignum maintenance for a duration of 168 days that this could also potentially (depending upon water depth etc.) provide enough time for colonial waterbirds such as Ibis and spoonbills to complete breeding.

Figure 27 Conceptual model showing the duration of water required for floodplain vegetation and the overlap with breeding requirements for waterbirds.

Environmental water requirements for native riparian, floodplain and wetland vegetation

A recent review of water requirements for key floodplain vegetation for the Northern Basin (Casanova, 2015) focused on five key species: *Eucalyptus camaldulensis* (River Red Gum)*, E. largiflorens* (Black Box)*, E. coolabah* (Coolibah)*, Acacia stenophylla* (River Cooba) and *Duma florulenta* (Tangled Lignum). This document provides a thorough review of the current understanding regarding these species and their water requirements.

For the purposes of this review and addressing assumption 2 a brief summary is provided for the five key floodplain vegetation species identified by Cassanova (2015) for the Northern Basin (

Table 11).

Roberts *et al.* 2000, identify two plant water regimes:

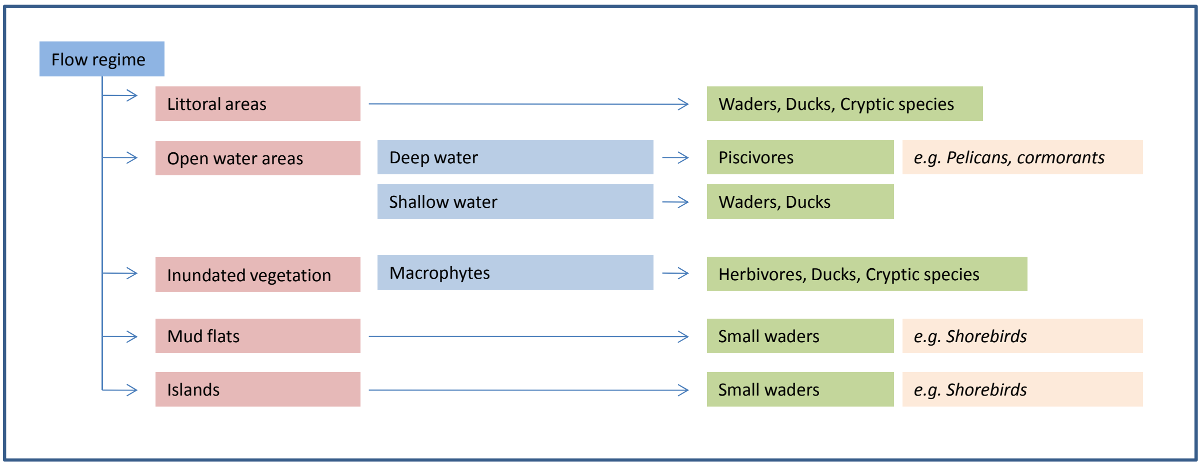
1) A maintenance water regime, defined as the water regime needed by an established mature plant to survive to long-term, and
2) A regeneration water regime: one that ensures periodic establishment or re-establishment of plants, whether from seed or other propagules.

Maintenance and regeneration requirements are usually quite different. The environmental conditions required for germination, or for survival of a seedling, are not the same as those required by the adult plant. For example, many emergent macrophytes germinate on wet muds, comparable to drawdown condition; only some have seedlings that can tolerate submergence. Shallow water is likely to be detrimental, at least until the plant reaches a critical stage: in contrast, adult plants can tolerate water depths ranging from 0 to about 1.5 meters (Roberts *et al.* 2000).

These two plant water regimes may have different implications for waterbirds. A maintenance water regime will maintain the existing vegetation type, structure and distribution – nesting or roosting habitat. A regeneration water regime will provide opportunities for new nesting and/or roosting habitats that were not previously available. It may also result in the extension of existing habitat areas.

Waterbird responses during a riparian vegetation targeted flow event are likely to be increases in abundance at sites with water as the water and inundated areas provide foraging areas and food resources (Figure 28) and an opportunity for birds to build body condition and maintain/improve health. Waterbirds may use floodplain vegetation as both foraging habitat, and as a source of food. Different feeding guilds respond to water conditions in different ways (Berens *et al.*, 2011, Ntiamoa-Baidu *et al*. 2008). Piscivores, such as pelicans and cormorants, require deeper water that can support fish populations while waders utilize shallower water and exposed mud flats and islands. Waterbird foraging habitat preferences are determined by their foraging methods, visual surface foraging waders (e.g dotterals) require very shallow water or exposed mud in order to see their prey, whereas tactile feeders (e.g ibis) can utilize exposed mud or shallow water areas. The availability of different foraging habitats and food resources alters with patterns of inundation and drying.

A



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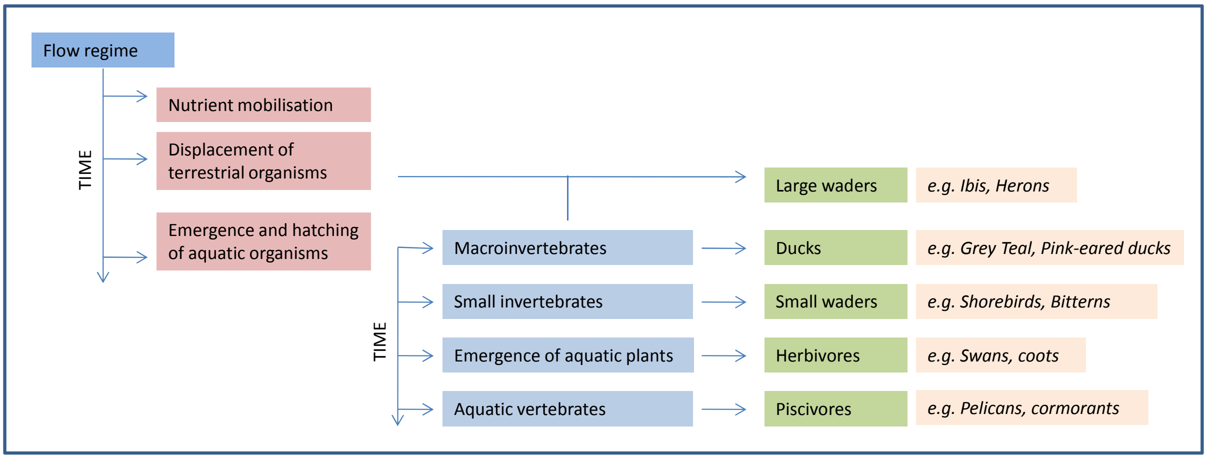

Figure 28 Conceptual models waterbird utilisation of A) foraging habitat types and B) food resources following inundation.

Table 11. Water requirements for key floodplain species, (Roberts and Marston 2000, Capon *et al.* 2009, Cassanova 2015).

Community	Common Name	Scientific Name	Maintenance flow requirements	Regeneration flow requirements
Forests and Woodlands	River red gum	Eucalyptus camaldulensis	Flood frequency 1 or 2-3 years; duration 4-7 months; winter-spring	Large flood, late spring early summer, followed by wet winter-spring or shallow and brief or pulsed winter-spring floods, and even brief or shallow summer flooding. Seeds die >10 days saturation.
	Black Box	Eucalyptus largiflorens	Flood frequency 1 in 3 to 7 years; duration 2-4 months. Declines when 1 in 10 years. Can have too much flooding.	Extensive flooding long enough to saturate soil, slow recession
	Coolibah	Eucalyptus coolabah	1 in 10-20 years; duration few to several weeks; summer and autumn likely flooding	Shallow flooding and wet soils
	River cooba	Acacia stenophylla	1 in 10-20 years for several weeks	Occurs after flooding. Longer flood period for increased seedling abundance
Shrublands	Tangled lignum	Duma florulenta	Flood frequency every 1 or 12-18 months 5-15cm depth 4-6 months inundation. Spring-summer and late summer floods. On average 1 in 5 years for 7 months.	Regeneration from seeds optimal in waterlogged or shallow flooded soils[a].

Role of vegetation in waterbird life cycles

Vegetation plays an integral role in the life cycle of waterbirds. At various stages of their life cycle (Figure 29) waterbirds rely upon vegetation for nesting materials in which to lay eggs and raise chicks to fledging; as a food resource for some species (herbivores; Table 3; Figure 30); and it also provides roosting sites for birds after they disperse from natal wetlands (Figure 30). The maintenance and regeneration of floodplain vegetation through the provision of environmental flows ensure that vegetation is available and in a suitable condition to fulfil these roles for waterbirds (Table 12).

