Review of science behind the waterbird breeding indicator for the Narran Lakes

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Review of the science behind the waterbird breeding indicator for the Narran Lakes

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Cover image: [Clear Lake, Narran Lakes Nature Reserve and nesting Straw-necked Ibis (P. Terrill)]

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Executive summary

Background

This project is funded through the Murray-Darling Basin Authority's (MDBA) Northern Basin Review program. A key element of the Northern Basin Review is to improve the understanding of the water requirements of aquatic ecosystems in the Barwon-Darling and Condamine-Balonne river systems. This includes improving understanding of flow thresholds for waterbird breeding in the Narran Lakes. The Narran Lakes when flooded can provide breeding habitat for some of the largest colonies of Straw-necked Ibis (*Threskiornis spinicollis*) in the Murray-Darling Basin (MDB).

This review documents the outcomes of a collaborative project between the NSW Office of Environment and Heritage (OEH), the Australian National University (ANU), the University of New South Wales (UNSW), the Queensland Department of Science, Information Technology and Innovation (DSITI) and the Queensland Department of Natural Resources and Mines (DNRM).

In 2010 the Integrated Catchment Assessment and Management (iCAM) research group at ANU were commissioned by the NSW Department of Environment, Climate Change and Water (now NSW OEH), to develop a Decision Support System (DSS) for the management of the Narran Lakes. The Narran DSS links outputs from a hydrological model (producing daily time series of inundation area, flow and volume) to Ecological Response Models (ERM). The waterbird breeding ERM in the Narran DSS uses Straw-necked Ibis as the indicator species. Straw-necked Ibis can congregate to breed in large numbers in a relatively small number of wetlands in the MDB. The size of Straw-necked Ibis breeding events has been linked to river flow thresholds which, once met, can trigger extensive flooding of their breeding and feeding habitat. The Straw-necked Ibis models in the Narran DSS are made up of two components: breeding initiation (the probability of nesting occurring and predicted number of nests) which is based primarily on flow thresholds being met; and nest abandonment (the probability that birds will abandon their nests) if the duration of flooding is not maintained.

Project objectives

This project was carried out between February 2015 – May 2016, this timeframe being important as it represented the time available for the MDBA to capture new information to inform the Northern Basin Review.

The broad objectives of this project were to:

- Review the performance of the hydrological model and Straw-necked Ibis breeding ERM within the original Narran DSS using new information and knowledge (Stage 1)
- Improve the ability of the Narran DSS to predict hydrological and ecological outcomes, including the probability of achieving a Straw-necked Ibis breeding event in the Narran Lakes under different water resource development scenarios (Stage 2)
- Further develop science and knowledge about the hydrology and ecology of the Narran Lakes system (Stage 2).

Review of hydrological and Straw-necked Ibis breeding models

In the first part of the project (Stage 1) new hydrological and Straw-necked Ibis breeding information was collated and the performance of the hydrological and ERMs in the Narran DSS were reviewed to support the improvement of the models over a Stage 2 phase. Stage 1 identified that hydrology modelling for the Narran Lakes needed to be upgraded to improve representation of water recession and the distribution of flows between the lakes and the outer floodplain, using new information from the river flow and rainfall gauge network, and inundation mapping from Landsat satellite imagery. To undertake this task, it was necessary to revise the section of the Condamine-Balonne Integrated Quantity-Quality Model (IQQM) that represented the Narran Lakes system (downstream from Wilby Wilby, on the Narran River).

During Stage 1 it was also identified that the flow event definition implemented in the Narran DSS and flow thresholds in the Straw-necked Ibis ERM needed to be revised as the Narran DSS only correctly predicted breeding in 41% of cases (overall model accuracy was 38%) when compared to available breeding records for the 1975-2014 period. Over Stage 2 the input parameters for the Straw-necked Ibis ERM were refined through further analysis of an extended historical breeding and flow record (1971-2014) together with expert opinion to revise the flow event definition and develop flow event-based thresholds that incorporated a seasonality trigger. This information was also used to make recommendations for the MDBA's review of Environmental Water Requirements (EWR) for the Narran Lakes.

In Stage 2, further examination of hydrological information and the Straw-necked Ibis breeding record was used to evaluate the performance of the upgraded IQQM and Narran DSS. The rationale for updating the IQQM and Straw-necked Ibis breeding models are presented in this report. The upgraded Narran DSS was used to evaluate the results of five water resource development scenarios. Recommendations for further development of the models are also presented in this report.

Key findings

- The representation of the Narran Lakes system in IQQM was improved over the Stage 2 project by using multi-delay lags depending on flow rates to route flow from Wilby Wilby (GS422016) to Narran Park (GS422029) on the Narran River and through model calibration against observed flows. Simulation results showed improvement in the representation of river flows at the Wilby Wilby and Narran Park gauges, water levels at Back Lake (GS422034) in the Northern Lakes, and inundated surface area of the Northern Lakes and Narran Lake compared to results from the earlier Rayburg and Thoms (2008) hydrology model.

- Expert workshops and analysis of the historical flow information and Straw-necked Ibis breeding records from 1971-2014 were used over Stage 2 to develop the spatial representation of the IQQM and Narran DSS models and investigate potential triggers for breeding of Straw-necked Ibis including cumulative river flow volumes, flow timing, flow duration and water levels. Through this analysis the flow event definition implemented in the Narran DSS was revised to a start threshold of 100 ML/day at the Wilby Wilby gauge on the Narran River and an end of flow event threshold which coincided with a drop in water level below 120.746 m Australian Height Datum (AHD) at the Back Lake gauge (representing around 1.08 m on the gauge sustained for greater than 10 days). Water levels at the Back Lake gauge represent the filling and drying down of the Northern Lakes which support the largest colonies of Straw-necked Ibis. Overall this revised flow event definition had a high model accuracy for explaining the occurrence of known breeding records.

- Using the updated Straw-necked Ibis breeding record (18 recorded breeding events across 15 flow events in the Narran Lakes Nature Reserve from 1971-2014) the Classification and

Regression Tree (CART) analysis indicated that there was a high probability of breeding when total cumulative flows exceeded 154,000 ML at Wilby Wilby in the first 90 days of the flow event. The analysis also indicated that flows greater than 20,000 ML at Wilby Wilby recorded in the first 10 days of the event may also be an important threshold for Straw-necked Ibis breeding in the Narran Lakes Nature Reserve.

- Further examination of the historical record indicated that large-scale Straw-necked Ibis breeding in the Narran Lakes Nature Reserve could be linked to widespread flooding of the whole Narran Lakes system. There were six flow events where large-scale Straw-necked Ibis breeding (> 50,000 nests) was recorded and both maximum modelled inundated area (16,746 ha ± 10,331) and cumulative flows over the whole event (364,842 ML ± 360,732) were high. This is supported by recent analysis by Thomas *et al.* (2016) which showed that cumulative flows of 250,000 ML at Wilby Wilby resulted in a cumulative inundated area of about 16,600 ha across the Narran Lakes.
- There was a strong effect of season on the timing of breeding with 73% of known Straw-necked Ibis breeding events initiated in Narran Lakes Nature Reserve occurring in the six months between October and March over the 1971-2014 period. Incorporating rainfall in the CART analysis identified local rainfall (recorded at Walgett) may also be a predictor for Straw-necked Ibis breeding. The CART analysis identified a first threshold when cumulative flows over the first 90 days was 154,000 ML (P = 1.00) and a second threshold (contingent on the first), when total rainfall over the first 90 days was greater than 162 mm (P = 0.57).
- Water depth can be an important factor influencing the initiation of breeding and the likely success of Straw-necked Ibis breeding. The most detailed observations of the impact of water levels on the breeding success of Straw-necked Ibis in the Narran Lakes were undertaken in 2008 where a decline of water depth of more than 30 cm over 40 days during chick stage was associated with nest abandonment by Straw-necked Ibis.
- The cumulative flow thresholds identified from the CART analysis, and the identified relationships between the occurrence of breeding and both season and inundation across the Narran Lakes system, were used to update the breeding initiation component of the ERM in the Narran DSS. When the performance of the upgraded Narran DSS was compared to the observed breeding data from 1971-2014, 10 of the 15 observed breeding events had a predicted likelihood of breeding initiation of 0.99 and three were predicted to be marginal events with a likelihood of breeding initiation of 0.43. Two events met the 90 day flow criteria during a sub-optimal time of the year and, consequently, had a lower predicted likelihood of breeding initiation (0.198). This constitutes a much improved performance from that of the 2010 version of the DSS which used a 12 month cumulative flow threshold of more than 100,000 ML.
- The nest abandonment component of the DSS was updated to reflect current conceptual expert understanding and should be considered preliminary. Breeding success and hydrological data would need to be routinely collected during future breeding events to further update the nest abandonment relationships (*see recommendations*).
- The updated models were used to simulate three water recovery scenarios for comparison against the without development and baseline scenarios. Analysis of IQQM outputs by the Narran DSS indicated all three water recovery scenarios increased the total number of flow events compared to baseline conditions. Of the three different water recovery scenarios the MDBA SDL scenario performed the best in terms of total number of flow events above the

154,000 ML cumulative flow threshold over 90 days, with 16 events identified compared to 29 events identified in the without development scenario for the 119 year period.

- The outcomes of the water recovery options for Straw-necked Ibis breeding initiation for the 1895-2014 period (based on total flow events where the probability of breeding was moderate to high (P ≥0.43)), were 49, 54 and 63 flow events, for the existing recovery, Northern Standard and MDBA SDL scenarios, respectively. This was an improvement from the baseline scenario where 45 such flow events were predicted (in comparison to the without development 79 flow events were predicted where the probability of breeding was greater than 0.43).

- For the 1895-2014 modelled period all water recovery scenarios reduced the average interval between defined flow events where a threshold of 154,000 ML was recorded in 90 days at some point during a flow event (from baseline conditions of every 8.5 years to 7.3 years for the existing recovery and Northern Standard scenarios, and 5.6 years under the MDBA SDL scenario). In comparison these conditions would have been met on average every 3.3 years under the without development scenario.

Recommendations

1. Revision of the site specific flow indicators for the Narran Lakes (MDBA 2012) should reconsider specified cumulative inflow volumes, location of hydrological indicator gauges, timing of flows, duration of flooding and interval between events:

    - The trigger inflow volume of 100,000 ML at Wilby Wilby over 12 months should be revised to reflect that the majority of Straw-necked Ibis breeding records in the Narran Lakes Nature Reserve occurred over spring-autumn months and were associated with cumulative flows of at least 154,000 ML required over the first 90 days of a flow event with more than 20,000 ML recorded at Wilby Wilby in the first 10 days.

    - The IQQM re-calibration showed the high performance for the Narran Park gauge. Use of the Narran Park and Back Lake gauges as the source of hydrological information for site specific indicators for the Straw-necked Ibis breeding in the Narran Lakes should be considered in future reviews following the collection of a longer time series of flow and colonial waterbird breeding data.

    - The three month flow period represents a minimum duration of flooding with flows of greater duration more likely to support conditions conducive to successful Straw-necked Ibis breeding and other waterbird species.

    - The current eight-year interval between flow events should be revised to two occasions in an eight year period to provide greater breeding opportunities for Straw-necked Ibis in the Narran Lakes. This recommendation is based on life-history traits of the Straw-necked Ibis and under the assumption that there are also other opportunities for breeding elsewhere in the MDB during the eight year interval.

2. An extended monitoring and evaluation strategy for the Narran Lakes system is needed to support the management of Straw-necked Ibis breeding and wetland vegetation, allow for improved understanding of EWR for the Narran Lakes and further refinement of hydrological, Straw-necked Ibis breeding and vegetation models that underpin the Narran DSS.

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Glossary

AIC	Akaike Information Criterion for measuring the relative quality of statistical models by considering the *goodness of fit* of the model
ANU	Australian National University
ARI	Annual Recurrence Interval
Baseline	Scenario which simulates the development allowed under the current ROP
Basin Plan	The Basin Plan is developed under the *Commonwealth Water Act (2007)* and provides a coordinated approach to water use across the MDB
Bayesian Network	A graphical model that encodes probabilistic relationships among variables
BDL	Baseline Diversions Limit
CART	Classification and Regression Tree analysis
CF	Cumulative Flow
CEWO	Commonwealth Environmental Water Office
CPT	Conditional Probability Tables for Bayesian Networks
ct.accuracy	Model accuracy for the classification tree analysis
ct.precision	Model precision for the classification tree analysis
ct.sensitivity	Model sensitivity for the classification tree analysis
DECCW	NSW Department of Environment, Climate Change and Water (now NSW Office of Environment and Heritage (OEH))
DEM	Digital Elevation Model
DNRM	Queensland Department of Natural Resources and Mines
DPI Water	NSW Department of Primary Industries – Water
DSITI	Queensland Department of Science, Information Technology and Innovation
DSS	Decision Support System
ESLT	Environmentally Sustainable Level of Take
EWR	Environmental Water Requirements
ERM	Ecological Response Model
GL	Gigalitre
GLM	Generalised Linear Modelling
IBI	Inter-Breeding Interval
iCAM	Integrated Catchment Assessment and Management
IQQM	Integrated Quality and Quantity Model
m AHD	Australian Height Datum (metres)
MDBA	Murray-Daring Basin Authority
MDB	Murray-Darling Basin
M&E	Monitoring and Evaluation (Strategy)
MI	Mutual Information statistic
ML	megalitre
NPWS	NSW National Parks and Wildlife Service
NR	Nature Reserve
OEH	NSW Office of Environment and Heritage
Without development	No water extraction (all diversions and storages are turned off in scenario)
ROP	Resource Operations Plan
rt.error	Resubstitution error reported in the regression tree analysis
SD	Standard Deviation
SDL	Sustainable Diversion Limits
SE	Standard Error
SILO	Scientific Information for Land Owners database of historical climate records for Australia
T	Temperature
UNSW	University of New South Wales
WRP	Water Resource Plan
WSE	Water Surface Elevation

1 Introduction

1.1 Environmental water requirements for the Narran Lakes

One of the key requirements of the Basin Plan (*Commonwealth Water Act 2007*) is to establish environmentally sustainable limits on the quantities of surface water and groundwater that may be taken for consumptive use in the Murray-Darling Basin (MDB), termed Sustainable Diversion Limits (SDLs). SDLs are the maximum long–term annual average volumes of water that can be taken from the MDB and they represent an Environmentally Sustainable Level of Take (ESLT) (MDBA 2012).

The Narran Lakes are one of the nine environmental assets the Murray-Darling Basin Authority (MDBA) used to inform the ESLT in the Northern Basin (MDBA 2011). In 2012 the MDBA set ecological targets for the Narran Lakes and documented the Environmental Water Requirements (EWR) using site-specific flow indicators (inflow volumes over a specified period of time). Four of the indicators are primarily based on empirical studies linking flows and vegetation responses, and one is primarily based on a link between gauged flows and colonial waterbird breeding events (MDBA 2012). When flooded the Narran Lakes can support a high diversity of colonial and non-colonially nesting waterbird species, and provide breeding habitat for some of the largest colonies of Straw-necked Ibis (*Threskiornis spinicollis*) in the Northern Basin (Brandis and Bino 2016).

The ecological target for waterbirds in the Narran Lakes focused on providing a flow regime which supports the habitat requirements of waterbirds and was conducive to successful breeding in colonially-nesting waterbirds (MDBA 2012). The MDBA adopted an inflow volume of 100,000 ML over 12 months (at Wilby Wilby (GS442016) on the Narran River, 30 km north of the Narran Lakes) as a threshold for Straw-necked Ibis breeding in the Narran Lakes (MDBA 2012). This annual threshold was identified by Thoms *et al.* (2007) and implemented in a Decision Support System (DSS) for the Narran Lakes developed over 2008-10 (Rayburg and Thoms 2008; ANU Enterprise 2011). The MDBA also specified a flow indicator of 250,000 ML over six months to inundate lignum shrublands throughout the broader Narran Lakes floodplain (MDBA 2012), further supporting waterbird and wetland vegetation habitat requirements.

Most recently the MDBA have been undertaking a review of relevant science underpinning the SDLs for the northern MDB to inform the Northern Basin Review, which included a review of thresholds for Straw-necked Ibis breeding in the Narran Lakes.

1.2 Narran Lakes Decision Support System

In 2010 a DSS for the management of Narran Lakes (the ‘Narran Lakes IBIS DSS’) was prepared for the NSW Office of Environment and Heritage (OEH) (formerly the NSW Department of Environment, Climate Change and Water (DECCW)) by the Integrated Catchment Assessment and Management (iCAM) Centre at the Australian National University (ANU) (ANU Enterprise 2011). The DSS followed on from a prototype DSS developed in 2008 which linked a ‘hydrology-hydraulic’ model of the Narran Lakes system (Rayburg and Thoms 2008) with a knowledge-based Straw-necked Ibis breeding model. Straw-necked Ibis were chosen as the indicator species for waterbird breeding as they breed in response to large river flows and can congregate in large numbers. The size of their breeding events has been linked to river flow thresholds which once met can trigger extensive flooding of their breeding and feeding habitat.

The IBIS DSS linked outputs from the Rayburg and Thoms (2008) hydrological model (producing daily time series of inundation area, flow and volume) to Ecological Response Models (ERMs). The ERMs are Bayesian Networks representing relationships between flows and vegetation species and communities, and waterbird breeding in the wetland system (Merritt *et al.* 2009).

The IBIS DSS approach has been used for three separate wetland systems in the Northern Basin (the Narran Lakes system, the Gwydir Wetlands and Macquarie Marshes) and was designed to capture the best available scientific knowledge to support a systematic approach to exploring wetland management options by comparing current and alternative environmental flow scenarios (Merritt *et al.* 2010). The Narran Lakes IBIS DSS (referred to as the 'Narran DSS' in the remainder of this report) integrates available knowledge on the responses of Straw-necked Ibis and wetland vegetation in the Narran Lakes system to the timing and quantity of water inflows from the Narran River. These knowledge sources included local (wetland specific) and regional (MDB) ecological and hydrological data, and expert understanding.

The Straw-necked Ibis breeding models contained within the Narran DSS are made of up two components: breeding initiation (the probability of nesting occurring and predicted number of nests); and nest abandonment (the probability that birds will abandon their nests). In the Narran DSS one of the major parameters for predicting likelihood of breeding was a cumulative inflow volume of 100,000 ML at Wilby Wilby on the Narran River, calculated from the preceding 12 months. The parameters used to predict the likelihood of birds abandoning their nests were the length of a hydrologic event, the minimum depth of water under nests, maximum day-to-day decreases in Water Surface Elevation (WSE) and the number of 'cold' days during the event (Merritt *et al.* 2009). Further background on the DSS is provided in Section 3.1 and documented in the IBIS DSS final report (ANU Enterprise 2011).

1.3 Project objectives

This review is a collaborative project between NSW OEH, ANU, the University of New South Wales (UNSW), Queensland Department of Science, Information Technology and Innovation (DSITI) and the Queensland Department of Natural Resources and Mines (DNRM) completed over February 2015 – May 2016. This project timeframe was important to support the MDBA's Northern Basin Review. The project was designed to integrate the best available science and expertise from state agencies and university researchers to improve understanding of the patterns of flooding and thresholds for Straw-necked Ibis breeding in the Narran Lakes system.

The overarching objectives of this project were to:

- Review the performance of the hydrological and Straw-necked Ibis breeding models within the 2010 version of the Narran DSS using new information and knowledge
- Improve the ability of the Narran DSS to predict hydrological and ecological outcomes, including the probability of achieving a Straw-necked Ibis breeding event in the Narran Lakes under different water resource development scenarios
- Further develop science and knowledge about the hydrology and ecology of the Narran Lakes system.

Following the release of the 2010 version of the Narran DSS, UNSW and NSW OEH collated information on flow events and Straw-necked Ibis breeding events in the Narran Lakes (Brandis 2010; Brandis *et al.* 2011; Spencer *et al.* 2015a). Additionally, iCAM conducted further analysis of the Narran DSS and implemented a habitat suitability model for Straw-necked Ibis in addition to the breeding response models. DSITI also further developed hydrological modelling for the Narran Lakes section of the Condamine-Balonne Integrated Quantity-Quality Model (IQQM) (DSITIA 2014).

This new information was used in a Stage 1 project in early 2015 to review the original elements of the Narran DSS, specifically the underlying hydrology model and Straw-necked Ibis ERM (Merritt *et al.* 2015). Following this review, potential options to update the IQQM and/or Narran DSS were developed to be considered as part of the Stage 2 project (see Section 2.2). The option selected by the MDBA for Stage 2 included revision of both the hydrological model and Narran DSS with the view that the updated science would also inform re-consideration of the EWR for the Narran Lakes.

Specific outcomes of the Stage 2 project were:

- improved hydrological representation of the Narran Lake system using the updated IQQM (provided by DSITI), specifically the temporal and spatial performance of the model
- improved understanding on flow triggers for the initiation and likely success of Straw-necked Ibis breeding events in the Narran Lakes to support the revision of ERMs in the Narran DSS and review of Narran Lakes EWR
- an upgraded Narran DSS with revised spatial representation, Straw-necked Ibis breeding models and updated interface.

1.4 Scope of this report

This report documents a review of the Narran DSS and identifies key elements that were updated to inform the review of the EWR for Straw-necked Ibis breeding in the Narran Lakes, and management of the Narran Lakes system by State and Commonwealth governments. Specifically, this report documents:

- an assessment of the hydrology and Straw-necked Ibis breeding ecological response models underpinning the 2010 version of the Narran DSS, including testing of the outputs of the IQQM for the Condamine-Balonne system against available inundation mapping and river flow gauge data, and predictions from the Narran DSS against the observed historical flow and Straw-necked Ibis breeding record (Section 3.1)
- a review of available literature on local (Narran) and regional (MDB) information on Straw-necked Ibis responses to flow thresholds (Section 3.2)
- results of workshops with experts in the Narran Lakes hydrology and waterbird ecology to review assumptions in the Straw-necked Ibis ERM and further analysis of the historical flow and breeding record (1971-2014) to improve the Narran DSS and understanding of the evidence, and nature of, relationships between flow indicators and thresholds for Straw-necked Ibis breeding in the Narran Lakes (Sections 3.2-3.3)
- an assessment of outcomes from the DSS for Straw-necked Ibis breeding in the Narran Lakes under five different water resource development scenarios to inform the review of SDLs in the Northern Basin (Section 3.4).

2 Methodology

2.1 Study site: Narran Lakes

The Narran Lakes are a terminal wetland located 75 km north-west of Walgett, NSW, in the northern MDB (Figure 1). The climate of the Narran Lakes system is semi-arid with annual average rainfall being 514 mm (CSIRO 2008). The wetland receives inflows from the Narran River, an eastern distributary of the Lower Balonne system, covering about 27,809 ha consisting of a Northern Lakes region (Clear Lake, Back Lake and Long Arm), a Southern Lake region (Narran Lake) and associated floodplain habitat (Table 1; Figure 1).

In total 54 species of waterbirds have been recorded in the Narran Lakes Nature Reserve since 1971 (Brandis and Bino 2016). Floodplain vegetation in the Narran Lakes mainly consists of large stands of lignum shrublands (*Duma florulenta*) with small patches of common reed (*Phragmites australis*), river cooba (*Acacia stenophylla*), coolibah (*Eucalyptus coolabah*) and river red gum (*Eucalyptus camaldulensis*) which when flooded can provide breeding habitat for large numbers of colonially-nesting waterbirds and waterfowl (Magrath 1991; NSW NPWS 2000; Brandis and Bino 2016). The Northern Lakes were gazetted in the Narran Lake Nature Reserve (26,840 ha) in 1988 (NSW NPWS 2000) and recognised in the Narran Lakes Ramsar Site (8,447 ha) in 1999 due to its significance for a large diversity and number of breeding waterbirds (RIS 1999).

As for other parts of the lower Condamine-Balonne catchment, flows in the Narran River are highly variable among years and when they occur they are of relatively high magnitude for short duration, with intervening years typically consisting of little or no flow (Thoms *et al.* 2002). Large floods typically reach the Narran Lakes after heavy rain in the upper Condamine-Balonne catchment in Queensland. Inflows to the Narran system split between Clear Lake and Narran Lake with Back Lake, Long Arm and the outer floodplain receiving inflows during large flow events via lignum feeder channels (P. Terrill *pers. comm.* 2015). The Narran Lake can fill up to 2 m deep and hold water for up to two years, and Clear Lake fills to 1.5 m and can hold water for 12 months if no further inflows are received after the flood peak (NSW NPWS 2000) (Table 1).

Table 1 Surface area and volume of water stored in each of the major Narran Lakes features (adapted from MDBA 2012). * The estimated water retention time for each wetland feature is calculated for events where no further inflows occur as floodwaters recede.

Feature	**Surface area (ha)**	**Storage volume (ML)**	**Water retention (months)***
Narran Lake	12,290	122,876	15-24
Intervening Storages	1,130	4,035	-
Clear Lake	540	4,476	6-12
Back Lake	130	861	3
Long Arm	150	0.6	2
Narran Floodplains	13,569	13,573	<1
Total	**27,809**	**145,822**	**-**

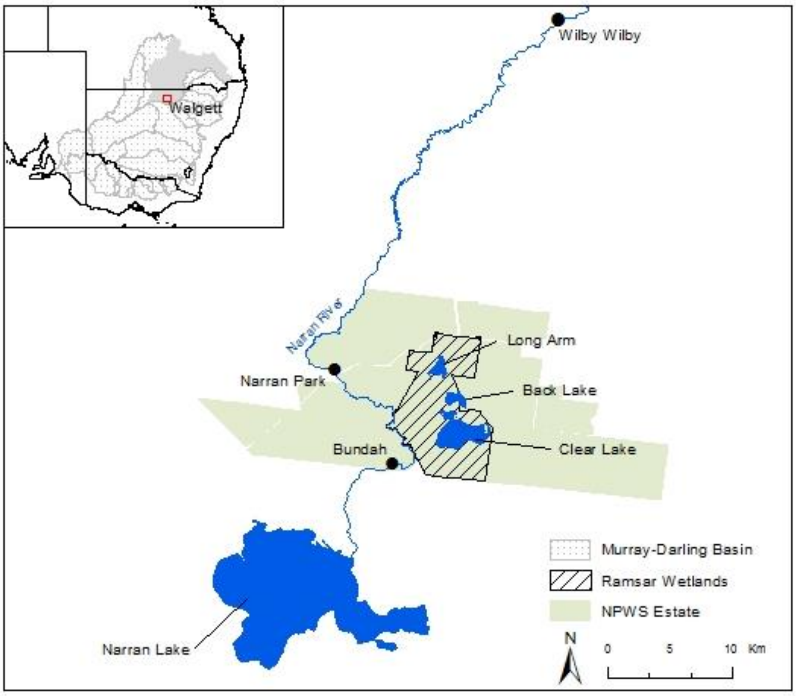


Figure 1 Location of the Narran Lakes in the Condamine-Balonne catchment (shaded in inset showing the MDB) and its major features including the Northern Lakes (Clear Lake, Back Lake and Long Arm), Narran Lake and inflow gauges upstream at Wilby Wilby (GS422016), Narran Park (GS422029) and Bundah (GS422031) on the Narran River.

2.2 Project milestones and key tasks

Several steps were required to review the science behind the Narran Lakes flow indicators for waterbird habitat and breeding (Table 2). Stage 1 was completed over February-June 2015 and comprised of a review of new information and the performance of the Narran DSS and IQQM hydrology model by comparing model outputs with observed inundation mapping, river flow data and Straw-necked Ibis breeding records as detailed in Merritt *et al.* (2015). The focus of Stage 2 was to upgrade the IQQM and Narran DSS through further analysis of new information and expert knowledge. These experts included: Peter Terrill (former NSW OEH Senior Wetland and River Conservation Officer for NSW DECCW), Dr Peter Berney, Dr Jessica Heath, Adam Henderson, Tim Hosking, Debbie Love, Dr Jennifer Spencer, Robert Smith, Rachael Thomas, Dr Li Wen (NSW OEH), Dr Gilad Bino and Dr Kate Brandis (UNSW), Paul Harding, Dr Jonathan Marshall (Queensland DSITI), Dr Shahadat Chowdhury and Neal Foster (NSW DPI Water). Once completed the upgraded models were used to run scenarios to determine the outcomes of different water recovery options for the Narran Lakes.

Table 2 Details employed to complete each milestone and achieve the project objectives for the Narran Lakes waterbird review project.

Stage	Milestone	Objective	Description of activities
1 (February – June 2015)	**1**	Collation of new hydrological and waterbird breeding information	• New river flow data (from 2002 onwards) and mapping of inundated areas in the Narran Lakes using Landsat satellite imagery (1988-2013) (Thomas & Heath 2014) was used assess the performance of the hydrology models and to improve the hydrological modelling representation of the distribution of flows in the Narran Lakes system during Stage 2. • Breeding observations from recent events (in 2008, 2010 and 2012) were compiled (Spencer *et al.* 2015a) for review of the Straw-necked Ibis breeding models currently implemented in the Narran DSS. This information was used to update the historical Straw-necked Ibis breeding record to further investigate breeding and flow relationships in Stage 2.
	2	Review of the performance of the hydrological and ecological response models	Review of ecological response and hydrological models contained in Narran DSS using observation data and hydrological information as detailed in Merritt *et al.* (2015) was completed. This included: • Review of the hydrological model underpinning the Narran DSS including the spatial and temporal representation • Review of the hydrological model inputs to the Straw-necked Ibis breeding models including the use of the annual inflow trigger • Review of the flow event definition (start/end of flows) across the hydrological zones • Review of the ecological response models using observational data and hydrological information including review of habitat condition and fledgling recruitment models against observed data • Review of the spatial representation of Straw-necked Ibis breeding models in the Narran DSS
	3 & 4	Develop a prioritisation framework to evaluate options to upgrade the current DSS	A prioritisation framework was developed for evaluating options for improving the existing ecological response models with the Narran DSS and hydrology modelling. In this milestone a range of options, including their scope, timeframe and implementation costs, were explored for improving the Narran DSS. This approach was used to evaluate whether the Conditional Probability Tables (CPT) in the Narran DSS documented in ANU Enterprise (2011) could be revised using updated information (see Merritt *et al*. 2015).
2 (July 2015 – May 2016)	**5**	Development of a work plan for upgrading the current DSS	Following the Stage 1 process a program of work was developed for improving the Straw-necked Ibis breeding ecological response models and the hydrological model supporting the Narran DSS (see Appendix 1).
	6	Report on elicitation workshop outcomes and findings	Elicitation workshops with experts on the Narran Lakes were held during August 2015 to review the hydrological and Straw-necked Ibis breeding models and improve understanding of the evidence and nature of relationships between flow indicators and thresholds for Straw-necked Ibis breeding (Spencer *et al.* 2015b). Further analysis was conducted during September 2015 to review the flow event definition window which was needed to identify critical start and end thresholds for flow events in the Narran Lakes (see Section 3.2).
	7	Incorporate DSS upgrades and report on DSS performance and results of scenario testing.	The IQQM hydrology model (DSITI 2015) and the Narran DSS were upgraded during August-December 2015 using recommendations from the Stage 1 and 2 project (including the expert workshops) and further analysis of Straw-necked Ibis breeding flow relationships in the Narran Lakes (Section 3.3). The predicted outcomes for Straw-necked Ibis breeding in five scenarios were summarised (Section 3.4) to support the MDBA's Northern Basin Review.

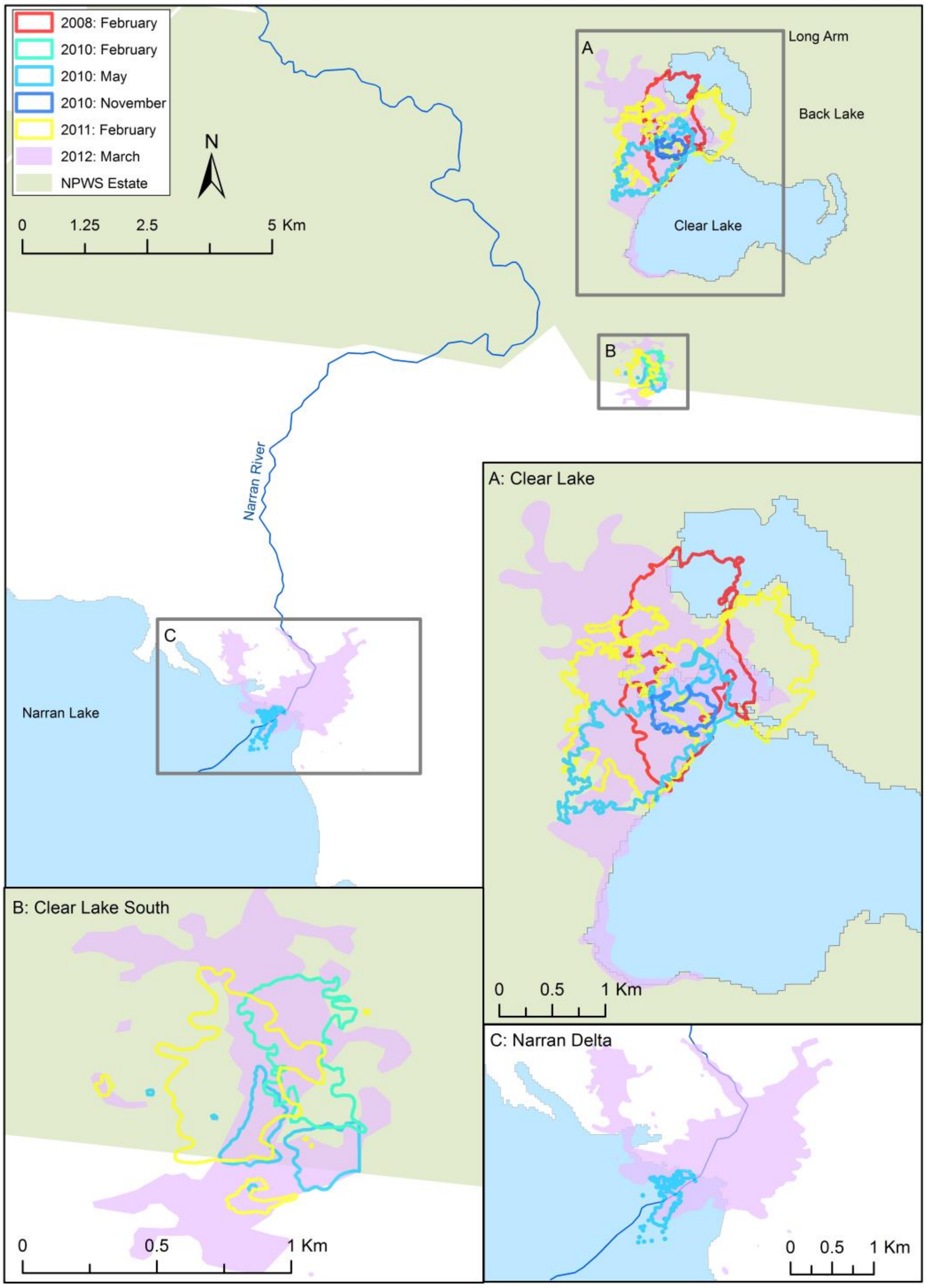
2.2.1 Collate new hydrological and waterbird breeding information

Since completion of original Rayburg and Thoms (2008) hydrology model, the river gauge network has been expanded and automated in parts of the Narran system to provide accessible records of flow at Narran Park (GS422029) from 2002 onwards, the Bundah gauge (GS422031) from 2008 onwards, and Back Lake gauge (GS422034) from 2009 onwards. Inundation mapping from Landsat satellite imagery for the period 1988-2013 (196 maps in total) was also completed by Thomas and Heath (2014) and was used to assess the IQQM performance in representing flooding in the Narran Lakes and the surrounding floodplain during a concurrent project by DSITI in early 2015 (see Section 3.1 for details of the IQQM calibration and performance assessment).

New information from the Narran Lakes and other parts of the MDB were used to review the Straw-necked Ibis breeding models in the Narran DSS (Merritt *et al.* 2015). This included analysis of all known Straw-necked Ibis breeding data (1971-2014) from scientific reports (Beruldsen 1985; Ley 1998a, 1998b; Ley 2003; Brooker 1993), unpublished records (Henderson 1999; 2000; Magrath 1991; Smith 1993; Terrill 2008; 2010; Mulholland 2010; Spencer *et al.* 2015a) and on-ground observations by Brandis *et al.* (2011) during the 2008 breeding event where detailed measures of breeding success were undertaken.

The total numbers of nests were not reliably recorded across all of the breeding records (four records of Straw-necked Ibis breeding had no estimates of total nests) (see Appendix 2), and where recorded the survey method used to estimate total number of nests varied markedly in coverage and timing (including estimates of start and end dates of breeding). There were at least two breeding events where there were several periods of nesting within the same breeding event (e.g. 2007-08; 2010-11) making it difficult to estimate total numbers of nests. Most estimates of colony sizes was based on aerial and/or ground surveys. For breeding events in 2008-12, colony boundaries and estimates of total number of nests were digitised from vertical aerial photography flown from a fixed-wing aircraft with imagery ranging in resolution from 3-6 cm over three colony locations in the Narran Lakes: the main colony location on the western edge of Clear and Back Lakes (‘Clear Lake’), the southern boundary of Clear Lake (‘Clear Lake South’ and also referred to as ‘South Arm’) and the inflow point into the Narran Lakes (‘Narran Delta’) (Figure 2) (Spencer *et al.* 2015a).

Analysis of Straw-necked Ibis breeding relationships was restricted to known nesting (18 breeding records in total) in the Narran Lakes Nature Reserve only. Probable records for 1978 and 1981 (Brooker 1993), and completely abandoned nesting attempts in March-April 1997 (Ley 1998b) and January-February 2010 (Terrill 2010) were excluded from the analysis (see Appendix 2). Records for Straw-necked Ibis breeding were restricted the Nature Reserve, as they were less reliably recorded outside of the reserve (i.e. the Narran Delta), and where records are available for the Narran Delta smaller colonies were observed compared to the Back Lake-Clear Lake colony site (Figure 2; Appendix 2).



Spencer, J., Donley, V., Knight, H., Fontaine, K, and Simpson, S. (2015). Colony boundaries for waterbird breeding events in the Narran Lakes recorded during 2008-2012. Version 1. NSW Office of Environment and Heritage. June 2015.

Figure 2 Location and extent of waterbird breeding colonies in the Narran Lakes system based on interpretation of high resolution photography captured on six occasions from 2008-12. Note that the nesting species in the Clear Lake South region (*inset B*) were primarily egrets and cormorants, while the Clear Lake (*inset A*) and Narran Delta (*inset C*) regions supported colonies of Straw-necked Ibis.

