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Linking wetland hydrology to ecological outcomes in the Lowbidgee wetlands in Southern New South Wales

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Abstract: The Lowbidgee Floodplain (Lowbidgee) is an ephemeral wetland system located in semi-arid southern New South Wales. The wetlands provide critical fish and waterbird habitats, and are a refuge for biodiversity. In its natural state, many of the wetlands in Lowbidgee are characterised by variable and unpredictable patterns of high and low flows and water levels. Previous studies indicate that the Lowbidgee floodplain is undergoing accelerated ecological degradation since the 1960s. The ecological degradation can be recognised through declining biodiversity, encroachment of terrestrial species, colonisation by exotic species, and deterioration of the floodplain forests. This degradation is primarily due to changes in the flooding regime, and principally a decrease in flooding frequency due to river regulation. There has been a renewed investment in providing water for the environment to address this declining ecological condition.

To optimise environmental water management, the LYNC decision support system (DSS) was developed based on the Eco Modeller framework. 60 key wetlands in the Lowbidgee are represented in LYNC. LYNC applies habitat models to daily hydrological time series for each of these 60 key wetlands to transparently evaluate and report the relative ecological outcomes of different watering scenarios. . LYNC contains habitat models for interpreting the hydrological regime for 17 species. In this paper we focus on river red gum (*Eucalyptus Camaldulensis*) in the Yanga National Park, an area of the Lowbidgee that is predominantly a river red gum forest.

We ran the cell-based IQQM hydrological model for eight scenarios that investigated different options in the amount and timing of delivery of environmental water. The LYNC DSS was used to model habitat condition for each hydrological scenario. The best overall habitat scores across the wetlands are provided under the predevelopment scenario. The environmental water application scenarios indicated that, given a set volume of water, the timing of water delivery has a significant effect on the suitability of the habitat conditions. Additionally the method of water delivery (over-bank flooding versus active diversions) gives a different spatial pattern to habitat suitability. This study has demonstrated the potential value of habitat models to quantitatively test environmental water planning options. As with all modelling, the habitat models represent our current understanding of the water needs of the different target species and it is important to continue to refine and test the underlying assumptions of the habitat models as more ecological data becomes available.

Key words: *Decision support system; Environmental water delivery options; Habitat quality*

1. INTRODUCTION

The widespread decline and degradation of lowland floodplain wetlands (MEA, 2005) has prompted a global campaign to restore these ailing ecosystems (Acreman and Ferguson, 2010). In the Murray-Darling Basin (MDB), Australia's largest river system, where most floodplain wetlands occur, an estimated 90% of the floodplain wetlands have been lost as a result of flow regulation (Beeton et al. 2006). The remaining wetlands are under increasing pressure due to the lack of flooding (Kingsford and Thomas. 2004; Wen et al, 2009). The Australian governments have taken a range of actions to arrest the trend of ecological degradation observed in lowland floodplains. The provision of environmental water to targeted sites is among the most implemented methods (DEWHA, 2010).

Despite the large amount of resources being put into restoration programs – e.g. The Australian Government's *Water for the Future* program has $3.1 billion for purchasing water entitlements to help restore the health of important rivers, wetlands and floodplains across the Murray-Darling Basin. (DEWHA, 2010) – many projects fail to achieve the stated restoration objectives (Mika, et al. 2010). Although there is extensive literature about ecological restoration planning including providing a "guiding image" (preferred states) (Palmer et al. 2005); prioritisation (Hobbs, 2007); identifying recovery trajectories and reference sites (Hughes et al 2005); it seems that there is a lack of sophisticated decision support systems (DSS) that provide explicit and logical means to move from ecological objectives to on-the-ground strategies. By linking water resource availability, flow-ecology relationship, and ecological outcomes, a DSS could allow river managers and researchers to predict the outcomes of environmental flow applications and compare different environmental water management strategies (Merritt et al. 2009; Marsh and Cuddy, 2010).