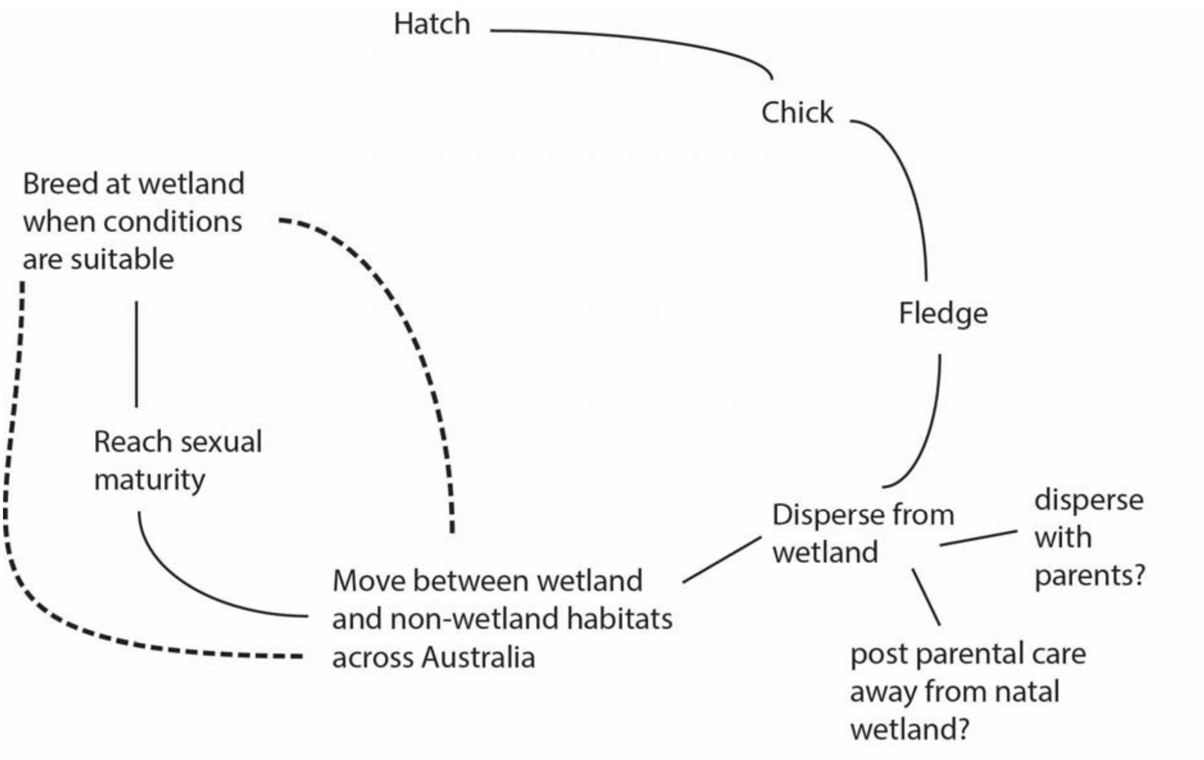

Figure 29 Generalised life-cycle of a waterbird.

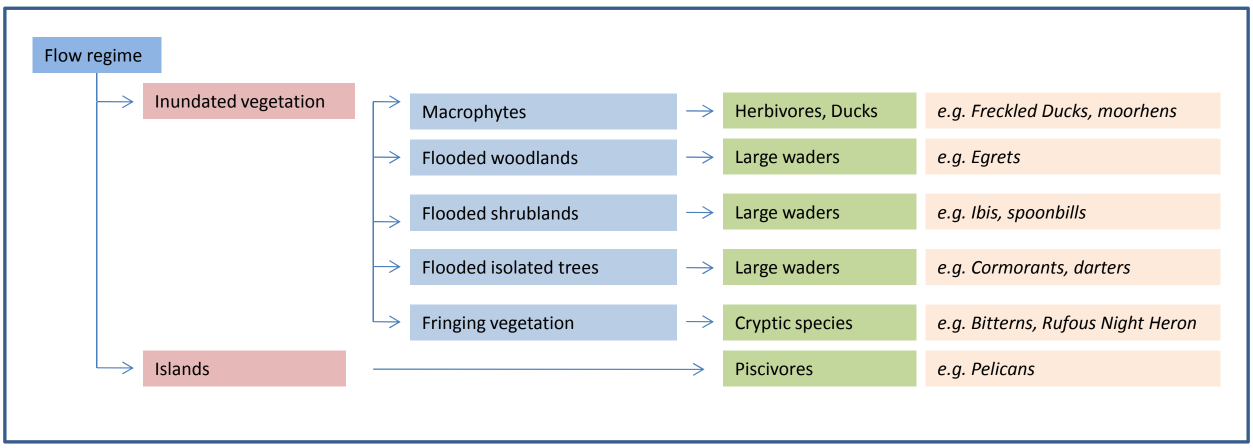

Figure 30 Waterbird breeding habitat conceptual model.

Figure 30 illustrates the use of different inundated vegetated habitat types by difference groups of waterbirds. High waterbird species diversity at wetland sites is related to habitat diversity, both nesting and foraging habitats. Environmental flows that maintain and/or enhance the quality and diversity of habitat types (habitat complexity) should result in high waterbird species diversity (Willson, 1974; Solbreck 1977; Lor and Malecki, 2006).

The importance of Narran Lakes as a colonial waterbird breeding site is contributed to by the large expanse and condition of Tangled Lignum. Historical records of colony locations in the Narran Lakes Nature Reserve show that colony establishment is always on Lignum and is centralized around the large expanse of channelized Lignum between Back and Clear Lakes (OEH, 2015). The expert opinion workshop identified a range of knowledge gaps regarding this assumption;

1) The role of plant condition, particularly Lignum, on use by waterbirds for nesting. It is not known whether the condition of Lignum plays a role in Ibis nest site selection. This may similarly apply to other plant and waterbird species.
2) The role of plant distribution and density in the landscape in providing suitable nesting sites.
3) The impact of regeneration versus maintenance. Flows targeting regeneration of Lignum may result in the infilling of channels and currently unvegetated areas of Clear and Back Lakes. The impact of this is unknown, but the general opinion was that it may impact on colonial waterbird nesting if the channelized lignum patches became infilled.

Table 12 Key floodplain vegetation species and their role in waterbird life cycles.

Common Name	Scientific Name	Function	Waterbird species
River red gum	Eucalyptus camaldulensis	Roosting Nesting	Egrets Herons Cormorants Darter
Black Box	Eucalyptus largiflorens	Roosting Nesting	Egrets Herons Cormorants Darter
Coolibah	Eucalyptus coolabah	Roosting Nesting	Egrets Herons Cormorants Darter
River cooba	Acacia stenophylla	Nesting	Cormorants Darter Herons

Tangled lignum	Duma florulenta	Nesting	Ibis Spoonbills
Grass spp.	Poa	Food	Ducks Swans
Swamp Millet~	Panicum decompositum	Food	Ducks

~ Roberts and Marston 2000

Summary Assumption 2

That environmental water requirements for native riparian, floodplain and wetland vegetation have beneficial effects on life-cycle and habitat requirements for waterbirds.

- The provision of environmental flows that maintains the distribution, structure and health of native riparian, floodplain and wetland vegetation will ensure that habitat is available for roosting, nesting and foraging when required by waterbirds.
- The provision of water for native riparian, floodplain and wetland vegetation may provide opportunities for foraging and nesting, depending upon the hydrological characteristics of the flow event, seasonal timing and requirements of the individual waterbird species.
- For environmental water requirements that target regeneration of floodplain vegetation, impacts would generally be expected to be positive for waterbirds, although there could be some negative effects such as infilling of lignum channels at colony sites in Narran Lakes Nature Reserve.

Flow requirements for riparian, floodplain and wetland vegetation ecological targets
The Murray-Darling Basin Authority undertook a series of assessments of environmental water requirements for the proposed Basin Plan (MDBA, 2012). As part of this process key ecological targets were identified (Appendix C). The following vegetation targets were identified for the three key regions relevant to this report:

Narran Lakes

"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."

With regards to the results of this review we would recommend that this target not be altered. As discussed in this review, the impacts on waterbirds and the use of the traditional colony sites as a result to changes to the current distribution of Lignum is unknown. This has been identified as a knowledge gap and we would recommend further research into this area.

Lower Balonne

"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."

We do not have any recommendations regarding this target as a result of this review.

Barwon-Darling River upstream of Menindee Lakes

"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. The Barwon-Darling provides flows to the important Talyawalka Anabranch wetland area. The system is made up of a series of braided channels across the floodplain, interspersed by a series of intermittent wet and dry lakebeds and supports large areas of black box (Eucalyptus largiflorens) and river red gum (Eucalyptus camaldulensis) (Department of the Environment, Water, Heritage and the Arts 2010)."

The results of this review have identified this area as containing key wetland habitats, supporting high waterbird species diversity and abundances. The ability of these wetlands to support large waterbird numbers and a diverse range of species is reflective of habitat complexity, which is contributed to by the extent, health and diversity of the vegetation. We do not recommend any changes to this target but highlight the important ecological link between riparian, floodplain and wetland vegetation and waterbirds at these sites.

IDENTIFIED KNOWLEDGE GAPS

Regional scale wetlands

It was identified at the expert opinion workshop that there were significant knowledge gaps regarding the wetlands on the Narran River to the north of Narran Lake (Figure 31). While these wetlands are currently being used for agricultural production they fill from the Narran River in large flood events. Their role as roosting and foraging sites for waterbirds breeding at the Narran Lakes is poorly studied and undocumented; however, the consensus of opinion was that these wetlands potentially play an important role in supporting the birds that breed at Narran Lakes by providing food resources.

These wetlands include:

- Angeldool Lake (NSW, -29.1985, 147.9012)

The Lake covers an area of approximately 1100 ha when full. When Angeldool Lake is full water spills into Weetalabah Crrek and then fills Coocoran Lake (https://en.wikipedia.org/wiki/Angledool).

- Coocoran Lake (NSW, -29.3985, 147.8346)
- Grawin Creek floodplain (NSW, -29.578, 147.627) wetland between Coocoran Lake and Narran Lakes. This area of floodplain wetland does not have an officially registered name.

Hydrological modelling would be required to understand the volumes of water required to fill one or several of these wetlands. Essential to quantify the flow volumes required to fill. Peter Terrill suggested that 500,000 ML would be required. In addition the role of these wetlands in relation to waterbird breeding success would need further research to quantify the importance of these wetlands at the regional scale.

It was recommended by the expert workshop the inclusion of Angeldool Lake, Coocoran Lake and the mid Narran River floodplain as targets for watering.