2.2.2 Review performance of hydrological and ecological response models

An assessment of the hydrological and ecological response models implemented within the 2010 version of the Narran DSS was completed in Stage 1. This included testing the performance of the available models against available observed flow and Straw-necked Ibis breeding data (see Section 3.1).

In the Narran DSS the input hydrology data is used to define ecologically relevant flow events and calculate various hydrological parameters (see ANU Enterprise 2011). The input data used to drive the hydrology model are daily time-series of flow discharge at Wilby Wilby (ML/d) on the Narran River, rainfall (m) and evaporation (m). The daily discharge at Wilby Wilby gauge can use observed data (Narran @ Wilby Wilby, 422016, Culgoa Basin, http://realtimedata.water.nsw.gov.au/water.stm) or modelled outputs from IQQM. Rainfall time-series can either be regionally derived (e.g. from Lightning Ridge, Walgett and Brewarrina) or local (e.g. East Mullane) while evaporation estimates were derived from regional data (Rayburg and Thoms 2008; ANU Enterprise 2011) (Table 3). Further information on the hydrological water balance model implemented in the original Narran DSS is detailed in Rayburg and Thoms (2008) and ANU Enterprise (2011).

Since completion of the Narran DSS project in 2010, Queensland DSITI have been reviewing and improving the IQQM for the Condamine-Balonne system which includes representation of the Narran Lakes (DSITIA 2014). The IQQM program was originally developed by the former NSW Department of Land & Water Conservation and the Condamine-Balonne model was developed by Queensland DERM using IQQM. The IQQM was further developed to simulate the flows and diversions in the Condamine-Balonne catchment and has been used to develop the Condamine-Balonne Water Resource Plan (WRP) and Resource Operations Plan (ROP) and used for the CSIRO Sustainable Yield Study (CSIRO 2008) and the Basin Plan. The IQQM representation of the Narran Lakes system was developed based on storage-area relationships derived from a Digital Elevation Model (DEM) constructed for the Narran Ecosystem Science Project (Thoms *et al.* 2007).

Table 3 Summary of inputs and outputs of the hydrological model implemented in the original Narran Lakes DSS (Rayburg and Thoms 2008; ANU Enterprise 2011).

Inputs	**Use in Hydrology model**
River flow	• daily time series at Narran @ Wilby Wilby, 422016, Culgoa Basin
Rainfall	• regional (Lightning Ridge, Walgett and Brewarrina) or local (East Mullane)
Evaporation	• regional data

Outputs	**Use in DSS**
Water surface elevation	• map the extent of inundation in the lakes • illustrate the spatial arrangement of inundation within the Northern and Narran Lakes
Water surface area	• measure the relative magnitude of inundation • indicate the potential inundated habitat area
Volume	• indicator of the magnitude of inundation

2.2.3 Develop a prioritisation framework to evaluate options to upgrade the DSS

Through the review process outlined above (detailed in Merritt *et al.* (2015)) six work plans were identified which ranged from a modest option focused on the development of either the hydrological model (*Option 1*) or DSS (*Option 2*) to full development of both types of models (*Option 6*) that could be implemented in Stage 2. A prioritisation framework was used to evaluate the six options against three criteria:

- *Criteria A:* does the option support the review of EWR as part of the Northern Basin review or in the future?
- *Criteria B:* can the option be implemented by the end of 2015?
- *Criteria C:* is there sufficient data or knowledge available to complete the tasks?

Each of the work plan options was ranked against these criteria (where *1 = worst; 5 = best*) and summed to give an overall benefit score in the prioritisation framework. An estimate of the cost of each option including the proposed in-kind contributions from the project team was also determined. The option of ‘doing nothing’ was not evaluated as the recommendations from the Stage 1 review highlighted that there was scope for significant improvements to the Narran DSS using new information and knowledge to better inform the Northern Basin Review.

Through this prioritisation process two options (*Options 3 and 5*), which included revision of the hydrological modelling and ERMs to allow for improved representation of flooding and thresholds for Straw-necked Ibis breeding in the Narran Lakes, were scored the highest in terms of overall benefit to the Northern Basin Review. *Option 5* differed to *Option 3* only in that it also included the development of a monitoring and evaluation (M&E) strategy for the Narran Lakes. Pursuing *Option 1* (IQQM upgrade only) or *Option 2* (DSS upgrade only) in isolation would not have allowed for improved modelling capability to support the review of EWR for the Narran Lakes. Equally it was felt that additional modelling tasks under *Option 4* and *Option 6* to allow for representation of successive breeding events (or staged breeding) during large floods would have been difficult to complete within the Stage 2 project.

2.2.4 Develop a work plan for upgrading the Narran DSS

Following the prioritisation of the six work plan options in Stage 1, it was recommended that *Option 3* be pursued primarily because the M&E strategy was not needed in the short-term for the review of EWR and the time constraints for Stage 2 would limit the coverage of this strategy which required a detailed joint initiative by State and Commonwealth partner agencies. Stage 2 commenced in August 2015 and was based on a work plan developed during July 2015 (see Appendix 1). The work plan for Stage 2 activities were based on the recommendations and key tasks identified in the Stage 1 project report (Merritt *et al.* 2015).

2.2.5 Report on elicitation workshop outcomes and findings

Preliminary updates to the IQQM and model performance were reviewed using expert elicitation workshops during August 2015 with participants including current and former staff from NSW OEH, MDBA, NSW Department of Primary Industries (DPI) - Water, Queensland DSITI, ANU and UNSW (Spencer *et al.* 2015b). The results of these workshops and further analysis of the historical Straw-necked Ibis breeding record against river flow and rainfall data were used to support the revision of the models during August-December 2015 (see Sections 3.2 – 3.3). Discussions from the workshops were also used to inform the testing of water planning scenarios with the upgraded Narran DSS (see Section 3.4) over the remainder of the Stage 2 project.

Hydrology workshop

Specific tasks as detailed in Appendix 1 and Section 3.3 were undertaken to develop the Narran Lakes reach of the Condamine-Balonne IQQM over the Stage 2 project including:

- a time series of inundation extents derived from 117 Landsat image dates (1988-2014) provided by NSW OEH (Thomas and Heath 2014) and new river flow gauge data were used to check the adequacy of the IQQM to represent the distribution of flows in floods of different magnitudes and subsequent water recession in the Narran Lakes system
- separation of the Northern Lakes into individual sub-zones (Clear Lake, Long Arm and Back Lake) and the addition of new storages to represent the outer floodplain areas
- water surface area curves for the Northern Lakes, Narran Lake and outer floodplain areas were updated in the IQQM based on NSW OEH water management areas (Thomas and Heath 2015a), a new inundation frequency map (Thomas and Heath 2015b, unpublished data) and expert knowledge.

During the hydrology workshop held in early August 2015 the performance of the upgraded IQQM was reviewed against expert knowledge and data from inundation mapping and flow gauge data. These results were discussed by the workshop attendees to evaluate the performance of the upgraded IQQM, identify additional sources of hydrological data to calibrate the model and provide feedback to assist the next stage of model development over the remainder of Stage 2.

Waterbird workshop

A waterbird workshop was held in late August 2015, one of the main objectives of the workshop being to review the structure, states and assumptions of the Straw-necked Ibis breeding models in the Narran DSS. The important components in the Straw-necked Ibis ERMs were conceptualised in the original DSS as the number of birds at the site, the suitability of conditions to trigger breeding, the likely number of nests and the likelihood of abandonment (see Section 3.1.2). During the waterbird workshop, the importance of each component of the Straw-necked Ibis breeding model was discussed and, where needed, modifications required to improve the confidence in the predictive capability of the DSS were identified (see Section 3.3).

Review of flow event definition

The flow parameters used to define the flow event definition in the Narran DSS were also discussed in the waterbird workshop to identify the most appropriate way of classifying flow events. In the Narran DSS flow events are defined based on start and end thresholds. In the 2010 version of the Narran DSS the start threshold was set as the WSE at the Northern Lakes (measured at the Back Lake gauge) above which a flow event starts. The flow event continued until the inundated area dropped below the end WSE threshold. In the original configuration if a 'new' event started within 28 days, it was treated as part of the previous event (ANU Enterprise 2011). However, this 28-day threshold was implemented such that it can be modified based on new data and/or expert opinion (see Section 3.3).

Assumption 1. The start and end threshold parameters were both set to 120.4 m AHD during development of the Narran DSS in 2008.

Assumption 2. Events that start within 28 days of the end of the preceding event were considered the same event.

Assumption 3. The start and end dates of a hydrological event were the same for both the Northern Lakes and Narran Lake.

Sensitivity tests on the 2010 version of the Narran DSS were undertaken for the waterbird workshop and indicated that there was little change in the calculated flow events for thresholds less than 35 days. Sensitivity tests were also performed on the WSE threshold at the Back Lake gauge by varying the threshold between by 0.1 m between 120.1 and 120.7 m AHD. The calculated start of flow events was similar for all thresholds, although as the threshold value was increased the end of flow events was earlier. The original 'event windows' are shown in Figure 3 for the 1974 to 2014 period.

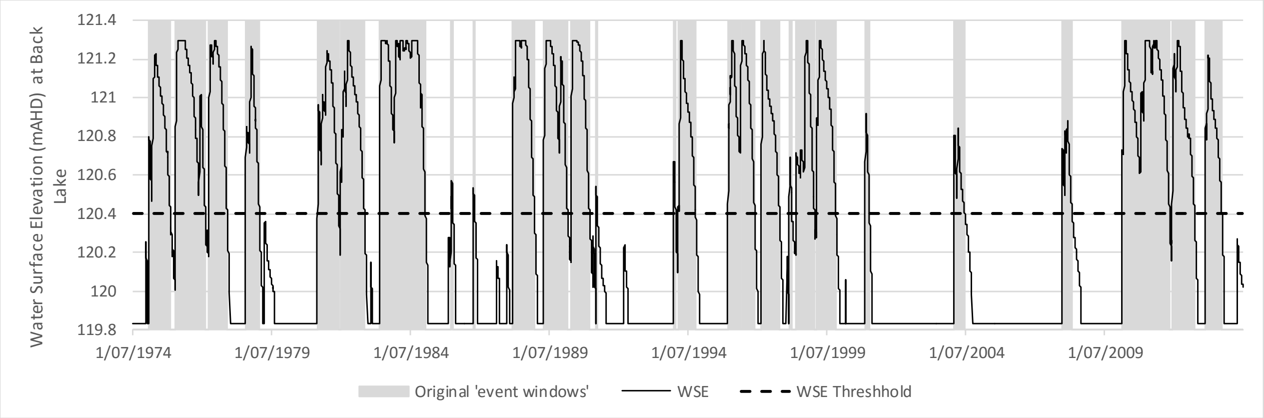


Figure 3 Flow event windows calculated using the ANU Enterprise (2011) event definition rules.

Following the expert workshops, further analysis of the flow record at Wilby Wilby gauge was undertaken to identify historic flow events. Seven potential flow events definitions were identified in the expert workshops (Table 4). A 100 ML/day threshold at Wilby Wilby was thought to be minimum flow required to reach the Narran Lake Nature Reserve (P. Terrill *pers. comm.* August 2015) and this was tested as a threshold to start flow events. It was thought that when flows at Wilby Wilby drop below 40 ML/day flows no longer reach the Northern Lakes (P. Terrill *pers. comm* 2015) and so this value was investigated as a threshold to end flow events.

Water levels at the Back Lake gauge (422034) were also thought to be an appropriate parameter to define the end of a flow event as the lake levels represent the duration of flooding more closely than the river gauges which disconnect from the Narran Lake system as floodwaters recede. Two WSE thresholds (m AHD at Back Lake) were investigated: 120.4 and 120.746 m AHD following advice from the waterbird workshop. 120.4 m AHD is the original WSE threshold implemented in the Narran DSS following advice from Dr Scott Rayburg at which Clear and Back lakes are connected, below this Back Lake will no longer be draining back to Clear Lake, although there will still be about 30 cm depth of residual water at the Back Lake gauge. The 120.746 m AHD WSE threshold represents 1.08 m at the Back Lake gauge (422034) or 28 cm at the old Back

Lake staff gauge. In 2008 Straw-necked Ibis started nesting when water levels were at 120.746 and some nest abandonment was observed when water levels dropped below this level (*P. Terrill pers. comm. August 2015*).

Flow records for Narran Park gauge were also investigated but flows were only measured from 2002 onwards and so did not match the full breeding record. On examining the river flow data there was a non-linear relationship between the flows recorded at Wilby Wilby and the flows at Narran Park. The lag was not consistent across years and varied depending on the flow volume. For example, during larger flows the river is connected to the outer floodplain and takes longer to reach the Narran Park gauge (see Section 3.3.1).

To evaluate which flow event definition best matched historical breeding events the performance of statistical models was evaluated using each flow event definition as a predictor of breeding events. For each flow event definition, hydrological metrics were calculated and historic breeding record assigned (1971-2014). In some cases, large flow events covered two breeding events and were therefore consolidated (see Section 2.2.1). The following hydrological metrics were included in the analysis: total cumulative flow of event (ML), total cumulative flow in the first 10, 30, 60, and 90 days (ML), duration of flow event (days) and the inter-breeding interval (IBI) (days) (see Section 3.2).

Table 4 Start and end thresholds used for seven flow event definitions assessed in the Stage 2 project.

Formulation	**Flow event definition**		
	Start threshold	**End threshold**	**Event Filter**
F100_40	>100 ML/day @Wilby Wilby	<40 ML/day @Wilby Wilby	None
F100_40_WSE120.4	>100 ML/day @Wilby Wilby	<40 ML/day	Flows that do not result in water levels above 120.4 mAHD are not counted as events
F100_WSE120.4	>100 ML/day @Wilby Wilby	<120.4 mAHD @Back Lake	None
WSE120.4	>120.4 mAHD @Back Lake	<120.4 mAHD @Back Lake	None
F100_40_WSE120.746	>100 ML/day @Wilby Wilby	<40 ML/day @Wilby Wilby	Flows that do not result in water levels above 120.746 mAHD are not counted as events
F100_WSE120.746	>100 ML/day @Wilby Wilby	<120.746 mAHD @Back Lake	None
WSE120.746	>120.746 mAHD @Back Lake	<120.746 mAHD @Back Lake	None

The seven flow event formulations were assessed using Classification and Regression Tree analyses (CART) (Breiman *et al.* 1984) in the rpart package (Therneau *et al.* 2015) in R (R Core Team 2015). Classification trees are non-parametric statistical method requiring no assumptions about the underlying distribution and splits data on the basis of an exhaustive search of all possibilities to produce a classification tree. The rpart program builds classification or regression models using a two stage procedure and the resulting models represented as binary trees. The

CART analysis starts by finding the single variable which best splits the response variable (i.e. Straw-necked Ibis breeding) into two groups using the Gini index. This process is then repeated separately to each sub-group, and so on recursively until no improvement can be made.

Each classification tree model (i.e. breeding/no breeding recorded) for each flow event formulation was assessed using three measures of model performance:

$$\text{accuracy} = \left(\frac{\sum \text{true predictions } 0/1}{\sum \text{number of flow events}}\right)$$

$$\text{precision} = \left(\frac{\sum \text{true breeding predictions}}{\sum \text{breeding predictions}}\right)$$

$$\text{sensitivity} = \left(\frac{\sum \text{true breeding predictions } 0/1}{\sum \text{number of breeding events}}\right)$$

2.2.6 Incorporate DSS upgrades and report on results of scenario testing

Following the recommendations from the hydrology workshop, the IQQM was further revised during August-November 2015 with the recalibration of the Narran reach of the Condamine-Balonne IQQM detailed in Section 3.3.1 and in DSITI (2015). Once revisions to the IQQM were completed, the following outputs were provided for use in the Narran DSS for scenario testing:

- predicted flows at Wilby Wilby, Narran Park and Bundah gauges
- predicted water levels, volumes and inundated surface areas of Back Lake, Clear Lake and Narran Lake
- predicted inundated surface areas of the Northern, Central and Southern Floodplains

Stages 1 and 2 provided new information that was used to update the Bayesian Network structure and parameterisation of the Straw-necked Ibis ERMs in the Narran DSS. The best performing flow event formulation was implemented in the Narran DSS along with the revised ERMs (see Section 3.3.3 – 3.3.4). The updated DSS was then used to evaluate outcomes for Straw-necked Ibis breeding under five water resource development scenarios for the Condamine-Balonne system to support the Northern Basin Review. The impacts of the water recovery options compared to the 'without development' and 'baseline' scenarios are summarised in Section 3.4.

3 Results and Discussion

3.1 Review of hydrological models and ecological response models

3.1.1 Hydrology modelling

Temporal representation

The review of hydrology modelling in Stage 1 indicated that there was a strong case for replacing the Rayburg and Thoms (2008) hydrology model implemented in the Narran DSS with an alternative source of hydrological inputs (Merritt *et al.* 2015). The Rayburg and Thoms (2008) hydrology model was not coded within the Narran DSS model. Rather, the hydrology model developers provided an executable version of the model to support the Narran DSS. Within the Narran DSS interface users can load daily data series (discharge at Wilby Wilby, rainfall and evaporation), name the scenario run and run the hydrology executable. Time-series outputs from the Rayburg and Thoms executable were then used within the DSS to define hydrological parameters required by the ERM.

Rayburg and Thoms (2008) acknowledged that the real-time version of their hydrology model would be unsuitable for long-term scenario modelling until such a time when higher quality data (i.e. flows from the Narran Park gauge, on-site rainfall and evaporation data, water levels for the Northern Lake) would be available for a sufficient length of time to allow for detailed model calibration and validation. The executable for Rayburg and Thoms hydrology model that was provided to the DSS developers was constrained to run a 40-year period regardless of the start and end date of the input data set. Furthermore, the hydrology model covered the Northern Lakes, Narran Lake and the intervening floodplain surface areas largely corresponding to the frequently flooded zones (annual recurrence interval less than five years) (ANU Enterprise 2011) and did not cover the less frequently inundated floodplain areas between the Northern Lakes and Narran Lake.

Since the IQQM was originally calibrated in 1996, the Condamine-Balonne IQQM has been updated to include additional information collected by Thoms *et al.* (2007) and local flow gauging data from Wilby Wilby (GS422016) and Narran Park (GS422029) (DSITIA 2014), and on-ground measurements during the February 2004 flood event (Cameron *et al.* 2004). There was only one small flow event in 2004 during this period (Figure 4). In the IQQM the rainfall on the lakes is estimated using the Data Drill information from the Scientific Information for Land Owners (SILO) database (https://www.longpaddock.qld.gov.au/silo/). The Data Drill rainfall in SILO is estimated from nearby rainfall stations using a spline technique (DSITI 2015).

In 2014, DSITI compared modelled flows at Wilby Wilby and Narran Park from the Condamine-Balonne IQQM with measured flows to assess the ability of the model to represent the inflow to the Narran system. This initial analysis indicated that there was good agreement between modelled and measured flows at the Wilby Wilby gauge for the period 2000 to 2013 (coefficient of efficiency 0.77, r coefficient 0.79) (DSITIA 2014). In 2014, the IQQM was revised and calibrated using the full 2002 -2014 flow time series from the Wilby Wilby gauge. This time series, which included the large events in 2010-2013, showed that large floods travel slower than the small floods. This comparison showed that the original IQQM did not accurately predict the timing of the peak flow or the shape of the flow hydrograph at the Narran Park gauge.

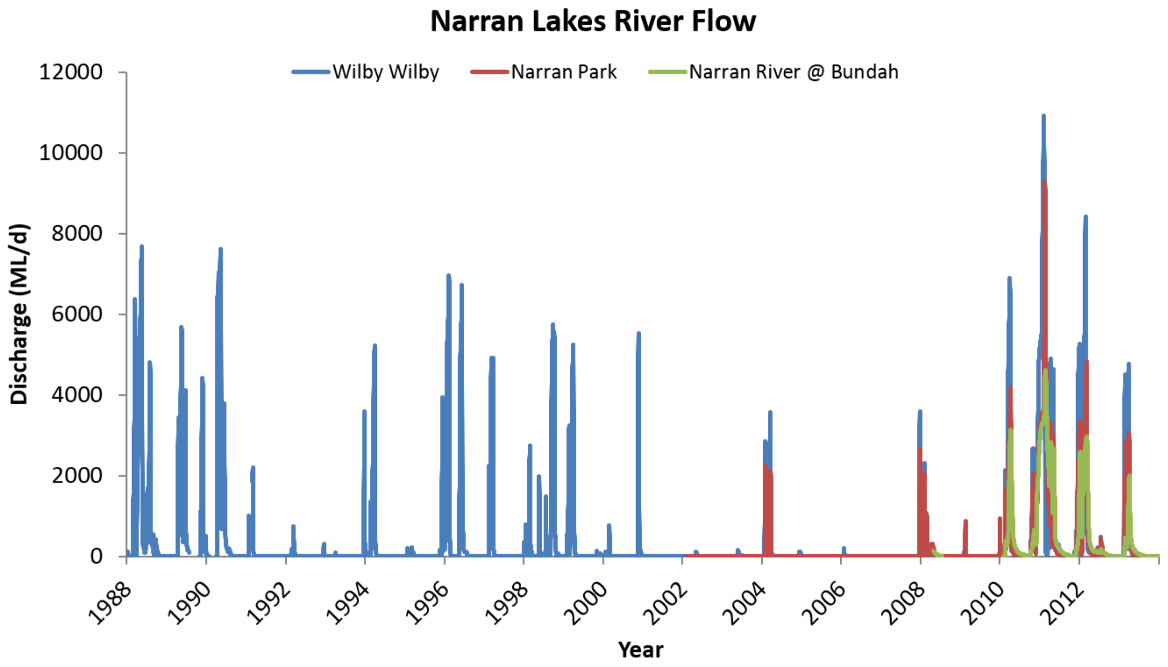
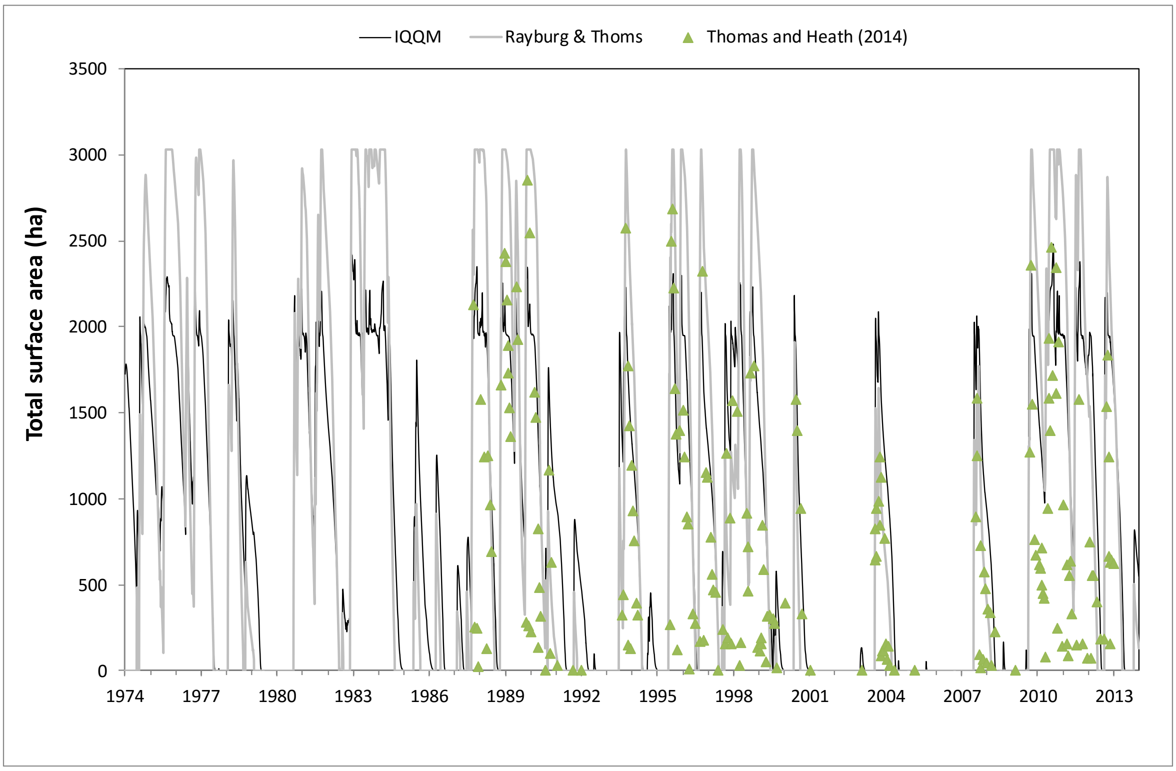


Figure 4 River flow gauge data Wilby Wilby (GS422016), Narran Park (GS422029) and Bundah (GS422031) for flows into the Narran Lakes for the 1988-2013 period.

As part of Stage 1 of this project, the ability of the Rayburg and Thoms (2008) and IQQM models to predict the flooding behaviour of the Narran Lakes was assessed by comparing the model predictions of the inundated surface area of the lakes with estimates based on satellite imagery by Thomas and Heath (2014) and the extended flow record for the 2002-14 period from the new gauges which included a greater range of flow events (Figure 4). When compared to inundation mapping, there was reasonable agreement for the Northern Lakes with the IQQM predictions, but the Rayburg and Thoms (2008) model inundated surface area predictions were much higher (Figure 5). The Rayburg and Thoms (2008) model inundated surface area predictions for the Narran (Southern) Lake were much closer than the IQQM which appeared to be underestimating total inundated area for the Narran Lakes during large flood events (Figure 5).

When compared to recent data from the Back Lake gauge (422034), both hydrological models underestimated peak WSE in the Northern Lakes by 0.5 m or more (Figure 6). This was further supported by onground observations by NSW National Parks and Wildlife (NPWS) staff (R. Smith, *pers. comm.* March 2015). Local evaporation rates and rainfall are thought to be important determinants in water levels in the lakes once river flows recede. It was considered that these errors in the hydrological model's ability to represent WSE and therefore flood duration adequately would impact the ability of the Straw-necked Ibis ERMs to accurately represent duration of flooding and therefore, the likelihood for nest abandonment (see Section 3.2.4). Following the review of the hydrological models performance in Stage 1, it was recommended that additional water gauge information from Wilby Wilby, Back Lake, Narran Park and Bundah collected in recent years be used to improve the IQQM (see Section 3.3.1). Other sources of water level data that were identified included information derived from time-lapse photographs from fixed and interactive cameras and water level loggers in South Arm (south of Clear Lake), Pelican Lagoon (western side of Back Lake) and Clear Lake from 2012 onwards (P. Terrill *pers. comm.* April 2015), however, these did not capture large flow events of interest.



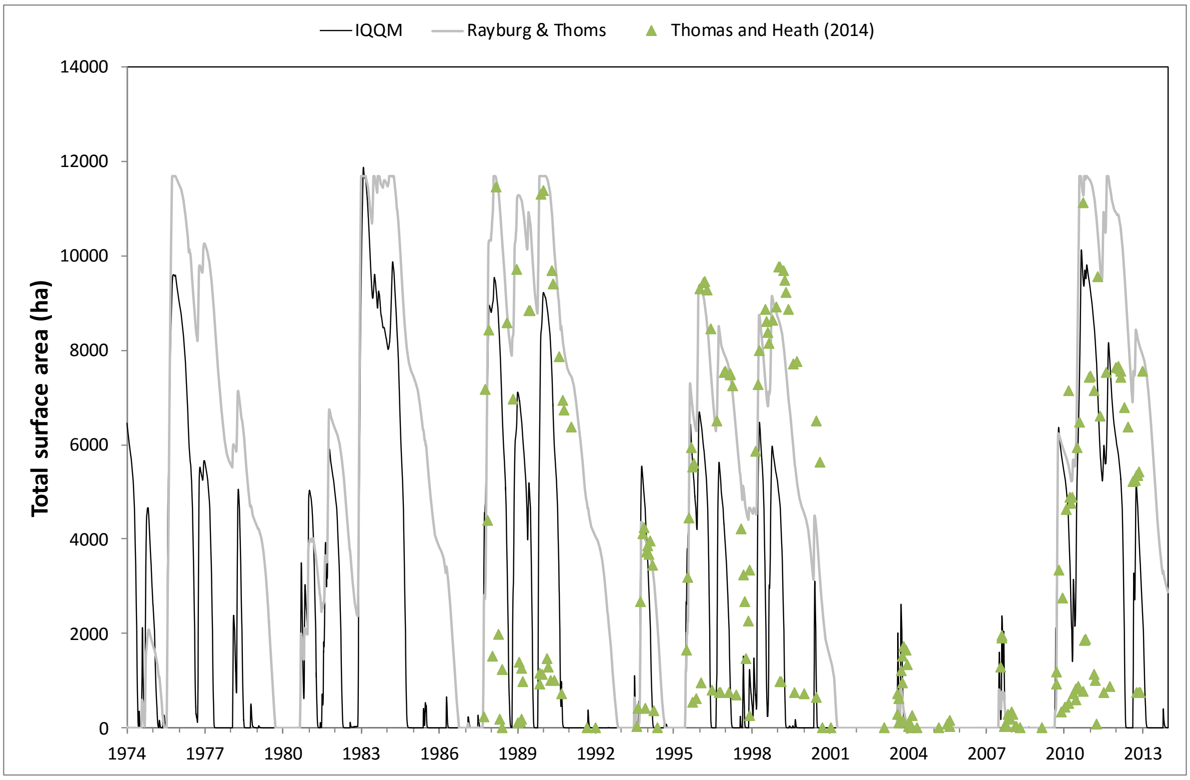


Figure 5 Comparison of modelled inundated surface area in the Northern Lakes (upper) and Narran Lake (lower) from the IQQM (2014) and Rayburg and Thoms (2008) models using the Wilby Wilby recorded flows from 1/7/1974 to 29/6/2014 relative to observed inundated area mapped from Landsat imagery for available dates between 1988-2013 (Thomas and Heath 2014).

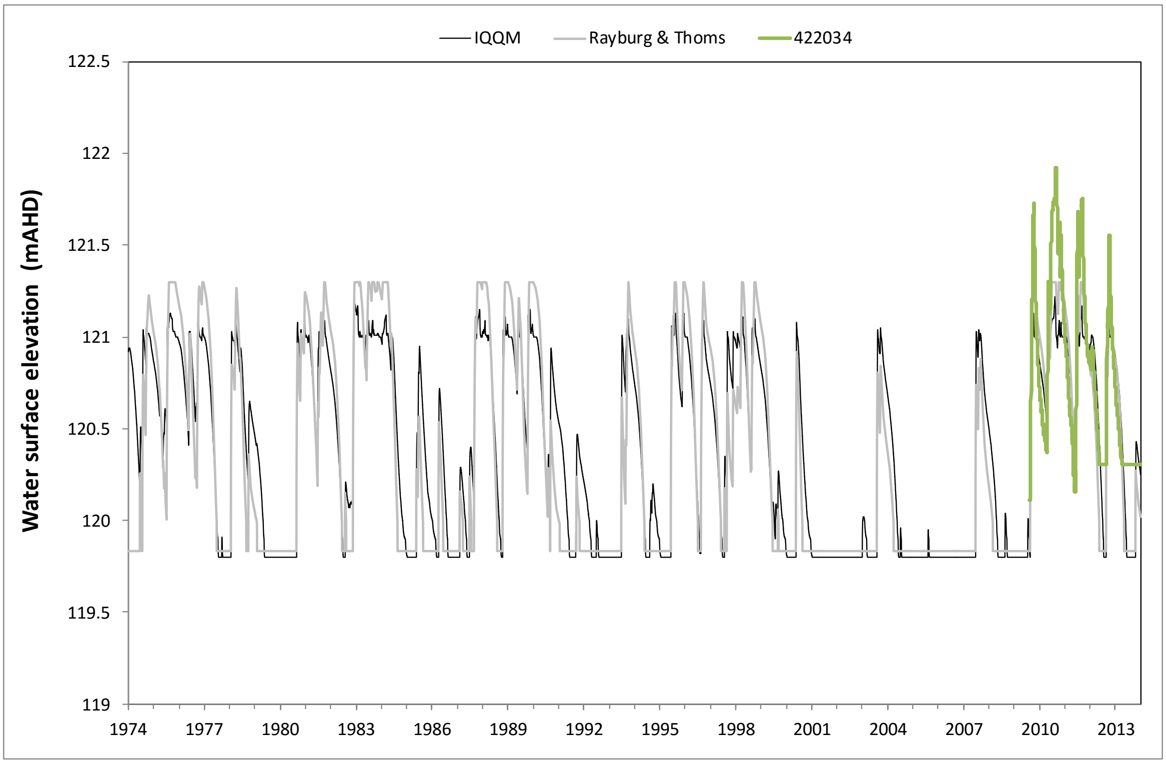


Figure 6 Comparison of predicted water surface elevation in the Northern Lakes using the Rayburg and Thoms (2008) and IQQM (2014) hydrology models from 1/7/1974 to 29/6/2014 to recorded water levels at the Back Lake gauge (422034) from 2010-2013.

Spatial representation

In the original (1996) development of the IQQM for the Condamine-Balonne system the Narran Lakes was represented by one storage cell only. In the next stage of IQQM development the DEM and water balance model developed by Rayburg and Thoms (2008) were used to split the Narran Lakes into two storages in IQQM, where separate Narran Lake (12,290 ha) and the Northern Lakes (1,950 ha) storages were represented in the model. These two storages largely corresponded to frequently flooded zones (probability of flooding more than once in five years) (Thoms *et al.* 2007), however, this did not include the floodplain areas connecting the Northern Lakes and Narran Lake or the area to the south of Narran Lake which support wetland vegetation communities (Capon 2010).

Thomas and Heath (2014) noted inundation mapping showed that there was clear connectivity between the Northern Lakes and the outer floodplain during large floods but that these floodplain areas went beyond the defined boundary of the Rayburg and Thoms (2008) and DSITI (2014) hydrology models and recommended these areas be modelled separately. Thomas and Heath (2015a) proposed new hydrological zones for the Narran Lakes system based on a composite of the geomorphological units of Thoms *et al.* (2007), Wetlands of NSW (Kingsford *et al.* 2004) and historical inundation maps derived from 1990 satellite imagery (Figure 7). In Stage 1 it was recommended that the spatial representation of the hydrological zones be developed using new information provided by Thomas and Heath (2015a) and further analysis of flow paths through development of an inundation frequency map (see Section 3.3.2).

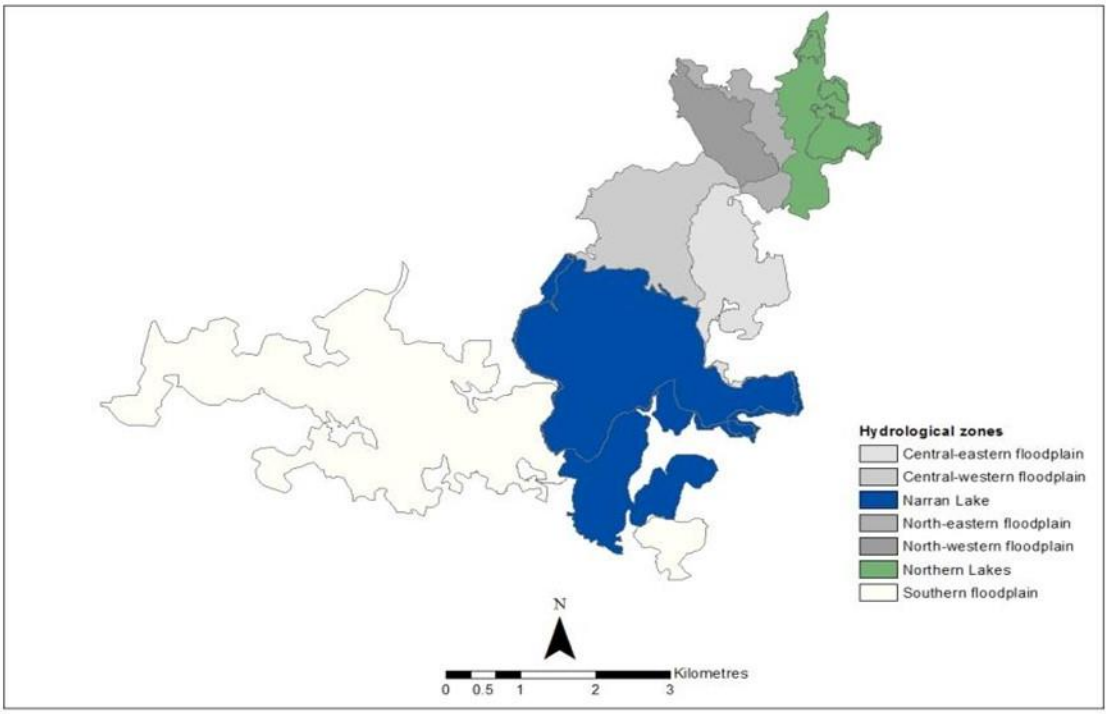


Figure 7 Hydrological zones delineated for the Narran Lakes system to include outer floodplain zones by Thomas and Heath (2015a).

3.1.2 Ecological response modelling

Straw-necked Ibis breeding models

Straw-necked Ibis were chosen as the indicator species for the waterbird breeding ERM in the Narran DSS as they are responsive to flooding and can congregate in large numbers (tens of thousands to hundreds of thousands) to breed in the Narran Lakes. In the original conceptualisation of Straw-necked Ibis breeding in the Narran Lakes, important parameters were thought to include the number of birds at the site, the suitability of conditions to trigger breeding, the likely number of nests and the likelihood of nest abandonment (Figure 8) (see ANU Enterprise 2011). Model relationships were estimated where possible using available literature and expert knowledge. The relationship between the annual cumulative inflow volume and nest numbers was estimated from breeding records reported in Thoms *et al.* (2007) (Table 5) (for more information see ANU Enterprise 2011).

Table 5 Conditional Probability Table (CPT) documenting predicted relationships between cumulative annual inflow at Wilby Wilby and the number of Straw-necked Ibis nests in the Narran Lakes (*Source*: Table 16 in ANU Enterprise 2011). Note that the probabilities presented were based on expert opinion and information collated during the Narran Ecosystem Project (see Figure 6.75 in Thoms *et al.* 2007).