LYNC (Lowbidgee -Yanga and Nimmie- Caria) is a customised decision support system for the Lowbidgee Floodplain built using Eco Modeller (eWater CRC, 2010) as the framework for applying habitat models to time series data and reporting the predicted ecological response. LYNC works as a warehouse of information, containing maps, publication materials, fact sheets, habitat models and model documentation. The DSS captures the best available scientific knowledge in a way that is relevant to decision makers, and that is highly interactive and easy to use (SKM, 2011). In this study, we demonstrated the use of LYNC for optimising environment water delivery by running, comparing and analysing eight management scenarios. These scenarios compared pre-development, the current Water Sharing Plan, and a range of options relating to the seasonal scheduling of water delivery.

2. METHODOLOGY

2.1 Study Site – Yanga National Park

Yanga National Park, which is part of the broad Lowbidgee floodplain, is located in semi-arid southern New South Wales, and it encompasses a range of ephemeral wetland systems (Fig. 1). The predominant wetland types in the Park include tree-dominated wetland (e.g. river red gum *Eucalyptus camaldulensis* forests and woodlands) and shrub-dominated wetland (e.g. lignum *Muehlenbeckia florulenta* swamps). Ephemeral freshwater lakes (e.g. Yanga Lake and Lake Tala) and marshes (e.g. the Avenue), paleochannels, floodrunners, and anabranches scattered within the forested floodplain, forming an array of habitats that play a critical role in the life cycles of the many fish and waterbird species.

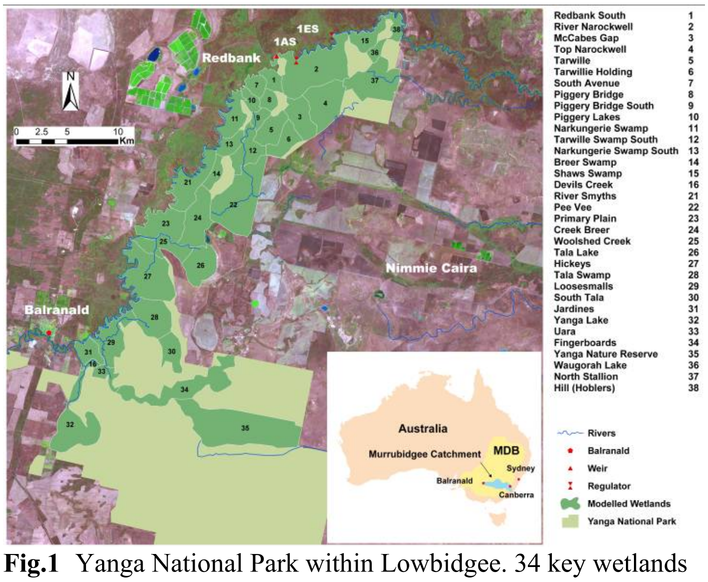

Fig.1 Yanga National Park within Lowbidgee. 34 key wetlands in the Park are modelled as cells in IQQM. Insert shows the location of Murrumbidgee Catchment within Australia's Murray-Darling Basin (MDB).

With an area of about 80,000 ha, the Park is renowned for its wetlands as critical fish and waterbird habitats and refuge for biodiversity in arid and semi-arid Australia (Maher 1990; Kingsford and Thomas, 2004; Wen *et al*. 2009). The Park is an essential part of the Lowbidgee Floodplain, which is listed in the *Directory of Important Wetlands in Australia* (Environment Australia, 2001). In its natural state, many of the wetlands in the Park are characterised by variable and unpredictable patterns of high and low flows and water levels. Like many other floodplains in the southern Murray-Darling Basin (MDB), Yanga National Park has been affected by years of low river flow and infrequent flooding due to increasing of water resource development for agricultural and urban use. Reduction in Murrumbidgee river flow has substantially reduced the volume of water entering Yanga, which has subsequently led to a decrease in inundation extent, duration and frequency (Wen 2009). Because inundation is one of the fundamental drivers of the ecological functioning of the floodplain, water resource development has changed the ecological character of the Park, including a reduction in waterbird species and abundance (Kingsford and Thomas, 2004; Wen et al 2011); diminution and fragmentation of aquatic habitats, in particular the habitat of the endangered southern bell frog (Spencer and Wassens 2010); and deterioration of vegetation condition (Kingsford and Thomas, 2004; Wen *et al.* 2009).