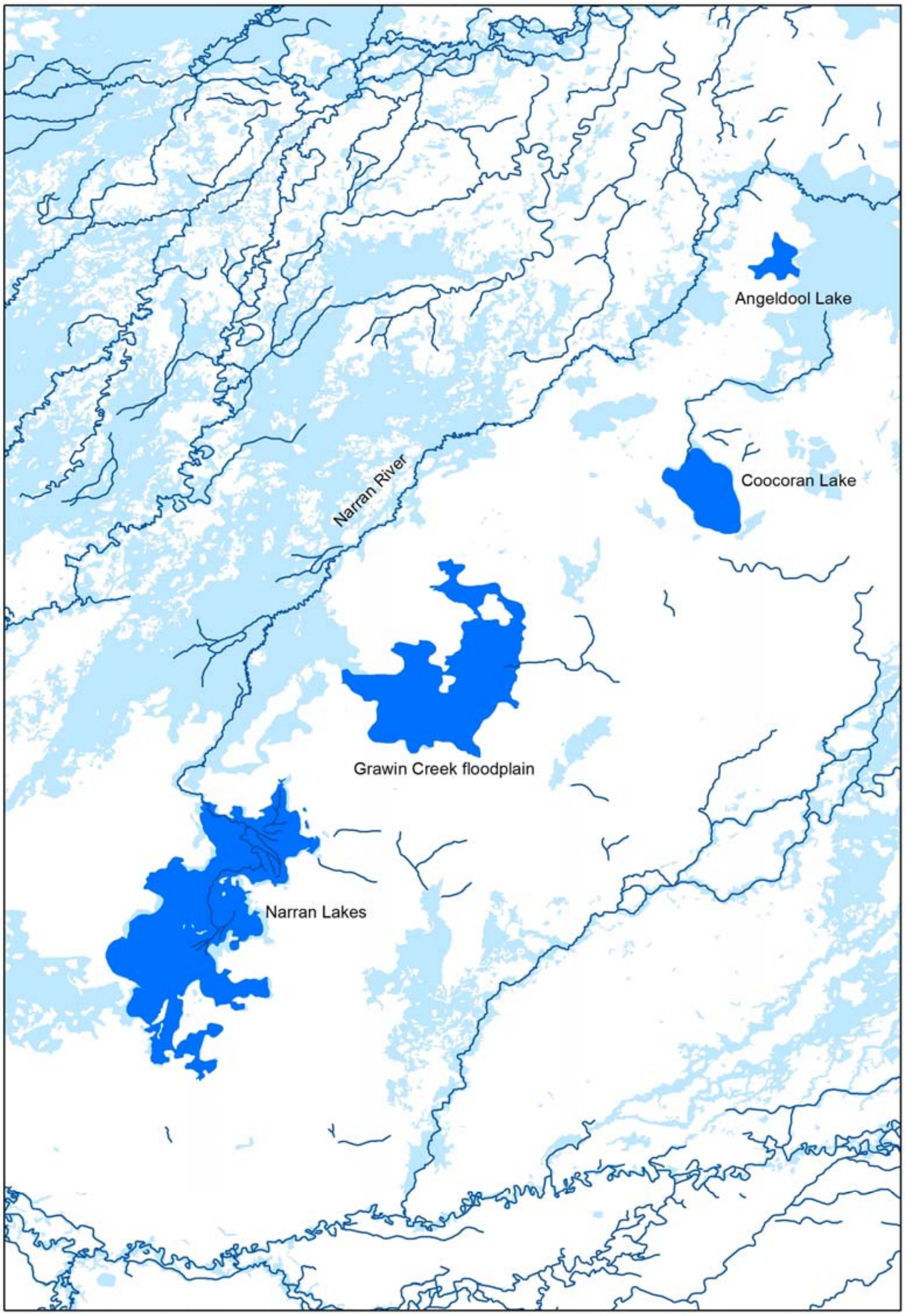

Figure 31 Narran River floodplain wetlands

Figure 32 Coocoran Lake full (25/9/2013) and dry (14/8/2009) source: Google Earth 2015.

Waterbird ecology

There remain gaps in our understanding of the following aspects of waterbird ecology:

Food resources during breeding

Food resources are understood to be a key driver of the success of waterbird breeding (Gawlik 2002). Much of the research on chick provisioning and food resources for wading birds is based on international studies (Gawlik 2002, Gawlik *et al.* 2010, Beerens *et al.*, 2011, Lorenz 2014). Adequate food resources are required throughout the breeding event to support both adult and juvenile birds. Research in Australia has been limited to a small study looking at prey items during the 2008 breeding event at Narran Lakes (Jenkins et al, 2008) and more recently a study by Brandis *et al.* (in prep) looking at shifts in straw-necked ibis diets during a breeding event in the Lowbidgee 2010-2011. Current research being undertaken by Brandis *et al.* is exploring new methods in elemental analysis and stable isotope analysis to study diet in waterbirds.

Further research in this area will enable greater understanding of the food resource requirements for waterbirds and quantify the food requirements of waterbirds during breeding events. These data will add critical information that can be used during the decision making process associated with water delivery for waterbird breeding (Merritt *et al.* 2016).

Pre-breeding habitat requirements

Prior to the laying of eggs there is a period of time required for waterbirds build-up of body condition (Briggs *et al.* 1991), undertake courtship and pairing, and nest building. Other than knowing these stages prior to breeding exist, very little is known regarding the details of each stage. For example, some birds, such as ibis are very quick to progress through these stage to egg laying, while other birds, such as swans take longer. This may have to do with the temporary and unpredictable nature of the wetlands they breed at. Similarly we have very little understanding of what the habitat requirements, including hydrological conditions, need to be during these stages to ensure that it progresses to egg laying. It is common that ibis will begin the nest building phase (trampling lignum) and then not lay eggs (Kingsford pers. comm). Further research into the habitat requirements prior to egg laying will provide critical information to water managers targeting the establishment of breeding colonies. For example, environmental flow releases in the Lachlan in 2015 attracted several thousand ibis, however, it is unclear whether they will progress to egg laying and their habitat requirements during this period are unknown.

Nesting habitat quality

Colonial waterbirds use traditional colony sites in the Murray Darling Basin at key wetlands when conditions are suitable (e.g. Narran Lakes, Macquarie Marshes, Lowbidgee Wetlands, Gwydir Wetlands). Many of these sites are the target of environmental flows aiming to ensure viable wetland habitats. However, with regards to colonial nesters such as ibis and spoonbill, we have very little understanding about the conditions (structure, health, spatial distribution) of the nesting substrate (lignum, phragmites etc) that make it suitable for nesting. Further research into answering the question 'what is suitable nesting habitat?' would allow for improved management of flows that aim to maintain floodplain vegetation as suitable nesting habitat.

Waterbird movements

The current scientific understanding regarding the movement of waterbirds between wetland sites is very poor. Waterbirds are nomadic and can travel large distances between wetland habitats. They congregate in large number for breeding and then disperse in small groups once breeding is complete. Our understanding of where the birds go and come from is very limited. A current research project, the Feather Map of Australia (Brandis 2015) funded by UNSW and ANSTO is using elemental analyses and stable isotope techniques on feathers to greater understand the movements of waterbirds around Australia and wetland health (https://www.ecosystem.unsw.edu.au/content/rivers-and-wetlands/wetland-ecology-and-stable-isotopes/feather-map-of-australia).

Floodplain vegetation

Changes in vegetation distribution and structure

It was identified at the expert opinion workshop that the effects of environmental flows that targeted floodplain vegetation, specifically lignum in the Narran Lake Nature Reserve, were largely unknown. While the flooding frequency required for lignum maintenance is understood (Capon *et al.* 2009), it was identified that the impacts of flows on channel infilling and promotion of lignum expansion into currently un-vegetated areas was unknown.

Floodplain vegetation as a food resource for waterbirds

It was identified at the expert opinion workshop that a knowledge gap exists in our understanding of the role floodplain vegetation plays in providing food resources for herbivorous species or waterbirds e.g swans, duck spp. The identification of plant species that provide key food resources for specific species (e.g. Swamp millet seed *Panicum decompositum* are important food for some duck spp. (Roberts and Marston 2000) will improve environmental flow targets for floodplain vegetation and strengthen ecological the link between vegetation diversity and waterbird diversity.

Future Research Workplan

Knowledge gaps		Current studies	Research required
Wetland ecology	Importance of regional scale wetlands in Narran River catchment:Lake Coocoran, Angeldool Lake, Grawin Ck floodplain		Hydrological studies to determine water requirements. Ecological study to identify role of these wetlands in the regional landscape and as contributors to the Narran Lakes Nature Reserve as a key waterbird breeding site.
Waterbird ecology	Food resources during breeding	Brandis *et al.* (UNSW/ANSTO)	Additional funding to allow for increased field sampling and data processing.
	Pre-breeding habitat requirements		Ecological research required during the pre-breeding phase, particularly for ibis. Research to be conducted during the pre-breeding phase, when ibis first appear at wetland sites
	Nesting habitat requirements		Ecological research required involving waterbird ecologists and botanists to quantify habitat metrics that are important to waterbirds regarding nesting habitat.
Waterbird movements	Movement of waterbirds between wetland sites	Brandis *et al.* (UNSW/ANSTO) EWKR (UNSW/CSIRO) ET application (CSIRO/UNSW) ARC Linkage application Nov. 2015 (MDBA/Deakin Uni)	Improved funding for waterbird tracking methods (GSM, satellite, stable isotopes, elemental analysis). Ability to complement existing research programs, and improve sample sizes and numbers of target species.
Floodplain vegetation	Channel infilling and expansion of lignum areas		Hydrological/geomorphological and botanical study to research rates of channel infilling, and resulting changes in lignum extent and other floodplain vegetation communities
	Floodplain vegetation as waterbird food resources	Proposed Capon and Brandis	Funding required to undertake a review of available data on herbivorous waterbird diets and the role of floodplain vegetation in species diversity at wetland sites

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Appendix A Attendees at the Waterbird Workshop, UNSW, Sydney, 28th August, 2015.