Annual inflow (ML)	**Predicted number of nests**				
	0	**<1,000**	**1,000-50,000**	**50,000 - 100000**	**>100,000**
0-100,000	0.950	0.050	0	0	0
100,000-150,000	0.025	0.950	0.025	0	0
150,000-200,000	0	0.800	0.200	0	0
200.000-300,000	0	0.700	0.260	0.030	0.010
300,000-400,000	0.001	0.049	0.100	0.500	0.350
400,000-500,000	0	0.050	0.300	0.400	0.250
> 500,000	0	0.010	0.030	0.060	0.900

The likelihood of conditions being unsuitable for Straw-necked Ibis breeding in the Narran Lakes, and therefore birds abandoning their nests, was thought to be driven by four parameters: duration of inundation above 120.4 metres Australian Height Datum (m AHD) in the Northern Lakes as below this WSE Clear Lake and Back Lake are essentially disconnected), minimum depth under nests, the number of consecutive cold days and the maximum day-to day decrease in water levels (ANU Enterprise 2011). The importance of each of these parameters was weighted in the Narran DSS, with greater importance given to inundation duration (0.4) and water depth under nest (0.4), followed by decrease in WSE (0.1) and air temperature (0.1) (Figure 8; Table 6). The weighting of each parameter was determined from expert knowledge of the site and available literature (ANU Enterprise 2011). Inundation duration was considered a critical variable in determining overall abandonment and so a partial override was applied by Merritt *et al.* (2009) such that when the inundation duration was less than 60 days the outcome of the nest abandonment variable was “High”.

In the 2010 Narran DSS it was thought that inundation of the Northern Lakes had to be maintained for at least 66 days to allow for birds to lay and incubate the eggs and to feed their young through to successful fledging. This was based on information in Carrick (1962) which documented Straw-necked Ibis breeding behaviour noting birds incubate their eggs for around 24 days, with fledgling occurring 28 days after hatching and young birds being fed by adults for another 14 days after leaving the nest. This information was used to develop the original abandonment model (see Figure 9, (top left panel)), where nest abandonment is considered certain when duration is less than 66 days and conversely, there is increasing confidence that nest abandonment is unlikely when flood duration is greater than 100 days.

For events of longer duration, duration and depth under nest (risk of nest inundation) were assigned higher importance than change in water levels and air temperature, based on the expert opinion of Dr Scott Rayburg and the ANU model developers (ANU Enterprise 2011). The Narran DSS also assumed that a decrease in water levels would lead to abandonment of nests (ANU Enterprise 2011), with nest abandonment thought to be unlikely if the decrease in water level was <0.5 cm/day (see Figure 9, (bottom left panel)). However, there was considerable uncertainty as to whether nest abandonment would occur if water level decrease was greater than 1 cm/day. The abandonment model also assumed that low minimum temperatures could trigger abandonment of nests. The temperature threshold was set at 3°C, with the number of consecutive days at or below this temperature increasing the likelihood of abandonment although this threshold was not based on any quantitative data. The Narran DSS calculated the number of times each state occurred (e.g. two to three consecutive cold days, or more than five consecutive cold days) during an event and converted this to a probability. In the Stage 1 review this temperature threshold was thought to be conceptually sound in terms of acting as a proxy for seasonality effects although there was uncertainty around the figure set as an appropriate temperature threshold and the influence of temperature on the likelihood of nest abandonment (Merritt *et al.* 2015). The option of using season (i.e. specified months of the year) rather than air temperature was recommended and was investigated further in Stage 2 (see Section 3.2.3).

Note that after completion of the second phase of the Narran DSS in 2010, the habitat condition model for Straw-necked Ibis developed for the Gwydir Wetlands and Macquarie Marshes IBIS DSS applications (Merritt *et al.* 2010) was implemented in the Narran DSS. This model predicts the likely suitability of a hydrological event for providing habitat conditions suitable (poor, moderate or good) for breeding of Straw-necked Ibis using information summarised for the MDB by Rogers (2011). The habitat model assumptions were not reviewed as part of this project and therefore no testing of the habitat condition models has been undertaken.

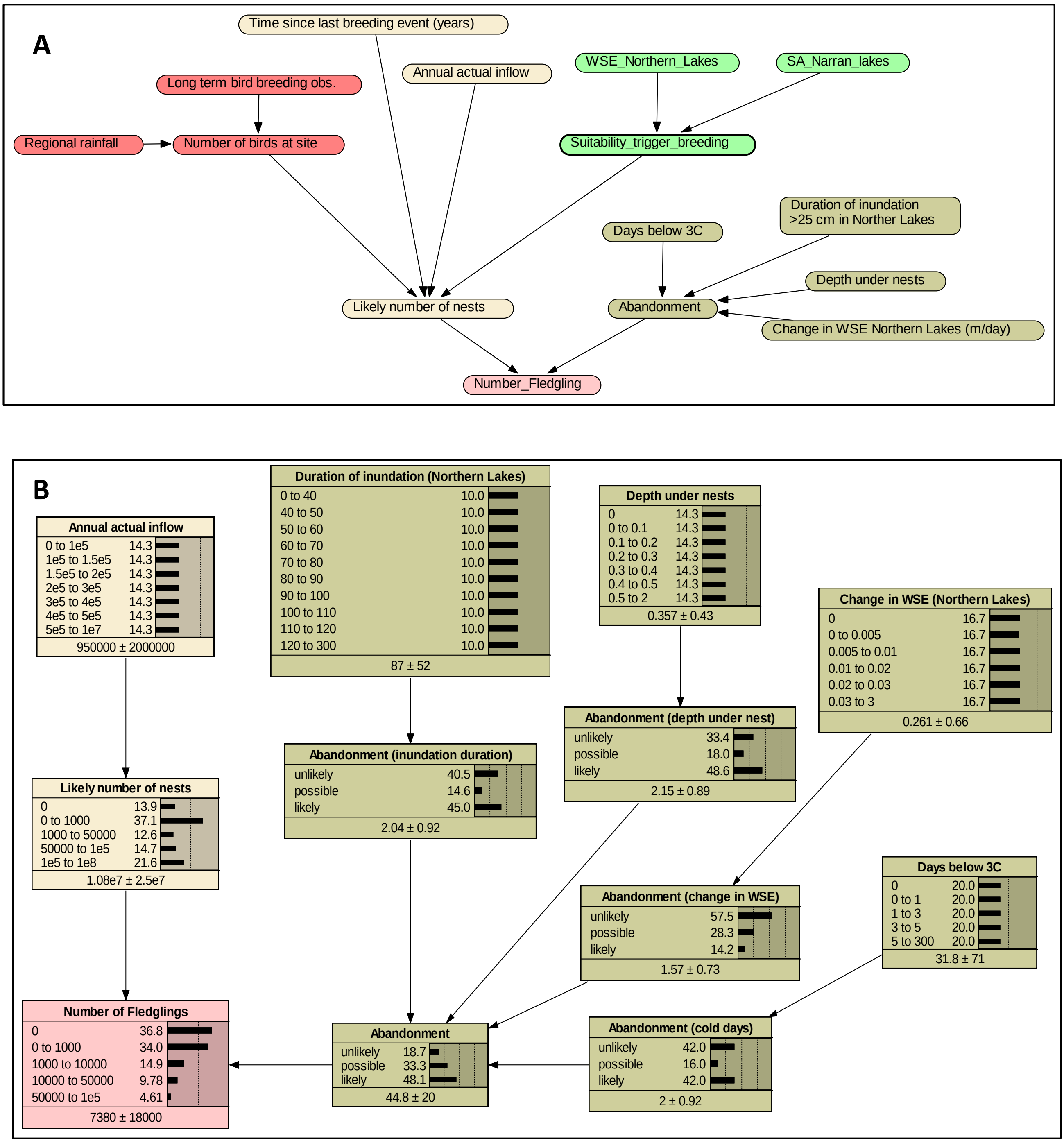


Figure 8 (A) Original conceptual model (2008) and (B) Bayesian Network configuration (2010) in the Narran DSS representing the key factors influencing the Straw-necked Ibis breeding models including the likelihood of breeding (number of nests), nest abandonment and the predicted number of fledglings (from ANU Enterprise 2011).

Table 6 Review of variables and assumptions used to populate the straw-necked breeding models in the Narran DSS.

Model component^	Parent variable	Model states	Data source	Underlying assumptions in DSS development (2008-10)
Abandonment	Inundation duration (days)	0, <60, 60-70, 70-80, 80-90, 90-100, 100-110, 110-120, >120	Expert elicitation, literature	• Inundation duration must allow for birds to reach breeding condition, build nests, lay and incubate the eggs and finally to feed their young through to successful fledging • Depth under nest calculated as the difference between the average nest height (assumed to be 121.5 m AHD) and WSE • WSE recession is critical (although the DSS model code does allow consideration of WSE rise) • Temperatures below 3°C may trigger abandonment, with the number of consecutive days at this temperature increasing the likelihood • Overall likelihood of abandonment is a weighted average of the four input variables: Inundation duration (0.4), Depth (0.4), Change in WSE (0.1) and Temperature (0.1)
	Depth under nest (m)	0, 0-0.1, 0.1-0.2, 0.2-0.3, 0.3-0.4, 0.4-0.5, >0.5	Expert elicitation	
	Maximum change in WSE during the event (m)	0, <0.5, 0.5-1, 1-2, 2-3, >3	Expert elicitation	
	The number of days in a row below a temperature threshold (days)	0, 1, 2-3, 4-5, >5	Expert elicitation	
Number of nests	Actual annual inflow (ML)	0-100,000; 100,000-150,000; 150,000-200,000; 200,000-300,000; 300,000-400,000; 400,000-500,000; >500,000	Expert elicitation, Thoms *et al*. (2007)	• The flow-breeding trigger relationship and flow-number of nests relationship is the same (i.e. both related to annual flow) • The annual flow is calculated for the preceding 12 months
	Time since last breeding event (years)		Expert elicitation	S. Rayburg (*pers.comm.*) hypothesised that nesting behaviour may be linked to the critical thresholds for time since last breeding event in the context of habitat availability for the Northern Basin.
Breeding trigger	*WSE in the northern lakes*		Expert elicitation	The suitability of the Narran and Northern Lakes for colonial nesting species such as the Straw-necked Ibis was considered to be primarily due to sufficient water depth in nesting areas, and availability of feeding grounds.
	Inundated surface area on Narran Lake		Expert elicitation	
Number of birds	*Observations of long term trends in bird numbers*	*Decreasing, no change, increasing*	Thoms *et al*. (2007)	N/A
	Regional rainfall	*Low, average, high*	N/A	N/A
Fledgling numbers	Abandonment	Unlikely, possible, likely	Expert elicitation	The total number of predicted fledglings was based on the predicted number of nests and predicted nest abandonment. It was assumed that Straw-necked Ibis had on average 3-4 eggs per nest.
	Nest numbers	0, <1,000, 1,000-50000, 50,000-100000, >100,000	Expert elicitation	

^Note that although the detail in italics was included in the prototype DSS in 2008 it was removed from the Narran DSS in 2010 following review of the underlying assumptions that showed there was insufficient evidence to support their inclusion (ANU Enterprise 2011).

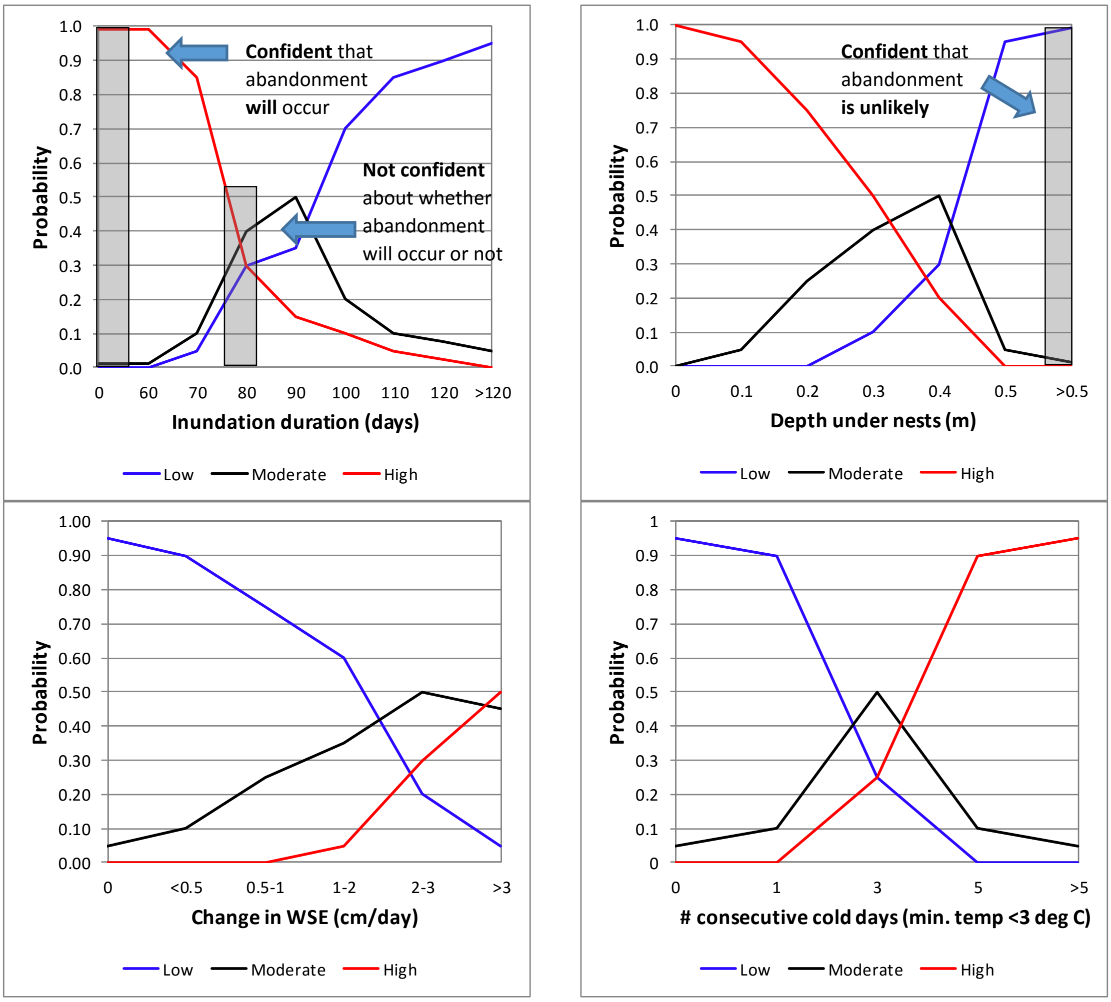


Figure 9 Relationships between individual input variables and the likelihood of nest abandonment (low, moderate and high): inundation duration (top left), depth under nests (top right), change in Water Surface Elevation (WSE) (bottom left) and minimum air temperature (bottom right) (from Merritt *et al.* 2015).

The performance of the Straw-necked Ibis breeding data-based models in the Narran DSS was assessed in Stage 1 by comparing breeding predictions with available historical Straw-necked Ibis breeding data for the same period. This preliminary analysis identified that the 100,000 ML annual cumulative flow threshold in the breeding initiation model needed to be revised as the Narran DSS was only 41% correct in predicting breeding (overall model accuracy was 38%) when compared to available breeding records for the 1975-2014 period (Merritt *et al.* 2015).

This comparison between modelled and observed breeding data also highlighted that the flow event definition needed to be revised as the Narran DSS failed to identify breeding when flow events were of long duration (>600 days) when multiple breeding events were recorded within the same flow event (Merritt *et al.* 2015). Recommendations for Stage 2 were to investigate alternative flow thresholds that could be linked to the occurrence of breeding in Straw-necked Ibis and whether the flow trigger for breeding could be modified to incorporate a timing component (i.e. season rather than minimum air temperature). A summary of recommendations from Stage 1 for improving the Straw-necked Ibis ERMs in the Narran DSS is provided in Table 7 below.

Table 7 Summary of review of Straw-necked Ibis breeding models undertaken in Stage 1 and recommendations for improving the Narran DSS in Stage 2 (from Merritt *et al.* 2015).

Model component	**Narran DSS (2010) representation**	**Recommendations for upgrade of the Narran DSS (2015)**
Cumulative flows (breeding trigger)	Trigger and size of breeding event based on annual inflow of >100,000 (ML) at Wilby Wilby	Investigate alternative flow indicators including total event flow, peak flow and flow duration. Total flow volume seems to be broadly supported as an indicator (of initiation and size of a breeding event and likelihood of abandonment) but could be revised to accommodate a three or six month trigger prior to and during the breeding period. Review flow event definition assumptions to allow for greater separation of defined flow events that are meaningful for both Straw-necked Ibis breeding responses and management of inflows into the Narran Lakes (see Section 3.2.1).
Season (breeding trigger)	Timing is reflected in the model as affecting abandonment through its impact on minimum temperatures. It is also an explicit variable in the Straw-necked Ibis habitat model. However, it is not explicitly used as a breeding trigger.	An exploratory analysis that links flow and timing to the size of breeding should be undertaken to quantify the significance of flow timing (i.e. season on breeding events). This required further analysis of historical breeding data and associated hydrological (e.g. flow) and climate (e.g. rainfall, daytime temperature) data in Stage 2 (see Sections 3.2.3 and 3.2.5). In addition to the analysis of the flow timing trigger it was also recommended that expert opinion should also be used to evaluate 1) the relationships between timing and breeding trigger, and 2) how the different variables, including timing, should be aggregated.
Water depth and risk of nest abandonment	In the habitat condition model in the Narran DSS, change in water depth was indirectly captured by specifying an 'event threshold' (WSE = 120.4 m AHD) and duration requirement. In the Straw-necked Ibis breeding model, change in depth is partly captured by the change in WSE and the depth under nests variables. However, the DSS models the variability of WSE over the event period through the change in WSE variable and does not explicitly consider the different stages of the breeding cycle.	Investigate whether it is feasible to implement water recession in the Narran DSS with help from experts and new gauging information, and how to quantify the impacts on Straw-necked Ibis ERM. Investigate uncertainty in the hydrological model (be it the Rayburg and Thoms model currently implemented in the DSS or the updated IQQM) in representing water recession. Quantify the impact of uncertainty in the hydrological model on the flow event definition and ecological outcomes in the Narran DSS representing water recession. Undertake analysis of variability in water depth from local gauging data recorded during the breeding events that occurred from 2010-12 to support model development. Undertake more detailed analysis and expert review of the Straw-necked Ibis breeding models by testing the model predictions for nest abandonment against observed Straw-necked Ibis data where available and different WSE thresholds (i.e. 120.4 mAHD and 120.746 mAHD).
Food availability	Not currently represented	Explore the importance and feasibility of explicitly modelling food availability or other suitable proxy for

		wetland productivity (e.g. total inundated surface area) in the Narran DSS based on expert opinion.
Vegetation in providing breeding habitat	Not currently represented	Historical records of colony locations in the Narran Lakes show that the colonies always establish on the flooded lignum. It was acknowledged that if a direct representation of the link between the condition of lignum as a breeding habitat requirement for Straw-necked Ibis was desired, this can be implemented in DSS, although the relationships would be difficult to quantify due to lack of data.
Spatial representation	In the Narran DSS, the ecological models capture three larger locations: the Northern Lakes, the Narran Lake, and the intervening floodplain area. In recent breeding events (i.e. 2010 and 2012), Straw-necked Ibis have also been recorded as nesting in areas of lignum in the Narran Lake Delta.	It was recommended that the spatial requirement of the Northern Lakes complex be reviewed based on Straw-necked Ibis breeding data and hydrological data resolution. If feasible, this region could be segregated to better represent the spatial dynamics of the system. Note that this recommendation was conditional on revision of the rules defining flow events for the different storages in the Narran DSS.
Temporal representation	Temporally, the DSS estimates the ecological outcome for the whole hydrological event which implicitly assumes that the breeding activity starts at the beginning of each event. This is likely to vary according to the time of year (i.e. the lag between the start of flooding and breeding initiation is generally longer in autumn than in summer months) (see Section 3.2.3).	Investigate whether it is feasible or desirable to capture successive overlapping nesting events (i.e. second layers). This component would rely on expert knowledge of Straw-necked Ibis breeding behaviour and detailed start and end dates for known breeding records.

Wetland vegetation models

Note that a review of the underlying assumptions of the wetland vegetation ERMs and their performance was beyond the scope of this project and so only a brief summary is provided here. Further information on the development of the vegetation ERMs are detailed in ANU Enterprise (2011) which notes that the data used to develop these models was limited to that collected as part of the Narran Ecosystem Project (Thoms *et al.* 2007).

Three data-based population and condition vegetation ERMs have been developed and implemented in the Narran DSS: lignum shrublands, ephemeral herbfields and floodplain tree patches (ANU Enterprise 2011). The frequency of flooding across the Narran system (years since wet) is a key parameter in the vegetation ERMs. The condition of lignum is of most relevance to the management of Narran Lakes for Straw-necked Ibis breeding as it provides major nesting habitat during flooding. A Bayesian Network was constructed for lignum (Figure 10) based on the experimental microcosm experiments conducted in the Narran Ecosystem Project (Thoms *et al*. 2007). Input variables were (annual) recurrent interval (RI) and years since wet. The model estimates percentage of lignum cover, number of clumps, mean height of the clumps, mean perimeter of the clumps, mean greenness (health) and the number of clumps that have leaves or flowers (Figure 10). These inputs were selected based on the availability of data in 2010 and the existing input variables in the prototype Narran DSS (ANU Enterprise 2011).

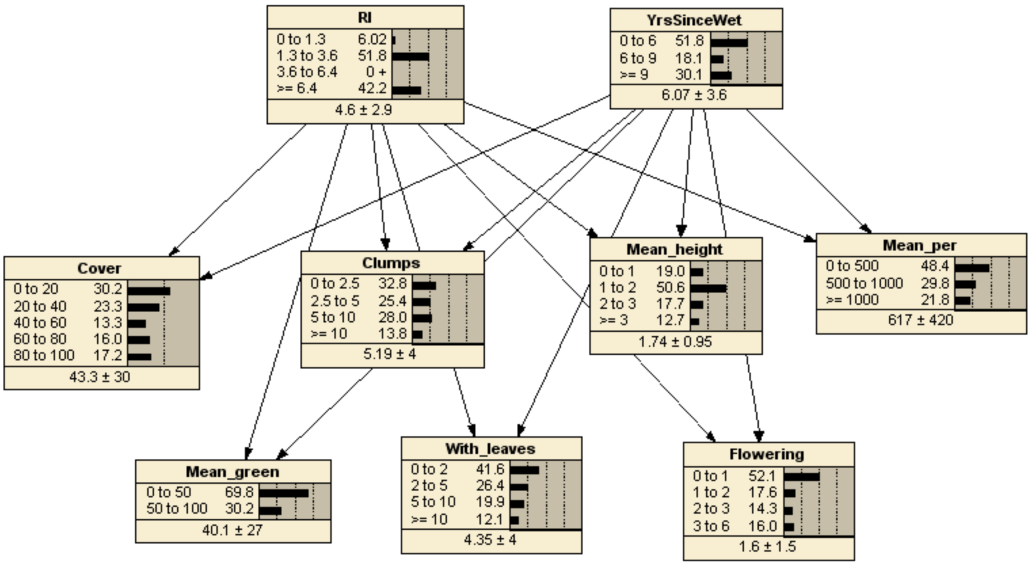


Figure 10 The lignum condition ERM was developed based on data from the Narran Ecosystem Project (Thoms *et al.* 2007) (Source: ANU Enterprise 2011).

In addition to the data-based ERMs described above vegetation habitat models were also developed by ANU Enterprise (2011) based on expert understanding of vegetation water requirements. These habitat models predicted the likely habitat condition (poor, moderate, or good) for the 1) maintenance and survival, and 2) regeneration and reproduction of vegetation. Habitat conditions were estimated under each flood attribute (e.g. flood duration, timing, inter-flood dry period), based on water requirements of that flood attribute as detailed in ANU Enterprise (2011). In the Narran DSS the habitat conditions under each flood attribute are averaged so that an overall habitat score for the vegetation model can be calculated under different flow scenarios.

Note that the assumptions underpinning the vegetation ERMs in the Narran DSS (as detailed in ANU Enterprise 2011) were not reviewed as part of this project and therefore no testing of the vegetation ERMs has been undertaken. However, recommendations for further development of the vegetation ERMs outlined in ANU Enterprise (2011) remain relevant today.

Summary of recommendations from Stage 1

Following the review of the available hydrological and ecological response models in Stage 1 four key issues emerged that needed to be addressed before the Narran DSS could be used to inform the Northern Basin Review (see Merritt *et al.* 2015):

- development of the Narran component of the Condamine-Balonne IQQM to include better representation of flow paths, floodplain losses, water retention and water recession in the Narran Lakes using information extracted from the improved gauge network system
- modification of the spatial representation of the IQQM and Narran DSS to better represent the distribution of flows between the Northern Lakes and Narran Lake and flooding in the outer floodplain using a combination of existing wetland boundaries (Thomas and Heath 2015a) and development of an inundation frequency map
- revision of the flow event definition and underlying assumptions of the Straw-necked Ibis ERMs in the Narran DSS through analysis of breeding data available for 1971-2014
- investigation of the annual flow trigger (100,000 ML at Wilby Wilby) and alternative breeding triggers (including flow timing) in the Narran DSS.

3.2 Review of factors influencing Straw-necked Ibis breeding

3.2.1 Cumulative flows

Colonial waterbird breeding is known to be closely linked to cumulative river flows as many species breed in response to large flows that inundate suitable nesting habitat. For example, daily river flows measured for 30-50 day periods and/or cumulative total flow for a three- or six-month period have produced useful predictors for colonial waterbird breeding events (e.g. Arthur *et al.* 2012; Kingsford and Johnson 1998; Kingsford and Auld 2005; Wilson *et al.* 2010; Bino *et al.* 2014b). Arthur *et al.* (2012) reported that flow characteristics were highly correlated and thresholds for colonial waterbird breeding in parts of the MDB could also be expressed in terms of the total flow volume between July–December (at Barmah-Millewa Forest and Macquarie Marshes) and peak flow in September or October (at Lake Merreti).

In the review of EWR for the Narran Lakes, the MDBA (2012) recognised that most Straw-necked Ibis breeding records for the Narran Lakes have occurred when recorded annual flows at Wilby Wilby on the Narran River have been in excess of 100,000 ML and large breeding events (>50,000 nests) were thought to require total annual volumes of more than 300,000 ML. These flow thresholds were based on data presented in Rayburg and Thoms (2008) showing the timing of 16 known breeding records and cumulative annual flows from 1965-2004. In Rayburg and Thoms (2008) the 12-month 100,000 ML flow threshold was identified for the 16 known breeding records for 1965-2004, with the majority of these breeding events (11 in total) associated with cumulative annual inflows of greater than 250,000 ML at Wilby Wilby.

Subsequent analysis by Brandis (2010) for the 1971-2008 period showed that total annual flow volumes of 100,012 ML at Wilby Wilby were most commonly associated with breeding and that annual flows larger than 160,183 ML resulted in Straw-necked Ibis breeding. Brandis (2010) identified five events below the 100,000 ML threshold that resulted in Straw-necked Ibis breeding with the lowest annual flow that initiated breeding being 46,782 ML. This breeding event was in 2008 when total flows were not sufficient and environmental flows were delivered to support the event (Brandis *et al.* 2011;

MDBA 2012). In Brandis (2010) analysis, flow events were defined as periods when total daily flow volumes exceeded 100 ML at the Wilby Wilby gauge and completion of an event when total daily flow volumes fell below the 100 ML daily threshold and continued to zero.

In Stage 2 of this project CART analyses were used to identify the best flow event definition for predicting the occurrence of Straw-necked Ibis breeding events (see Section 2.2.5). All seven flow event formulations performed well (88-95% model accuracy, in terms of number of breeding events correctly captured by a given flow event definition). Precision (number of flow events where breeding did occur captured in the flow event formulation) was highest for flow event definitions 3, 4 and 6 which had water surface elevation at the Back Lake gauge built into the end definition of a flow event. Including a flow rate of <40 ML/d at Wilby Wilby as part of the flow event end definition did not improve model precision (Figure 11; Table 8).

On-ground observations in the main colony site at Back Lake over 2010-12 showed that when water levels drop below 120.746 m AHD at the Back Lake gauge the success of ibis breeding becomes marginal with water starting to drain back to Clear Lake (at 120.4 m AHD water has dropped at Back Lake and it is now disconnected from Clear Lake) (P. Terrill, *pers. comm. November 2015*). Based on this advice it was decided to use flow event definition 6 where flow volumes of 100 ML/day or more were recorded at the Wilby Wilby gauge on the Narran River, and the end of a flow event when the water levels in the Northern Lakes dropped below 120.746 m AHD at the Back Lake gauge (representing around 1.08 m). It is important to recognise that this revised flow event definition specifically describes conditions needed for the initiation and maintenance of Straw-necked Ibis breeding in the main colony site in the Northern Lakes and not to smaller flow events that can inundate Clear Lake and Narran Lake which may support breeding in other waterbird species and the water requirements of wetland vegetation.

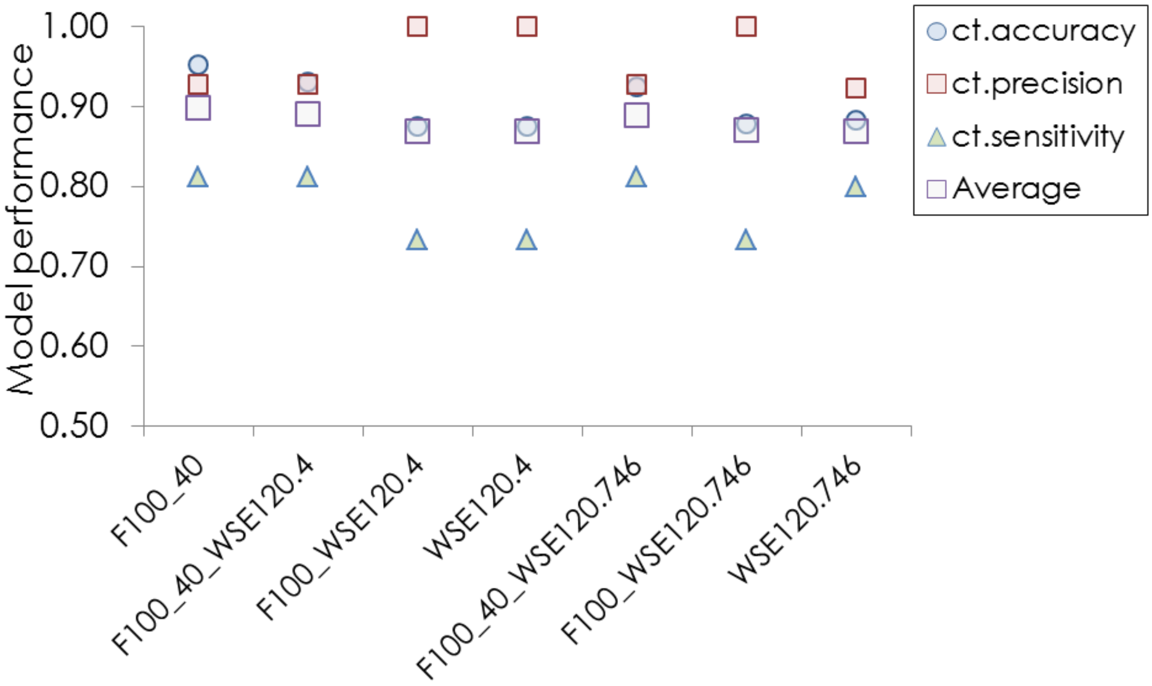


Figure 11 Accuracy (ct.accuracy), precision (ct.precision) and sensitivity (ct.sensitivity) of classification tree models on each flow event definition where F100 represents flows more than 100 ML/day at Wilby Wilby and the sensitivity to the model to different water surface elevations (WSE) m AHD at the Back Lake gauge (see Table 5 for flow event definitions).

Using the flow event definition 6 there were 33 flow events between 1971-2014 with cumulative flows for each event being on average 202,461 ML in total (± 217,011 SD; 12,625 – 1,073,279 ML) and with an average duration of 165 days (± 106 SD; 21 – 604 days). Of the 33 flow events, 15 events were associated with confirmed Straw-necked Ibis breeding records, and three of these had more than one breeding event within the same flow event (May 1983-Jan 1985; Feb 1988-Nov 1988; and Apr 1990-Oct 1990) (see Appendix 2).

Using confirmed records of Straw-necked Ibis breeding from 1971-2014, the CART analysis indicated that there was a probability of breeding of P = 1.00 (11 flow events, 11 breeding events) when total cumulative event flows exceeded 154,000 ML at Wilby Wilby in the first 90 days of the flow event. A second (contingent on the first) breeding threshold was also identified where flow volumes in the first 10 days from the beginning of flow event were greater than 20,000 ML there was a breeding probability of P = 0.43 (7 flow events, 3 breeding records). However, if both the total flow volume of event was smaller than 154,000 ML and in the first 10 days cumulative flow volumes were lower than 20,000 ML Straw-necked Ibis breeding probability was only P = 0.07 (15 flow events, 1 breeding record) (Figure 12). In isolation there were 14 flow events where the 20,000 ML threshold over the first 10 days was met with nine of these flow events associated with breeding records (Figure 13).

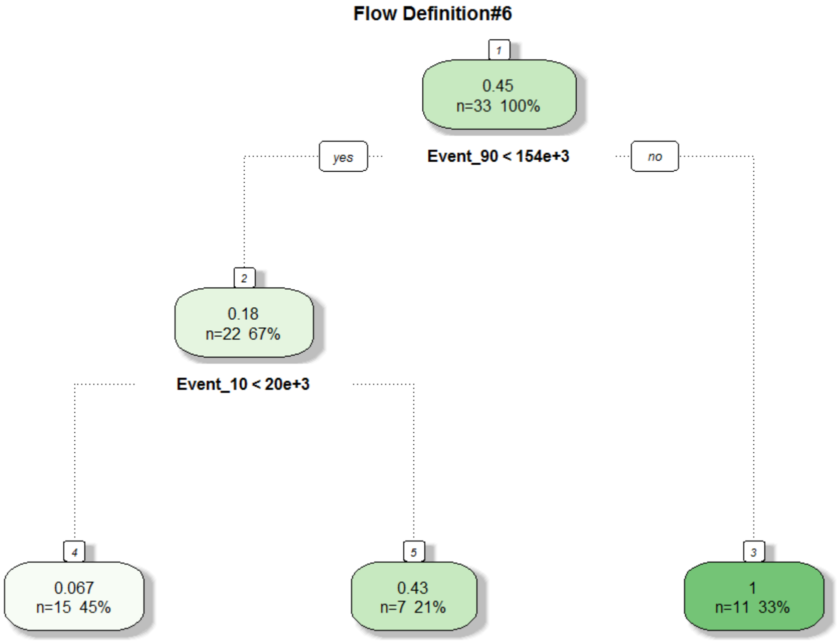


Figure 12 Results of CART analysis for flow event definition #6 identifying cumulative flow triggers for Straw-necked Ibis breeding in the Narran Lakes. Most simply, the darker boxes indicate the increasing probability of breeding under the two flow thresholds identified in the CART analysis.

Table 8 Thresholds, breeding probabilities and measures of performance of the CART analyses on the seven flow event formulations.

#	Flow event start[1]	Flow event end[1]	First threshold\P(breeding)[2]	Second threshold\P(breeding)[2]	Accuracy[3]	Precision[4]	Sensitivity[5]	Average[6]
1	100 ML/d	<40 ML/d	D90 - 149GL\0.93	D10-21GL\0.43	0.95	0.93	0.81	0.90
2	100 ML/d	<40 ML/d & <120.4 mAHD	D90 - 149GL\0.93	D10-21GL\0.43	0.93	0.93	0.81	0.89
3	100 ML/d	>120.4 mAHD	CF-196GL\1.00	D10-20GL\0.43	0.88	1.00	0.73	0.87
4	>120.4 mAHD	<120.4 mAHD	CF-183GL\1.00	D60-12GL\0.29	0.88	1.00	0.73	0.87
5	100 ML/d	<40 ML/d & <120.746 mAHD	D90 - 149GL\0.93	D10-22GL\0.43	0.92	0.93	0.81	0.89
6	**100 ML/d**	**<120.746 mAHD**	**D90 - 154GL\1.00**	**D10-20GL\0.43**	0.88	1.00	0.73	0.87
7	>120.4 mAHD	<120.746 mAHD	CF-140GL\0.92	Duration 116 days\0.21	0.88	0.92	0.80	0.87

[1] flowed measured at Wilby Wilby gauge (ML/d), WSE (mAHD) measured at Back Lake gauge

[2] identified thresholds and breeding probabilities based on the CART analysis

[3] $\left(\frac{\sum true\ predictions\ (0/1)}{\sum number\ of\ flow\ events}\right)$

[4] $\left(\frac{\sum true\ breeding\ predictions\ (0/1)}{\sum number\ of\ breeding\ predictions}\right)$

[5] $\left(\frac{\sum true\ breeding\ predictions\ (0/1)}{\sum number\ of\ breeding\ events}\right)$

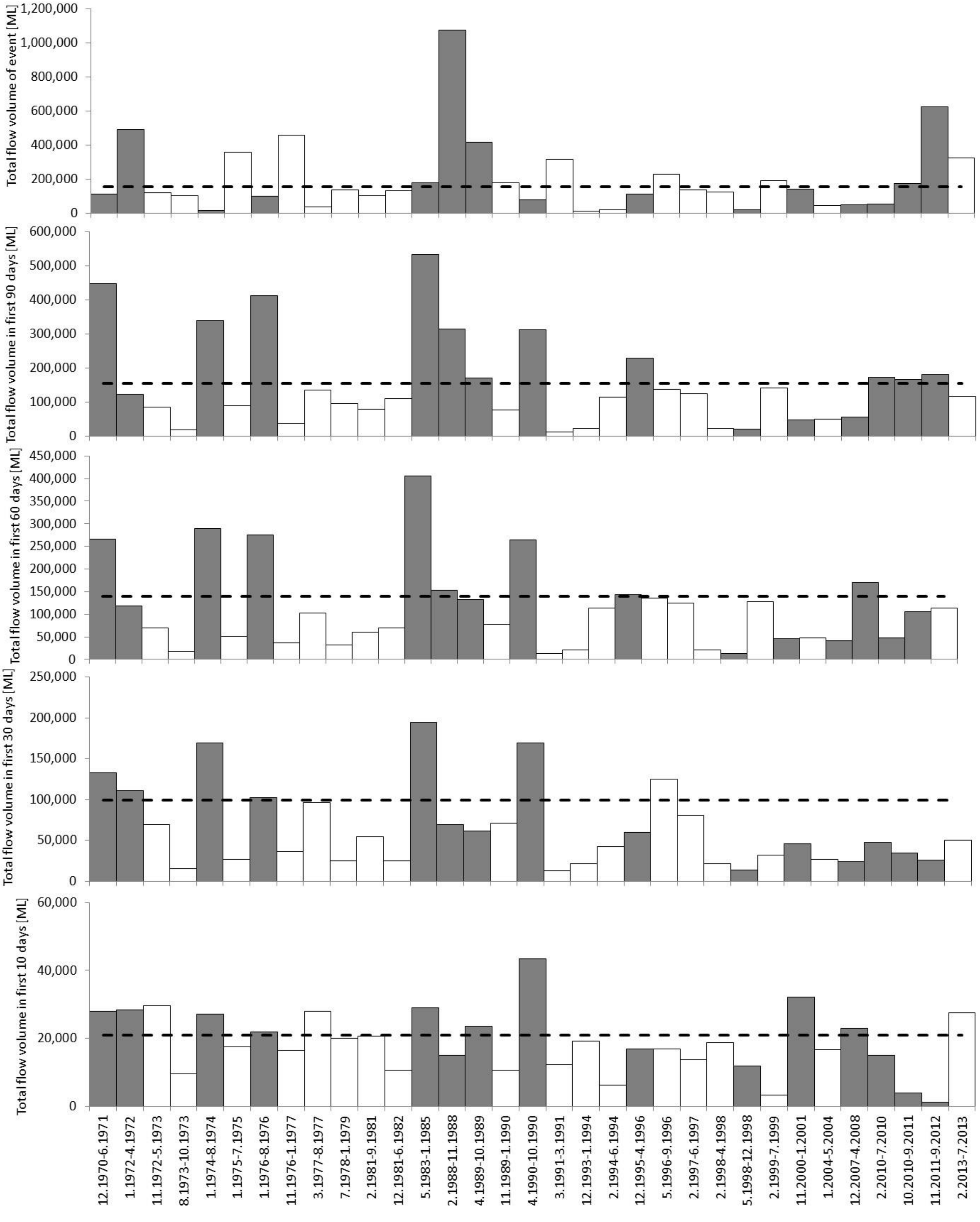


Figure 13 Flow events since 1971 and breeding events (grey shaded) along with identified single threshold as per Table 9 (dashed line).