Although both hydrological modelling and decision support systems cover all important wetlands in Lowbidgee Floodplain, this study focuses on Yanga National Park due to the availability of flow data. In this study, the key wetlands in the Park are represented as 34 cells (Fig. 1) – a term used in the hydrological model (to be consistent, they are referred to as wetlands). The delineation of the wetlands was primarily based on a detailed hydrodynamic simulation from which hydraulic relationships were defined. Each of the wetlands has its own hydrological sequence to explicitly describe the local distribution of flood area, depth and volume. Therefore, each wetland has its own set of flood attributes for a given period, and subsequently the ecological response model outputs vary across wetlands.

2.2 Hydrological simulations

A stand-alone cell-based IQQM (Integrated Quality and Quantity Model) hydrological model was developed for the Redbank Forest jointly by NSW Office of Environment and Heritage and Office of Water in 2010 (Mackay *et al*, this volume). The Redbank IQQM covers the entire Yanga National Park and the Murrumbidgee reach between downstream Maude Weir and upstream Balranald Weir. The cell-based IQQM was built upon the hydraulic relationships derived from the outputs of a detailed hydrodynamic model simulation (MIKE 21) with a grid size of 20 m.

A total of eight scenarios were modelled (Table 1). Each scenario run generates daily time series of surface water area, volume, and water depth for the 34 wetlands, which are the hydrological inputs for the decision support system (see below). The modelling period is from 1 July 1974 to 30 June 2009. The amount of environmental water allocation (Table 2) was based on the application records (DEWHA, 2011) and the *Framework for Determining Commonwealth Environmental Watering Actions* (DEWHA, 2009).

Table 1 Inputs to the Redbank cell-based IQQM for eight scenarios

Scenarios	River flow	Diversions
Predevelopment	Simulated flow [a]	-
Water Sharing Plan	Simulated flow [b]	Simulated flow [c]
Actual	Gauge records	Estimation by State Water [d]
No-Action	Gauge records	-
Watering option 1	As WSP	All e-Water [e] delivered in summer
Watering option 2	As WSP	All e-Water delivered in spring
Watering option 3	As WSP	2/3 e-Water delivered in summer and 1/3 delivered in spring
Watering option 4	As WSP	1/3 e-Water delivered in summer and 2/3 delivered in spring

a. River flow at downstream Maude Weir simulated by Murrumbidgee “predevelopment” IQQM
b. River flow at downstream Maude Weir simulated by Murrumbidgee WSP IQQM
c. Modeled diversion from the Murrumbidgee by Murrumbidgee WSP IQQM
d. Monthly diversions into Yanga estimated by State Water
e. e-Water = Environmental water, the availability was adopted from Department of the Environment, Water, Heritage and the Arts (DEWHA, 2009), and was applied on the top of modelled WSP diversions.

Table 2 The amount (GL) of environmental water applying to Yanga National Park

Climate	Extreme dry	Dry	Median	Wet
Objectives	Avoid damage	Capacity for recovery	Maintain resilience	Improve health
E-water	10	10	4	100

2.3 Decision Support System (DSS)

Ecological outcomes of each hydrological scenario was modelled using LYNC – a decision support system (DSS) built by SKM and eWater CRC (SKM, 2011). LYNC is built with the Eco Modeller, which provides a framework for applying ecological response models to time series data and reporting the predicted ecological response (eWater CRC, 2010).

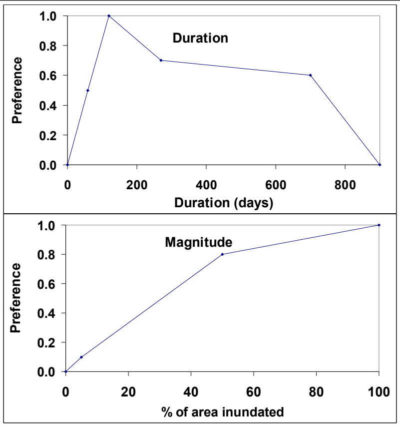

Fig. 2 An example of habitat preference curves (river red gum)