Peter Terrill	Consultant
Mike Maher	Consultant
Rob Clemens	University of Queensland
Neal Foster	NSW Office of Water
Richard Kingsford	Centre for Ecosystem Science, UNSW
Sam Capon	Griffith University
Gilad Bino	Centre for Ecosystem Science, UNSW
Kate Brandis (convener)	Centre for Ecosystem Science, UNSW
Claire Sives (scribe)	Centre for Ecosystem Science, UNSW

Apologies

Jennifer Spencer NSW Office of Environment and Heritage

Appendix B Records of waterbird breeding at Narran Lake and Narran Lakes Nature Reserve 1971-2014.

Site	species breeding	breeding events	number birds	number nests	reference/s
Narran Lakes Nature Reserve	Australian Pelican	1971	200	100	Smith 1993
Narran Lakes Nature Reserve	Glossy Ibis	1971	400	200	Smith 1993
Narran Lakes Nature Reserve	Great Cormorant	1971	400	200	Smith 1993
Narran Lakes Nature Reserve	Little Black Cormorant	1971	400	200	Maher memo
Narran Lakes Nature Reserve	Little Pied Cormorant	1971	400	200	Maher memo
Narran Lakes Nature Reserve	Pied Cormorant	1971	400	200	Smith 1993
Narran Lakes Nature Reserve	Great Egret	1971	600	300	Maher memo
Narran Lakes Nature Reserve	Intermediate Egret	1971	600	300	Smith 1993
Narran Lakes Nature Reserve	Nankeen Night Heron	1971	1000	500	Maher memo
Narran Lakes Nature Reserve	Straw necked Ibis	1971	20000	10000	Smith 1993
Narran Lakes Nature Reserve	Australian White Ibis	1971	unknown no.	unknown no.	Maher memo
Narran Lakes Nature Reserve	Blue billed Duck	1971	unknown no.	unknown no.	Maher memo
Narran Lakes Nature Reserve	Darter	1971	unknown no.	unknown no.	Maher memo
Narran Lakes Nature Reserve	Grey Teal	1971	unknown no.	unknown no.	Maher memo
Narran Lakes Nature Reserve	Hardhead	1971	unknown no.	unknown no.	Maher memo
Narran Lakes Nature Reserve	Musk Duck	1971	unknown no.	unknown no.	Maher memo
Narran Lakes Nature Reserve	Pacific Black Duck	1971	unknown no.	unknown no.	Maher memo
Narran Lakes Nature Reserve	Royal Spoonbill	1971	unknown no.	unknown no.	Smith 1993
Narran Lakes Nature Reserve	Straw necked Ibis	1972	unknown no.	unknown no.	Smith 1993
Narran Lakes Nature Reserve	Glossy Ibis	1974	unknown no.	unknown no.	Smith 1993
Narran Lakes Nature Reserve	Straw necked Ibis	1974	unknown no.	unknown no.	Smith 1993

Site	species breeding	breeding events	number birds	number nests	reference/s
Narran Lakes Nature Reserve	Australian White Ibis	1974			Smith 1993
Narran Lakes Nature Reserve	Glossy Ibis	1976	unknown no.	unknown no.	Smith 1993
Narran Lakes Nature Reserve	Straw necked Ibis	1976	unknown no.	unknown no.	Aldis in Magrath, 1991
Narran Lakes Nature Reserve	Australian White Ibis	1976			Smith 1993
Narran Lakes Nature Reserve	Pacific Heron	1978	23	12	Brooker 1983
Narran Lakes Nature Reserve	Great Cormorant	1978	56	28	Brooker 1983
Narran Lakes Nature Reserve	Glossy Ibis	1978	100	50	Brooker 1983
Narran Lakes Nature Reserve	Glossy Ibis	1978	1323	662	Brooker 1983
Narran Lakes Nature Reserve	Straw necked Ibis	1978	520	260	Brooker 1983
Narran Lakes Nature Reserve	Australian Pelican	1978	13245	6623	Brooker 1983
Narran Lakes Nature Reserve	Glossy Ibis	1978	100	50	Smith 1993
Narran Lakes Nature Reserve	Glossy Ibis	1981	10	5	Brooker 1983
Narran Lakes Nature Reserve	Great Cormorant	1981	20	10	Brooker 1983
Narran Lakes Nature Reserve	Australian Pelican	1981	30	15	Brooker 1983
Narran Lakes Nature Reserve	Pied Cormorant	1981	50	25	Brooker 1983
Narran Lakes Nature Reserve	Royal Spoonbill	1981	100	50	Brooker 1983
Narran Lakes Nature Reserve	Straw necked Ibis	1981	100	50	Brooker 1983
Narran Lakes Nature Reserve	Pacific Heron	1981	150	75	Brooker 1983
Narran Lakes Nature Reserve	Australian White Ibis	1983	unknown no.	unknown no.	Maher memo
Narran Lakes Nature Reserve	Glossy Ibis	1983	unknown no.	unknown no.	Maher memo
Narran Lakes Nature Reserve	Straw necked Ibis	1983		200000	Maher memo
Narran Lakes Nature Reserve	Australian Pelican	1984	unknown no.	unknown no.	Beruldsen, 1985
Narran Lakes Nature Reserve	Australian White Ibis	1984	unknown no.	unknown no.	Beruldsen, 1985

Site	species breeding	breeding events	number birds	number nests	reference/s
Narran Lakes Nature Reserve	Darter	1984	unknown no.	unknown no.	Beruldsen, 1985
Narran Lakes Nature Reserve	Glossy Ibis	1984	unknown no.	unknown no.	Beruldsen, 1985
Narran Lakes Nature Reserve	Great Cormorant	1984	unknown no.	unknown no.	Beruldsen, 1985
Narran Lakes Nature Reserve	Great Cormorant	1984	unknown no.	unknown no.	Beruldsen, 1985
Narran Lakes Nature Reserve	Intermediate Egret	1984	unknown no.	unknown no.	Beruldsen, 1985
Narran Lakes Nature Reserve	Little Black Cormorant	1984	unknown no.	unknown no.	Beruldsen, 1985
Narran Lakes Nature Reserve	Little Egret	1984	unknown no.	unknown no.	Beruldsen, 1985
Narran Lakes Nature Reserve	Little Pied Cormorant	1984	unknown no.	unknown no.	Beruldsen, 1985
Narran Lakes Nature Reserve	Nankeen Night Heron	1984	unknown no.	unknown no.	Beruldsen, 1985
Narran Lakes Nature Reserve	Pied Cormorant	1984	unknown no.	unknown no.	Beruldsen, 1985
Narran Lakes Nature Reserve	Pied Cormorant	1984	unknown no.	unknown no.	Beruldsen, 1985
Narran Lakes Nature Reserve	Royal Spoonbill	1984	unknown no.	unknown no.	Beruldsen, 1985
Narran Lakes Nature Reserve	White faced heron	1984	unknown no.	unknown no.	Beruldsen, 1985
Narran Lakes Nature Reserve	White necked heron	1984	unknown no.	unknown no.	Beruldsen, 1985
Narran Lakes Nature Reserve	Straw necked Ibis	1984	unknown no.	unknown no.	Beruldsen, 1985
Narran Lakes Nature Reserve	Musk Duck	1988	40	20	Maher memo
Narran Lakes Nature Reserve	Black Fronted Dotterel	1988	100	50	Maher memo
Narran Lakes Nature Reserve	Blue billed Duck	1988	100	50	Maher memo
Narran Lakes Nature Reserve	Red Kneed Dotterel	1988	100	50	Maher memo
Narran Lakes Nature Reserve	Dusky Moorhen	1988	120	60	Maher memo
Narran Lakes Nature Reserve	Freckled Duck	1988	120	60	Maher memo
Narran Lakes Nature Reserve	Purple Swamphen	1988	120	60	Maher memo
Narran Lakes Nature Reserve	Darter	1988	240	120	Maher memo

Site	species breeding	breeding events	number birds	number nests	reference/s
Narran Lakes Nature Reserve	Pacific Black Duck	1988	240	120	Maher memo
Narran Lakes Nature Reserve	Pied Stilt	1988	240	120	Maher memo
Narran Lakes Nature Reserve	Australian Wood Duck	1988	240	120	Maher memo
Narran Lakes Nature Reserve	Australian Pelican	1988	600	300	Smith 1993
Narran Lakes Nature Reserve	Black Swan	1988	600	300	Maher memo
Narran Lakes Nature Reserve	Eurasian Coot	1988	600	300	Maher memo
Narran Lakes Nature Reserve	Grey Teal	1988	600	300	Maher memo
Narran Lakes Nature Reserve	Hardhead	1988	600	300	Maher memo
Narran Lakes Nature Reserve	Little Black Cormorant	1988	600	300	Maher memo
Narran Lakes Nature Reserve	Little Pied Cormorant	1988	600	300	Maher memo
Narran Lakes Nature Reserve	Pink eared Duck	1988	600	300	Maher memo
Narran Lakes Nature Reserve	Royal Spoonbill	1988	600	300	Smith 1993
Narran Lakes Nature Reserve	Black tailed Native Hen	1988	1100	550	Maher memo
Narran Lakes Nature Reserve	Nankeen Night Heron	1988	1100	550	Maher memo
Narran Lakes Nature Reserve	Australian White Ibis	1988	2000	1000	Maher memo
Narran Lakes Nature Reserve	Glossy Ibis	1988	5800	2900	Maher memo
Narran Lakes Nature Reserve	Straw necked Ibis	1988	142000	71000	Maher memo
Narran Lakes Nature Reserve	Intermediate Egret	1989	20	10	Smith 1993
Narran Lakes Nature Reserve	Little Pied Cormorant	1989	120	60	Maher memo
Narran Lakes Nature Reserve	Australian White Ibis	1989	180	90	Maher memo
Narran Lakes Nature Reserve	Great Egret	1989	300	150	Maher memo
Narran Lakes Nature Reserve	Little Black Cormorant	1989	400	200	Maher memo
Narran Lakes Nature Reserve	Glossy Ibis	1989	720	360	Smith 1993