To investigate alternative flow thresholds under the flow event definition, we carried out additional CART analyses constraining cumulative flow durations include cumulative flows over the entire flow event (Table 9). Although with lower model performance, when cumulative flows over the entire event (average duration 218 days ± 125 SD) were used, a threshold of greater than 157,000 ML was identified using the constrained CART analysis (Table 9; Figure 13).

Table 9 lists other possible flow thresholds and demonstrates that the 90 day threshold (154,000 ML) is still the best performing model. Alternative flow thresholds produce well-performing models including 157,000 ML over the entire flow event, as well as 99,000 ML over the first 30 days, and 21,000 ML over the first 10 days of the flow event alone. Note this analysis differs to the first CART analysis where the 20,000 ML 10 day threshold is a second threshold contingent on first 90 day threshold (see Figure 12). Where the 10 day threshold is implemented alone the overall model performance is lower (breeding probability of P = 0.75) compared to the other flow thresholds identified.

Table 9 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 alone). [1] Re-substitution error rate identifies the best fit model.

Flow metric	First threshold	P(breeding)	rt.error[1]
Event cumulative flow	157GL	0.92	0.90
90-day cumulative flow	154GL	1.00	0.91
60-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

There were four flow events associated with Straw-necked Ibis breeding which did not meet the 154,000 ML 90-day trigger. This included two large-scale breeding events in 1998 and 2007-08 (when more than 50,000 nests was recorded; see Table 2) and breeding events in the 1971-72 (90 day volume 121,804 ML) and 2000-01 (90 day volume 46,565 ML) where no colony size information is available (see Appendix 2). The 1998 flow event started in May 1988, following successive flow events over 1996 and 1997 and a large flow peak which occurred over September-October 1998 (total cumulative flow of the event was 190,185 ML). This resulted in a delayed Straw-necked Ibis breeding response with nesting commencing in mid-September after the first 90 days of the defined flow event and a total cumulative flow of 190,185 ML for this particular event. As noted earlier, the large breeding event in 2007-08 (90 day volume 55,159 ML) was unusual in that it occurred during an extended period of drought across the MDB when breeding opportunities for Straw-necked Ibis would have been limited and there was evidence of mortality of chicks because of insufficient flows to sustain water depth and inundation in the colony site during chick rearing (Brandis *et al.* 2011).

3.2.2 Total inundated area

Using the revised flow event definition, 33 flow events were identified in total from 18/12/1970 – 7/07/2013 and 15 of these flow events supported Straw-necked Ibis breeding in the Narran Lakes Nature Reserve. Three large extended flow events (5/1983 – 1/1985; 2/1988 – 11/1988 and 4/1990 - 10/1990) supported at least two separate breeding events in the same flow event (see Appendix 2). The size of colonies was variable ranging in size from 50 nests in 1981 (Brooker 1993) to more than 130,000 nests in 2012 (Spencer *et al.* 2015a).

Rayburg and Thoms (2008) reported that there were no events when Straw-necked Ibis breeding took place when total inundated area of the Narran Lakes was less than 6,000 ha and only two breeding events when the Northern Lakes were less than full. In more recent analysis of flooding relationships in the Narran Lakes, Thomas *et al.* (2016) reported that a cumulative flow of 250,000 ML at Wilby Wilby resulted in a cumulative inundated area of about 16,600 ha in the Narran Lakes system.

Estimates of colony sizes vary across the historical breeding record but using available estimates for 11 flow events (see Appendix 2), there is evidence that Straw-necked Ibis breeding is associated with widespread flooding of the Narran Lakes system. Maximum modelled inundated surface area for the whole Narran Lakes system from the updated IQQM for the 1971-2014 period (see Section 3.3.1) was high (17,761 ha ± 8,235) for the 15 flow events associated with Straw-necked Ibis breeding. Estimates of maximum inundated area for the remaining 18 flow events not associated with breeding records was lower (9,285 ha ± 3,891). There were six flow events were large-scale Straw-necked Ibis breeding (> 50,000 nests) was recorded and both maximum modelled inundated area (16,746 ha ± 10,331) and cumulative flows over the whole event (364,842 ML ± 360,732) were high.

One outlier was the 2007/08 flow event where 74,000 Straw-necked Ibis nests were recorded but this event was thought to be a marginal event in terms of optimal conditions for breeding due to low cumulative event flows (55,159 ML) and limited flooding of the surrounding floodplain (maximum modelled inundated surface area being 4,050 ha and maximum inundated surface area observed from available Landsat imagery was 4,132 ha) (Thomas and Heath 2014)) despite the 10 day threshold being met (23,026 ML recorded at Wilby Wilby) in late December 2007 (Brandis *et al.* 2011; Rayburg and Thoms (2008)).

These preliminary findings suggest that large-scale flooding of the Narran Lakes system may be an important trigger for large-scale breeding events providing the most favourable conditions (in terms of flood supplies and total nesting habitat available for Straw-necked Ibis to breed), however, further monitoring of colony sizes and inundated areas is needed to refine thresholds for the magnitude of breeding in relation to total inundated area and total cumulative flows over an event.

3.2.3 Flow timing (season)

In the MDBA EWR assessment for the Narran Lakes the timing of the colonial waterbird breeding flow indicator was thought to be preferably summer and autumn but was not constrained to this period to reflect that high flows in the system depend on the occurrence of heavy rainfall and are largely unregulated events (MDBA 2012). The initiation of colonial waterbird breeding is often associated with high flow events, although the timing of flooding can be influential in determining whether breeding is triggered (Brandis 2010; Carrick 1962; Harper 1990; Kingsford and Auld 2005).

Straw-necked Ibis can respond quickly to suitable flow conditions (Brandis and Bino 2016). In previous breeding events in Narran Lake the lag period between the start of a flow event and the commencement of breeding in Straw-necked Ibis was longer following autumn flooding compared to summer flooding (Magrath 1991). Colonial waterbird breeding in Australia seldom occurs in winter (June-August) (McKilligan 1975) when temperatures are low. This pattern may reflect the vulnerability of chicks to exposure during winter months, with temperature becoming a selection factor and/or also limited food availability in the surrounding floodplain. However, there are few data available for Australian colonial waterbirds regarding the temperature at which adults may abandon nestlings. McCosker (1996) reported adults deserting nests in the Gwydir Wetlands leading to the death of chicks during winter and noted that this was probably because of cold temperatures. There are also records of a small number of Straw-necked Ibis attempting to breed in the Narran Lakes Nature Reserve during winter 1989 and 1990 when water levels remained high (approximately 0.9 m, or 121.366 m AHD at Back Lake gauge) resulting in some unsuccessful clutches (Magrath 1991). The availability of an abundant food supply may be another selective factor. For example, invertebrates are a major source of food for colonial waterbirds (McKilligan 2005; Carrick 1959) but cold temperatures can impact on invertebrate emergence (Cummins and Klug 1979; Jenkins and Boulton 2003).

All breeding data for Straw-necked Ibis in the Narran Lakes Nature Reserve for the 1971-2014 period (22 records in total including probable and failed records, see Appendix 2) was used to determine the timing of initiation of breeding colonies using information included in the survey data e.g. nesting stage, presence of eggs/chicks. This analysis showed that there was a strong seasonality to the timing of breeding events in the Narran Lakes Nature Reserve with 59% of breeding events beginning in January (14%), February (18%) or March (27%), and 73% of all breeding events initiated in the six months between October and March (Figure 14).

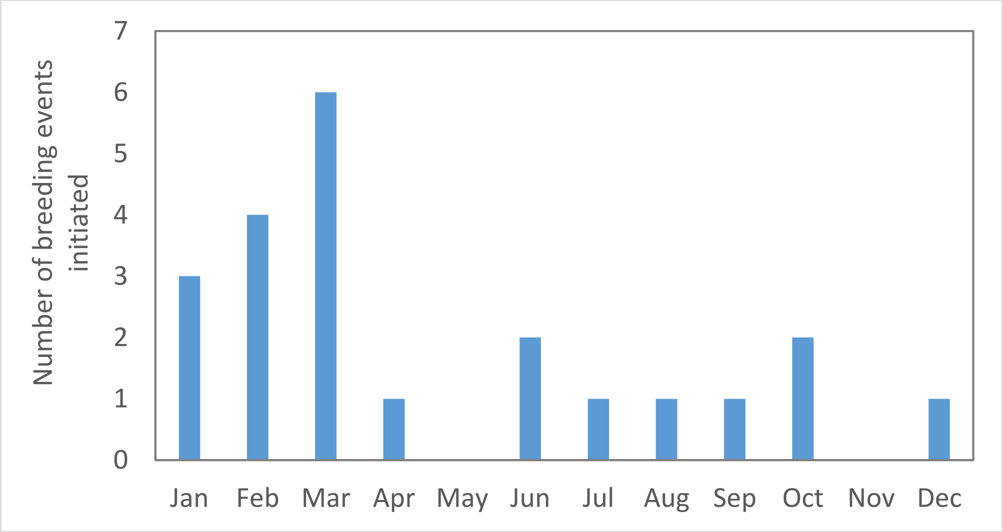


Figure 14 The timing of initiation of all known Straw-necked Ibis breeding events (n=22) that started in each month in the Narran Nature Reserve (1971-2014).

3.2.4 Depth and duration of flooding

In addition to suitable flow timing, the duration of flood events can determine the success of breeding with longer floods providing greater opportunities for building up of condition, courtship, construction of nests and egg laying, incubation, rearing and fledging of chicks (Brandis and Bino 2016). Water depth can be an important factor influencing the initiation of breeding and the success of Straw-necked Ibis events (Carrick 1962; Henderson 2000; Brandis *et al.* 2011). Analysis of flood events that resulted in breeding in the Narran Lakes are typically characterised by an initial flow followed by a secondary flow (Thoms *et al.* 2007) that can extend the duration and depth of flooding around nests.

In the 2010 version of the Narran DSS, 66 days was implemented in the Straw-necked Ibis breeding models to represent a threshold for the minimum duration of flooding needed for breeding. Below 66 days there was a zero probability in the Narran DSS of successful Straw-necked Ibis breeding (see Section 3.1.2). Marchant and Higgins (1990) report the total duration of nesting as greater than 63 days to account for laying, incubation (21 days), chick rearing (28 days) and the post-fledgling period (14 days). These observations are broadly consistent with observations by Brandis *et al*. (2011) in the Narran Lakes where six stages of young were described based on development (one egg stage and five chick stages): egg (1–20 days old); 'downy chick' (recently hatched, downy feathered, 21–25 days old); 'squirter' (larger chicks with some feather development, that remained in nests, 26–30 days old); 'runner' (mixture of developed and down feathers, ability to leave the nest on foot, 31–35 days old); flapper' (could not fly, flapped while moving between nests, 36–40 days old); and 'flyer', (young juvenile that could fly, 41–45 days old). This development time from egg to fledgling would represent the minimum time for Straw-necked Ibis to rear their young successfully as it does not include the lag time before birds commence nesting and the time for birds to build their nests which can be 10-28 days after the floodwaters arrive (Carrick 1962; P. Terrill *pers. comm* 2015) or longer when flows start in autumn and winter months (Magrath 1991).

This information provides evidence for a minimum requirement of flooding of between 73-94 days to support successful Straw-necked Ibis breeding. This flood duration assumes that adult birds all synchronise their breeding cycle to commence nest building and laying roughly on the same date which is not always the case (Brandis *et al.* 2011). The probability of breeding under the thresholds identified in Section 3.2.1 (154,000 ML over the first 90 days and 20,000 ML over the first 10 days of the flow event) also increased when the total duration of the flow event increased (Brandis and Bino 2016).

A duration of 90 days or more would encompass the flooding requirements (from incubation, chick rearing to fledging) of at least 14 more waterbird species, including non-colonial waterbird species that are known to breed in the Narran Lakes system (Brandis and Bino 2016). During the egg laying, incubation and chick rearing phase of breeding the provision of flooded habitat and maintenance of water levels can be important in Straw-necked Ibis reproductive success (Brandis *et al.* 2011). Information on the habitat requirements of birds during the post-fledgling period, either at the colony site or elsewhere (Brandis and Bino 2016). However, the availability of food resources during this post-fledgling period is likely to be critical for the survival of young birds during their first year. It is likely that floods of long duration will provide greater opportunities for waterbird species to successfully raise their young to independence and for survival of young during the post-dispersal period.

Although not consistently recorded across the breeding record, there are observations of Straw-necked Ibis nests and/or young being abandoned in 1997 (Ley 1998b), 2008 (Brandis 2010) and 2010 (P. Terrill *pers. obs.* 2010) due to falling water levels. The most detailed records of the impact of water levels on the breeding success was in 2008 (Brandis *et al.* 2011; Kingsford *et al.* 2008) where a decline of water depth of more than 30 cm over 40 days during chick stage was associated with nest abandonment of Straw-necked Ibis (Brandis *et al.* 2011). Straw-necked Ibis began nesting at Narran Lakes Nature Reserve in mid- January 2008. Surveys of the colony began on the 29 January 2008 and continued until all chicks were fledged by 24 April 2008. There were two clear breeding events (colony 1 and 2), varying in start dates and location of breeding. Colony 1 was established on 15 January 2008, 16 days after the initial peak flow reached Narran Park gauge (nesting on lignum and phragmites (44.5 ha) between Clear and Back Lakes. Straw-necked Ibis were estimated to make up about 97% of all nesting birds, Glossy Ibis (*Plegladis falcinellus*) 2% and Australian White Ibis (*Threskiornis molucca*) only 1%. The second flow peak inundated 7% (322 nests) of the low lying survey nesting sites in colony 1. Between the 9 and 19 February 2008 survey, colony 2 (145 ha) established adjacent to colony 1

(Figure 15; Figure 16). In total, there were 71,872 Straw-necked Ibis nests on the 24 February (post-inundation of colony 1): 22,280 nests were in colony 1 (31% of nests) and 49,592 nests were in colony 2 (69%). Nest density was higher in colony 1 with about 501 nests ha^{-1} compared with 342 nests ha^{-1} in colony 2.

Results of nest surveys found that in colony 1 60% of eggs hatched and 94% of chicks fledged, while in colony 2, 40% of eggs hatched with only 17% of chicks fledging (Table 10). The relationship between date of nest establishment and offspring success was not significant ($Z = 0.771$, $p = 0.441$); the deviance explained was only 1%. Water depth at the nest site was a significant explanatory variable in explaining reproductive success where depth was higher in successful nests compared to unsuccessful nests (Figure 17): at the egg stage in colony 1 ($p = 0.0196$); chick stage in colony 2 ($p = <0.001$); and overall (eggs and chicks) offspring success in colony 2 ($p = 0.0353$). Even though median depth was lower in colony 2 for successful than unsuccessful nests (Table 11 & Figure 17A), the variance was high and so there was no significant difference between means ($p = 0.1909$). Median water depth in colony 2 was lower than the median depth in colony 1, for all nesting stages (Figure 17). Nest density was not significant for either colony at any stage of nesting (Brandis *et al.* 2011). No temporal autocorrelation was detected in the models (Brandis *et al.* 2011).

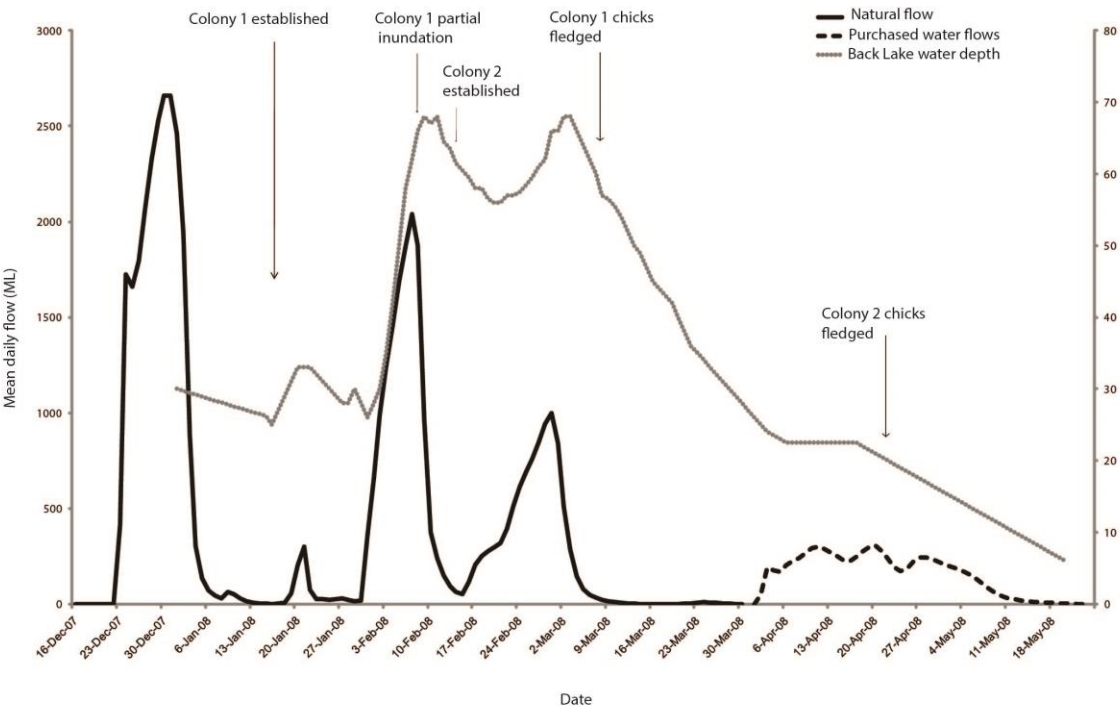


Figure 15 Daily flows at Narran Park gauge during the inundation of Narran Lakes Nature Reserve and stages of Straw-necked Ibis breeding from December 2007 – May 2008 (from Brandis (2010)).

Table 10 Summary of breeding effort for ibis nesting at Narran Lakes. Standard error shown in parentheses.

Variable	**Colony 1** **n = 242**	**Colony 2** **n = 475**
Mean clutch size	1.88 (0.12) 1.44 (0.16)[a]	1.95 (0.07)
Hatching rate	0.60 (0.06)	0.40 (0.05)
Mean no. chicks per nest at day 22	0.94 (0.14)	0.17 (0.08)
Mean daily mortality rate at egg stage[b]	0.04 (0.01)[a]	0.06 (0.01)
Mean daily mortality rate at chick stage[b]	0.01 (0.004)	0.06 (0.1)
Probability of surviving egg stage (17 days)	0.50	0.35
Probability of surviving chick stage (35 days)	0.70	0.11
Probability to survive from egg to fledgling	0.35	0.04

[a] Post inundation colony 1

[b] Mayfield 1975

n = number of sampled nests

Table 11 Mean (±SE) maximum and minimum heights (cm) of nests above the water, water depth at each nesting site (cm) and results of t-tests at comparable stages of chick development (days in parentheses) for colonies 1 and 2.

Chick development (days)	**Variable**	**Colony 1**	**Colony 2**	**t**	**Df**	**p**
Egg (1-20)	Nest height max.	48.84 (2.63)	33.97 (2.09)	4.393	60	<0.001
	Nest height min.	23.78 (1.55)	15.4 (1.21)	4.227	60	<0.001
	Water depth	36.28 (1.88)	71.27 (2.32)	-11.70	60	<0.001
Downy chick (21-25)	Nest height max.	21.35 (1.16)	40.81 (1.5)	-10.04	78	<0.001
	Nest height min.	12.16 (1.02)	26.02 (0.77)	-11.034	78	<0.001
	Water depth	84.39 (2.14)	57.71 (1.99)	8.95	77	<0.001
Squirter (26-30)	Nest height max.	33.49 (1.28)	52.68 (2.04)	-7.652	74	<0.001
	Nest height min.	24.14 (1.54)	36.59 (1.11)	-6.681	74	<0.001
	Water depth	69.87 (1.26)	41.22 (2.08)	10.91	55.15	<0.001
Runner (31-35)	Nest height max.	25.00 (1.30)	62.69 (2.40)	-13.834	57.95	<0.001
	Nest height min.	17.95 (1.32)	49.49 (1.81)	-14.095	67.31	<0.001
	Water depth	76.06 (1.68)	30.28 (2.20)	11.66	48.03	<0.001
Flapper/Flyer[a] (36-45)	Water depth	47.50 (1.98)	39.45 (4.29)	2.026	41	0.049

[a] nests no longer used from this stage of chick development (therefore nest heights not recorded).

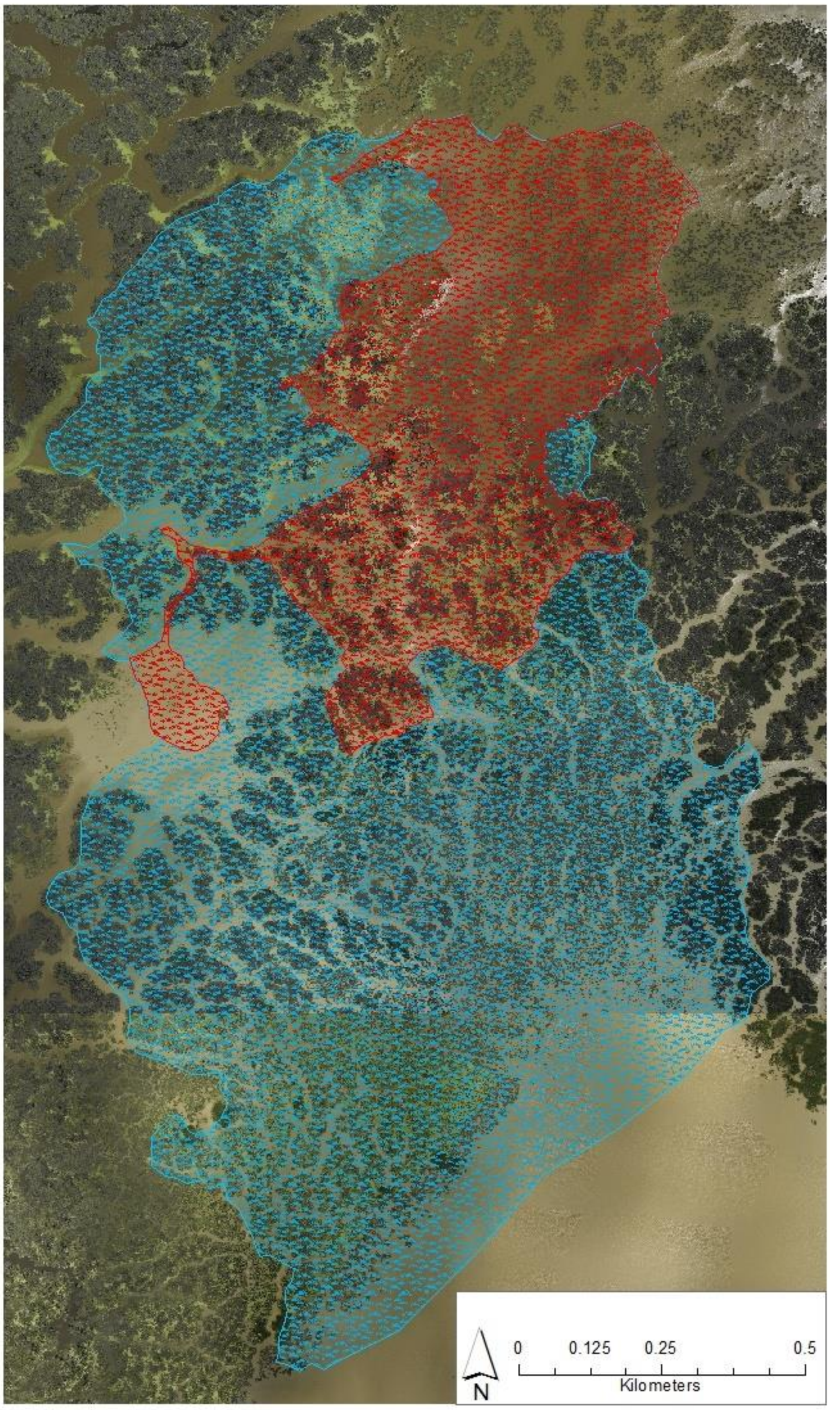


Figure 16 Extent of Colony 1 (29th Jan. 2008) (red area) and Colony 2 (19th Feb. 2008) (blue area) boundaries between Clear and Back Lakes overlayed with high resolution aerial photography.

The high mortality in colony 2 was potentially due to insufficient flows to sustain water depth and inundation in the colony site during chick rearing (Figure 15). Desertion by adults has been recorded in ibis species when there is sufficient flow to stimulate breeding but where subsequent falling water levels cause desertion of nests (McCosker 1996; Leslie 2001). Water depth and breeding success relationships were generally negative, with decreasing water depths resulting in decreased success. However, increasing water depths as a result of natural flows, resulted in the inundation of nests at the egg stage in colony 1. This could be seen in the high variance of depth in colony 1, with some unsuccessful nests and higher depths than successful nests.

Responses to water depth may be a determining factor or a surrogate cue for other factors impacting on reproductive success such as wetland area which determines the availability of food resources, and increased risk from land predators. Falling water levels are probably the proximate stimulus for desertion but the ultimate factor is probably lack of food resources that decline as floods decrease. This was indicated by the poor condition of many dead chicks. Predation of birds by land predators was not observed during this breeding event, possibly because the wetland did not completely dry out (Brandis *et al.* 2011). The importance of food resources and how they change during breeding events is poorly known (Jenkins *et al*. 2009; Brandis unpublished data 2010-11 from the Lowbidgee wetlands), however, it is widely acknowledged that sufficient food supplies need to be available for the duration of the breeding event and post-fledging period to support both adult birds and their young (Brandis and Bino 2016).

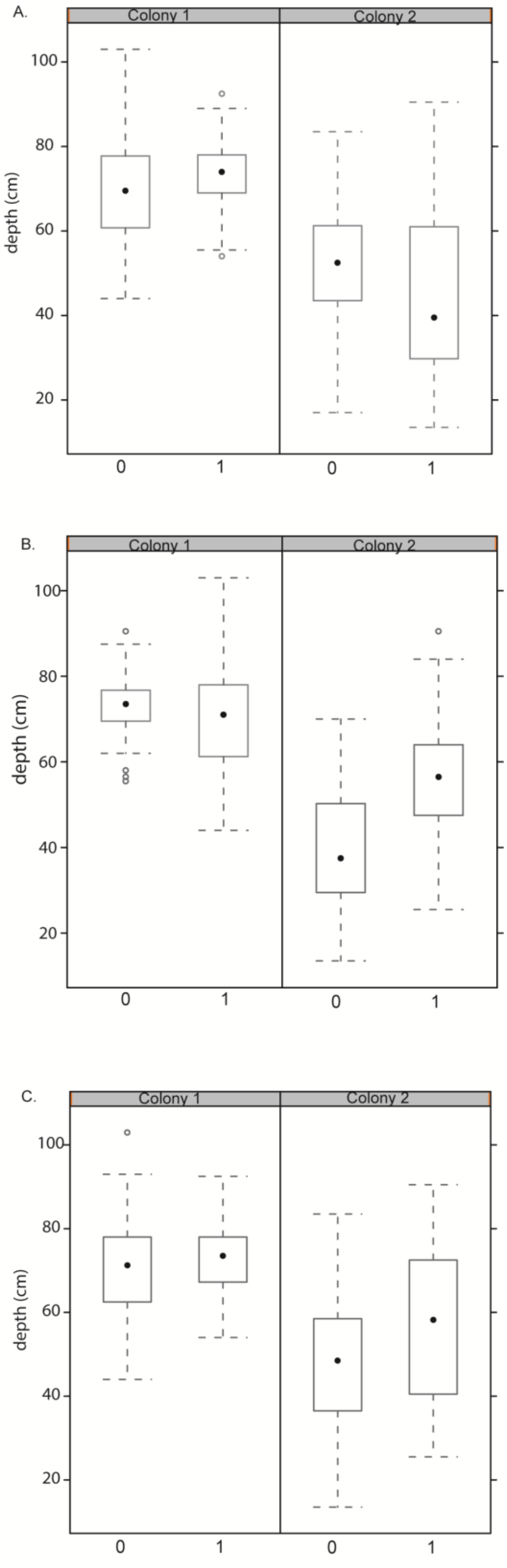


Figure 17 Plots illustrating the relationship between water depth (cm) and nest site success (0/1) for each colony at A) egg, B) chick and C) all offspring stages (eggs and chicks). The filled circle represents the median, the lower and upper bounds of the box represent the 25th and 75th quartiles of the data respectively, while the whiskers show the extreme data point no more than 1.5 times the interquartile range from the box, unfilled circles represent outliers.

The change in water level in the Northern Lakes as a driver for the likelihood of Straw-necked Ibis abandoning their nests was reviewed during the waterbird workshop during the Stage 2 project. This change in water level (at the Back Lake gauge 422034) was represented in the 2010 version of the DSS to include a 'rate of rise' and 'rate of fall' parameter. Through the discussions at the workshop it was decided to remove the 'rate of rise' component of this model in the Narran DSS as on-ground observations of colonies in the Narran Lakes and elsewhere have shown that birds will re-nest rather than desert the whole colony in response to rising floodwaters. The rise also tends to impact the early nesters or less experienced birds which subsequently re-nest at a higher level or build up the height of already established nests. More mobile chicks (runners and flappers stage) can also move themselves to higher lignum bushes in response to rising floodwaters which are usually indicative of further flows in the system and are beyond the influence of management actions. The falling of water levels below the 120.746 m AHD threshold and the 'rate of fall' was thought to be more crucial in terms of maintaining nests containing eggs and young (immobile chicks) as rapidly dropping water levels have been linked to desertion of nests in previous breeding events in the Narran Lakes (documented in 1997, 2008 and 2010) most likely because it is indicative of greater predation risk to foxes and pigs and generally reduced availability of food resources to support rearing of chicks. However, further monitoring of water levels and nesting success is required to determine the impact of water level thresholds on different stages of nesting in terms of likelihood of nest abandonment.

3.2.5 Rainfall

In the Condamine-Balonne region most of the rainfall occurs in summer months and runoff is highest in summer and early autumn (CSIRO 2008). In examining total rainfall at the Brewarrina and Walgett gauges during the flow events coinciding with breeding events in the Narran Lakes, total rainfall over the duration of flow event was found to be highly correlated with cumulative flows and duration of each flow event but not with average air temperature over the flow event. Similarly, total rainfall over the first 90 days of flow event was found to be highly correlated with cumulative flows over the first 90 days but not with duration of each flow event and average air temperature over the first 90 days (Table 12 and Table 13).

Incorporating rainfall and temperature in the CART analysis identified rainfall at Walgett as being a predictor for Straw-necked Ibis breeding. The CART analysis identified a first threshold when cumulative flows over the first 90 days was 154,000 ML (P = 1.00) and a second threshold (contingent on the first), when total rainfall over the first 90 days was greater than 162 mm (P = 0.57) (Figure 18).

When considering only cumulative rainfall over the first 90 days of flow event, a first threshold was identified when total rainfall was greater than 184 mm (P = 0.92) and a second when rainfall was greater than 136 mm (P = 0.43) (Figure 19).

Table 12 Pearson correlation between rainfall and hydrological metrics including total cumulative flow (CF), flow duration, total cumulative over 10, 30, 60 and 90 day (D) periods from the start of each flow event, and minimum and maximum air temperature.

	D90.Rain.Brewarrina	CF.Rain.Brewarrina	D90.Rain.Walgett	CF.Rain.Walgett
Duration	0.36	0.85	0.54	0.95
Event_CF	0.44	0.82	0.54	0.87
Event_10	0.21	0.16	0.05	0.11
Event_30	0.33	0.50	0.29	0.48
Event_60	0.44	0.65	0.42	0.63
Event_90	0.50	0.70	0.51	0.69
D90.Rain.Brewarrina	1.00	0.73	0.83	0.51
CF.Rain.Brewarrina	0.73	1.00	0.77	0.93
D90.Rain.Walgett	0.83	0.77	1.00	0.71
CF.Rain.Walgett	0.51	0.93	0.71	1.00
D90.Tmin.Walgett	0.15	-0.10	0.11	-0.18
CF.Tmin.Walgett	-0.23	-0.33	-0.27	-0.38
D90.Tmin.Brewarrina	-0.38	-0.41	-0.40	-0.41
CF.Tmin.Brewarrina	0.11	-0.15	0.06	-0.23
D90.Tmax.Walgett	-0.07	-0.30	-0.12	-0.37
CF.Tmax.Walgett	-0.33	-0.44	-0.37	-0.48
D90.Tmax.Brewarrina	-0.23	-0.29	-0.29	-0.34
CF.Tmax.Brewarrina	-0.14	-0.34	-0.16	-0.38

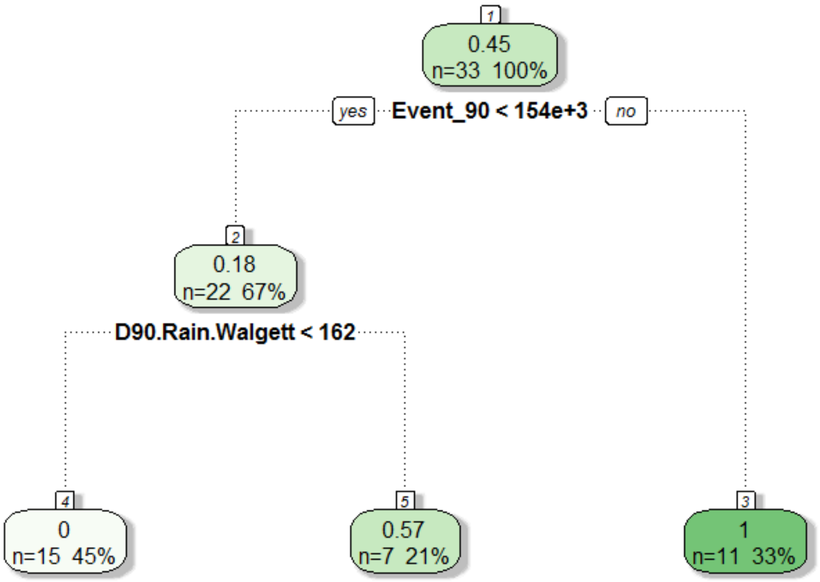


Figure 18 Classification tree of Straw-necked Ibis breeding based on 33 flow events identified from 1971-2013 when rainfall and ambient air temperatures in Walgett and Brewarrina are considered.

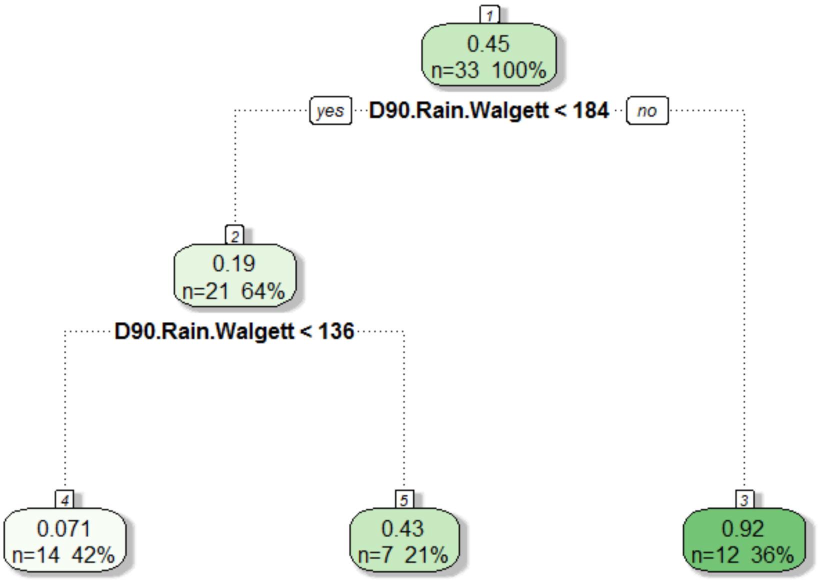


Figure 19 Classification tree of Straw-necked Ibis breeding based on 33 flow events identified from 1971-2013 when rainfall and ambient air temperatures in Walgett and Brewarrina are considered.

Table 13 Environmental conditions (rainfall and temperature) recorded at Brewarrina and Walgett during the first 90 days of flow events where Straw-necked Ibis were recorded breeding at Narran Lakes. See full details in Appendix 3.