LYNC has a total of 17 habitat models (all using the same model structure as Fig. 2) for a range of species including river red gum (*Eucalyptus camaldulensis*), black box (*Eucalyptus largiflorens*), and lignum (*Muehlenbeckia florulenta*); waterbirds including ibis, egrets, and un-specked hardyhead (*Craterocephalus, stercusmuscarum*), and the endangered southern bell frog (*Litoria raniformis*). These habitat models evaluate the flow hydrographs in terms of magnitude, duration, inter-flood periods, rate of change, and timing with reference to preference curves (Fig. 2). The preference curves describe the 'preferred' habitat conditions for each key species identified for the Lowbidgee. The preference curves are based on flow-ecology relationships, which inherited from the Murray Flow Assessment Tools (Young et al. 2003) but fine-tuned with consulting with scientists working in the Lowbidgee. Firstly, the habitat model analyses the input time series and converts them to a daily score of habitat suitability. The daily score of habitat suitability is achieved by taking the minimum daily value across the five pre-defined preference curves. The model then creates and reports an annual score which is the ratio of the annual total daily scores and the annual total daily maximum possible scores to give a relative performance measure for each year for each species for the watering scenario.

For each hydrological scenario, LYNC reports the annual habitat quality score for all modelled species within every wetland. In this paper, we focus on the survival and maintenance of river red gum forest, the predominant overstory species in the Park (Wen et al. 2009).

2.4 Statistics

A preliminary analysis shows that the annual scores (based on water year, i.e. July first to June 30) of habitat quality for all species in each wetland are not normally distributed. Instead of transforming the data, we used nonparametric tests to compare the ecological outcomes of the scenarios. We used the Kolmogorov-Smirnov test (k-s test) and Mann–Whitney *U* test to compare the cumulative distribution and median variance of the modelled habitat quality scores, respectively. These statistical analyses were conducted using R 2.13.0 (R Development Core Team, 2011).

3. RESULTS AND DISCUSSION

Temporal changes in wetland habitat quality

We used the mean (averaged across wetlands) scores to analyse the dynamics of habitat quality for the maintenance and survival of river red gum (Fig. 3).

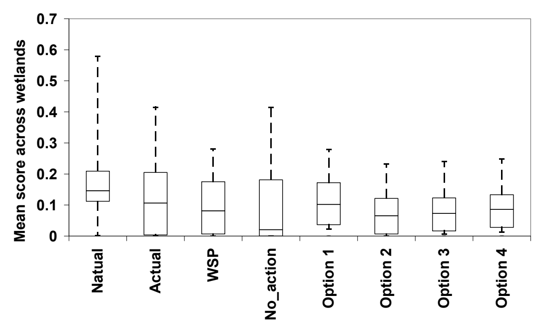

Fig.3 Average habitat quality for the survival and maintenance of river red gum forest under the eight watering scenarios

The natural (no regulation and diversion) scenario produced a significantly higher habitat quality than any other senario (Fig. 3 and Table 3).Although there is no artificial flow diversion into Yanga National Park under the natural condition, the river discharge down stream of Maude is dramatically higher (Fig. 4). Therefore, more over-bank flows might occur under natural conditions resulting in more frequent inundation. In addition, the temporal distribution of the mean habitat quality of the natural scenario was significantly different from the other scenarios except for the actual scenario (Table 4).

The no-action scenario (i.e. with actual river flows but no water diverted into the Park) produced the poorest habitat quality (Fig. 3). However, only three scenarios (the natural, actual and option 1) produced significantly higher scores according to Mann-Whitney test (Table 3).
Nevertheless, the K-S test revealed that the temporal distribution of the mean habitat quality of the no-action scenario was significantly different from other scenarios (Table 4).

Table 3. Mann–Whitney *U* test results for spatial mean habitat quality

	Actual	WSP	No-Action	Option 1	Option 2	Option 3	Option 4
Natural	*	***	**	**	***	***	***
Actual		**	**	N.S	***	**	*
WSP			N.S	***	N.S	N.S	N.S
No-Action				*	N.S	N.S	N.S
Option 1					***	***	***
Option 2						***	***
Option 3							***

N.S, Not significant (P>0.05); *, P<0.05; **, P<0.01; and ***, P<0.001

Overall, the ecological outcomes of all the investigated environmental water management options were all significantly lower than the natural scenario (Fig. 3, Table 3). Compared with the actual scenario, option 1 (i.e. delivering water during winter – spring) was the only one of the five investigated delivery options that produced comparable outcomes, while the scores of the other three options were significantly lower (Table 3). As the river flows (downstream of Maude) were comparable (Fig. 4), the differences in ecological outcomes were probably due to the distinct water diversion patterns (Fig. 5). Under the actual scenario, there was more water diverted into Yanga National Park, especially during drought.