Site	species breeding	breeding events	number birds	number nests	reference/s
Narran Lakes Nature Reserve	Straw necked Ibis	1989	17000	8500	Magrath, 1991
Narran Lakes Nature Reserve	Black Swan	1989	unknown no.	unknown no.	Maher memo
Narran Lakes Nature Reserve	Eurasian Coot	1989	unknown no.	unknown no.	Maher memo
Narran Lakes Nature Reserve	Freckled Duck	1989	unknown no.	unknown no.	Maher memo
Narran Lakes Nature Reserve	Grey Teal	1989	unknown no.	unknown no.	Maher memo
Narran Lakes Nature Reserve	Hardhead	1989	unknown no.	unknown no.	Maher memo
Narran Lakes Nature Reserve	Pacific Black Duck	1989	unknown no.	unknown no.	Maher memo
Narran Lakes Nature Reserve	Pink eared Duck	1989	unknown no.	unknown no.	Maher memo
Narran Lakes Nature Reserve	Australian Wood Duck	1989	unknown no.	unknown no.	Maher memo
Narran Lakes Nature Reserve	Intermediate Egret	1990	10	5	Smith 1993
Narran Lakes Nature Reserve	Australiasian Shoveller	1990	20	10	Maher memo
Narran Lakes Nature Reserve	Red Kneed Dotterel	1990	20	10	Maher memo
Narran Lakes Nature Reserve	Great Egret	1990	40	20	Maher memo
Narran Lakes Nature Reserve	Eurasian Coot	1990	100	50	Maher memo
Narran Lakes Nature Reserve	Great Cormorant	1990	100	50	Smith 1993
Narran Lakes Nature Reserve	Great Cormorant	1990	100	50	Maher memo
Narran Lakes Nature Reserve	Hardhead	1990	100	50	Maher memo
Narran Lakes Nature Reserve	Australian Wood Duck	1990	100	50	Maher memo
Narran Lakes Nature Reserve	Yellow billed Spoonbill	1990	100	50	Maher memo
Narran Lakes Nature Reserve	Australian Pelican	1990	200	100	Smith 1993
Narran Lakes Nature Reserve	Black Swan	1990	200	100	Maher memo
Narran Lakes Nature Reserve	Darter	1990	200	100	Maher memo
Narran Lakes Nature Reserve	Grey Teal	1990	300	150	Maher memo

Site	species breeding	breeding events	number birds	number nests	reference/s
Narran Lakes Nature Reserve	Pacific Black Duck	1990	300	150	Maher memo
Narran Lakes Nature Reserve	Pink eared Duck	1990	300	150	Maher memo
Narran Lakes Nature Reserve	Little Black Cormorant	1990	400	200	Maher memo
Narran Lakes Nature Reserve	Little Pied Cormorant	1990	400	200	Maher memo
Narran Lakes Nature Reserve	Royal Spoonbill	1990	400	200	Smith 1993
Narran Lakes Nature Reserve	Nankeen Night Heron	1990	1000	500	Maher memo
Narran Lakes Nature Reserve	Australian White Ibis	1990	2000	1000	Maher memo
Narran Lakes Nature Reserve	Straw necked Ibis	1990	100000	50000	Smith 1993
Narran Lakes Nature Reserve	Black Fronted Dotterel	1990	unknown no.	unknown no.	Maher memo
Narran Lakes Nature Reserve	Black tailed Native Hen	1990	unknown no.	unknown no.	Maher memo
Narran Lakes Nature Reserve	Masked Lapwing	1990	unknown no.	unknown no.	Maher memo
Narran Lakes Nature Reserve	Pacific Heron	1990	unknown no.	unknown no.	Maher memo
Narran Lakes Nature Reserve	Black fronted plover	1990			Smith 1993
Narran Lakes Nature Reserve	Great Egret	1996	100	50	Ley, 1998a
Narran Lakes Nature Reserve	Royal Spoonbill	1996	300	150	Ley, 1998a
Narran Lakes Nature Reserve	Darter	1996	400	200	Ley, 1998a
Narran Lakes Nature Reserve	Great Cormorant	1996	800	400	Ley, 1998a
Narran Lakes Nature Reserve	Australian White Ibis	1996	1000	500	Ley, 1998a
Narran Lakes Nature Reserve	Pied Cormorant	1996	1500	750	Ley, 1998a
Narran Lakes Nature Reserve	Little Black Cormorant	1996	5000	2500	Ley, 1998a
Narran Lakes Nature Reserve	Straw necked Ibis	1996	204000	102000	Ley, 1998a
Narran Lakes Nature Reserve	Australian Wood Duck	1996	unknown no.	unknown no.	Ley, 1998a
Narran Lakes Nature Reserve	Banded Lapwing	1996	unknown no.	unknown no.	Ley, 1998a

Site	species breeding	breeding events	number birds	number nests	reference/s
Narran Lakes Nature Reserve	Black Swan	1996	unknown no.	unknown no.	Ley, 1998a
Narran Lakes Nature Reserve	Black fronted Dotterel	1996	unknown no.	unknown no.	Ley, 1998a
Narran Lakes Nature Reserve	Black winged Stilt	1996	unknown no.	unknown no.	Ley, 1998a
Narran Lakes Nature Reserve	Freckled Duck	1996	unknown no.	unknown no.	Ley, 1998a
Narran Lakes Nature Reserve	Glossy Ibis	1996	unknown no.	unknown no.	Ley, 1998a
Narran Lakes Nature Reserve	Great crested grebe	1996	unknown no.	unknown no.	Ley, 1998a
Narran Lakes Nature Reserve	Hoary headed grebe	1996	unknown no.	unknown no.	Ley, 1998a
Narran Lakes Nature Reserve	Marsh Sandpiper	1996	unknown no.	unknown no.	Ley, 1998a
Narran Lakes Nature Reserve	Masked Lapwing	1996	unknown no.	unknown no.	Ley, 1998a
Narran Lakes Nature Reserve	Pink eared Duck	1996	unknown no.	unknown no.	Ley, 1998a
Narran Lakes Nature Reserve	Red capped Plover	1996	unknown no.	unknown no.	Ley, 1998a
Narran Lakes Nature Reserve	Red kneed Dotterel	1996	unknown no.	unknown no.	Ley, 1998a
Narran Lakes Nature Reserve	Red necked Avocet	1996	unknown no.	unknown no.	Ley, 1998a
Narran Lakes Nature Reserve	Sharp tailed Sandpiper	1996	unknown no.	unknown no.	Ley, 1998a
Narran Lakes Nature Reserve	Yellow billed Spoonbill	1996	unknown no.	unknown no.	Ley, 1998a
Narran Lakes Nature Reserve	Brolga	1997	3		Ley, 1998b
Narran Lakes Nature Reserve	Banded Lapwing	1997	8		Ley, 1998b
Narran Lakes Nature Reserve	Yellow billed Spoonbill	1997	15		Ley, 1998b
Narran Lakes Nature Reserve	Hoary headed grebe	1997	20		Ley, 1998b
Narran Lakes Nature Reserve	Pied Cormorant	1997	80	40	Ley, 1998b
Narran Lakes Nature Reserve	Great Cormorant	1997	100	50	Ley, 1998b
Narran Lakes Nature Reserve	Royal Spoonbill	1997	100	50	Ley, 1998b
Narran Lakes Nature Reserve	Darter	1997	140		Ley, 1998b