	Brewarrina (average ± SD [min – max])		
	Rainfall	**Max Temp**	**Min Temp**
Non-breeding	90.6 ± 46.4 [30.8 - 175.5]	28.9 ± 4.9 [19.6 - 35.8]	14.1 ± 4.2 [6.5 - 20.2]
Breeding	242.4 ± 117.2 [53.4 - 510]	26.5 ± 4.3 [19.5 - 34.1]	13.1 ± 3.8 [6.5 - 20]
Overall	159.6 ± 114.2 [30.8 - 510]	27.8 ± 4.8 [19.5 - 35.8]	13.7 ± 4.0 [6.5 - 20.2]
	Walgett (average ± SD [min – max])		
Non-breeding	117.4 ± 51.1 [47.5 - 241]	14.6 ± 4.3 [5.9 - 21.2]	29 ± 4.9 [18.1 - 35.7]
Breeding	245.8 ± 96.8 [95.6 - 413.4]	14.9 ± 4.9 [5.7 - 20]	27.4 ± 5.9 [17.2 - 34.3]
Overall	175.8 ± 98.5 [47.5 - 413.4]	14.7 ± 4.5 [5.7 - 21.2]	28.3 ± 5.3 [17.2 - 35.7]

In future analyses of the contribution of rain to predicting Straw-necked Ibis breeding events it would be beneficial to examine local rainfall records including those from East Mullane, properties neighbouring the Narran Lakes Nature Reserve and automated rainfall gauges installed within the reserve (at Back Lake and Bundah gauges and the Pelican Lagoon RM-Cam).

3.2.6 Time since last breeding event

In the EWR for the Narran Lakes it was assumed that the eight-year period between 1999 and 2008 represented the maximum desirable number of years between nesting opportunities for key waterbird species in the Narran Lakes (MDBA 2012). 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 (Brandis and Bino 2016). The current eight-year maximum between events specified in the EWR represents high risk because this threshold could feasibly provide only one breeding opportunities within the lifespan of a Straw-necked Ibis at the Narran Lakes and it assumes there are other opportunities for birds to breed elsewhere.

In the original Narran DSS it was hypothesised that the size of the breeding event was influenced by the drought and other opportunities for breeding in that time period across the Northern Basin; however, this hypothesis was not represented in the DSS model due to a lack of evidence (ANU Enterprise 2011). Although there were no quantitative data to support this assumption the 2008 breeding event in the Narran Lakes was the first breeding in about seven years, so if natal site fidelity was playing a role in the occurrence of Straw-necked Ibis breeding, it may have been the only opportunity for breeding some individuals had in their lifetime.

When Inter-breeding Interval (IBI) was incorporated into a Generalised linear model analysis along with 90 and 10-day cumulative flows of the historical Straw-necked Ibis breeding and flow relationships using the updated record from 1971-2014, there was some a significant association with 90-day cumulative flows but not with IBI (Figure 20). Based on these findings, further information on natal fidelity of Straw-necked Ibis and their use of neighbouring wetlands in the Northern Basin are required to further investigate this relationship.

Table 14 Generalised linear model output when considering 90 and 10-day cumulative flows along with IBI.

	Estimate	Std. Error	z value	Pr(>|z|)
Intercept	-4.26	1.93	-2.21	0.03
Event_90	2.15E-05	9.91E-06	2.17	0.03
Event_10	4.09E-05	5.30E-05	0.77	0.44
IBI	7.32E-04	6.93E-04	1.06	0.29

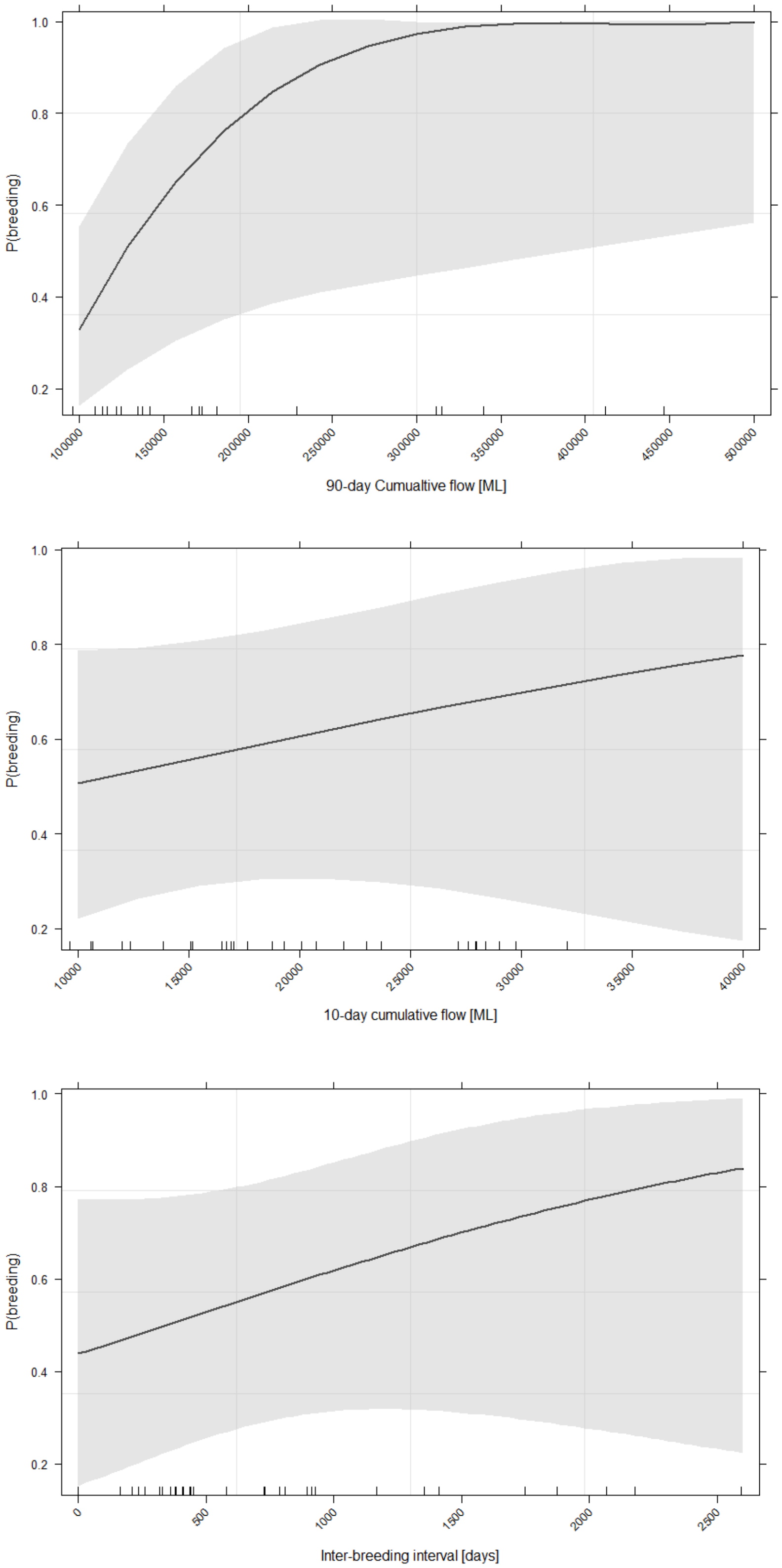


Figure 20 Predicted probability of Straw-necked Ibis breeding as a function of explanatory variables (including 90-day, 10-day cumulative event flow (ML) when considering IBI (days) (explanatory variables are held constant at average value).

3.2.7 Summary of improved understanding

The review of available literature and new breeding and flow data for the Narran Lakes has allowed for an improved understanding of triggers for Straw-necked Ibis breeding in the system. Key findings from this review completed over the Stages 1 and 2 of this project and the implications for revision of the Straw-necked Ibis breeding ERMs are summarised in Figure 21 and Table 15 below.

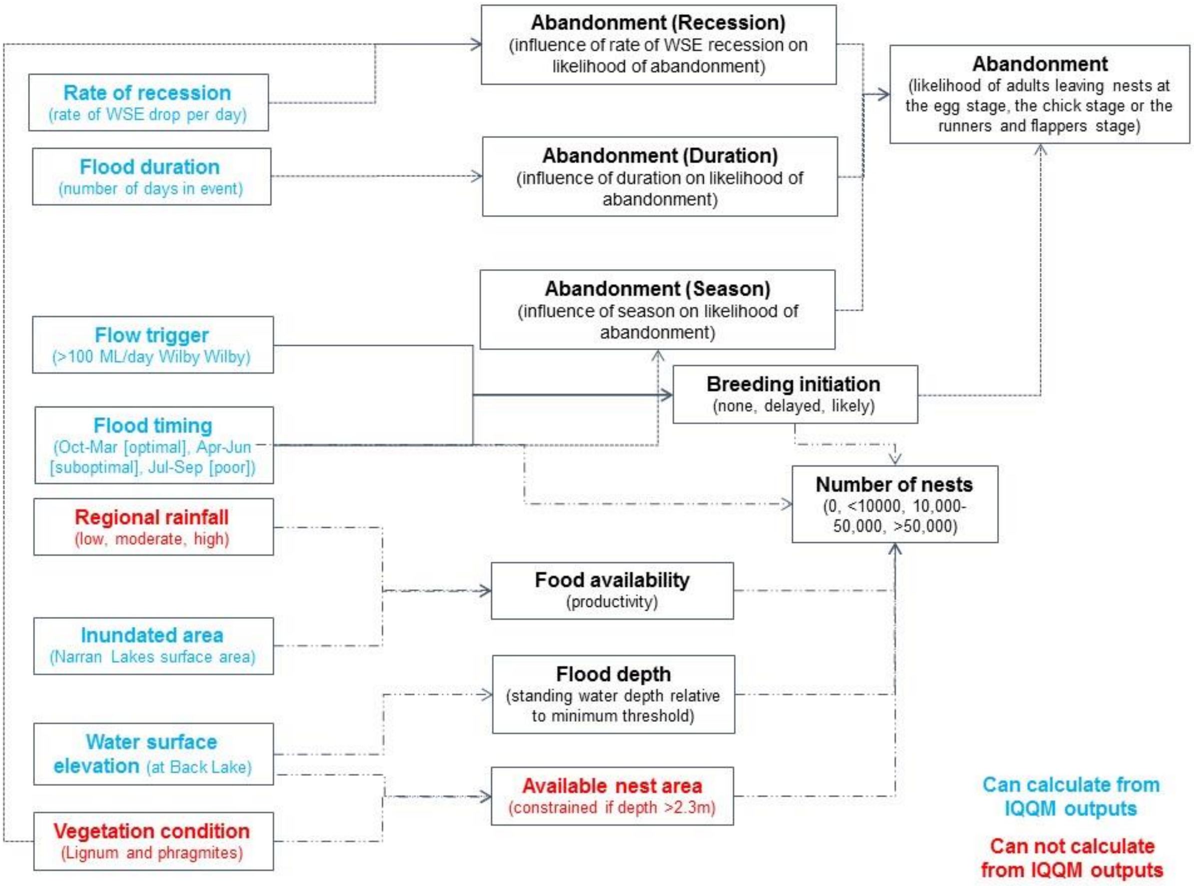


Figure 21 Revised conceptual model showing factors influencing Straw-necked Ibis breeding initiation and fledging of young at the Narran Lakes. The representation of these factors in the revised Narran DSS are discussed further in Section 3.3.

Table 15 Summary of parameters in the Straw-necked Ibis breeding models and review of how they are represented in the Narran Lakes DSS during the expert workshop held in August 2015 (from Spencer *et al.* 2015b). The results of these discussions were used to update the conceptual model for Straw-necked Ibis breeding in the Narran DSS (see Figure 21 above).

Parameters	**Model component**	**Workshop discussion and results of the analysis**	**Implications for upgrade of the Narran DSS**
Time since last breeding event (years)	Number of nests	Likely to be influential but there is insufficient evidence or data to populate model relationships relating to long-term breeding observations and the time since last breeding event. There is also limited data (mostly from bird banding records) documenting the average life span of a Straw-necked Ibis. However, it was recognised that the average period between events is likely to be critical threshold for condition of nesting habitat and the opportunity for breeding across the Northern Basin and the current eight year interval is too long between flow events to support the maintenance and restoration of waterbird populations.	Leave these parameters out of model (consistent with current version)
Long-term breeding observations			
Local rainfall	Number of nests	Likely to be influential particularly for large flood events where local rainfall can be intense, augmented water levels in the Narran system. As Straw-necked Ibis rely on terrestrial invertebrates regional rainfall is also likely to be a driver of food availability. The regional rainfall gauges could be used as a proxy for what is occurring regionally. Access to hand recorded rainfall records at East Mullane would be the most valuable if accessible*. **Historical rainfall records were not obtained within the time frame for the Stage 2 project.*	Exclude this parameter until local rainfall data is available for the Narran system
Number of birds at a site	Number of nests	Likely to be influential but no quantitative analysis to demonstrate the influence of the total number of birds at the site. The coverage of the historical Straw-necked Ibis breeding record also does not record total numbers of adults consistently.	Leave this parameter out of model (consistent with current version)
Annual flow at Wilby Wilby	Number of nests	Previous analysis e.g. Thoms *et al*. (2007) Brandis (2010) have shown strong relationships between breeding and river flows at the Wilby Wilby gauge. Analysis of the updated Straw-necked Ibis breeding and flow relationships for 1971-2014 indicate a daily flow starting threshold of >100 ML/day is required at the Wilby Wilby gauge for the initiation of breeding with more than 154,000 ML over 90 days required for successful completion of Straw-necked Ibis breeding and there is evidence that a 10 day threshold of >20,000 ML is also important for triggering breeding.	Reconfigure in model based on results of testing of flow formulations against breeding record (see Section 3.2.1)
Water depth (WSE) Northern Lakes	Suitability for nesting/ likelihood of nest abandonment	Clear Lake and Back Lake are essentially disconnected at 120.4 m AHD WSE and only about 30cm depth of water in deeper channels and waterbodies. Water depths greater than 120.746 m AHD WSE are thought to support successful breeding (P.Terrill *pers. obs*). Although the improved IQQM now allows for the modelling of flows in the separate Back and Clear Lake components, the resolution of the historical Straw-	Include in model

		necked Ibis breeding records do not allow for separation of events based on location. Therefore it was decided to model the likelihood of breeding in the Northern Lakes as a whole entity.	
Inundated surface area of Narran Lake system	Suitability for nesting/ number of nests	The original conceptual model included the area of Narran Lake as a proxy for food availability in the Narran system. Straw-necked Ibis can feed on large amounts of terrestrial invertebrates such as locusts on the wider floodplain but as Narran Lake recedes muddy margins are exposed and provide additional feeding habitat for ibis. Large-scale Straw-necked Ibis breeding (>50,000 nests) can be associated with large-scale flooding and total cumulative flows of more than 250,000 ML. Recent analysis of inundation patterns in the Narran Lakes by Thomas *et al.* (2016) demonstrated that a cumulative flow of 250,000 ML resulted in a cumulative inundated area of about 16,600 ha in the Narran Lake system.	Include in model using information from Section 3.2.2
Days below 3C (number of cold days)	Likelihood of abandonment	This 3^{0} C air temperature threshold was set in the Phase 1 DSS and broadly translates to a seasonality preference curve as ibis tend not to breed or have unsuccessful breeding in winter/early spring (Jul-Sep), and also conditions are not ideal. During the workshop it was agreed this be replaced by a true seasonality component as analysis of nesting events demonstrated an optimal period for breeding between October and March. There is lag effect following the flow pulse with breeding thought to start within four weeks of flooding if the time of year is optimal (P. Terrill *pers. comm*) but it was recognised that this lag before breeding starts is longer in suboptimal months.	Replace temperature parameter with seasonal grouping reflecting the optimal months for breeding being between October-March (see Section 3.2.3)
Depth of water under nests	Likelihood of abandonment	The depth of water under nests was thought to be a critical driver for nest abandonment documented by Brandis *et al.* (2011) and by other field surveys by NSW State agency staff e.g. in 1996 by Mike Maher and February 2010 by Peter Terrill. The influence of nesting habitat availability in relation to lignum height was discussed which could be linked to on-ground measures of lignum height and total area but this is not a reliable indicator of habitat availability. Brandis (2010) analysis of nest heights from the 2008 event showed no relationships between nest height and breeding success (*unpublished data*).	Water depth is built into the flow event definition and not specified separately in the nest abandonment model.
Change in WSE Northern Lakes (cm/day)	Likelihood of abandonment	Sensitivity analysis for this component demonstrated that this ERM was not sensitive to day to day differences in WSE. It was recommended that the 'Rate of Rise' component of the model be removed as on-ground observations have shown birds will re-nest rather than desert nests in response to a rise in water levels which is usually indicative of further flows in the system. In some years this rate of rise may also indicate ideal conditions for second clutches. Inundation of nests usually impacts early nesters who will rebuild nests in a new location or add material to the existing nest. Sustained declines in water level below a threshold e.g. below 1.08 m on the Back Lake (422034) gauge was thought to be indicative	Exclude this parameter until further development of the nest abandonment model

		of a greater risk of abandonment perhaps due to greater accessibility of nests to ground predators such as foxes and pigs.	
Duration of inundation (>120.4 m AHD in the Northern Lakes)	Likelihood of abandonment	Known life history parameters for the Straw-necked Ibis (e.g. Marchant and Higgins (1990)) dictate that this should be at least 63 days to account for laying, incubation (21 days), chick rearing (28 days) and the post-fledgling period (14 days) but it was considered at least 10 extra days are required to account for the lag before breeding commences and nest building. The 120.4 m AHD in the Northern Lakes is based on advice from Scott Rayburg in the original DSS development. In the waterbird workshop, Peter Terrill recommended this threshold be increased to 120.746 m AHD at the Back Lake (representing 1.08 m on the gauge). This was thought to represent conditions for Straw-necked Ibis breeding in the system as observed during the management of the 2008-12 breeding events. It was also discussed how the abandonment model could be split into eggs, chicks and runners/flappers stages to accommodate the expected decrease in the likelihood of abandonment in later stages of the breeding compared to the early laying and incubation period.	The duration of suitable water depths (i.e. >120.746 mAHD) is built into the flow event definition and not specified separately in the nest abandonment model. Expand model to represent different stages of nesting (i.e. eggs, young chicks and advanced chicks (runners/flappers)).
Number of fledglings	Fledgling recruitment	It was discussed how the number of fledglings is too difficult to represent adequately in the DSS even in ideal flow conditions as other factors influencing breeding success including productivity, parental experience and predation may influence overall fledging numbers.	Delete this parameter

3.3 Upgrade of the Narran DSS

3.3.1 Recalibration of the hydrology model

Following Stage 1, it was recommended that the Condamine-Balonne IQQM be used to provide hydrology inputs to the Narran DSS as this gave greater capacity to model a wide range of flow events and access new flow gauge data (from Back Lake (GS422034), Bundah (GS422031) and Narran Park (GS422029)), and to improve representation of the outer floodplain outside of the main Northern and Narran Lake regions (see Section 3.1.1).

As part of Stage 2, two sections of the IQQM were calibrated: the first section was the reach from the Wilby Wilby gauge (GS422016) to the Narran Park gauge and the second section was the Narran Lakes system itself (for full details see DSITI 2015). The Back Lake and Narran Park gauges were the prime source of information for the calibration of the IQQM during Stage 2 followed by the inundation mapping provided by Thomas and Heath (2014).

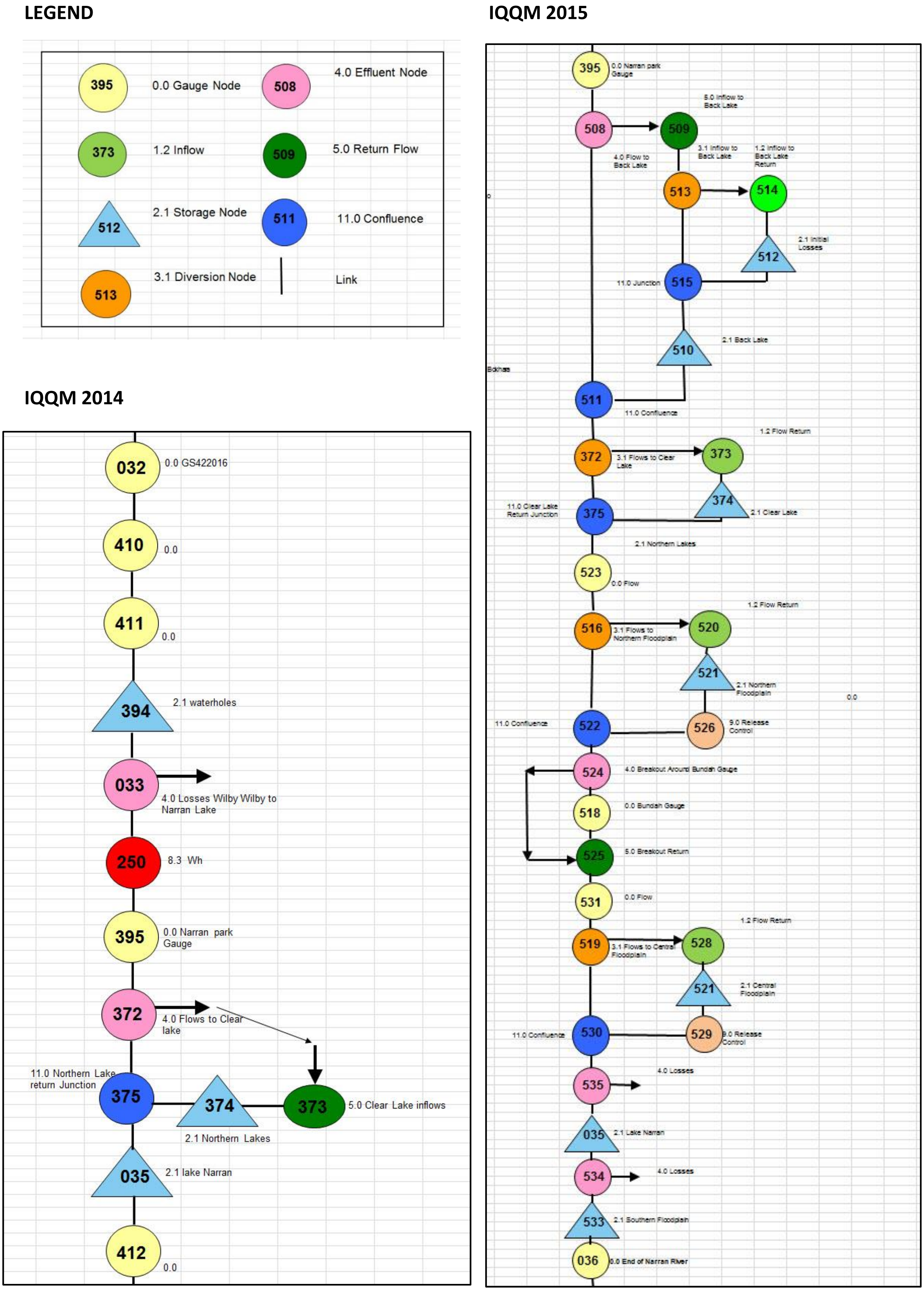
Revised lag

In Stage 2 the IQQM was updated using a lag and routing method based on the method developed by Laurenson and Mein (1986). The original model had a lag time between Wilby Wilby and Narran Park of two days based on one flood event. However, a closer examination of the records showed that the lag varied from no lag (only routing) for low flows (<500 ML/d) to a lag of 11 days for the highest flood event (>7,000 ML/d). This variation was thought to be caused by the delay caused by flows spreading onto the floodplain and taking longer to drain back to the river during high flow events. The IQQM was then modified to represent the routing using parallel links with different lags depending on the magnitude of flows (see DSITI 2015). Appendix 4 shows a comparison between the modelled flows and the recorded flows at the Narran Park gauge for selected flow events.

Connections to the outer floodplain

The second stage of the re-calibration involved extending the model to Wilby Wilby and simulating flows for the period from January 1965 to June 2014 and comparing with observed flows at Wilby Wilby. This simulation was undertaken to check that the model still reproduced the recorded levels and flows. Inundation surface area relationships represented in the IQQM were also compared with observed inundated surface area estimates determined from satellite imagery (by Thomas and Heath (2014)), particularly for the earlier period in the 1990s when there was extensive flooding of the lakes system. In the IQQM nodes usually represent open-water storages, such as a lake, however, the same set up has been used in the updated IQQM to also represent floodplains that hold water during a flood event and then dry out with evapotranspiration (Figure 22).

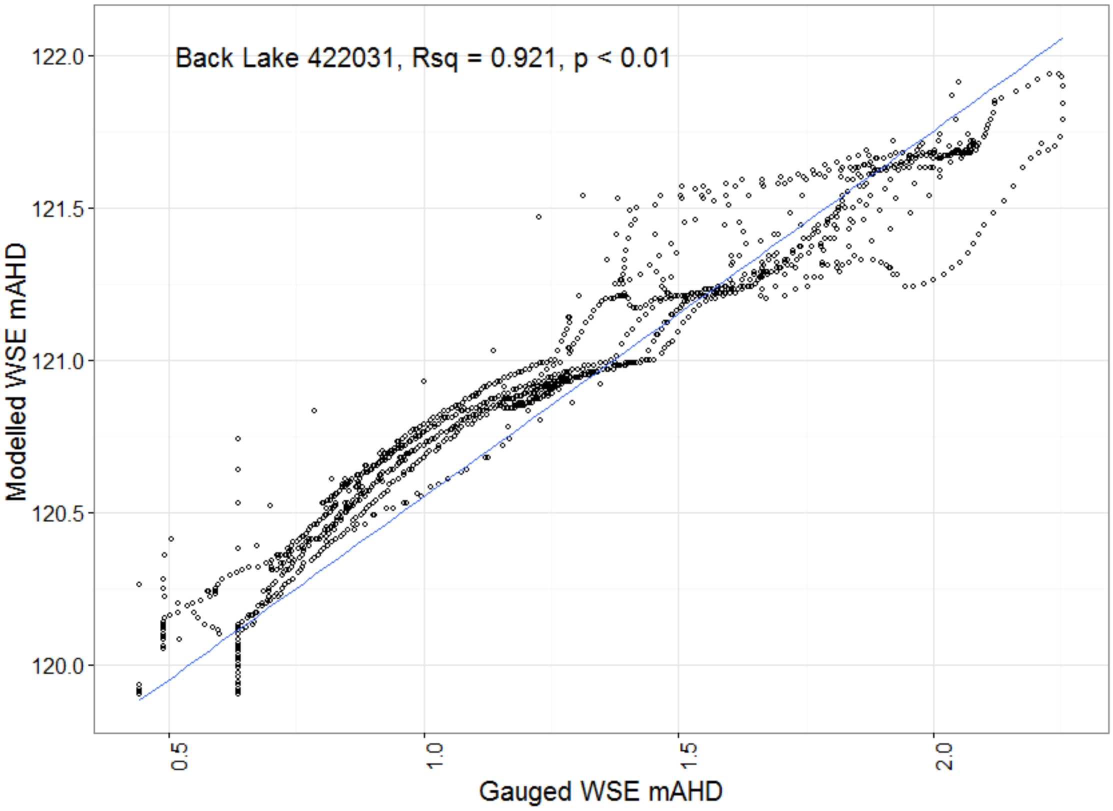
A storage node has also been added to represent initial losses in the model due to seepage. This node represents the amount of water needed to wet the system after an extended dry period. An initial loss node was used in the representation of Back Lake to achieve agreement with the recorded levels (DSITI 2015). The effluent nodes were used to represent flow leaving the main channel and spreading onto the adjacent floodplain. The links connect the nodes and are used to represent the routing of the flow from one node to the other. During the initial set up of the model, a breakout around the Bundah gauge was established to represent floodplain flow that may not be captured in the rating of the gauge. Subsequent investigation showed that this breakout flow was not needed to achieve calibration. Similarly, with the initial loss in the central floodplain, it was found that it was not needed to reproduce the flooded surface areas derived from the satellite imagery. The flows predicted at the Bundah and Back Lake gauges in the revised IQQM had generally good agreement with recorded flows (Figure 23).


LEGEND

IQQM 2015

IQQM 2014

Figure 22 Original (left) and updated (right) representation of flows into the Narran Lake system in IQQM on the 11 August 2015 (from Spencer *et al.* 2015b).



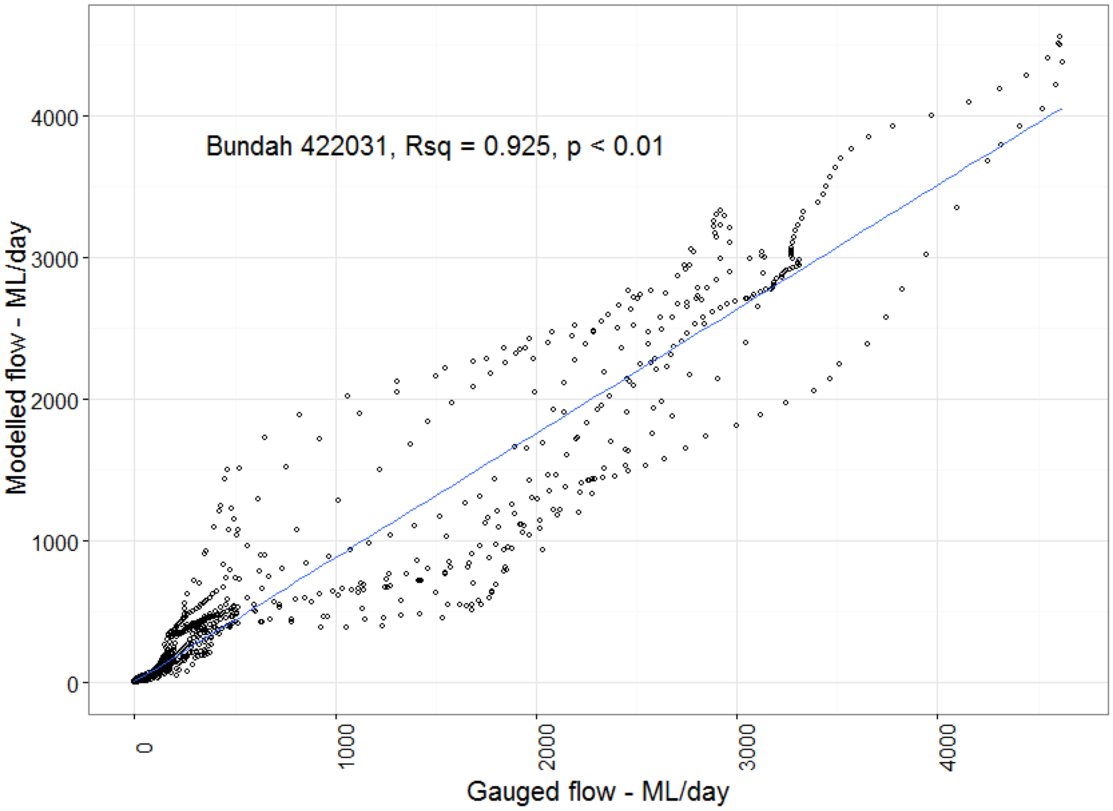


Figure 23 Comparison of modelled and observed flows at the Back Lake (water level (m AHD) (upper) and Bundah gauges (flows (ML/day) (lower) for the 2010-14 period.

Although the agreement between the updated IQQM and measurements of inundated surface area in the lakes by inundation mapping (Thomas and Heath (2014)) was not as good as the agreement with the modelled and observed river flow data, the differences were thought to be caused by the dynamic nature of the system. For example, the flood event in 2010-11 was one of the highest floods in over 90 years of record at St George and followed one of the driest periods of record. There can also be changes in the hydraulic capacity of discharge channels from Clear Lake to Narran Lake (due to head height, vegetation growth, debris, snags and siltation) during and between events affecting the distribution of flows.

Further comparisons of the IQQM predicted inundated surface areas with available inundation mapping indicated that the predicted water surface areas in the Southern Floodplain were lower in some events than the observed inundation areas. However, this could be explained in some circumstances, for example the 2010-11 flooding period, by the influence of intense local rainfall observed on the Southern Floodplain during this event (Figure 24) (P. Terrill. *pers. comm.* Aug 2015).

Improved water recession

The representation of the lakes was improved so that Back Lake was represented separately to Clear Lake and the adjacent floodplains were added as separate storages. In earlier versions of the IQQM it was recognised that water recession in the model was not represented adequately (see Section 3.1.1). Capturing the recession was essential for modelling the likelihood of nest abandonment by Straw-necked Ibis and the delineation of flow events. In the upgrade of the IQQM the lake evaporation used in the IQQM was also adjusted to improve the model's representation of the drying of the lakes (DSITI 2015). The original lake evaporation files were based on the pan evaporation measured at St George and Beardmore Dam adjusted using pan factors to account for the difference between the pan evaporation and the lake evaporation. A seepage component was included. It was found that the seepage component was not required for the Narran Lake which held water for longer (DSITI 2015).

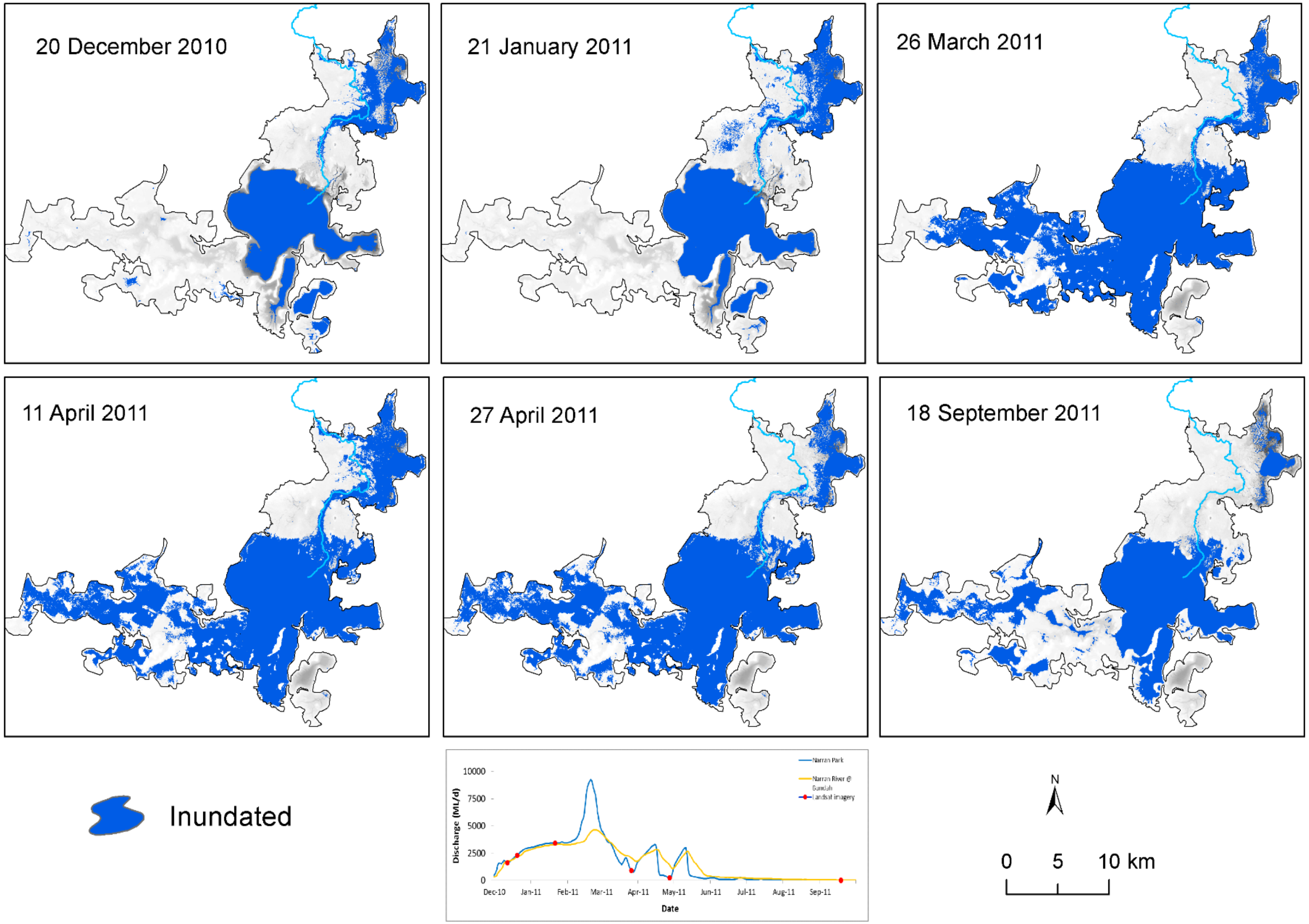


Figure 24 Time series of inundation distribution in the Narran Lakes system during the 2010-11 flood event (Thomas and Heath 2014) showing the progression of flooding through the Northern, Central and Southern floodplains (which would also have received local rainfall) and then retraction of inundation to the Northern Lakes and Narran Lake.

3.3.2 Revised spatial representation

Following the examination of recent data, the spatial coverage of the IQQM and Narran DSS was expanded to six storages in place of the original two storages (Northern and Southern Lakes) in the models. The 'Northern Lakes' node was separated into the sub-zones Back Lake-Long Arm and Clear Lake-Lignum Swamp, and the Southern (Narran) Lake node was retained. The three additional storages were added to the updated IQQM: the Northern Floodplain, Central Floodplain and Southern Floodplain (Figure 25) to account for losses to the outer floodplain. Note to simplify the IQQM and Narran DSS the Thomas and Heath (2015a) hydrological zones of the North-eastern and North-western floodplain were combined into a "Northern Floodplain" storage, and the Central-eastern and Central-western were combined into a "Central Floodplain" storage (Figure 25 and Table 16).

Information derived from the inundation mapping and recent flow gauge data was used to represent relationships and division of flows between the lakes and floodplain cells in the updated IQQM (DSITI 2015). The original IQQM also had connections between the Barwon and the Southern Lake (Narran Lakes overflow). But this was difficult to represent accurately and the degree of connection was not thought to be as high as reported in the sustainable yields project (CSIRO 2008). The DEM developed through the Narran Ecosystem Project (Thoms *et al.* 2007) was used to derive the surface area curve relationships for the six new storages in the revised IQQM. The DEM relationships were used in the updated IQQM to calculate volumes, water surface areas and water levels (DSITI 2015).