Site	species breeding	breeding events	number birds	number nests	reference/s
Narran Lakes Nature Reserve	Straw necked Ibis	1997	2300	1150	Ley, 1998b
Narran Lakes Nature Reserve	Straw necked Ibis	1997	2500	1250	Ley, 1998b
Narran Lakes Nature Reserve	Yellow billed Spoonbill	1998	40	20	Henderson, 1999
Narran Lakes Nature Reserve	Pied Cormorant	1998	80	40	Henderson, 1999
Narran Lakes Nature Reserve	Great Cormorant	1998	100	50	Henderson, 1999
Narran Lakes Nature Reserve	Darter	1998	240	120	Henderson, 1999
Narran Lakes Nature Reserve	Little Black Cormorant	1998	400	200	Henderson, 1999
Narran Lakes Nature Reserve	Little Pied Cormorant	1998	1000	500	Henderson, 1999
Narran Lakes Nature Reserve	Royal Spoonbill	1998	3000	1500	Henderson, 1999
Narran Lakes Nature Reserve	Glossy Ibis	1998	5000	0	Henderson, 1999
Narran Lakes Nature Reserve	Australian White Ibis	1998	30000	15000	Henderson, 1999
Narran Lakes Nature Reserve	Straw necked Ibis	1998	100000	50000	Henderson, 1999
Narran Lakes Nature Reserve	Australiasian Grebe	1998	unknown no.	unknown no.	Henderson, 1999
Narran Lakes Nature Reserve	Australiasian Shoveller	1998	unknown no.	unknown no.	Henderson, 1999
Narran Lakes Nature Reserve	Banded Lapwing	1998	unknown no.	unknown no.	Henderson, 1999
Narran Lakes Nature Reserve	Black Fronted Dotterel	1998	unknown no.	unknown no.	Henderson, 1999
Narran Lakes Nature Reserve	Black Swan	1998	unknown no.	unknown no.	Henderson, 1999
Narran Lakes Nature Reserve	Black tailed Native Hen	1998	unknown no.	unknown no.	Henderson, 1999
Narran Lakes Nature Reserve	Black winged Stilt	1998	unknown no.	unknown no.	Henderson, 1999
Narran Lakes Nature Reserve	Eurasian Coot	1998	unknown no.	unknown no.	Henderson, 1999
Narran Lakes Nature Reserve	Grey Teal	1998	unknown no.	unknown no.	Henderson, 1999
Narran Lakes Nature Reserve	Hardhead	1998	unknown no.	unknown no.	Henderson, 1999
Narran Lakes Nature Reserve	Masked Lapwing	1998	unknown no.	unknown no.	Henderson, 1999

Site	species breeding	breeding events	number birds	number nests	reference/s
Narran Lakes Nature Reserve	Pink eared Duck	1998	unknown no.	unknown no.	Henderson, 1999
Narran Lakes Nature Reserve	Plumed Whistling Duck	1998	unknown no.	unknown no.	Henderson, 1999
Narran Lakes Nature Reserve	Red Kneed Dotterel	1998	unknown no.	unknown no.	Henderson, 1999
Narran Lakes Nature Reserve	Red necked Avocet	1998	unknown no.	unknown no.	Henderson, 1999
Narran Lakes Nature Reserve	Whiskered Tern	1998	unknown no.	unknown no.	Henderson, 1999
Narran Lakes Nature Reserve	Australian Wood Duck	1998	unknown no.	unknown no.	Henderson, 1999
Narran Lakes Nature Reserve	Darter	1999	40	20	Henderson, 1999
Narran Lakes Nature Reserve	Great Cormorant	1999	100	50	Henderson, 1999
Narran Lakes Nature Reserve	Great Cormorant	1999	100	50	Henderson, 1999
Narran Lakes Nature Reserve	Yellow billed Spoonbill	1999	100		Ley, 2003
Narran Lakes Nature Reserve	Pied Cormorant	1999	148	74	Henderson, 1999
Narran Lakes Nature Reserve	Banded Lapwing	1999	unknown no.	unknown no.	Henderson, 1999
Narran Lakes Nature Reserve	Black winged Stilt	1999	unknown no.	unknown no.	Henderson, 1999
Narran Lakes Nature Reserve	Masked Lapwing	1999	unknown no.	unknown no.	Henderson, 1999
Narran Lakes Nature Reserve	Red capped Plover	1999	unknown no.	unknown no.	Henderson, 1999
Narran Lakes Nature Reserve	Royal Spoonbill	2000	383	191	Cawthorne 2001
Narran Lakes Nature Reserve	Straw necked Ibis	2000	unknown no.	unknown no.	Kingsford pers. comm
Narran Lakes Nature Reserve	Yellow billed Spoonbill	2000		5	Ley, 2003
Narran Lakes Nature Reserve	Banded Lapwing	2001			Ley, 2003
Narran Lakes Nature Reserve	Australian White Ibis	2008	1000	500	Brandis, 2008
Narran Lakes Nature Reserve	Glossy Ibis	2008	1000	500	Brandis, 2008
Narran Lakes Nature Reserve	Straw necked Ibis	2008	140000	74000	Brandis, 2008
Narran Lakes Nature Reserve	Eurasian Coot	2008	unknown no.	unknown no.	Brandis, 2008

Site	species breeding	breeding events	number birds	number nests	reference/s
Narran Lakes Nature Reserve	Darter	2008	unknown no.	unknown no.	Brandis, 2008
Narran Lakes Nature Reserve	Freckled Duck	2008	unknown no.	unknown no.	Brandis, 2008
Narran Lakes Nature Reserve	Great crested grebe	2008	unknown no.	unknown no.	Brandis, 2008
Narran Lakes Nature Reserve	Grey Teal	2008	unknown no.	unknown no.	Brandis, 2008
Narran Lakes Nature Reserve	Gull billed tern	2008	unknown no.	unknown no.	Brandis, 2008
Narran Lakes Nature Reserve	Hoary headed grebe	2008	unknown no.	unknown no.	Brandis, 2008
Narran Lakes Nature Reserve	Musk Duck	2008	unknown no.	unknown no.	Brandis, 2008
Narran Lakes Nature Reserve	Nankeen Night Heron	2008	unknown no.	unknown no.	Brandis, 2008
Narran Lakes Nature Reserve	Pacific Black Duck	2008	unknown no.	unknown no.	Brandis, 2008
Narran Lakes Nature Reserve	Pied Cormorant	2008	unknown no.	unknown no.	Brandis, 2008
Narran Lakes Nature Reserve	Pink eared Duck	2008	unknown no.	unknown no.	Brandis, 2008
Narran Lakes Nature Reserve	Plumed Whistling Duck	2008	unknown no.	unknown no.	Brandis, 2008
Narran Lakes Nature Reserve	Royal Spoonbill	2008	unknown no.	unknown no.	Brandis, 2008
Narran Lakes Nature Reserve	Whiskered Tern	2008	unknown no.	unknown no.	Brandis, 2008
Narran Lakes Nature Reserve	Australian Wood Duck	2008	unknown no.	unknown no.	Brandis, 2008
Narran Lakes Nature Reserve	Straw necked Ibis	2010	unknown no.	10681	OEH API – J Spencer
Narran Lakes Nature Reserve	Egrets	2010	unknown no.	unknown no.	OEH API – J Spencer
Narran Lakes Nature Reserve	Straw necked Ibis	2010	unknown no.	13303	OEH API – J Spencer
Narran Lakes Nature Reserve	Australian White Ibis	2010	unknown no.	unknown no.	OEH API – J Spencer
Narran Lakes Nature Reserve	Cormorants	2010	unknown no.	3000	P. Terrill pers comm
Narran Lakes Nature Reserve	Egrets	2010	unknown no.	unknown no.	OEH API – J Spencer
Narran Lakes Nature Reserve	Royal Spoonbill	2010	unknown no.	unknown no.	OEH API – J Spencer
Narran Lakes Nature Reserve	Yellow billed Spoonbill	2010	unknown no.	unknown no.	OEH API – J Spencer

Site	species breeding	breeding events	number birds	number nests	reference/s
Narran Lakes Nature Reserve	Straw necked Ibis	2010	unknown no.	6651	OEH API – J Spencer
Narran Lakes Nature Reserve	Australian White Ibis	2010	unknown no.	unknown no.	OEH API – J Spencer
Narran Lakes Nature Reserve	Cormorants	2010	unknown no.	unknown no.	OEH API – J Spencer
Narran Lakes Nature Reserve	Egrets	2010	unknown no.	unknown no.	OEH API – J Spencer
Narran Lakes Nature Reserve	Straw necked Ibis	2011	unknown no.	14367	OEH API – J Spencer
Narran Lakes Nature Reserve	Australian White Ibis	2011	unknown no.	308	OEH API - Jspencer
Narran Lakes Nature Reserve	Egrets	2011	unknown no.	227	OEH API - Jspencer
Narran Lakes Nature Reserve	Royal Spoonbill	2011	unknown no.	1	OEH API - Jspencer
Narran Lakes Nature Reserve	Straw necked Ibis	2012	unknown no.	131442	OEH API - Jspencer
Narran Lakes Nature Reserve	Australian White Ibis	2012	unknown no.	631	OEH API - Jspencer
Narran Lakes Nature Reserve	Cormorants	2012	unknown no.	1174	OEH API - Jspencer
Narran Lakes Nature Reserve	Egrets	2012	unknown no.	2905	OEH API - Jspencer
Narran Lake	Australian Pelican	1991	5000	2500	Smith 1993
Narran Lake	Straw necked Ibis	1991	500	250	Smith 1993
Narran Lake	Australian Pelican	1996	1000	500	Ley, 1998a
Narran Lake	Straw necked Ibis	1996	unknown no.	500	Ley, 1998a
Narran Lake	Royal Spoonbill	1996		unknown no.	Ley, 1998a
Narran Lake	Australian White Ibis	1998	20	10	Henderson, 1999
Narran Lake	Darter	1998	30	15	Henderson, 1999
Narran Lake	Royal Spoonbill	1998	450	225	Henderson, 1999
Narran Lake	Royal Spoonbill	1998	480	240	Henderson, 1999
Narran Lake	Black Swan	1998	1000	500	Henderson, 1999
Narran Lake	Australian Pelican	1998	2300	1150	Henderson, 1999
Narran Lake	Straw necked Ibis	2010	unknown no.	6029	OEH API - Jspencer
Narran Lake	Australian White Ibis	2012	unknown no.	236	OEH API – J Spencer
Narran Lake	Cormorants	2012	unknown no.	10045	OEH API – J Spencer
Narran Lake	Royal Spoonbill	2012	unknown no.	1635	OEH API – J Spencer
Narran Lake	Straw necked Ibis	2012	unknown no.	21410	OEH API – J Spencer

Appendix C Site specific ecological targets for Narran Lakes, Lower Balonne and Barwon-Darling upstream of Menindee

Narran Lakes (ref: Assessment of environmental water requirements for the proposed Basin Plan: Narran Lakes; MDBA 2012)

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 Provide a flow regime which supports recruitment opportunities for a range of	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
	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)

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	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)

Lower Balonne (ref: Assessment of environmental water requirements for the proposed Basin Plan: Lower Balonne; MDBA 2012)

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 • Provide a flow regime which supports 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	Protecting the water-dependent ecosystems and their vital habitat requires retaining the current state of the wetlands and the surrounding vegetation. Coolibah – Black Box Woodland of the northern riverine plains in the Darling Riverine Plains and Brigalow Belt South bioregions is listed as Endangered Ecological Community under the *Threatened Species Conservation Act* 1995. Coolibah is typically the dominant tree species in these woodlands and may occur in association with a wide range of other species including river cooba (*Acacia stenophylla*), black box and river red gum (NSW Scientific Committee 2011). It is common for a dense understorey of lignum to also form in these Woodland communities (Hunter 2005). Coolibah-Black Box Woodland provides habitat features important to a range of fauna (NSW Scientific Committee 2011). These features include grassy understorey, patches of thick regenerating *Eucalyptus* saplings and large hollow bearing trees (NSW Scientific Committee 2011). The Lower Balonne has high ecological and hydrological connectivity to the Ramsar-listed Narran Lakes Nature Reserve which is as an important site for colonial waterbird breeding. The link between waterbird breeding and inundation of habitat which provides foraging and nesting opportunities is relatively well understood. The broader Lower Balonne floodplain is likely to provide foraging habitats and in doing so supports major bird breeding events in the Narran Lakes system. 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 watercourses and their associated floodplain provides for the exchange of carbon and nutrients (Thoms 2003). The connections are considered essential for the functioning and integrity of floodplain-river ecosystems. The maintenance of natural patterns of longitudinal and lateral connectivity is essential to the viability of populations of many aquatic species (Bunn and Arthington 2002). Vital habitat within the Lower Balonne includes in-channel waterholes and billabongs that act as refugia during drought. The use of drought refugia by aquatic organisms is often the key to the survival of population stocks and strongly influences the capacity of populations to recover when the drought breaks and connectivity is restored, such as endangered fish and invertebrate species (Lake 2003).

Barwon-Darling River upstream of Menindee Lakes (ref: Assessment of environmental water requirements for the proposed Basin Plan: Barwon-Darling River upstream of Menindee Lakes; MDBA 2012

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 Barwon-Darling provides flows to the important Talyawalka Anabranch wetland area. The system is made up of a series of braided channels across the floodplain, interspersed by a series of intermittent wet and dry lakebeds and supports large areas of black box (*Eucalyptus largiflorens*) and river red gum (*Eucalyptus camaldulensis*) (Department of the Environment, Water, Heritage and the Arts 2010). Kingsford et.al (1997) identified Poopelloe Lake, Talyawalka Creek and Pelican Lake within the Teryaweynya system as well as the Darling River floodplain near Louth are known or predicted to support 20,000 or more waterbirds. On this basis, a target has been identified that centres on flows to support moderate to large breeding events by colonial nesting waterbirds. The Barwon-Darling River upstream of Menindee Lakes is recognised as containing vital habitat for native fish populations including vulnerable and endangered species such as Murray cod (*Maccullochella peelii peelii*) and silver perch (*Bidyanus bidyanus*). Investigations undertaken at various locations in the Murray–Darling Basin indicate that flow patterns and variability are important for native fish and flows are linked to parts of the life cycle of various species. For example: • a number of fish species, such as golden perch (*Macquaria ambigua*) and silver perch, require flow pulses or floods for spawning (Humphries *et al.* 1999); • monitoring has shown that flows are an important factor in the larval survivorship and subsequent recruitment of Murray cod (Cheshire and Ye 2008); • connectivity between the main river and adjacent wetlands, anabranches and still water habitats provided by increased flows are essential for larvae and juveniles of species such as flathead gudgeons *(Philypnodon grandiceps)* and Australian smelt *(Retropinna semoni)*, which require high concentrations of small prey to feed on and develop (Humphries *et al.* 1999). The natural morphology of the Barwon-Darling system includes deep channels, deep pool areas, suspended load depositional 'benches', higher floodplain 'benches', braided channels, terminal wetland complexes, gravel beds and riffle zones (NSW Department of Primary Industries 2007). In addition the adjacent floodplains contain an extensive range of floodrunners, anabranches and billabongs (SKM 2009). When flooded these areas are considered to be important and work on similar rivers has established they provide large amounts of dissolved organic carbon, which is essential to aquatic ecosystem functioning (Thoms *et al.* 2005).

Appendix D Total waterbird abundance at each wetland in the Talyawalka Ananbranch and Teryaweynya Creek system 1983-2013 (Source: Australian Waterbird Survey).

Survye year	Boolaboolka Lake	Brummeys Lake	Dead Horse Lake	Dennys Lake	Dry Corner Swamp	Eucalyptus Lake	Frenchmans Swamp	North Lake	North Lake Swamp N	Pelican Lake	Ratcatchers Lake	Unnamed Wetlands	Victoria Lake	Wallace Lake	Waterloo Lake
1983					355		3			12546					
1984		575				109				69			7896		5954
1985										340			3038		2262
1986										752			2192		
1988												21			
1990			860			37905				23424					4587
1991	1098	16859				576					144		1369		1093
1992													8829		731
1998						11								2	
1999		398											1650		
1989												45			
1990												61			
1991												12			
1995												9			
1999												652			
2000		786		3108		582									
2001													4821		
2003												437			

2008	0	0	0	0	0	0		0	0	0	0		0		0
2010		0	0	0		0		0	0	0	0		0	0	0
2011						2306							14768		2002
2012		1040	0		0	7482		0	0	232			24922	0	6374
2013		871		290		842				0			291		291

Appendix E Results of analysis of flows associated with waterbird breeding events at key wetland sites (Table 2) in the Condamine-Balonne and Barwon-Darling River Systems

Wetland site	**Year**	**Month**	**Gauge**	**3-Month total flow volume (ML)**	**1-Month total flow volume (ML)**	**%**	**% for month**	**Long term average for month**	**Long term standard deviation for month**	**Long term average monthly flows**	**Long term standard deviation of monthly flows**
Darling River 1 (e)	1983	October	Darling River@ Wilcannia Main Channel	2,553,030	594,197	90.20%	90.80%	191,691	306,058	193,488	297,802
Darling River 1 (e)	1984	October	Darling River@ Wilcannia Main Channel	2,365,960	993,307	96.60%	94.80%	191,691	306,058	193,488	297,802
Darling River 1 (e)	1987	October	Darling River@ Wilcannia Main Channel	85,524	32,715	37.20%	29.50%	191,691	306,058	193,488	297,802
Darling River 1 (e)	1988	October	Darling River@ Wilcannia Main Channel	1,089,035	343,270	81.70%	84.60%	191,691	306,058	193,488	297,802
Darling River 1 (e)	1990	October	Darling River@ Wilcannia Main Channel	2,858,394	996,705	96.70%	95.90%	191,691	306,058	193,488	297,802
Darling River 1 (e)	1998	October	Darling River@ Wilcannia Main Channel	2,767,235	1,265,630	98.40%	98.90%	191,691	306,058	193,488	297,802
Darling River 2 (f)	1984	October	Darling River@ Wilcannia Main Channel	2,365,960	993,307	96.60%	94.80%	191,691	306,058	193,488	297,802
Darling River 2 (f)	1987	October	Darling River@ Wilcannia Main Channel	85,524	32,715	37.20%	29.50%	191,691	306,058	193,488	297,802
Darling River 2 (f)	1991	October	Darling River@ Wilcannia Main Channel	210,036	14,290	24.50%	24.40%	191,691	306,058	193,488	297,802
Darling River 2 (f)	1995	October	Darling River@ Wilcannia Main Channel	1,216	86	6.40%	7.10%	191,691	306,058	193,488	297,802

Wetland site	Year	Month	Gauge	3-Month total flow volume (ML)	1-Month total flow volume (ML)	%	% for month	Long term average for month	Long term standard deviation for month	Long term average monthly flows	Long term standard deviation of monthly flows
Darling River 2 (f)	2000	October	Darling River@ Wilcannia Main Channel	71,410	17,938	27.90%	26.50%	191,691	306,058	193,488	297,802
Talywalka Creek (u)	1983	October	Darling River@ Wilcannia Main Channel	2,553,030	594,197	90.20%	90.80%	191,691	306,058	193,488	297,802
Talywalka Creek (u)	1984	October	Darling River@ Wilcannia Main Channel	2,365,960	993,307	96.60%	94.80%	191,691	306,058	193,488	297,802
Talywalka Creek (u)	1989	October	Darling River@ Wilcannia Main Channel	1,369,290	111,734	61.30%	63.20%	191,691	306,058	193,488	297,802
Unnamed wetland 2 (o)	1988	October	Culgoa River@U/S Collerina - (Birrie River@Talawanta+Culgoa River@Brenda)	11,938	3,490	78.90%	85.20%	4,175	15,939	8,782	72,742
Warrambah Creek Claypan (q)	1990	October	Culgoa River@U/S Collerina - (Birrie River@Talawanta+Culgoa River@Brenda)	57,477	608	69.80%	77.40%	4,175	15,939	8,782	72,742
Warrambah Creek Lagoon (r)	1998	October	Culgoa River@U/S Collerina - (Birrie River@Talawanta+Culgoa River@Brenda)	99,610	72,983	94.20%	99.00%	4,175	15,939	8,782	72,742
Warrambah East Claypan (s)	1998	October	Culgoa River@U/S Collerina - (Birrie	99,610	72,983	94.20%	99.00%	4,175	15,939	8,782	72,742