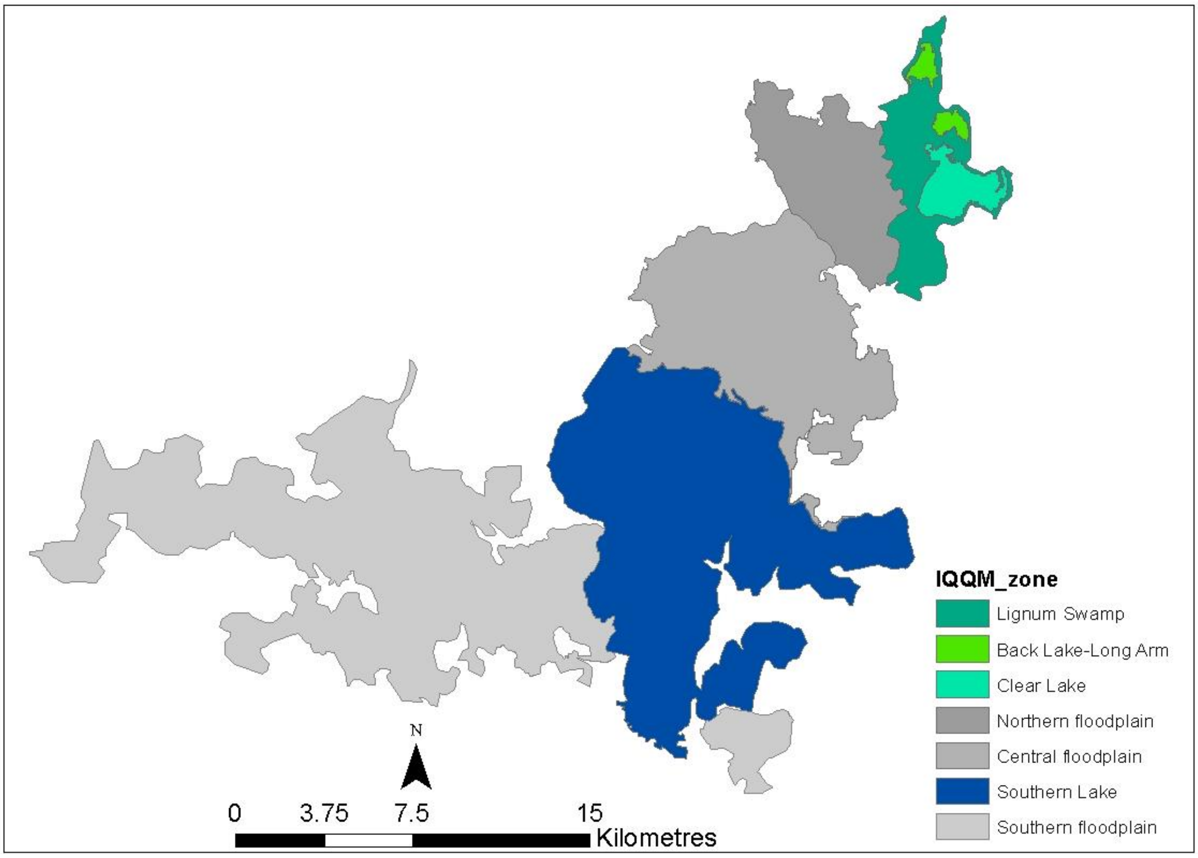


Figure 25 Hydrological zones used to define the update spatial configuration of the IQQM (Thomas and Heath 2015a).

Table 16 Total surface areas (ha) for features of the Narran Lakes system (see Figure 29) represented in the revised IQQM derived from a DEM for the system (DSITI 2015) and hydrological zones delineated by Thomas and Heath (2015a).

Feature	IQQM (2015)	Thomas and Heath (2015)
Back Lake-Long Arm*	704	260
Clear Lake and Lignum Swamp*	2,293	2,738
Total Northern Lakes*	**2,997**	**2,998**
Central Floodplain	6,960	6,975
Northern Floodplain	3,188	3,199
Narran (Southern) Lake	12,454	12,556
Southern Floodplain	11,000	15,236

*The Northern Lakes System is made up of Clear Lake, Back Lake, Long Arm and Lignum Swamp

During Stage 2 an inundation frequency map for the Narran Lakes was created using 117 inundation maps across 20 flow events that occurred between 1988 and 2007 (Thomas and Heath 2015b). In this analysis inundation probabilities were classified into frequency zones to show the relative likelihood of inundation occurrence across the different hydrological regions of the Narran Lakes landscape (Figure 26). This inundation frequency map clearly shows the braided channels through lignum swamplands in areas west of the Northern Lakes. These act as feeder channels connecting the Narran River to the Northern Lakes in major floods. These flow paths were used to inform the distribution of flows during large flood events and the subsequent revision of the IQQM (DSITI 2015).

The frequency zones identified by Thomas and Heath (2015b) were also used to re-define the probability of flooding for each of the six storages represented in the updated IQQM and Narran DSS. The spatial resolution of Straw-necked Ibis colony sites in Brandis (2010) and Spencer *et al.* (2015a) is finer than that represented in the Narran DSS which links the Straw-necked Ibis models to hydrology in the combined Northern Lakes complex. Straw-necked Ibis colonies are also known to establish outside of the Narran Lakes Nature Reserve in the ‘Narran delta’ upstream of the major inflow point into Narran Lake (Ley 1998a; Spencer *et al.* 2015a) and this includes the most recent flood events in 2010 and 2012 (Figure 2). However, in the Narran DSS upgrade it was decided to limit the Straw-necked Ibis breeding ERM to the Back Lake and Long Arm cell where the majority of nests have been recorded historically and where there is currently the greatest confidence in the representation of water levels in the hydrology modelling.

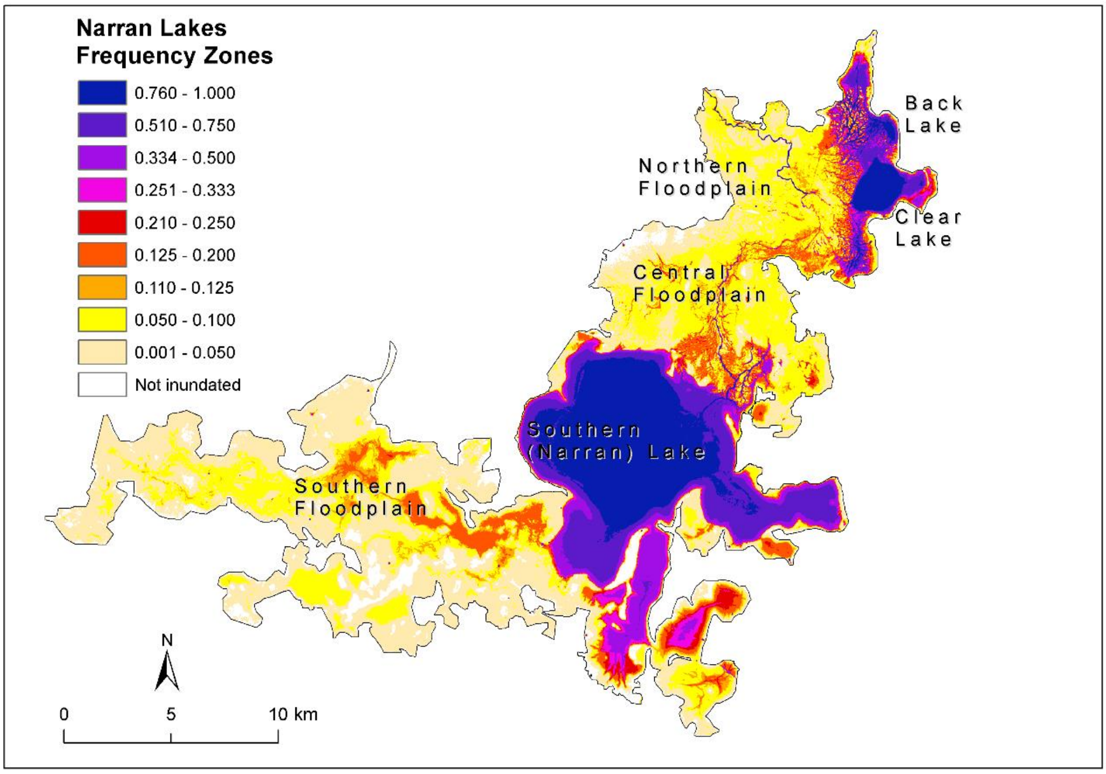


Figure 26 Inundation frequency zones of the Narran Lakes system as indicated by the ranges of the probability of inundation occurrence calculated from 117 Landsat satellite image used to produce inundation maps acquired for 20 flow events between 1988 and 2007 (Thomas and Heath 2015b).

3.3.3 Revised flow event definition

Based on the review of flow event definition (detailed in 3.2.1) the assumptions for calculating flow events in the Narran DSS were revised as follows:

Assumption 1. The start threshold was set to 100 ML/day at Wilby Wilby Gauge and the event continues as WSE rises in Back Lake. When water levels recede below 120.746 m AHD at Back Lake Gauge the event ends.

Assumption 2. Events that start within 10 days of the end of the preceding event are considered the same flow event.

The start and end thresholds in Assumption 1 were shown in Section 3.2.1 to provide the best performing flow event definition formulation. The event windows for 01/01/1971 to 30/06/2014 historic flow is shown in Figure 27 together with flow (ML/day) at Wilby Wilby and WSE (m AHD) at Back Lake.

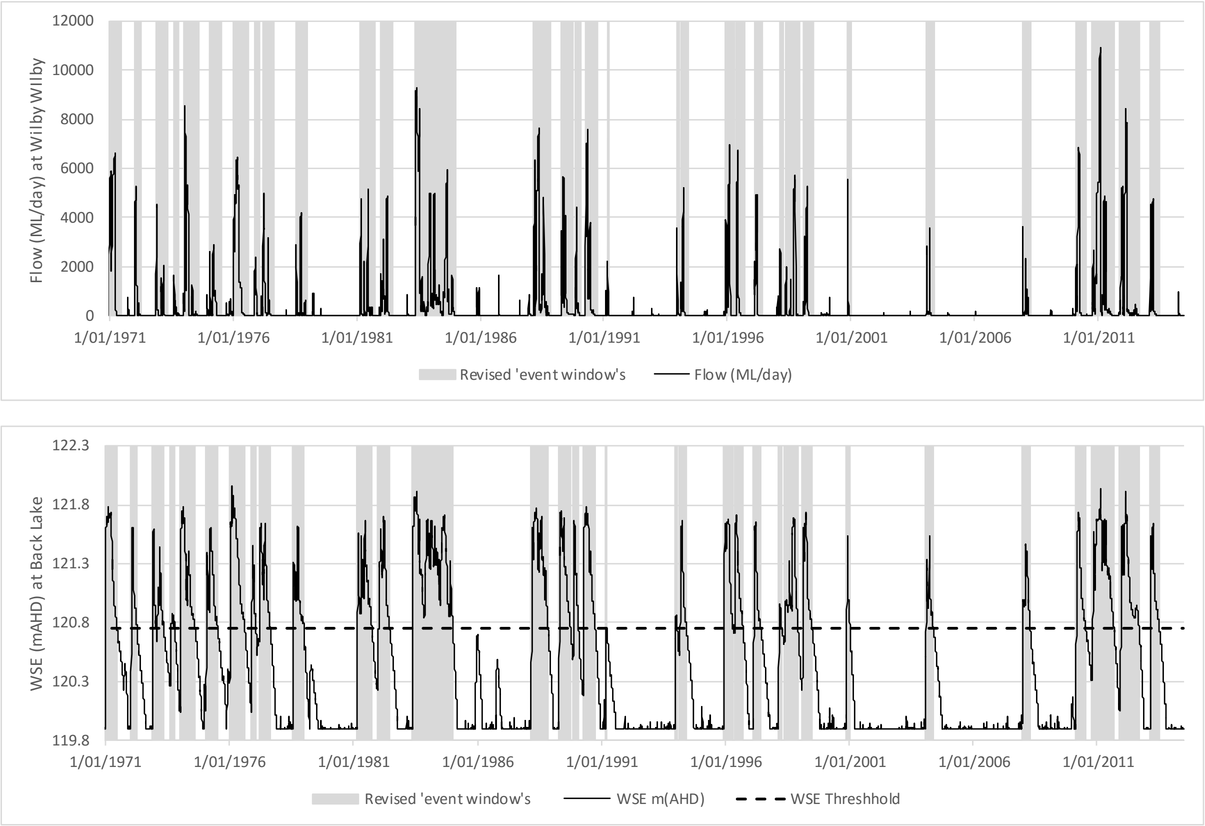


Figure 27 Defined 'event window' using the revised event definition rules (upper: flow (ML/day) at Wilby Wilby; lower: WSE (m AHD) at Back Lake).

A simple sensitivity test was performed to test the sensitivity to Assumption 2 above by setting the threshold to five days, 10 days, 15 days and 20 days. Over the modelled period, the 10 day, 15 day and 20 day thresholds defined the same number and characteristics of flow events. Decreasing the threshold from 15 to days split one event into two events in early 1973 (Figure 28 – upper panel). In this case, the event started when flows exceeded 100 ML/day at Wilby Wilby and continued for 63 days until WSE at Back Lake dropped below 120.746 m AHD (Figure 28 – bottom left). Six days later, two consecutive flow pulses (Figure 28 – bottom right) elevated WSE levels above 120.746 m AHD for a further 104 days.

Figure 28 ‘Event windows’ using four threshold values to merge events (Assumption 2) for the period 01/09/1972 to 31/08/1974 (*upper*). WSE at Back Lake (mAHD) (*bottom left*) and flow in ML/day at Wilby Wilby (*lower righ*t) are shown for the period where the five day threshold splits one event into two events). The 10 day threshold was implemented in the revised flow event definition.

3.3.4 Revised Straw-necked Ibis ERM

The Straw-necked Ibis ERM has been revised based on the recommendations and revised conceptual model from the expert workshops and the analyses of Straw-necked Ibis breeding data (see Section 3.2, Appendix 5). The revised ERMs now features three components: breeding initiation, number of nests and abandonment of nests (Figure 29). The model no longer incorporates a fledgling recruitment component which estimated the total number of fledglings (ANU Enterprise 2011). As outlined in Table 15, this decision was made at the workshop as there are many other factors influencing the number of fledglings other than flow (e.g. productivity, parental experience and predation) there was insufficient knowledge to model fledgling numbers.

The Bayesian Network (BN) approach, linked to event summaries of hydrological model outputs, was selected for use in the original Narran DSS so that the DSS could “represent the appropriate spatial and temporal representation of hydrology whilst utilising the strengths of BNs, namely: explicit representation of uncertainty, the capacity to use a broad range of data to populate the network, and representation of ecological processes at a level appropriate to the amount of available data” (ANU Enterprise 2011). This model approach remains appropriate as the ecological data and understanding used to improve the model is still quite limited or incomplete, highly uncertain and there remains some reliance upon expert opinion. See Box 1 for an overview of BN modelling approach.

The model was populated (parameterised) with probabilities based on data, where available, and/or expert knowledge. As expert knowledge was the primary parameterisation method for the nest abandonment model, the model outputs should be considered preliminary subject to the collection of more on-ground data. The model has been constructed such that all outputs are aligned to water management needs and are measurable, so that the models can be refined with future monitoring.

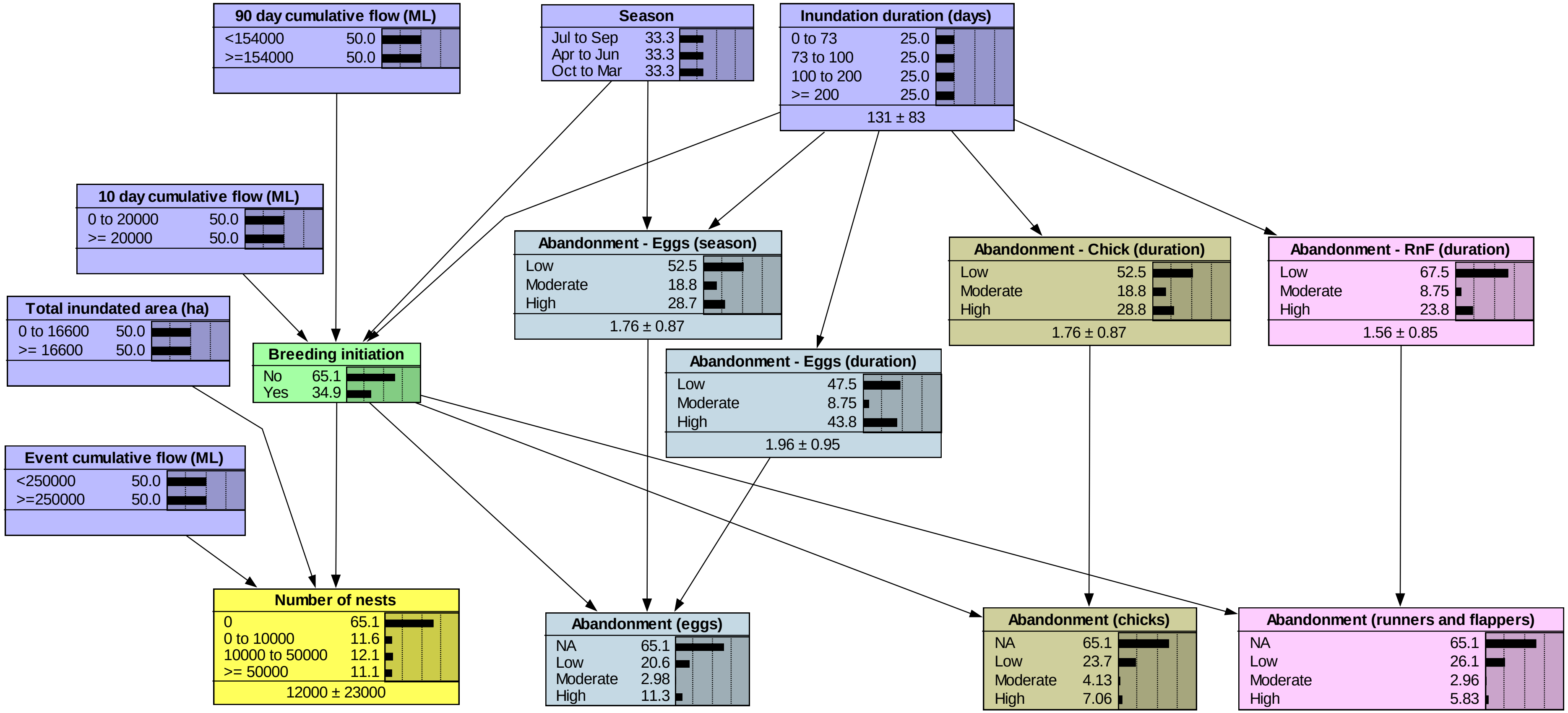
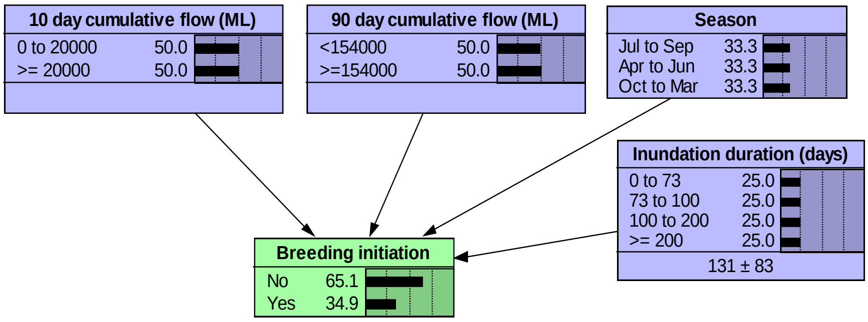


Figure 29 Revised Bayesian Network structure and variable states in the Straw-necked Ibis ERM in the Narran DSS.

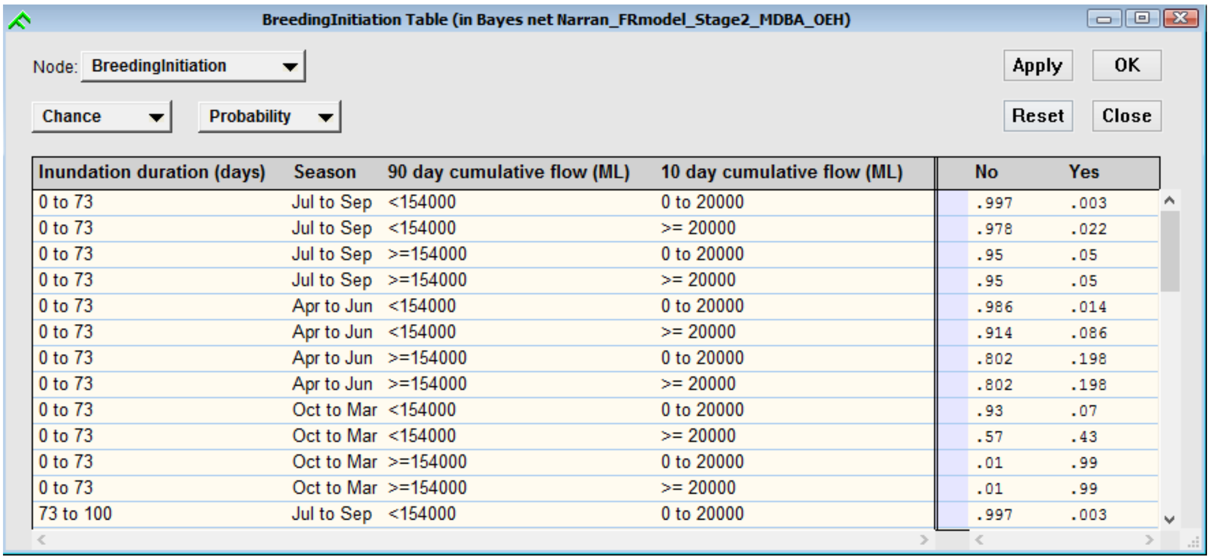
Box 1. Overview of Bayesian Networks (adapted from ANU Enterprise, 2011)

Bayesian Networks (BN) are graphical models that probabilistically specifies the causal chain of relationships between variables. In the context of environmental flows, the BN approach can be used to link flow scenarios from hydraulic-hydrologic models with measurable responses (e.g. breeding initiation in the figure below). In the updated Narran DSS, the ecological response model for Straw-neck Ibis relates hydrological parameters and season to breeding initiation, nest numbers and abandonment. Potentially, other biophysical factors (e.g. water quality, grazing pressure) could also be included in a BN to represent the influence of non-hydrological drivers and pressures on ecological response.

Depending on the level of knowledge, variables can be expressed qualitatively (e.g. low, medium, high) or quantitatively (<20,000 ML, ≥20,000 ML). Probabilities are used to describe how variables combine and these probabilities can be estimated using expert knowledge and/or data.



Every child variable in a BN – i.e. a variable that has links feeding into it from other (parent) variables – has a conditional probability table (CPT) attached to it. The CPT specifies the probability that the child variable will be in a particular state (e.g. Breeding = Yes) given the states of its parent's variables. Each row in the CPT defines the probability distributions across the states of the child variable for a given combination of the states of the parent variables; this relationship must be specified for each possible combination of parent variable states (see below).



Node: BreedingInitiation

Chance

Probability

Inundation duration (days)	Season	90 day cumulative flow (ML)	10 day cumulative flow (ML)	No	Yes
0 to 73	Jul to Sep	<154000	0 to 20000	.997	.003
0 to 73	Jul to Sep	<154000	>= 20000	.978	.022
0 to 73	Jul to Sep	>=154000	0 to 20000	.95	.05
0 to 73	Jul to Sep	>=154000	>= 20000	.95	.05
0 to 73	Apr to Jun	<154000	0 to 20000	.986	.014
0 to 73	Apr to Jun	<154000	>= 20000	.914	.086
0 to 73	Apr to Jun	>=154000	0 to 20000	.802	.198
0 to 73	Apr to Jun	>=154000	>= 20000	.802	.198
0 to 73	Oct to Mar	<154000	0 to 20000	.93	.07
0 to 73	Oct to Mar	<154000	>= 20000	.57	.43
0 to 73	Oct to Mar	>=154000	0 to 20000	.01	.99
0 to 73	Oct to Mar	>=154000	>= 20000	.01	.99
73 to 100	Jul to Sep	<154000	0 to 20000	.997	.003

Being graphical models, BNs offer an advantage where a flexible and adaptable modelling approach is required, where knowledge elicitation is needed to define model structure and relationships, or in participatory contexts. BNs can be used to analyse and communicate relationships that are not easily expressed mathematically (Pearl, 2000). Given this, they have often applied by modelling communities to a range of ecological and environmental issues. However, they are typically not well suited to situations where there is a need to represent complexity in detail or where spatial or temporal dynamics need to explicitly represented (or cannot be handled by coupling BNs to another model type (e.g. a hydrological model)).

Input nodes

Seven variables are input to one or more of the model components. These variables are defined in Table 17 below. The likelihood of breeding initiation (Yes or No) is defined by the cumulative flow of the first 90 days of the flow event, the cumulative flow of the first 10 days of the flow event and the season. Where flow events do not meet either of the flow thresholds at the start of the event, the whole flow event is checked to identify whether these thresholds are met at any point during the flow event. If so, the likelihood of breeding initiation is updated as are the season and duration parameters. When the season is 'optimal' (October to March) and the duration of the flow event exceeds 73 days, or if the duration exceeds 200 days (regardless of the season at the start of the hydrological event), the conditional probabilities are based on the results of the CART analysis in Section 3.2.1 (see Table 18). When these season is 'suboptimal' (April to June) or 'poor' (July to September) based on expert opinion the likelihood of breeding is weighted lower (Table 19).

Breeding initiation

The likelihood of breeding initiation (Yes or No) is defined by the cumulative flow of the first 90 days of the flow event, the cumulative flow of the first 10 days of the flow event and the season. Where flow events do not meet either of the flow thresholds at the start of the event, the whole flow event is checked to identify whether these thresholds are met at any point during the flow event. If so, the likelihood of breeding initiation is updated as are the season and duration parameters. When the season is 'optimal' (October to March) and the duration of the flow event exceeds 73 days, or if the duration exceeds 200 days (regardless of the season at the start of the hydrological event), the conditional probabilities are based on the results of the CART analysis in Section 3.2.1 (Table 18). When the season is 'sub-optimal' (April to June) or 'poor' (July to September) based on expert opinion the likelihood of breeding is weighted down (Table 19).

Table 17 Input variables of the Straw-necked Ibis model (RnF – young birds at the runners and flappers stage [31-40 days old]).

Name (states)	Definition	Child variables
90 day cumulative flow (<154,000 ML, ≥154,000 ML)	Cumulative flow (ML) for 90 days of the hydrological event.	Breeding initiation
10 day cumulative flow (<20,000 ML, ≥20,000 ML)	Cumulative flow (ML) for 10 days of the hydrological event.	Breeding initiation
Season	Suitability of season for Straw-necked Ibis breeding and fledgling development: July to September (poor), April to June (sub-optimal), October to March (optimal)	Breeding initiation Abandonment – Eggs (season)
Event cumulative flow (<250,000 ML, ≥250,000 ML)	Cumulative flow (ML) for the entirety of the hydrological event.	Number of nests
Inundated surface area (<16,600 hectares, ≥16,600 hectares)	Maximum recorded surface area (hectares) of flooding across the Narran Lakes system	Number of nests
Inundation duration (<73 days, 73-100 days, 100-200 days, ≥200 days)	Duration of the hydrological event (days)	Breeding initiation Abandonment – Eggs (duration) Abandonment – Chick (duration) Abandonment – RnF (duration)

Table 18 Probability of breeding initiation under optimal conditions of season and flood duration.

Cumflow90 (ML)	**Cumflow10 (ML)**	**Breeding initiation**	
		No	**Yes**
<154,000	<20,000	0.93	0.07
<154,000	>20,000	0.57	0.43
≥154,000	<20,000	0.01	0.99
≥154,000	>20,000	0.01	0.99

Table 19 Probability of breeding initiation under sub-optimal or poor season for events with flood duration less than 200 days.

Season	**Cumflow90 (ML)**	**Cumflow10 (ML)**	**Breeding initiation**	
			No	**Yes**
Jul-Sep	<154,000	<20,000	0.997	0.003
Jul-Sep	<154,000	>20,000	0.978	0.022
Jul-Sep	≥154,000	<20,000	0.95	0.05
Jul-Sep	≥154,000	>20,000	0.95	0.05
Apr-Jun	<154,000	<20,000	0.986	0.014
Apr-Jun	<154,000	>20,000	0.914	0.086
Apr-Jun	≥154,000	<20,000	0.802	0.198
Apr-Jun	≥154,000	>20,000	0.802	0.198

The sensitivity of the breeding initiation variable to its parent variables can be examined in Netica using the Mutual Information (MI) statistic. This statistic describes the average (across the parent node states) of the total change in probability experienced by the child node states when the parent node is set to a particular state. The higher the MI value, the more sensitive the output is to the corresponding input variable. The breeding initiation variable is most sensitive to 90 day cumulative flow (MI = 0.15), then season (MI = 0.12), then inundation duration (MI = 0.075) and lastly, the 10 day cumulative flow (MI = 0.008)**.** The strong influence of season reflects the weightings (based on observed timing of breeding) applied in the conditional probabilities in Table 19.

Number of nests

The likely number of nests (or magnitude of breeding) is defined by the cumulative flow of the whole event and the maximum area of flooding across the Narran Lakes system recorded during the flow event (see Section 3.2.2). The extent of flooding across the Narran Lakes system is used as a proxy for the productivity of the system and its capacity to support breeding Straw-necked Ibis. The categories in the model are 0 (when breeding trigger = No), <10,000 (small breeding events), 10,001 – 49,999 (medium breeding events) and ≥50,000 (large breeding events).

The conditional probability table (Table 20) for number of nests was estimated based on Straw-necked Ibis breeding observations where nest numbers were counted in the Narran Lakes Nature Reserve and analysis by Thomas *et al.* (2016) linking cumulative flows to inundated area (Table 21 and Appendix 2). This table replaces information presented in ANU Enterprise (2011) where a large number of states were presented based on limited data. Given the limited records, the categories and probabilities both need to be revisited and updated with information on nest numbers following observations of future breeding events. In particular, the rows shown in bold in the table are combinations of event cumulative flow and inundated surface area for which there was no data on nest numbers. The flat (even) distribution across the <10,000, 10,001-49,999 and >50,000 nests classes reflects this lack of knowledge. Whilst event cumulative flow and inundated surface area are considered conceptually important, the collection of future data may indicate that one of these variables could be used as a lone predictor of the size of breeding events. Alternatively, the decision to represent the relationship between nest numbers and both surface area and cumulative flow may be supported and further refined. It is also important to note that the capacity of IQQM to model surface area needs to be continually refined in the future to better capture the dynamic nature of inundation in the system. Currently, IQQM predicted surface areas in the Southern Floodplain area are underestimated compared with inundation mapping (see Section 3.3.1).

Table 20 Conditional probability table estimated from available nest counts (italics indicate combinations of inundated surface area and cumulative flow not represented in the available modelled IQQM flow scenario).

Breeding Initiation	**Inundated surface Area (ha)**	**Event cumulative flow (ML)**	**Estimated number of nests**			
			0	**<10,000**	**10,000-49,999**	**≥50,000**
No	<16,600	<250,000	100	0	0	0
No	<16,600	≥250,000	100	0	0	0
No	≥16,600	<250,000	100	0	0	0
No	≥16,600	≥250,000	100	0	0	0
Yes	<16,600	<250,000	0	66.7	22.2	11.1
Yes	**<16,600**	**≥250,000**	**0**	**33.333**	**33.333**	**33.333**
Yes	**≥16,600**	**<250,000**	**0**	**33.333**	**33.333**	**33.333**
Yes	≥16,600	≥250,000	0	0	50	50

Table 21 Estimated nest numbers where records available for the Narran Lakes Nature Reserve against cumulative flows for the whole flow event (from Wilby Wilby gauge) based on observed Straw-necked Ibis breeding events from 1971 – 2014. For each breeding record the modelled total inundated area for the Narran Lakes system is provided from the updated IQQM. Note that there are additional four records in the Nature Reserve where no estimates of total numbers of nests are available and generally smaller colonies have been recorded outside of the reserve (see Appendix 2).

Flow event	Estimated total nests	Event cumulative flow (ML)	Max inundated surface area (ha)	Category
4/1989-10/1989	8,500	177,331	16,037	<250000 ML; <16600 ha
12/1970-6/1971	10,000	489,738	22,604	>250000 ML; >16600 ha
2/2010-7/2010	13,303	172,847	12,494	<250000 ML; <16600 ha
10/2010-9/2011	21,018	625,134	27,180	>250000 ML; >16600 ha
2/1988-11/1988	71,000	414,866	21,940	>250000 ML; >16600 ha
5/1998-12/1998	50,000	190,185	12,314	<250000 ML; <16600 ha
4/1990-10/1990	50,000	317,668	24,915	>250000 ML; >16600 ha
12/2007-4/2008	74,000	55,159	4,050	<250000 ML; <16600 ha
12/1995-4/1996	102,000	229,107	12,003	<250000 ML; <16600 ha
11/2011-9/2012	131,442	323,653	23,470	>250000 ML; >16600 ha
5/1983-1/1985	200,000	1,073,279	31,895	>250000 ML; >16600 ha

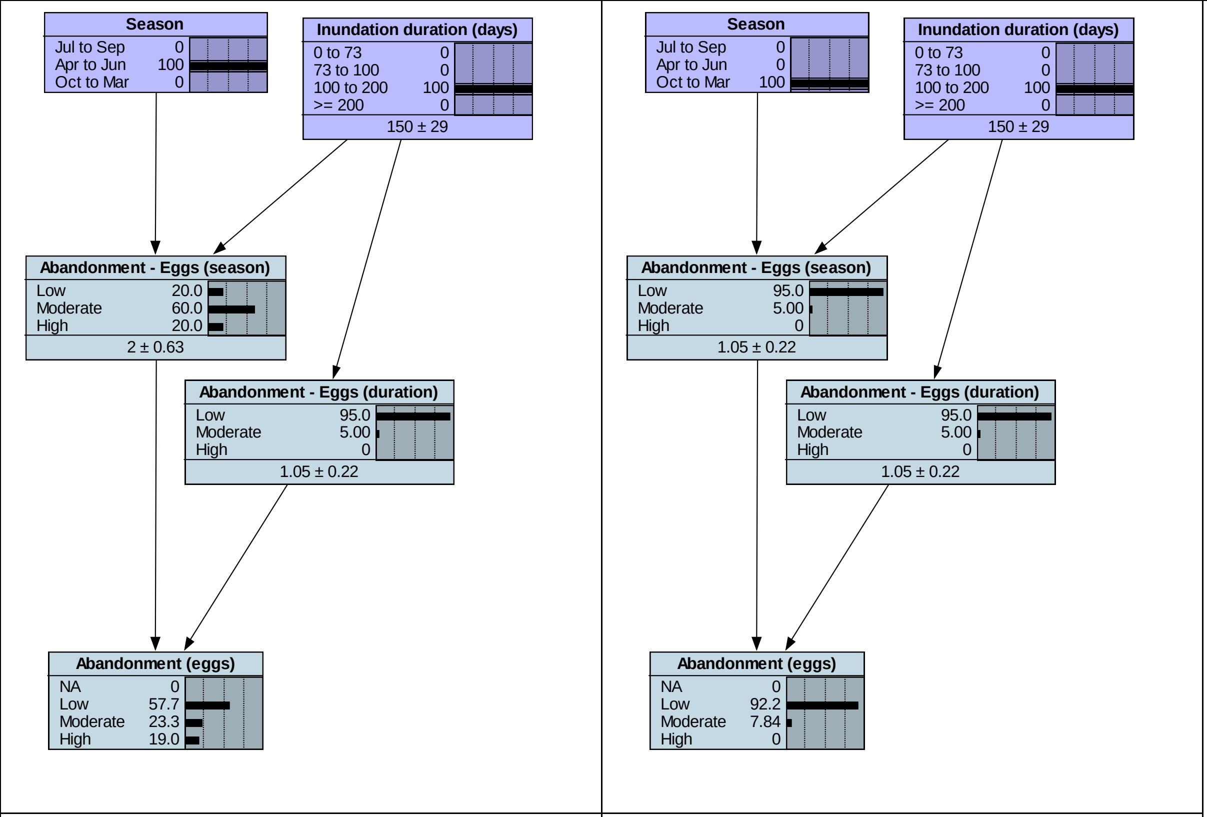
Nest abandonment

Following on from the outcomes of the Stage 2 waterbird workshop held in August 2015, the likelihood of abandonment (NA, Low, Moderate and High) was defined for 'Eggs', 'Chick' and 'Runners and Flappers' stages by the season (eggs only) and the duration of the flow event (all stages). These classes of chick development were defined based on the assumed sensitivity of adult birds to deserting their nests in the early stage (egg and chick) of development of their young. Therefore, the probability distributions are speculative and data needs to be collected to update these parameters – in Bayesian statistics terminology they are 'priors'. There was insufficient data with which to test or develop the conditional probabilities for this model. A summary of the key relationships in the abandonment components are in Table 22. The technical detail and CPTs for the nest abandonment component of the model are provided in Appendix 5 with an example for recorded failed nesting in the winter of 1989 and a successful event initiated in December 1970 provided in Figure 30.

Table 22 Key relationships and assumptions in the abandonment component of the Straw-necked Ibis model (see Appendix 5).

Input parameter	Assumptions
Season	• Relevant only to eggs stage • Unless inundation duration exceeds 200 days, an event starting in July is not suitable (poor) and 'high' abandonment of eggs is almost certain • Unless inundation duration exceeds 200 days, April to June is sub-optimal and there is some possibility of abandonment • If inundation duration exceeds 200 days or the timing of the start of the event is optimal (October to March) the likelihood of abandonment is 'low'

Inundation duration	• An inundation duration less than 73 days is likely to be of insufficient length to get through conditioning, nest preparation, and all of the fledgling stages (egg, chick, and flappers and runners). The likelihood of abandonment is almost certainly 'high' • If the inundation duration is between 73 and 100 days then the early nesters will be less likely to abandon as their young are more advanced ○ Birds with young at the egg stage (1-20 days old) will have a 'high' likelihood of abandonment as the event is unlikely to continue long enough for young to progress to stage where they can fly ○ Birds with young at the runners and flappers stage (31-40 days old) have a 'low' likelihood of abandonment as the event should continue long enough for young to progress to stage where they can fly ○ Birds with young at the chick stage (21-30 days old) have a likelihood of abandonment between that of parents of young at the egg and runners and flappers stage • An inundation duration greater than 100 days is likely to be of sufficient length to get through conditioning, nest preparation, and the fledgling stages (egg, chick, and flappers and runners)



Event 15 (1989)
Duration 177 days
90 day CF 170892 ML

Event 1 (1970-71)
Duration 187 days
90 day CF 446713

Figure 30 Using the Netica version of the Straw-necked Ibis model to illustrate the effect of season on nest abandonment predictions using an example initiated in autumn (13/4/1989) (*left*) compared to an earlier event initiated in summer (18/12/1970) (*right*) when events are both of similar duration.

3.3.5 Performance of the updated models

Updated IQQM

The flows predicted by the IQQM for the baseline scenario were compared with measured flows at the Wilby Wilby gauge. In the baseline scenario the model assumes all water users are active. Over the period of record at Wilby Wilby (1964 to date), the Condamine-Balonne catchment has changed from the without development case to close to the fully developed case. The IQQM predictions were compared with the measured flows for the most recent period from 2000 to 2014, when the actual level of development in the catchment agrees with the level of development in the IQQM.