Wetland site	Year	Month	Gauge	3-Month total flow volume (ML)	1-Month total flow volume (ML)	%	% for month	Long term average for month	Long term standard deviation for month	Long term average monthly flows	Long term standard deviation of monthly flows
			River@Talawanta+Culgoa River@Brenda)								
Balonne River (b)	1983	October	Balonne River @ Hastings	101,056	15,325	75.20%	93.80%	5,710	21,891	56,876	223,944
Unnamed wetland 1 (n)	1998	October	Balonne River @ Hastings	730,840	27,141	80.50%	95.90%	5,710	21,891	56,876	223,944
Kanowna West Swamp (h)	1983	October	Culgoa River@U/S Collerina - (Birrie River@Talawanta+Culgoa River@Brenda)	147,403	12,111	85.60%	91.10%	4,175	15,939	8,782	72,742
Dry Lake (g)	1983	August	Darling River@ Bourke Town	6,857,184	1,243,176	95.10%	95.70%	361,405	1,001,222	287,151	728,613
Dry Lake (g)	1984	February	Darling River@ Bourke Town	1,658,195	730,379	91.10%	88.80%	361,405	1,001,222	287,151	728,613
Dry Lake (g)	1988	November	Darling River@ Bourke Town	556,378	36,038	40.10%	49.20%	361,405	1,001,222	287,151	728,613
Dry Lake (g)	1990	September	Darling River@ Bourke Town	3,231,751	1,691,373	96.70%	95.60%	361,405	1,001,222	287,151	728,613

Wetland site	Year	Month	Gauge	3-Month total flow volume (ML)	1-Month total flow volume (ML)	%	% for month	Long term average for month	Long term standard deviation for month	Long term average monthly flows	Long term standard deviation of monthly flows
Dry Lake (g)	2008	May	Darling River@ Bourke Town	104,013	1,042	6.40%	5.60%	361,405	1,001,222	287,151	728,613
Bungil Creek Lagoon (c)	1984	October	Balonne River @ Weribone	1,062,434	13,813	61.30%	80.40%	18,154	61,124	107,478	366,407
Roma Golf Course Lagoon (l)	1988	October	Balonne River @ Weribone	86,970	11,956	58.60%	78.00%	18,154	61,124	107,478	366,407
Reedy Creek Dam (k)	1994	October	Balonne River @ Weribone	0	0	0.00%	0.00%	18,154	61,124	107,478	366,407
Unnamed wetland 3 (p)	1984	October	Balonne River @ Weribone	1,062,434	13,813	61.30%	80.40%	18,154	61,124	107,478	366,407
Yuleba Creek Waterholes (t)	1987	October	Balonne River @ Weribone	16,005	16,005	61.90%	82.90%	18,154	61,124	107,478	366,407
Ross Creek Dam (m)	1983	October	Maranoa River @ Mitchell	465	1	40.70%	54.50%	235	768	11,563	66,917
Ross Creek Dam (m)	1984	October	Maranoa River @ Mitchell	2,810	8	47.50%	69.60%	235	768	11,563	66,917
Armidillo Station Tank (a)	1984	October	Culgoa River@U/S Collerina - (Birrie River@Talawanta+Culgoa River@Brenda)	0	6,062	81.20%	87.20%	4,175	15,939	8,782	72,742
Charleys Creek Dam (d)	1983	October	Balonne River @ Weribone	186,643	41,799	73.40%	92.60%	18,154	61,124	107,478	366,407

Wetland site	Year	Month	Gauge	3-Month total flow volume (ML)	1-Month total flow volume (ML)	%	% for month	Long term average for month	Long term standard deviation for month	Long term average monthly flows	Long term standard deviation of monthly flows
Charleys Creek Dam (d)	1997	October	Balonne River @ Weribone	11,316	11,316	56.90%	75.60%	18,154	61,124	107,478	366,407
Narran Lake (i)	1978	October	Narran River @ Wilbby Wilby	73,674	16,207	83.30%	95.90%	2,685	9,535	11,828	31,285
Narran Lake (i)	1991	April	Narran River @ Wilbby Wilby	0	0	0.00%	0.00%	10,197	20,832	11,828	31,285
Narran Lake (i)	1996	February	Narran River @ Wilbby Wilby	229,011	95,871	96.10%	89.70%	25,488	47,005	11,828	31,285
Narran Lake (i)	1998	October	Narran River @ Wilbby Wilby	169,914	60,600	93.70%	100.00%	2,685	9,535	11,828	31,285
Narran Lake (i)	2010	May	Narran River @ Wilbby Wilby	156,260	1,016	64.70%	72.00%	11,899	31,730	11,828	31,285
Narran Lake (i)	2012	March	Narran River @ Wilbby Wilby	228,057	48,945	91.90%	77.00%	25,167	40,169	11,828	31,285
Narran Lake Nature Reserve (j)	1971	March	Narran River @ Wilbby Wilby	439,959	144,763	98.30%	97.90%	25,167	40,169	11,828	31,285
Narran Lake Nature Reserve (j)	1972	February	Narran River @ Wilbby Wilby	228,057	48,945	91.90%	86.10%	25,488	47,005	11,828	31,285
Narran Lake Nature Reserve (j)	1974	March	Narran River @ Wilbby Wilby	339,841	60,681	93.90%	81.20%	25,167	40,169	11,828	31,285
Narran Lake Nature Reserve (j)	1976	March	Narran River @ Wilbby Wilby	410,175	146,744	98.60%	100.00%	25,167	40,169	11,828	31,285

Wetland site	Year	Month	Gauge	3-Month total flow volume (ML)	1-Month total flow volume (ML)	%	% for month	Long term average for month	Long term standard deviation for month	Long term average monthly flows	Long term standard deviation of monthly flows
Narran Lake Nature Reserve (j)	1978	October	Narran River @ Wilbby Wilby	73,674	16,207	83.30%	95.90%	2,685	9,535	11,828	31,285
Narran Lake Nature Reserve (j)	1981	March	Narran River @ Wilbby Wilby	54,338	33,591	89.50%	72.90%	25,167	40,169	11,828	31,285
Narran Lake Nature Reserve (j)	1983	July	Narran River @ Wilbby Wilby	527,552	198,834	99.80%	100.00%	7,670	29,553	11,828	31,285
Narran Lake Nature Reserve (j)	1984	March	Narran River @ Wilbby Wilby	119,831	24,886	87.30%	70.80%	25,167	40,169	11,828	31,285
Narran Lake Nature Reserve (j)	1988	June	Narran River @ Wilbby Wilby	259,628	12,287	81.70%	88.00%	10,440	36,802	11,828	31,285
Narran Lake Nature Reserve (j)	1989	June	Narran River @ Wilbby Wilby	167,944	43,776	90.70%	92.00%	10,440	36,802	11,828	31,285
Narran Lake Nature Reserve (j)	1990	May	Narran River @ Wilbby Wilby	133,383	133,383	97.80%	98.00%	11,899	31,730	11,828	31,285
Narran Lake Nature Reserve (j)	1996	February	Narran River @ Wilbby Wilby	229,011	95,871	96.10%	89.70%	25,488	47,005	11,828	31,285
Narran Lake Nature Reserve (j)	1997	March	Narran River @ Wilbby Wilby	124,522	98,793	96.60%	93.70%	25,167	40,169	11,828	31,285
Narran Lake Nature Reserve (j)	1998	October	Narran River @ Wilbby Wilby	169,914	60,600	93.70%	100.00%	2,685	9,535	11,828	31,285
Narran Lake Nature Reserve (j)	1999	April	Narran River @ Wilbby Wilby	141,676	29,248	88.30%	87.70%	10,197	20,832	11,828	31,285

Wetland site	Year	Month	Gauge	3-Month total flow volume (ML)	1-Month total flow volume (ML)	%	% for month	Long term average for month	Long term standard deviation for month	Long term average monthly flows	Long term standard deviation of monthly flows
Narran Lake Nature Reserve (j)	2000	December	Narran River @ Wilbby Wilby	46,639	2,526	70.90%	64.70%	11,473	25,429	11,828	31,285
Narran Lake Nature Reserve (j)	2008	January	Narran River @ Wilbby Wilby	30,226	6,578	78.50%	71.40%	20,220	44,747	11,828	31,285
Narran Lake Nature Reserve (j)	2010	February	Narran River @ Wilbby Wilby	17,981	16,509	83.40%	65.30%	25,488	47,005	11,828	31,285
Narran Lake Nature Reserve (j)	2010	May	Narran River @ Wilbby Wilby	156,260	1,016	64.70%	72.00%	11,899	31,730	11,828	31,285
Narran Lake Nature Reserve (j)	2010	November	Narran River @ Wilbby Wilby	39,163	13,637	82.40%	90.10%	5,159	13,050	11,828	31,285
Narran Lake Nature Reserve (j)	2011	February	Narran River @ Wilbby Wilby	467,920	185,910	99.60%	100.00%	25,488	47,005	11,828	31,285
Narran Lake Nature Reserve (j)	2012	March	Narran River @ Wilbby Wilby	228,057	48,945	91.90%	77.00%	25,167	40,169	11,828	31,285