The improvements in the IQQM for the Narran Lakes system (as detailed in Section 3.3.1) has significant implications for the predictive capability of the Narran DSS. Understanding how water flows into and between the different parts of the Narran Lake system is central to the analysis of water recovery options and of current water access rules and the extent to which they could be altered or supplemented by other management interventions to improve environmental water outcomes for the Narran Lakes.

It should be noted that it is difficult to achieve a good agreement at the downstream end of a model covering such a large catchment, especially when the distribution of flows in the distributary section can change in response to floods modifying channel cross-sections and the impact of changes to riparian vegetation and floodplains. What is important in the modelling is the change in flows in response to changes to the diversions upstream. While the model may struggle to accurately reproduce the flow hydrographs at Wilby Wilby, it does give a good assessment of the possible impact of the change in the hydrograph caused by the change in diversions.

Over the whole period the volume of flow in the model agreed within 1 per cent. However, for individual flow events the predicted volume varied from +/- 15 % for the moderate events. For the largest events, the volume varied from -26 % for the 2011-12 event to +39 % for the 2013 event. These events were the largest events on record and were larger than the highest events used to calibrate the model. Further development of the IQQM will focus on improving the ability of the model to represent large events and simulate the change in losses from wet periods to extended dry periods.

Updated DSS

Following the changes made to the breeding component of the Straw-necked Ibis model over Stage 2, the performance of the upgraded Narran DSS was tested against observed breeding data from 1971-2014. Of the 15 predicted hydrological events where there are corresponding breeding observations, ten events and three events had a predicted probability of breeding initiation of 0.99 and 0.43, respectively (see Appendix 6). The remaining two flow events met the 90 day cumulative flow threshold, but were of a duration less than 200 days; in this case, the sub-optimal season (April to June) at the start of the event resulted in a low predicted likelihood of breeding (0.198). Observations of these events in winter of 1989 and 1990 indicated there was some failed nests associated with these flood events (Magrath 1991).

Overall, the revisions to the DSS have resulted in a considerable improvement in the predictive capability of the Narran DSS which only predicted 41% of known breeding occurrences for the 1975-2014 period using a 12-month cumulative flow trigger of more than 100,000 ML at Wilby Wilby (Merritt *et al.* 2015). However, with estimates of total nest numbers not consistently recorded for all breeding events, predictions of the size of breeding (nest numbers) in response to flow variables remain highly uncertain. This is reflected in the broad distribution in the nest numbers conditional probability table shown in Table 20.

As the nest abandonment variables are also based on nest success data for one breeding event (see Section 3.2.4) and expert opinion, they must also be considered preliminary. The model variables and outputs that are in need of further development before they can be used with confidence in water planning include the definition of variable’s states and updated probability distributions in the CPT.

The updated data analyses and improved conceptual understanding has improved the DSS capability and performance. However, there is still considerable knowledge uncertainty, given the limited amount of Straw-necked Ibis breeding data available for the Narran Lakes to develop the models and the high system complexity, which has implications for the model structure and parameterisation (and interpretation). An overview of the types of uncertainties relevant to this project and ways to deal with them is provided in Box 2. Further monitoring of flows and colonial waterbird breeding in the Narran Lakes will be important to test and further improve the Straw-necked Ibis breeding-flow relationships in the Narran DSS. This includes the relative importance of each of the identified flow thresholds and the timing of when they occur in the flow event. Given the preliminary nature of the nest abandonment model and limited amount of observed data documenting failed breeding, the scenario analysis in Section 3.4 does not include predictions on this component.

It is important to recognise that the Straw-necked Ibis model in the Narran DSS makes one prediction of breeding initiation, total nest numbers and nest abandonment for each defined flow event. It does not predict when, during the event, breeding will be initiated. Rather, it reflects whether or not hydrological conditions should support breeding initiation at some stage during the event. Furthermore, multiple nesting periods has been observed for large flood events and these ‘staged’ breeding events are not captured explicitly in the Narran DSS. The implementation of staged breeding predictions could be investigated in future development of the Narran DSS.

Box 2. Model uncertainty

There are a number of uncertainties in the context of this project and indeed all hydro-ecological and environmental water projects. As summary of the broad types of uncertainty and practical ways to deal with them are provided in the table below.

Type	Example relevant to this project	Most practical method for dealing with uncertainty
Observation data uncertainty	• There is uncertainty in observing and recording historical nest count data (e.g. the number recorded may not be accurate) due to differences in survey methods and coverage • There may also be omission of observation (some breeding events may not be observed/recorded) although this is thought to be unlikely for the 1971-2014 period	• Documentation of data limitations
Uncertainty in classification analysis	Uncertainty may be introduced by • the selection of variables (often first informed by conceptualisation, see below) • selection of classification techniques • the characteristics of variables	• Documentation of analysis including its assumptions • As more data becomes available and more knowledge is gained, the analysis techniques can be reviewed and possibly improved in the future
Uncertainty in conceptualisation: this relates to how we conceptualise the system (and represent it in a model)	• Knowledge in terms of water requirements of Straw-necked Ibis breeding is incomplete, and there can be several possible conceptualisations (all which may be equally plausible or fit-for-purpose). • For example, what breeding trigger to use: in the updates to the DSS, the selected classification (and therefore the conceptualisation) was the one considered to best match the available hydrological and ecological data, given management needs. Other conceptualisations of event definition that were tested provided similar level of performance.	• Documentation of conceptualisation, key assumptions and sources of knowledge (e.g. literature, experts), review conceptualisation with local and domain experts • In future development of the conceptual model and its representation in numerical models, it is recommended to undertake an ensemble modelling approach where several different ERM model structures would be considered and produce a range of possible results rather than one set of results
Uncertainty in implementation: this refers to the practical limitations in how to implement the conceptual model within a quantitative model and DSS. All modelling techniques have strengths and weakness and there will be trade-offs between different modelling techniques	• The need to discretise continuous variables in order to use BN modelling: (e.g.) the discretisation of flow duration and nest numbers	• A good model is judged by whether it fulfils the purpose of model development, and in decision type model, whether it can provide useful information to inform decisions. • Documentation of the rationale for choosing specific modelling technique and its limitations

3.4 Results of scenario testing

Following the recalibration of the Narran reaches, the Condamine-Balonne IQQM was used to simulate flow scenarios with five different levels of water resource development:

1. Baseline (MDBA 845), which simulates the development allowed under the Condamine-Balonne Resource Operations Plan (ROP) with all allocations taking their full entitlement
2. Existing water recovery (MDBA 980), which simulates the actual recovery of about 50 GL in the Lower Balonne as of December 2014
3. Northern Standard water recovery (MDBA R1022), which simulates the recovery of 140 GL from the Lower Balonne
4. MDBA Sustainable Diversions Limit (2800 SDL, MDBA 847), which simulates the recovery of a total of about 203 GL from the Upper and Middle Condamine and Lower Balonne
5. Without development (MDBA 844), where all diversions and storages were turned off

The IQQM sequence runs with an inbuilt memory that accounts for antecedent conditions. The period of simulation was from 1/1/1895 to 30/6/2014. The following information was extracted from the upgraded IQQM for use in the Narran DSS:

1. Predicted water levels, volume and water surface areas for Back Lake, Clear Lake and Narran Lake.
2. Predicted flows at Wilby Wilby, Narran Park and Bundah gauges.
3. Water surface area of Northern Lakes
4. Predicted water surface area of the Northern, Central and Southern floodplains.

The Narran DSS was used to identify flow event periods and calculate summary statistics for flow events in each of the water resource development scenarios. Flow events were identified using the revised flow event definition (where a flow event started at 100 ML/d at the Wilby Wilby gauge and ended when flows dropped below 120.746 m AHD for more than 10 days at the Back Lake gauge) (see Section 3.3.3).

Analysis of IQQM output files using the DSS indicated all three water recovery scenarios increased the total number of flow events compared to baseline conditions (Figure 31). With increasing levels of water recovery, there was increasing numbers of large flow events. Compared to without development conditions, the baseline scenario resulted in a 56% reduction in the occurrence of cumulative event flows greater than 250,000 ML reaching Wilby Wilby (and a 55% and 62% reduction in the occurrence of cumulative flows more than 100,000 ML and 154,000 ML over the whole flow event, respectively). Of the three different water recovery scenarios, the MDBA SDL scenario performed the best in terms of total number of defined flow events above the 250,000 ML cumulative flow event threshold, with 10 events identified compared to 18 identified in the without development scenario (Table 23). These flow volumes have been associated with large-scale Straw-necked Ibis breeding in the Narran Lakes Nature Reserve and extensive flooding of the Narran Lake system (see Section 3.2.2).

When the thresholds for breeding were applied the DSS identified a greater number of flow events suitable for initiating Straw-necked Ibis breeding in the Narran Lakes Nature Reserve with increasing levels of water recovery. Overall, the characteristics of flow events in the MDBA SDL (i.e. cumulative flows over 10 and 90 days at some point during the event) were more conducive to Straw-necked Ibis breeding with 63 flow events in total identified where the probability of breeding initiation was equal or higher than 0.43. This was 16 less than predicted for the without developent scenario. The next best scenario in terms of predicted outcomes for Straw-necked Ibis was the Northern Standard water recovery scenario where a greater number of large flow events initiated breeding (54 in total or a 20% increase relative to the baseline) (Figure 31). In total 13 events under the Baseline scenario corresponded to highly conducive flow conditions for breeding initiation (Pr=0.99) compared with 15 events under the CEWO 50GL and Northern Standard Scenarios, 19 events for the MDBA SDL and 30 events under the without development scenario.

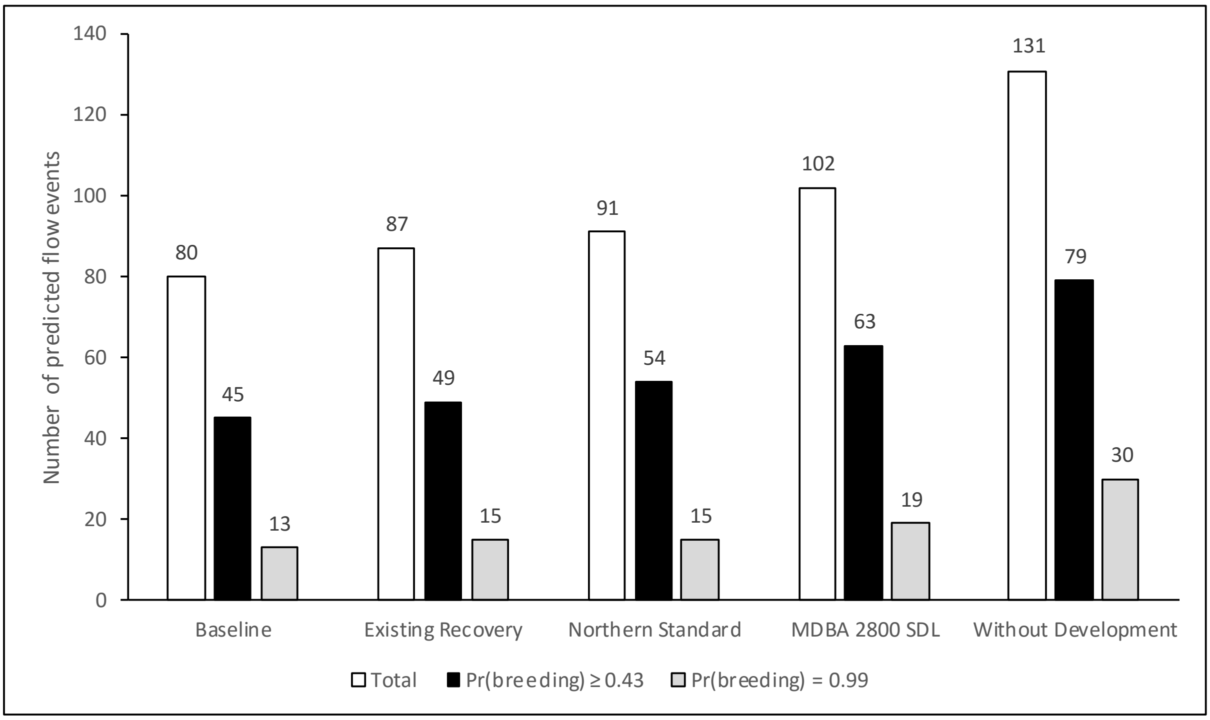


Figure 31 Total number of predicted flow events (using the revised flow event definition) and the total number of defined flow events where probability of breeding initiation was greater than P = ≥0.43 (filled bars) or equal to P= 0.99 for the five scenarios (1/1/1895 to 30/6/2014).

Table 23 Summary of the characteristics of modelled flow events over 100,000, 154,000 and 250,000 ML cumulative flow thresholds under the five scenarios for the period 1/1/1895 to 30/6/2014. Note that a defined flow event starts when river flows exceed 100 ML/d at Wilby Wilby and ends when water levels drop below 120.746 m AHD at Back Lake for more than 10 consecutive days.

Scenario	Total cumulative flow at Wilby Wilby (ML)	Total number of defined flow events	Average duration of defined flow events (days) ± SD	Average interval between defined flow events (years) ± SD
Baseline	>100,000	30	187 ± 81	3.3 ± 4.5
	>154,000	18	211 ± 91	5.8 ± 7.3
	>250,000	8	270 ± 97	12.3 ± 17.4
Existing Recovery	>100,000	33	193 ± 82	3.1 ± 4.1
	>154,000	20	220 ± 92	4.6 ± 6.8
	>250,000	8	279 ± 107	13.8 ± 18.4
Northern Standard	>100,000	34	193 ± 82	3.0 ± 4.1
	>154,000	22	212 ± 92	4.3 ± 4.9
	>250,000	8	280 ± 108	13.8 ± 18.3
MDBA 2800 SDL	>100,000	47	191 ± 98	1.9 ± 2.2
	>154,000	26	224 ± 120	3.9 ± 4.7
	>250,000	10	318 ± 140	10.9 ± 16.7
Without development	>100,000	66	196 ± 92	1.3 ± 1.3
	>154,000	47	214 ± 101	2.0 ± 1.8
	>250,000	18	278 ± 133	5.9 ± 7.3

With increasing levels of water recovery there were a greater number of defined flow events exceeding 154,000 ML cumulative flows over 90 days in spring-autumn months and a reduced average interval between suitable flow events (Table 24). As summarised in Table 26 below, the MDBA SDL scenario had the most impact on reducing the average interval between flow events that could provide the most suitable conditions for Straw-necked Ibis breeding.

Table 24 Summary of modelled flow events for the period 1/1/1895 to 30/6/2014 that could provide suitable breeding conditions (154,000 ML cumulative flows in 90 days at Wilby Wilby over spring-autumn months) under the five water resource development scenarios.

Scenario	**Total number of defined flow events***	**Average ± SD interval (in years) between defined flow events***
Baseline	11	8.5 ± 8.3
Existing Recovery	14	7.3 ± 8.2
Northern Standard	14	7.3 ± 8.2
MDBA 2800 SDL	16	5.6 ± 7.0
Without Development	29	3.3 ± 3.5

* defined flow events were where the start of a flow event exceeded 100 ML/d at Wilby Wilby and the end of a flow event where WSE drops below 120.746 m AHD at Back Lake for more than 10 days. The best predictor of the occurrence of Straw-necked Ibis breeding in the Narran Lakes Nature Reserve was 154,000 ML over the first 90 days of a defined flow event. This is implemented in the DSS although events that do not meet the 154,000 ML threshold are further examined to see if the 90 day threshold is met at any point during the event. This second step was implemented in order to assess the potential impacts of water recovery scenarios on events of long duration which initially may not see rapid increases in flow at the start of the event.

For large cumulative flow events associated with records of Straw-necked Ibis breeding the difference in the magnitude of cumulative flows recorded under the baseline and without development scenarios was larger in recent flow events (e.g., in 2007-2008 and 2010) compared to flow events recorded pre-development (e.g., in 1970-71 and 1976-77) (see Figure 32). For example, cumulative event flows for the 2007-08 flow event were predicted to reach 232,868 ML under the without development scenario and the 10 day and 90 day thresholds were larger (22,534 ML and 224,882, respectively) compared to the baseline scenario (63,125 ML CF Event, 21,324 ML D10 and 63,125 ML D90). The existing recovery, Northern Standard and MDBA SDL scenarios also did not meet the 90 day flow threshold for breeding although the MBDA SDL came closer (140,510 ML CF Event, 20,235ML D10 and 139,393 ML D90).

Increasing levels of water recovery increased the predicted total duration of the 2007-08 flow event from 126 days under baseline to 130 days under the existing recovery and Northern Standard scenarios, and 137 days under the MDBA SDL (147 days was predicted under without development). The 2007-08 flow event required active management of environmental flows to extend the duration of flooding and support the completion of Straw-necked Ibis breeding with some nest abandonment recorded following declines in water levels (see Section 3.2.4). For less marginal events such as the flow event recorded in autumn 2010 where breeding was observed, and the 10 and 90 day flow thresholds were met, the impact of the water recovery options is still shown by the impact on total flows over the first 90 days which were 179,953 ML under existing recovery, 201,198 ML under the Northern Standard and 230,776 ML under the MDBA SDL scenarios (compared to 168,059 ML under baseline and 278,898 ML under without development scenarios).

To compare the baseline against other scenarios, predicted flow events where the probability of breeding occurring (Pr(Breeding=Yes)) in the baseline scenario were compared against matching events under the other scenarios to explore whether the predicted likelihood of breeding occurring increased relative to the baseline scenario. Two situations were considered: (a) 0.43 (i.e. the 10 day cumulative flow threshold was met but the 90 day cumulative threshold was not) and (b) ≤0.07 (i.e. both the 10 day or 90 day cumulative flow thresholds were not met). In the second comparison, '<0.07' includes events that start in sub-optimal or poor seasons (and where the likelihood of breeding is weighted to be lower than optimal months; see Table 19) (see detailed results in Appendix 6).

Where predicted likelihood of breeding occurring is <0.07 (24 events) under the baseline scenario, there are corresponding events for all scenarios that have a ≥0.43 likelihood of breeding occurring: four for the existing recovery scenario, nine for the Northern Standard scenario, 12 for the MDBA SDL and 17 for the without development scenario (Appendix 6). One of the flow events under the MDBA SDL scenario predicted a probability of breeding of 0.99 compared with four under the without development scenario. For the Northern Standard, CEWO 50GL and MDBA SDL scenarios, three events had a predicted probability of breeding initiation of 0.022 indicating the 10 day cumulative flow threshold was met during the event, albeit in poor seasons. One such event was predicted under the without development scenario. Under conditions of sub-optimal season, two events had a predicted probability of breeding initiation of 0.086, under the CEWO 50 GL scenario, indicating the 10 day cumulative flow threshold was met during the event, compared with three (Northern Standard), five (without development) and six (MDBA SDL) events under the other scenarios.

Where the likelihood of breeding occurring was moderate (0.43) under the baseline scenario (32 defined flow events where only the 10 day cumulative flow threshold was met), the corresponding events for all scenarios (excluding the without development scenario) usually produced the same predicted likelihood of breeding. One event had an increased likelihood of breeding (0.99) for each of the existing recovery and Northern Standard scenarios and four for the MDBA SDL scenario – the additional water in the corresponding scenarios meant the 90-day cumulative flow threshold of 154,000 ML was met at some time during the event. The without development scenario had a larger number of corresponding events with increased likelihood of breeding (0.99 for 12 of the 32 events) but also some predictions of low likelihood of breeding (5 of the 32 events) compared to the baseline scenario ($p=0.198$, $p=0.086$ and $p=0.022$). The probability 0.198 indicates the 10 day and 90 day cumulative flow thresholds were met during the event but that the season at the point in time was sub-optimal (April to June). The probabilities 0.086 and 0.022 indicates the 10 day cumulative flow thresholds were met during the event, but that the season at the point in time was sub-optimal (April to June) or poor (July to September), respectively, and that the duration of the event from that point on was less than 200 days.

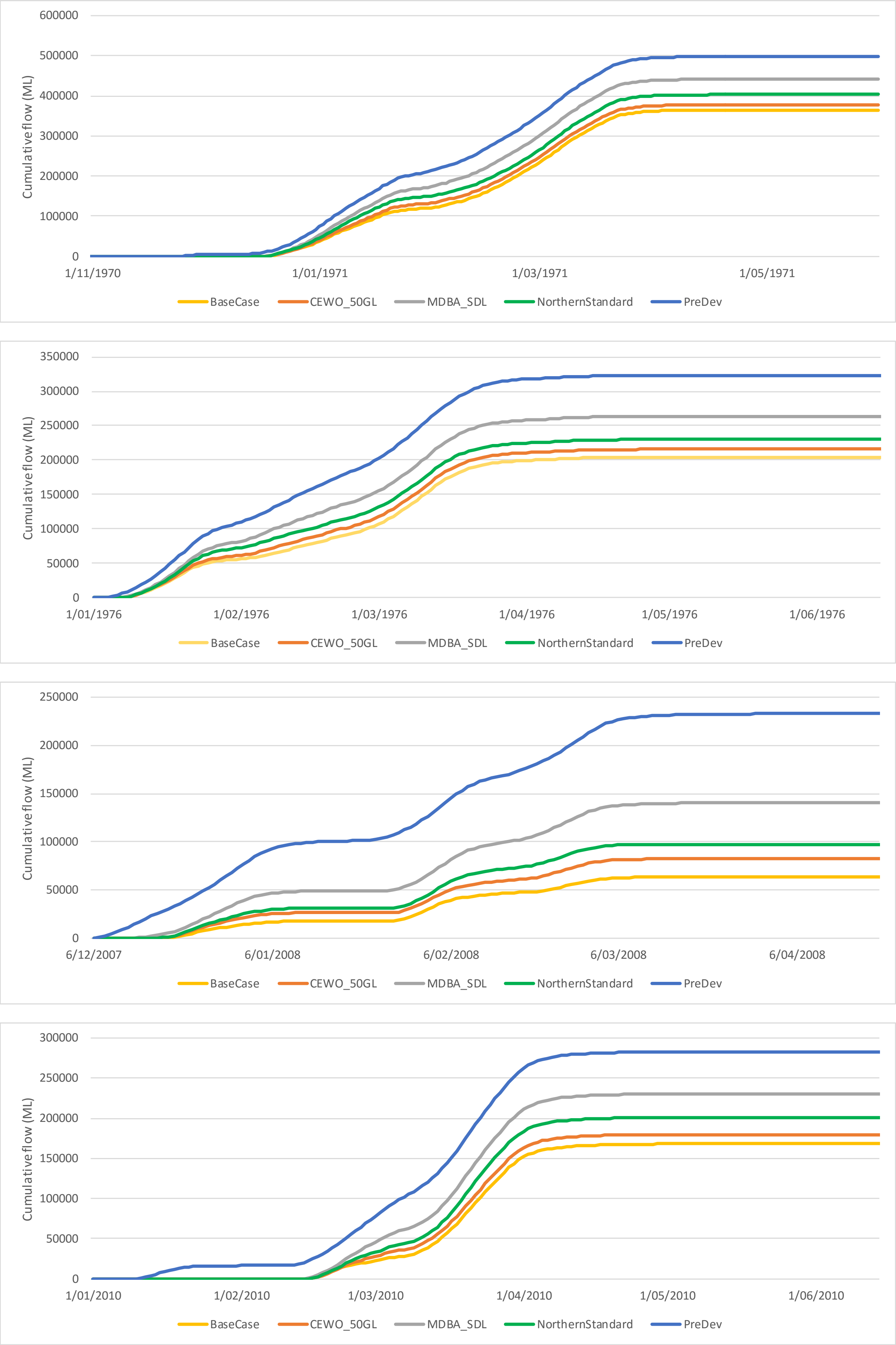


Figure 32 Comparison of cumulative flows at Wilby Wilby on the Narran River under five levels of water resource development for four flow events recorded from 1976-2010.

4 Conclusions and recommendations

This project comprised two stages that were completed over 2015-16 to support the review of EWR in the Narran Lakes. Stage 1 comprised of a review of new information and the performance of the hydrology models and Narran DSS by comparing model outputs with observed inundation mapping, river flow data and Straw-necked Ibis breeding records. An assessment of options and associated work plan to upgrade the Narran DSS was completed as part of Stage 1 to support Stage 2 carried out over the remainder of 2015. Over Stage 2, hydrological and Straw-necked Ibis breeding data were analysed and expert workshops were held to support the revision of the Condamine-Balonne IQQM and Narran DSS.

The Condamine-Balonne IQQM was revised to improve its ability to simulate the routing between the Wilby Wilby and Narran Park stream gauges using the latest available recorded flow data. A more detailed representation of the Narran Lakes system was developed and was calibrated using the Back Lake water level gauge and the Bundah stream gauge as well as inundated area for the lakes and floodplains derived from satellite imagery by the NSW OEH. The revised IQQM was able to reproduce the measured flows and levels. While the agreement between the simulated water surface areas of the lakes and inundated floodplain was not as good as the agreement with the measured flows and levels, the project team were still confident enough to use it as an input to the Narran DSS for testing flow scenarios.

The Straw-necked Ibis breeding models have been revised based on the recommendations and revised conceptual model from expert workshops (Figure 21) and the analysis of breeding data available for 1971-2014. The model now features three components: breeding initiation, number of nests and abandonment of nests (Figure 29). The flow event definition was also revised as part of this project and more closely reflects the flooding behaviour of the Narran Lakes system. Interrogation of the historical Straw-necked Ibis breeding record identified new breeding triggers based on cumulative flows over 10, 30, 60, and 90 days and the total flow event. The best predictors for a Straw-necked Ibis breeding event to occur were when cumulative flows at Wilby Wilby exceeded 154,000 ML in the first 90 days of the flow event and there was a total of at least 20,000 ML in the first 10 days. The implementation of the 10 day and 90 day cumulative thresholds in the Straw-neck Ibis breeding model and revised flow event definition greatly improved the predictive ability of the Narran DSS with respect to breeding initiation. However, the nest number and abandonment component of the revised model (and its implementation within the Narran DSS) needs further development. This will require future monitoring of the timing of nest abandonment, the stage of breeding at which abandonment occurs and hydrological conditions leading up to nest abandonment.

The upgraded IQQM and Narran DSS were used to simulate a number of water recovery scenarios for comparison with the without development and baseline scenarios. The recovery options were found to have the most effect on the duration, total cumulative flows over the 10 and 90 day thresholds and the time between large flow events (see Tables 23 and 24). The outcomes of the water recovery options for Straw-necked Ibis breeding, based on total flow events where the probability of breeding was greater than 0.43, were 63, 54 and 49 flow events, for the MBDA SDL, Northern Standard and Existing Recovery scenarios, respectively. In the without development scenario 79 flow events were predicted to have a high probability of breeding compared to 45 flow events under baseline conditions.

Recommendations for managing Straw-necked Ibis breeding

The improved understanding of Straw-necked Ibis breeding requirements in the Narran Lakes documented in this report and Brandis and Bino (2016) should be considered in the review of site-specific flow indicators for the Narran Lakes.

Revision of the site specific flow indicator for the Narran Lakes should include re-consideration of cumulative flow thresholds, timing of flows, duration of flooding and the interval between flow events:

- The total annual inflow volume of 100,000 ML at Wilby Wilby should be revised to reflect that the majority of Straw-necked Ibis breeding records in the Narran Lakes Nature Reserve occurred over spring-autumn months and were associated with cumulative flows of at least 154,000 ML required over 90 days.

- The three month flow period represents a minimum duration of flooding with flows of greater duration providing more likely to support conditions conducive to successful Straw-necked Ibis breeding and other waterbird species in the Narran Lakes.

- A second flow threshold that was associated with some Straw-necked Ibis breeding events was when cumulative flows of more than 20,000 ML at Wilby Wilby were recorded in the first 10 days of a flow event. This threshold has the potential to inform the onground management of flows into the Narran Lakes by state water managers and river operators, and could be further refined using findings from future M&E (see below).

- The current maximum period between events of six to eight years should be revised to two opportunities in eight years (representing low uncertainty) and two opportunities in 10 years (representing high uncertainty) to meet maintenance and restoration targets for Straw-necked Ibis breeding in the Narran Lakes. These recommendations are based upon life-history traits of the Straw-necked Ibis, and the assumption that opportunities for breeding are also provided elsewhere in the Basin.

While 100,000 ML cumulative flows over 12 months was specified as the indicator for waterbird breeding in the original Narran Lakes EWR, analysis of a greater time series of flows during this project has indicated that there are high risks in continuing to use this flow indicator. The risks include flow events being of shorter duration than required (i.e. less than 90 days) and of smaller magnitude (in terms of total inundated area and its impact on food resources) needed to support successful Straw-necked Ibis breeding in the Narran Lakes.

In the original EWR developed in 2012 it was assumed that the eight-year period between 1999 and 2008 represented the maximum desirable number of years between nesting opportunities for key waterbird species in the Narran Lakes (MDBA 2012). We recommend the Narran Lakes site-specific flow indicator representing the opportunities for Straw-necked Ibis breeding in the Narran Lakes is 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). These recommendations are based upon life-history traits of the Straw-necked Ibis, and the assumption that opportunities for breeding are also provided elsewhere in the Basin. Life history information for Straw-necked Ibis is limited but is thought to be between 10-16 years reaching sexual maturity at three to four years (Brandis and Bino 2016). The higher risk associated with adopting the two in ten years frequency is that there would be greater intervals between breeding events for Straw-necked Ibis and other waterbirds reducing opportunities for breeding during the life span of an individual and may result in declining populations. Where suitable flows occur to support two opportunities for breeding within an eight year period this would support both the maintenance of populations (through replacement of adult birds) and restoration of populations (by increasing total Straw-necked Ibis abundance).

Recommendations for further model development

The IQQM re-calibration showed the high performance for the Narran Park gauge (GS422029). Use of the Narran Park and Back Lake gauges as the source of hydrological information for site specific indicators for the Straw-necked Ibis breeding in the Narran Lakes should be considered in future review of EWR following the collection of a longer time series of flow and Straw-necked Ibis breeding data. The workshops held during this project also identified other sources of water level and local rainfall data not available for model calibration within the timeframe of the Stage 2 project. This included water level loggers installed in the Pelican Lagoon RM-Cam (between Clear and Back Lakes) and in the feeder channel in the southwest corner of Clear Lake; South Arm fixed camera (RM-Cam) captures images of a gauge plate in this channel from which a continuous record of water level can be derived; and the old gauge plate on the northern shore of Back Lake (which has records back to the early 1990s) (Spencer *et al.* 2015b).

Ongoing collection of flow data and Straw-necked Ibis breeding data is required for further development of the Narran DSS (see M&E requirements below). In particular, further investigation of cumulative flow thresholds over the first 10 days of a flow event are needed to guide onground management of flows. The Narran DSS does not currently capture multiple nesting events within one flow event. The Straw-necked Ibis breeding models in the Narran DSS could be further modified to calculate ERM outputs at defined periods throughout the flow event to represent conditions where successive (or staged) nesting periods are likely to occur (e.g. zero months, three months, six months etc) during large floods (>250,000 ML) of long duration (>nine months).

Monitoring and evaluation recommendations

The MDBA support annual aerial surveys undertaken by UNSW that encompass the Narran Lakes and other targeted wetlands as part of monitoring and evaluating the outcomes of the Basin Plan (Bino *et al.* 2014a). In recent years NSW NPWS have also undertaken onground annual spring waterbird (Spencer *et al.* 2014) and vegetation surveys in the Narran Lakes. Monitoring of colonial waterbird breeding has been undertaken by UNSW (using aerial and ground surveys), NSW OEH staff (using ground and aerial surveys, remote cameras, water level recorders and weather stations) and NSW DPI Water maintain the existing flow gauge network and opportunistically deploy water level loggers to monitor large flow events.

An extended M&E strategy for the Narran Lakes is needed to support the management of colonial waterbird breeding and wetlands vegetation, and allow for improved understanding of EWRs for the Narran Lakes. This should be supported by further refinement of hydrological, Straw-necked Ibis breeding and wetland vegetation models that underpin the Narran DSS. A comprehensive M&E strategy would include:

- Monitoring of the total number of colonial waterbird nests, start and end dates for breeding and quantitative measures of breeding success

- The collection of auxiliary data to document key hydrological parameters through deployment of additional water level loggers in Narran Lake, Narran Lake delta, South Arm and Long Arm colony sites and upgrade of water level logger in Clear Lake to a telemetered gauge, inundation mapping of the distribution of flooding over flow events, and maintenance of gauges to record local rainfall and temperature data.

Longer-term recommendations for future data collection and M&E to inform model development were not fully developed in this review as this task was outside of the scope for the project and of lesser importance for the immediate review of EWRs for the Narran Lakes. A comprehensive M&E program would include detailed studies that would inform future revisions of EWRs for the Narran Lakes system and would increase scientific understanding of the factors influencing the initiation, size and success of Straw-necked Ibis breeding and the condition and extent of key vegetation communities. The program should include studies of the diet and food availability for Straw-necked Ibis breeding events, and of local and regional influences on Straw-necked Ibis populations and their survival, as well as, research and monitoring of colonial waterbird breeding habitat (see recommendations in Brandis and Bino (2016)) in order to develop robust models to predict vegetation responses to flooding.

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Appendix 1 Detailed work plan for upgrade of the Narran Lakes DSS

Task	Description of tasks
1. Update IQQM to improve spatial representation of the model	DSITI will lead the Stage 2 hydrological modelling tasks which constitutes: • analysis of remote-sensed historical flooding extent data (provided by OEH) and available flow gauge data for the Narran Lakes to allow for improvement in the representation of flow paths, floodplain losses, water retention and recession in the IQQM • spilt of the Northern Lakes into their component areas (Clear Lake, Back Lake and Long Arm) • review of relationships that represent the division of flows and water recession within the Northern Lakes and between the Northern Lakes and the Narran Lake • following hydrology workshop in early August 2015 (see Task 3) revise model relationships in the IQQM based on expert advice and revised conceptual model on the distribution of flows in the Narran system • once IQQM updates are completed provide outputs for five agreed scenarios for DSS upgrades and testing over September-December 2015
2. Investigate uncertainty in representing water recession in the IQQM	ANU and DSITI will investigate the implications of uncertainty in representing water recession in the Northern Lakes and Narran Lake on DSS model outputs. The former will consider how sensitive the revised event definition rules, and therefore, outputs from the ERM, are to uncertainties in the rate of water recession in the Northern Lakes and Narran Lake.
3. Expert elicitation workshop on the Narran Lakes hydrology	This workshop will include representation by the project team and key stakeholders from MDBA, OEH and DPI Water. Key tasks and outcomes from the workshop will be: • Review recent IQQM development and the performance of the model against observed data • Develop a conceptual model representing the distribution of flows in the Narran Lakes system representing the distribution of flows in the Narran Lake system • Identify additional sources of data that can be used to improve the IQQM • Identify potential water planning scenarios to be reviewed by the MDBA and form the basis of the testing required as part of the Stage 2 report (see Task 13).
4. Hydrological event definition rules	ANU and DSITI will lead this component which will revise the rules used in the Narran Lakes IBIS DSS that are used to define flow events. ANU will firstly conduct tests to investigate the sensitivity of DSS outputs (both Northern Lakes and Narran Lake) to the event definition rules for the Northern Lakes. Specifically, ANU will: • Test impact of changes to Assumption 1 in the DSS (start and end WSE thresholds) • Test impact of changes to Assumption 2 in the DSS (that flow events which start within 28 days of the end of the preceding event are part of the preceding hydrological event) • Prepare material from this review for expert review workshop (Task 6)
5. Analysis of hydrological and ecological data	ANU, OEH and UNSW will work together will use results of historic hydrological and waterbird breeding and flow data, and model analysis, to support conceptualisation and ERM revisions.

	The first aspect of this work is to undertake further analysis of historic flow and breeding events. Specific activities are • Analyse event-based flow indicators including total event flow, peak flow and flow duration incorporating season to further investigate relationships between historical waterbird breeding events and flow thresholds • Undertake an exploratory analysis to quantify the significance of timing of flows using historical breeding data and associated hydrological and climate data (including local rainfall data) • Analyse variability in water depth from local gauging data recorded during the breeding events that occurred from 2010-12 • Investigate possible relationship between minimum temperature and waterbird breeding and abandonment • Investigate variability in nesting heights and how this might influence breeding thresholds These activities will contribute to the development of quantitative probabilistic relationships between hydrological parameters and waterbird breeding initiation, size and success The second aspect of this work (which will be led by ANU an undertaken in conjunction with the above analyses) is to undertake further tests of the ERM predictions against observed waterbird data. Specific activities are to: • Undertake more detailed comparisons of observed waterbird breeding data against DSS model output data using new event-based flow indicators for initiation of Straw-necked Ibis breeding and the size of a breeding event and the likelihood of abandonment • Review the effect of different temperature and water depth thresholds on the DSS model outputs for the likelihood of abandonment To conclude this component, OEH, ANU and UNSW will document the evidence for, and nature of, relationships between flow indicators and thresholds for Straw-necked Ibis breeding (initiation, size and success [and abandonment]).
6. Expert elicitation on the event definition assumptions and waterbird breeding relationships	Prior to the waterbird workshop (Task 7) ANU will run the historic hydrology scenario and document the predicted abandonment and success of Straw-necked Ibis breeding and UNSW will run preliminary analysis to investigate relationships between waterbird breeding and flow thresholds in the Narran Lakes. This information will be used in the workshop to: • Review how changes in water surface elevation should be represented in the fledgling recruitment model, including possible influence of rises and falls in WSE on abandonment • Investigate weighting or combination of the factors (duration [0.4], depth [0.4], temperature [0.1], change in WSE [0.1]) currently linked to the likelihood of abandonment in the fledgling recruitment model • Review the evidence to support a link between minimum temperatures and abandonment The workshop will discuss and identify relationships for breeding trigger and size [ANU, UNSW, OEH, Expert panel]. Specific activities are to: • Decide which threshold values best reflect ecologically significant ‘flow events’ in Northern Lakes • Review event definition rules specific to Narran Lake • Revise event definition rules specific for the less frequently flooded parts of the floodplain (that are not covered by the extent of the hydrology model) • Present results of waterbird breeding and flow threshold analyses from Task 3 and outcomes of further model testing above to expert panel for validation and feedback

	• Review the event definition assumptions to allow for greater separation of flow events that are meaningful for both waterbird breeding responses and management purposes • Elicit relationships between initiation of waterbird breeding or nest numbers and influencing variables (e.g. timing, duration etc) • If a direct representation of the link between vegetation as a habitat requirement for waterbirds is desired by water managers, investigate how this can be implemented in DSS (noting that these relationships will be difficult to quantify due to lack of data) • Define how the different variables affecting waterbird breeding, including timing, should be aggregated Using the outcomes from the workshop(s), the project team will: • Based on the outcomes from the analyses and workshops, ANU will revise event definition rules for Northern Lakes and create event definition rules for the Narran Lake and outer floodplain. • OEH, ANU and UNSW will revise existing conceptual model of Straw-necked Ibis breeding in the Narran Lakes system (including factors influencing initiation of breeding, estimated magnitude of breeding and likely success)[1] • Identify scope of model revisions based on conceptual model and available data and knowledge • Summarise information in a workshop outcomes report [1] This conceptual model is intended to be holistic; it will consider factors other than hydrology that may influence waterbird breeding in the Narran Lakes (e.g. food availability). However, these factors will be beyond the scope of model development within Stage 2 project budget and timelines.
7. Compile findings and outcomes from workshops into an interim report	This interim report will focus on the outcomes of workshop discussions reviewing the performance of the hydrological and waterbird breeding models underpinning the Narran Lakes IBIS DSS. During the workshop analysis of historical data and expert opinion was reviewed to inform the upgrade of the Narran Lakes IBIS DSS and the supporting models over the remainder of the Stage 2 project. This report documents the discussion, outcomes and finding of the workshops with regard to improved understanding of the evidence, and nature of, relationships between flow indicators and thresholds for Straw-necked Ibis breeding. This report will provide the basis for the Stage 2 project report.
8. Revise breeding component of Straw-necked Ibis ERM	Drawing on the workshop outcomes and data analyses described above, ANU will work with OEH and UNSW revise the breeding initiation and nest numbers component of the fledgling recruitment model. This will involve updating the Bayesian network (Bn) model using the Netica software. Specific activities are to: • Define alternative event-based flow indicators for waterbird breeding • Explicitly model breeding trigger and event size separately • Update the discretisation of breeding trigger and nest numbers variables and all their input variables • Update the CPT of all model variables
9. Revise abandonment component of Straw-necked Ibis ERM	Drawing on the workshop outcomes and data analyses described above the project team will revise the abandonment component of the fledgling recruitment model. This will involve updating the Bayesian network (Bn) model using the Netica software. Specific activities are to: • Revise calculation of the Change in WSE parameter to represent influence of increases and decreases in water level on the likelihood of abandonment • Update the discretisation of abandonment variable and all the input variables • Revise the weights or thresholds of the factors influencing the abandonment conditional probability tables • Update the CPT of all model variables

10. DSS model updates	The revised Bn model that is an output from the previous two work components can be used on its own to explore the relationship between hydrology parameters and likely ecological response. However, it cannot be used to analyse hydrology scenarios from IQQM. To allow this, ANU will update the model code and spatial representation of the Narran Lakes IBIS DSS. Specific activities are to: • Revise event definition rules and assumptions according to outcomes from component 4 • Revise 'Event Summary' model code for Northern Lakes • Develop new 'Event Summary' models for Narran Lake and floodplain areas • Implement changes to ERM from component 5-6 in the DSS model code • Create new storage(s) to represent central-eastern and central –western floodplain areas • Link ERM to Slt5 (Narran Lake) and new floodplain storages as required • Link lignum habitat and data-based models to newly defined central-eastern and central –western storages • Delete zone Fgt15 from the IBIS DSS model • Run DSS and check results
11. DSS interface updates	The DSS Interface will be updated to reflect the changes to the DSS model and code made in component 6. ANU will work with Peter Manger (original IBIS DSS software developer) to update the DSS interface. Specific activities are to: • Remove link to Rayburg and Thoms executable from DSS interface and set-up link to IQQM output files. The Gwydir IBIS DSS will be used as the template for the revised Narran IBIS DSS. Peter Manger will help ANU set-up the interface files for the revised model so that IQQM output scenarios provided by DSITI can be imported into the DSS (for the revised spatial representation) • Test DSS interface that the *Scenario* set-up page is working correctly (loading IQQM output files for hydrology scenarios, naming and running hydrology scenarios) • Update the *Hydrology / climate* page in the DSS interface to properly display event summary results for hydrology scenarios In addition, updates to the model code and documentation will include development of an ICMS plugin to export and save model code in text file format, allowing ANU to rapidly develop revised Narran IBIS DSS model, and updates to the ICMS technical specification and DSS documentation.
12. Scenario analysis	The revised IQQM and DSS will be used to run and analyse the results of five water resource development scenarios identified in the interim report. The predicted outcomes form these scenarios for Straw-necked Ibis breeding will be documented in the Stage 2 report which will provided to the MBDA and for wider review by key stakeholders in mid-October.
13. Finalisation of Stage 2 report	Following review by MBDA and key stakeholders comments on the Stage 2 report will be incorporated to allow for the report to be finalised by December.

Appendix 2 Records of Straw-necked Ibis breeding in the Narran Lakes 1971-2014

Defined flow event #	Breeding event #	Location	Year	Survey Month	Estimated number of birds	Estimated number of nests	Source of information
1	1	Narran Lakes NR	1971	March	20,000	10,000	Smith (1993)
2	2	Narran Lakes NR	1972		unknown no.	unknown no.	Smith (1993)
5	3	Narran Lakes NR	1974	May/June	unknown no.	unknown no.	Smith (1993)
7	4	Narran Lakes NR	1976	March/July	unknown no.	unknown no.	Aldis in Magrath (1991)
		Narran Lake/Narran Lake NR	1978	November	520	260*	Brooker (1993) (*probable record only)
		Narran Lakes NR	1981	May	100	50*	Brooker (1993) (*probable record only)
13	5	Narran Lakes NR/Narran Lake	1983	July/Nov	400,000	200,000	Marchant and Higgins (1990)
13	6	Narran Lakes NR	1984	May	unknown no.	unknown no.	Beruldsen (1985)
14	7	Narran Lakes NR	1988	April	unknown no.	25,000	Maher pers. comm. (2004)
14	8	Narran Lakes NR	1988	September	92,000	46,000	Smith (1993), Magrath (1991)
15	9	Narran Lakes NR	1989	June-Sep	18,000	8,500^	Magrath (1991), Smith (1993) (^some failed nests in July)
17	10	Narran Lakes NR	1990	July	unknown no.	unknown	Maher pers. comm. (2004)
17	11	Narran Lakes NR	1990	September	100,000	50,000	Smith (1993)
		Narran Lake	1991	April	500	250*	Smith (1993) (*note these were outside of NR)
		Narran Lake	1996	December	unknown no.	500*	Ley (1998a) (*note these were outside of NR)
21	12	Narran Lakes NR	1996	March	204,000	102,000	Ley (1998a)
		Narran Lakes NR	1997	July	2300	1150*	Ley (1998b) (* July and March surveys of same failed breeding event)
		Narran Lakes NR	1997	March	2500	1250*	Ley (1998b) (* July and March surveys of same failed breeding event)
25	13	Narran Lakes NR	1998	October	100,000	50,000	Henderson (1999)
27	14	Narran Lakes NR	2001	March	unknown no.	unknown no.	Kingsford (pers. comm.)
29	15	Narran Lakes NR	2008	Jan-May	140,000	74,000	Brandis (2010)
		Narran Lakes NR	2010	Feb	unknown no.	10,681*	Spencer et al. (2015a) (*failed event)
		Narran Lake	2010	May	unknown no.	6,029	Spencer et al. (2015a)
30	16	Narran Lakes NR	2010	May	unknown no.	13,303	Spencer et al. (2015a)

31	17	Narran Lakes NR	2010	November	unknown no.	6,651	Spencer et al. (2015a)
	17	Narran Lakes NR	2011	Feb	unknown no.	14,367	Spencer et al. (2015a)
		Narran Lake	2012	March	unknown no.	21,410	Spencer et al. (2015a)
32	18	Narran Lakes NR	2012	March	unknown no.	131,442	Spencer et al. (2015a)

defined flow events to inundate Straw-necked Ibis breeding habitat in the Narran Lakes Nature Reserve are based on the revised event definition where more than 100 ML/d is recorded at Wilby Wilby to start a flow event and a flow event ends when water levels drop 120.746 mAHD at the Back Lake gauge. Only breeding events were recorded in the Nature Reserve were included in the analysis (i.e. records for Narran Lake itself were excluded). Probable records in 1978 and 1981 and complete failed nesting attempts in March 1997 and February 2010 were also excluded from the analysis of breeding and flow relationships.

Appendix 3 Summary of hydrological parameters

Summary of defined flow event characteristics including: event and 90 day cumulative flows at Wilby Wilby (see Appendix 6 for start and end date for each defined flow event), cumulative rainfall, average maximum and average minimum air temperatures (T) at the Brewarrina and Walgett gauges during each flow event since the first record of Straw-necked Ibis breeding in 1971 (flow events coinciding with Straw-necked Ibis breeding records are highlighted).

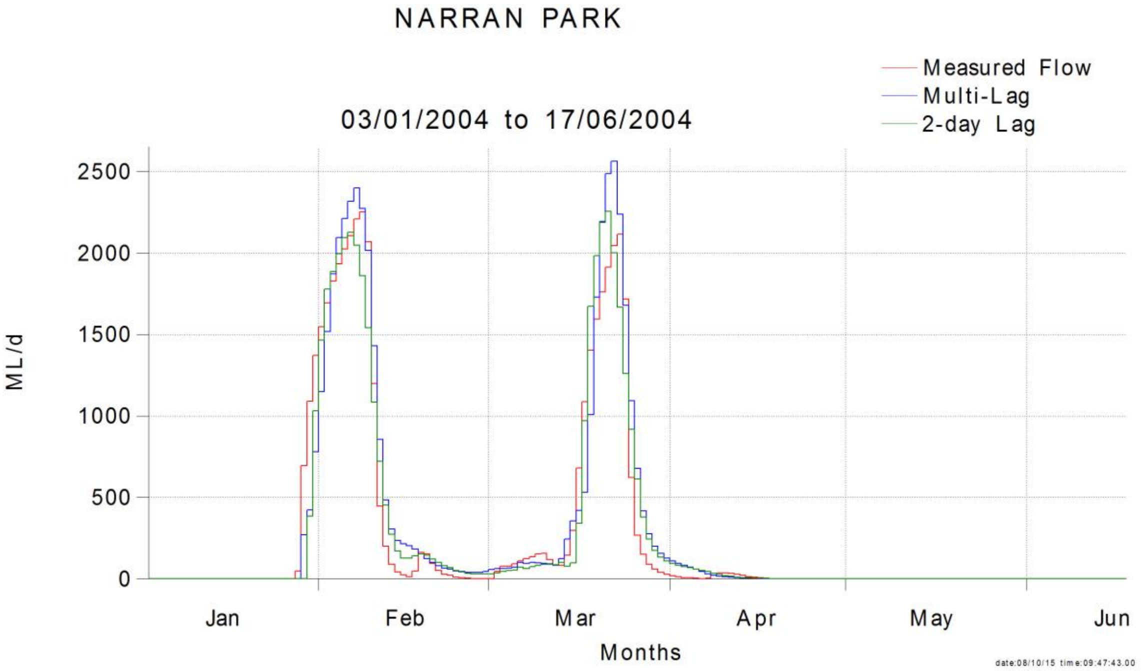
Defined flow Event #	Event Cumulative Flow Wilby Wilby	90 day Cumulative Flow Wilby Wilby	90 day Rain Brewarrina	Event Rain Brewarrina	90 day Rain Walgett	Event Rain Walgett	90 day Tmin Brewarrina	Event Tmin Brewarrina	90 day Tmax Brewarrina	Event Tmax Brewarrina	90 day Tmin Walgett	Event Tmin Walgett	90 day Tmax Walgett	Event Tmax Walgett
1	489,738	446,713	261.8	326.5	146.5	205.0	28.7	20.0	15.3	32.8	20.0	14.5	32.2	27.3
2	121,804	121,804	124.1	124.1	221.7	221.7	32.6	18.3	18.1	32.6	17.0	16.9	31.4	31.4
3	103,330	83,837	169.6	301.0	159.4	258.8	33.5	21.8	19.2	36.3	21.1	18.8	35.7	33.0
4	18,455	18,455	175.5	157.4	180.2	129.4	23.4	11.2	9.6	24.9	11.0	9.6	24.3	23.2
5	356,034	339,787	391.1	568.4	380.8	472.2	24.9	20.4	13.3	31.0	19.8	12.8	31.3	24.2
6	97,791	89,596	129.3	187.5	241.0	307.1	27.1	16.9	12.1	31.8	16.8	12.0	30.7	26.4
7	457,498	411,725	510.0	559.0	399.9	479.2	24.6	19.2	11.7	29.7	18.8	11.6	29.3	24.7
8	37,196	37,196	49.1	44.0	91.2	75.2	34.5	19.0	18.3	34.9	18.3	17.5	33.8	33.3
9	138,762	134,822	136.0	147.8	163.8	172.6	22.4	11.5	8.0	24.8	11.3	8.2	23.5	21.7
10	103,149	96,043	57.0	132.2	116.6	236.8	25.9	8.1	10.7	23.4	6.9	10.3	20.5	24.9
11	134,260	77,860	71.0	108.1	65.0	263.8	26.1	14.8	10.9	31.3	14.2	10.1	29.2	23.5
12	180,905	109,153	77.2	110.8	152.6	195.3	29.9	21.8	15.8	35.7	21.2	15.7	34.1	29.4
13	1,073,279	532,612	148.0	913.2	236.1	1112.6	25.4	6.3	11.8	17.5	6.8	10.3	17.2	22.0
14	414,866	314,812	136.2	281.2	264.0	441.4	25.3	15.1	10.8	27.6	14.7	11.0	24.7	23.8
15	177,331	170,892	166.3	203.6	218.6	267.4	19.5	8.4	6.5	18.9	9.9	7.8	20.2	20.4
16	77,351	77,351	36.6	36.6	56.8	56.8	35.8	20.3	20.2	35.7	18.5	18.3	34.5	34.5
17	317,668	311,495	305.8	363.2	238.6	326.7	20.4	9.7	8.5	20.3	8.8	7.8	20.3	20.2
18	12,625	12,625	30.8	0.0	125.6	5.0	34.9	13.8	18.7	28.5	12.8	18.9	27.5	34.1
19	21,393	21,393	42.0	11.6	52.0	24.0	35.5	20.1	18.9	34.9	19.2	17.8	33.8	34.1
20	113,625	113,625	79.8	90.8	112.0	112.0	27.2	13.5	12.4	27.8	12.1	11.1	27.1	26.5
21	229,107	229,065	53.4	53.4	95.6	95.8	32.4	19.3	17.5	34.0	17.7	16.1	33.0	31.6
22	137,529	137,307	91.4	114.4	111.7	149.7	19.6	6.5	6.5	18.4	5.9	6.0	18.1	19.2
23	124,614	124,614	41.8	96.2	47.5	56.8	28.3	15.1	13.9	30.3	13.8	12.4	29.6	27.0
24	21,765	21,765	92.8	0.0	58.8	0.0	34.0	15.3	17.7	29.1	14.5	16.8	29.0	34.2
25	190,185	20,093	260.7	432.8	186.8	343.8	22.3	6.0	10.1	17.6	5.7	8.7	17.6	21.5
26	141,859	141,698	158.7	240.7	124.2	191.0	25.6	15.9	12.6	28.7	14.3	11.2	28.7	25.8
27	46,565	46,565	238.0	193.6	180.0	154.2	34.1	21.0	20.0	35.1	19.5	18.2	34.3	32.8
28	48,588	48,577	103.8	172.1	126.4	153.5	31.0	18.9	16.2	34.1	16.9	14.2	32.9	30.3
29	55,159	55,159	293.0	398.2	225.4	258.7	30.2	18.4	16.8	31.3	17.8	16.0	31.8	30.9

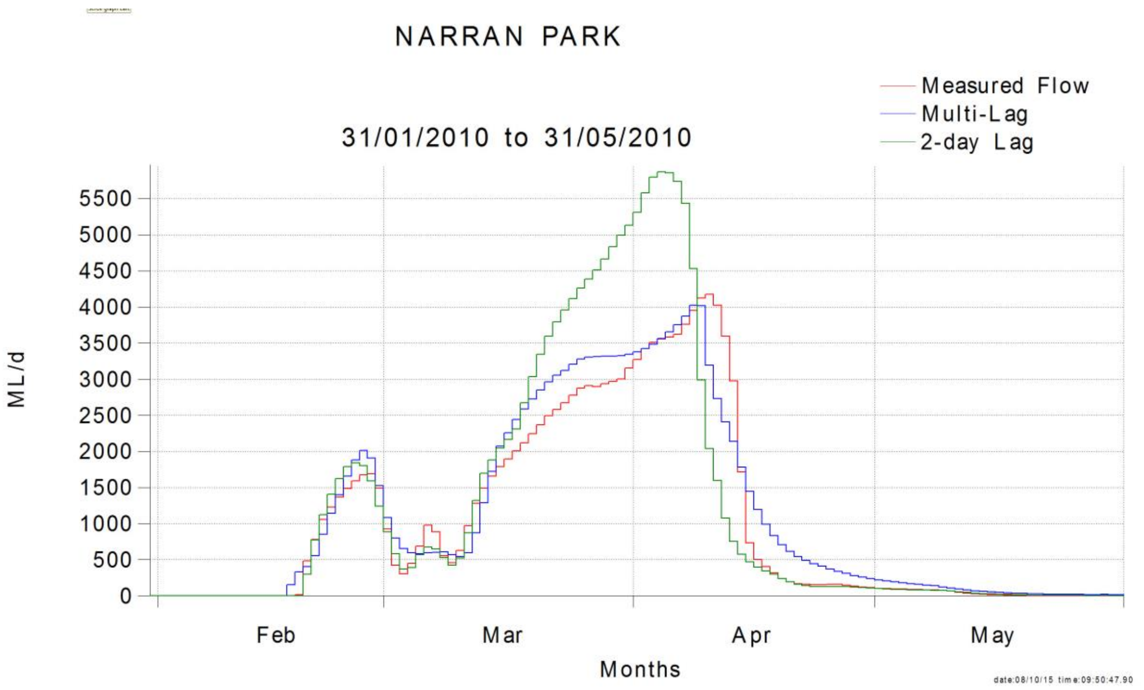
Defined flow Event #	Event Cumulative Flow Wilby Wilby	90 day Cumulative Flow Wilby Wilby	90 day Rain Brewarrina	Event Rain Brewarrina	90 day Rain Walgett	Event Rain Walgett	90 day Tmin Brewarrina	Event Tmin Brewarrina	90 day Tmax Brewarrina	Event Tmax Brewarrina	90 day Tmin Walgett	Event Tmin Walgett	90 day Tmax Walgett	Event Tmax Walgett
30	172,847	172,642	148.8	202.3	143.2	208.3	24.4	14.5	11.2	28.4	13.2	10.0	28.7	24.8
31	625,134	166,331	313.0	480.3	336.8	496.2	27.1	17.1	13.3	29.2	15.6	11.8	28.9	27.0
32	323,653	181,384	285.5	574.8	413.4	650.5	25.7	18.4	12.0	31.0	17.7	10.5	30.6	25.5
33	117,132	116,340	89.0	140.0	127.8	155.9	26.0	14.7	11.7	29.7	13.8	10.9	29.3	25.7

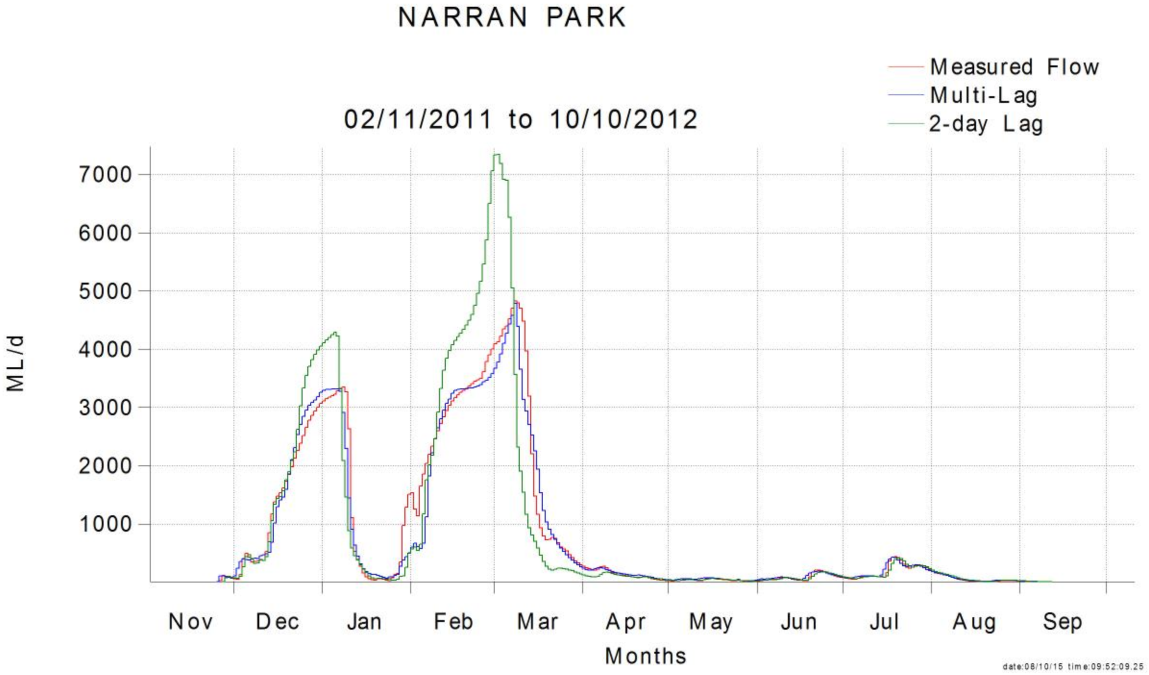
defined flow events to inundate Straw-necked Ibis breeding habitat in the Narran Lakes Nature Reserve are based on the revised event definition where more than 100 ML/d is recorded at Wilby Wilby to start a flow event and a flow event ends when water levels drop 120.746 mAHD at the Back Lake gauge.

Appendix 4 Revision of the Narran reach of the Condamine-Balonne IQQM

The routing in the IQQM Wilby Wilby to Narran Park reach was revised to take into account the variation in the lag with flow. The flows recorded at the Wilby Wilby gauge (GS422016) were used as inflow and the predicted flows at the Narran Park gauge (GS422029) were compared with the flows recorded at the gauge. The following figures show a comparison between the measured flow and the flow predicted using a 2-day lag and the flow predicted using a lag that varied with the flow as shown below. The multi-lag method that changed the lag depending on the flow gives a better representation of the timing and shape of the hydrograph for all flow events from the small flow event (<1,000 ML/d peak flow) in 2004 to a moderate flow event (>1,000 – <5,000 ML/d peak flow) in 2010 and large flow event (> 5,000 ML/d peak flow) in 2011 (from DSITI 2015).




NARRAN PARK
Measured Flow
Multi-Lag
2-day Lag
31/01/2010 to 31/05/2010
ML/d
5500
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
Feb
Mar
Apr
May
Months
date:08/10/15 time:09:50:47.90


NARRAN PARK
Measured Flow
Multi-Lag
2-day Lag
02/11/2011 to 10/10/2012
ML/d
7000
6000
5000
4000
3000
2000
1000
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Months
date:08/10/15 time:09:52:09.25

Appendix 5 Revised Conditional Probability Tables

This appendix details the assumptions and expert knowledge used to generate the CPT for the abandonment component of the revised Straw-necked Ibis model. The revised CPT for breeding initiation and size of breeding events (total number of nests) is presented in Section 3.3.4.

Nest abandonment

Season: The relationship between season and abandonment is assumed relevant **only** to the egg stage as season is based on the start of the event. The key assumptions about season that are used to populate the CPT below are:

- July to September is not suitable (poor) and abandonment is almost certain (high)
- April to June is sub-optimal and there is some possibility of abandonment
- October to March is optimal and there is little likelihood of abandonment

However, for large flood events with a duration greater than 200 days the impact of season is assumed negated. This was implemented to capture the large floods that may not start in an 'optimal' season but which should provide breeding opportunities in other months. An alternate approach would be to reconfigure the DSS to represent conditions for breeding across flow events, referred to as staged breeding in Merritt *et al.* (2015). This work program option was not selected given time constraints for the current Stage 2 project.

Predicted relationship between season and the likely abandonment of nests at the egg stage.

Season	**Abandonment – Egg (Season)**		
	Low	**Moderate**	**High**
Jul-Sep (poor)	0	0.05	0.95
Apr-Jun (sub-optimal)	0.2	0.6	0.2
Oct-Mar (optimal) [or when duration is >200 days]	0.95	0.05	0

Inundation duration: The relationship between inundation duration and abandonment has been modified from the ANU Enterprise (2011) by reducing the number of states for the inundation duration variable and developing relationships for the three represented stages of fledgling development. For all stages, inundation durations less than 73 days are likely to be of insufficient length to get through conditioning, nest preparation, and the fledgling stages (High = 0.95, Moderate = 0.05). Durations greater than 100 days are likely to be of sufficient length to get through conditioning, nest preparation, and the fledgling stages (egg, chick, and flappers and runners) (Low = 0.95, Moderate = 0.05). If the inundation duration is between 73 and 100 days then it is postulated that the earlier nesters will be less likely to abandon as their young are more advanced:

- *Eggs (1-20 days old):* the likelihood of abandonment is high as event is unlikely to continue long enough for young to progress to stage where they can fly
- *Chicks (21-30 days old):* there is a moderate likelihood of abandonment although the relationship is uncertain
- *Runners and flappers (31-40) days:* likelihood of abandonment is low as event should continue long enough for young to progress to stage where they can fly.

The relationships are shown in the table below.

Relationship between inundation duration and abandonment

Inundation Duration	**Likelihood of abandonment**		
Eggs			
	Low	**Moderate**	**High**
<73 days	0	0.05	0.95
73 – 100 days	0	0.2	0.8
100 – 250 days	0.95	0.05	0
>200 days	0.95	0.05	0
Chicks			
<73 days	0	0.05	0.95
73 – 100 days	0.2	0.6	0.2
100 – 250 days	0.95	0.05	0
>200 days	0.95	0.05	0
Runners and Flappers			
<73 days	0	0.05	0.95
73 – 100 days	0.8	0.2	0
100 – 250 days	0.95	0.05	0
>200 days	0.95	0.05	0

Overall relationships between duration, season and abandonment for the egg stage represented in the upgraded Narran DSS.

Abandonment due to Duration	**Abandonment due to Season**	**Likelihood of abandonment (eggs)**		
		Low	**Moderate**	**High**
Low	Low	0.95	0.05	0
Low	Moderate	0.667	0.333	0
Low	High	0	0.05	0.95
Moderate	Low	0.667	0.333	0
Moderate	Moderate	0.333	0.667	0
Moderate	High	0	0.05	0.95
High	Low	0	0.05	0.95
High	Moderate	0	0.05	0.95
High	High	0	0	1

Overall relationships between duration and abandonment for the chick and runner and flapper stages represented in the upgraded Narran DSS.

Abandonment due to duration	**Likelihood of abandonment (chicks/runners/flappers)**		
	Low	**Moderate**	**High**
Low	0.95	0.05	0
Moderate	0.5	0.5	0
High	0	0.05	0.95

Appendix 6 Outputs from the upgraded Narran DSS

Summary of outputs from the upgraded Narran DSS using flow event formulation 100 ML/d at the Wilby Wilby gauge and WSE (120.746 m AHD) at the Back Lake gauge. *Flow events that coincided with confirmed *Straw-necked Ibis breeding records in the Narran Lakes Nature Reserve (see Appendix 2) are indicated.*

Defined flow event #	Start Date	End Date	Cumulative Flow first 10 days (ML)	Cumulative Flow first 90 days (ML)	Cumulative Flow 10 day threshold (ML)[1]	Cumulative Flow 90 days threshold (ML)[1]	Season (suitability)	Breeding (No)	Breeding (Yes)
1*	18/12/1970	22/06/1971	27938	446713			Optimal	0.01	0.99
2*	6/01/1972	10/04/1972	28389	121804			Optimal	0.57	0.43
3	18/11/1972	9/05/1973	29749	83837			Optimal	0.57	0.43
4	8/08/1973	17/10/1973	9625	18455			Poor	0.996	0.003
5*	2/01/1974	13/08/1974	27136	339787			Optimal	0.01	0.99
6	17/01/1975	13/07/1975	17644	89596	20776		Optimal	0.57	0.43
7*	3/01/1976	15/08/1976	21963	411725			Optimal	0.01	0.99
8	15/11/1976	27/01/1977	16486	37196			Optimal	0.93	0.07
9	17/03/1977	27/08/1977	27974	134822			Optimal	0.57	0.43
10	19/07/1978	2/01/1979	20074	96043			Poor	0.978	0.022
11	19/02/1981	30/09/1981	20744	77860			Optimal	0.57	0.43
12	21/12/1981	18/06/1982	10629	109153		160359	Sub-optimal[1]	0.802	0.198
13*	14/05/1983	6/01/1985	29010	532612			Sub-optimal	0.01	0.99
14*	26/02/1988	8/11/1988	15139	314812			Optimal	0.01	0.99
15*	13/04/1989	6/10/1989	23690	170892			Sub-optimal	0.802	0.198
16	8/11/1989	31/01/1990	10586	77351	24715		Optimal	0.57	0.43
17*	9/04/1990	4/10/1990	43500	311495			Sub-optimal	0.802	0.198

18	2/03/1991	22/03/1991	12362	12625			Optimal	0.93	0.07
19	21/12/1993	24/01/1994	19288	21393			Optimal	0.93	0.07
20	19/02/1994	8/06/1994	6335	113625	22219		Optimal	0.57	0.43
21*	5/12/1995	22/04/1996	17017	229065			Optimal	0.01	0.99
22	15/05/1996	19/09/1996	16894	137307	24943		Sub-optimal	0.914	0.086
23	13/02/1997	7/06/1997	13834	124614	22685		Optimal	0.57	0.43
24	20/02/1998	13/04/1998	18770	21765			Optimal	0.93	0.07
25*	17/05/1998	10/12/1998	11964	20093		163542	Optimal[2]	0.01	0.99
26	3/02/1999	3/07/1999	3268	141698	23285		Optimal	0.57	0.43
27*	14/11/2000	12/01/2001	32078	46565			Optimal	0.57	0.43
28	25/01/2004	24/05/2004	16701	48577	21795		Optimal	0.57	0.43
29*	21/12/2007	20/04/2008	23026	55159			Optimal	0.57	0.43
30*	16/02/2010	17/07/2010	15074	172642			Optimal	0.01	0.99
31*	9/10/2010	6/09/2011	3879	166331			Optimal	0.01	0.99
32*	21/11/2011	13/09/2012	1230	181384			Optimal	0.01	0.99
33	15/02/2013	7/07/2013	27610	116340			Optimal	0.57	0.43

[1] Where the cumulative flow threshold were not met in the first 10 (>20,000 ML) or 90 days (>154,000 ML) the flow event was checked to determine whether these threshold were met over sequential 10 or 90 days at another point during each defined flow event. This occurred for flow events 12 and 25, with event 25 associated with breeding and event 12 meeting this threshold in a suboptimal season and no observed breeding. Flow events 12 and 25 did not meet the 10 day cumulative flow threshold at any point. There were seven flow events which met the 10 day cumulative flow threshold at a later point within each flow event (i.e. not in the first 10 days). These were flow events 6, 16, 20, 22, 23, 26 and 28, however, none of these flow events were associated with confirmed Straw-necked Ibis breeding. Only event 23 had a record of birds attempting to nest but abandoning eggs at an early stage because of rapidly falling water levels (Ley 1998b). [2] Despite a sub-optimal season at the start of the event, a larger flow was recorded later in the event and the long duration of the event (>200 days) meant that the season effect on breeding initiation was cancelled out.

Comparison of predicted flow events supporting Straw-necked Ibis breeding in Baseline scenario where Pr(Breeding = Yes) = 0.43 compared to the other water resource development scenarios (highlighted events indicate where expected outcomes for breeding are greater (in blue) or lower (in red) compared to predicted breeding initiation under the Baseline scenario).

Base Case			**CEWO 50GL**		**MDBA SDL**		**Northern Standard**		**PD**	
Event #	**Start**	**End**	**Event #**	**Pr(Breeding=Yes)**	**Event #**	**Pr(Breeding=Yes)**	**Event #**	**Pr(Breeding=Yes)**	**Event #**	**Pr(Breeding=Yes)**
1	30/01/1895	22/04/1895	1	0.43	1	0.43	1	0.43	1	0.43
3	18/01/1898	16/04/1898	4	0.43	6	0.43	5	0.43	6	0.43
6	17/06/1903	25/11/1903	7	0.43	9	0.43	8	0.43	11	**0.086**
8	11/02/1906	12/06/1906	9	0.43	11	0.43	10	0.43	15	**0.99**
11	24/02/1908	6/07/1908	13	0.43	14	**0.99**	13	0.43	18	**0.99**
12	24/01/1910	23/09/1910	14	0.43	17	0.43	14	0.43	21	**0.99**
17	6/02/1917	30/05/1917	19	0.43	25	0.43	20	0.43	29	0.43
18	2/10/1917	13/03/1918	20	0.43	26	0.43	21	0.43	30	**0.022**
21	5/01/1922	5/04/1922	23	0.43	29	0.43	24	0.43	35	**0.99**
23	24/10/1924	8/03/1925	25	0.43	31	0.43	26	0.43	37	0.43
24	15/02/1927	18/06/1927	26	0.43	34	0.43	27	0.43	40	0.43
27	17/12/1931	20/02/1932	29	0.43	37	0.43	30	0.43	45	0.43
30	24/03/1937	27/06/1937	32	0.43	40	0.43	33	0.43	49	0.43
35	27/02/1942	23/06/1942	37	0.43	45	0.43	38	0.43	55	0.43
36	11/01/1943	19/03/1943	38	0.43	46	0.43	39	0.43	56	0.43
37	26/02/1947	23/07/1947	40	0.43	48	0.43	41	0.43	61	**0.198***
40	26/10/1949	6/01/1950	43	0.43	52	0.43	45	0.43	65	0.43
43	3/03/1953	9/06/1953	46	0.43	55	0.43	48	0.43	69	0.43
44	30/01/1954	13/06/1954	47	**0.99**	56	**0.99**	49	**0.99**	70	**0.99**
50	10/02/1959	13/07/1959	53	0.43	61	0.43	55	0.43	76	**0.99**
51	5/12/1961	26/07/1962	54	0.43	64	**0.99**	56	0.43	79	**0.99**
52	24/01/1963	16/08/1963	55	0.43	65	0.43	57	0.43	80	**0.198***
54	7/01/1972	1/04/1972	59	0.43	72	0.43	61	0.43	90	0.43

56	19/01/1974	24/06/1974	61	0.43	74	0.43	63	0.43	93	**0.99**
59	20/03/1977	17/08/1977	64	0.43	78	0.43	66	0.43	97	0.43
60	23/02/1981	24/09/1981	66	0.43	80	0.43	68	0.43	100	0.43
61	12/03/1982	15/06/1982	67	0.43	81	0.43	69	0.43	101	**0.198***
68	23/02/1994	5/06/1994	75	0.43	88	0.43	77	0.43	110	0.43
71	12/02/1997	17/06/1997	78	0.43	91	0.43	80	0.43	114	**0.99**
74	11/02/1999	4/07/1999	80	0.43	93	**0.99**	82	0.43	116	**0.99**
75	26/01/2004	31/05/2004	82	0.43	96	0.43	85	0.43	121	**0.99**
76	20/12/2007	23/04/2008	83	0.43	98	0.43	86	0.43	125	**0.99**

** 10 day and 90 day flow thresholds met during the hydrological event but with sub-optimal season*

Comparison of predicted flow events in the Baseline that fail to support Straw-necked Ibis breeding due to neither flow threshold being met (Pr(Breeding = Yes) = 0.07, 0.014 and 0.0034 in optimal, sub-optimal and poor seasonal conditions respectively). Highlighted events indicate where expected outcomes for breeding are greater (in blue) compared to predicted breeding initiation under the Baseline scenario.

Base Case			CEWO 50GL		MDBA SDL		Northern Standard		PD	
Event #	Start	End	Event #	Pr(Breeding=Yes)	Event #	Pr(Breeding=Yes)	Event #	Pr(Breeding=Yes)	Event #	Pr(Breeding=Yes)
2	06/08/1897	21/10/1897	3	0.003	5	0.022	4	0.003	6	0.43
4	15/02/1899	28/03/1899	5	0.07	7	0.43	6	0.43	7	0.43
5	25/06/1901	29/09/1901	6	0.014	8	0.022	7	0.022	10	0.086
9	2/01/1907	17/02/1907	11	0.07	13	0.07	12	0.07	17	0.43
10	14/06/1907	9/08/1907	12	0.014	13	0.07	12	0.07	17	0.43
15	2/07/1913	15/09/1913	17	0.022	21	0.022	17	0.022	25	0.022
16	14/11/1916	26/01/1917	19	0.43	25	0.43	20	0.43	29	0.43
19	22/06/1920	16/10/1920	21	0.022	27	0.086	22	0.022	33	0.086
22	16/02/1924	26/05/1924	24	0.07	30	0.43	25	0.43	36	0.99
28	16/11/1933	21/01/1934	30	0.43	38	0.43	31	0.43	47	0.43
29	9/01/1935	28/03/1935	31	0.07	39	0.43	32	0.07	48	0.99
31	9/06/1938	15/08/1938	33	0.014	41	0.086	34	0.014	50	0.086
32	7/02/1939	26/07/1939	34	0.07	42	0.43	35	0.07	52	0.43
33	24/02/1940	19/06/1940	35	0.086	43	0.43	36	0.086	53	0.99
38	23/12/1947	18/03/1948	41	0.07	49	0.43	42	0.43	62	0.43
39	16/03/1949	25/06/1949	42	0.07	51	0.086	44	0.07	64	0.086
42	7/04/1952	25/08/1952	45	0.014	54	0.086	47	0.014	67	0.43
48	9/01/1957	5/04/1957	51	0.43	59	0.43	53	0.43	73	0.43
49	26/06/1958	4/09/1958	52	0.014	60	0.086	54	0.086	75	0.086
55	18/11/1972	17/01/1973	60	0.43	73	0.43	62	0.43	91	0.43
57	13/03/1975	20/05/1975	62	0.07	75	0.07	64	0.07	94	0.43
65	17/04/1989	14/09/1989	71	0.086	84	0.086	73	0.086	105	0.198
66	16/11/1989	22/01/1990	72	0.07	85	0.43	74	0.43	106	0.43
72	21/02/1998	30/03/1998	79	0.022	92	0.99	81	0.43	115	0.99