Table 4. K-S test results for spatial mean habitat quality

	Actual	WSP	No-Action	Option 1	Option 2	Option 3	Option 4
Natural	N.S	*	**	*	***	***	**
Actual		N.S	N.S	*	N.S	N.S	N.S
WSP			*	N.S	N.S	N.S	N.S
No-Action				***	*	***	***
Option 1					*	N.S	N.S
Option 2						N.S	N.S
Option 3							N.S

N.S = Not significant (P>0.05); * = P<0.05; ** = P<0.01; and *** = P<0.001.

Compared to the WSP scenario, option 1 was the only one that produced a significantly higher median score for river red gum maintenance and survival (Table 3). In addition, as the K-S test was not significant for all environmental water management options and WSP (Table 4), the temporal variation of habitat quality under these scenarios were the same.

Fig. 4 Monthly River flow at down stream of Maude Weir under three scenarios

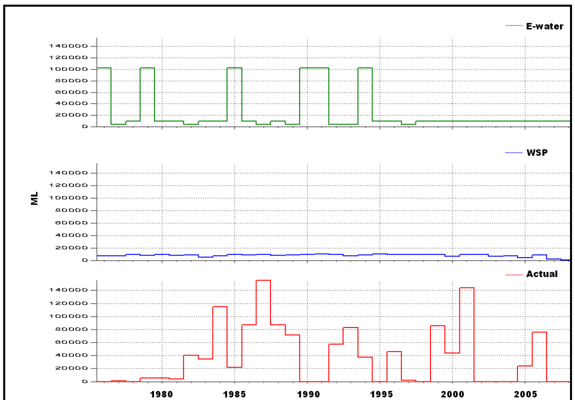

Fig.5 Yearly water diversions into Yanga National Park under three scenarios

Of all the investigated environmental water management options, the Mann-Whitney *U* tests indicated that option 1 has the best ecological outcomes followed by option 4, option 3 and option 2 and no-action. The differences were significant for both median (Table 3) and distribution (Table 4) in most cases.

Spatial comparisons of wetland habitat quality

We used the sum of annual scores of habitat quality over the period of 1974 to 2009 for each wetland (excluding Yanga Lake, Lake Tala, Yanga National Reserve and Fingerboard, in which no river red gum was observed) to compare the cumulative habitat conditions for the maintenance and survival of river red gum. Although highly variable, significantly higher scores were achieved under the natural conditions ($p<0.001$, Table 5). With more water diverted into the Park, and diversions occurring in winter, spring and early summer (Fig. 5), the actual scenario produced the second best outcomes. Option 1 ranked third and the difference was highly significant compared with other scenarios. The WSP and no-action were the only two scenarios which had similar low cumulative conditions in terms of median scores (Table 5), indicating that the more water should be allocated to environmental use under the existing WSP.

Table 5. Mann–Whitney *U* test results for cumulative habitat quality

	Actual	WSP	No-Action	Option 1	Option 2	Option 3	Option 4
Natural	***	***	***	***	***	***	***
Actual		***	***	***	***	***	***
WSP			N.S	***	***	**	*
No-Action				***	***	**	*
Option 1					***	***	***
Option 2						***	***
Option 3							**

N.S, Not significant (P>0.05); *, P<0.05; **, P<0.01; and ***, P<0.001

Comparing to other environmental water delivery options, Option 1 is clearly superior for maintaining River Red Gum habitat. On the other hand, option 2 (i.e. environmental water delivered in summer), was only slightly better than no-action and WSP scenarios (difference was significant in Mann-Whitney test (Table 5), but not significant in K-S test, results not shown).

To investigate the spatial variations in habitat quality, we mapped the cumulative scores for all modelled scenarios (Fig. 6). Spatially, the northern wetlands have higher scores than the southern ones, and wetlands close to the River channel are in better condition. Under all scenarios but the natural, LYNC predicted that a number of wetlands, including North Stallion, Pee Vee and Devils Creek, would become unsuitable for river red gum.

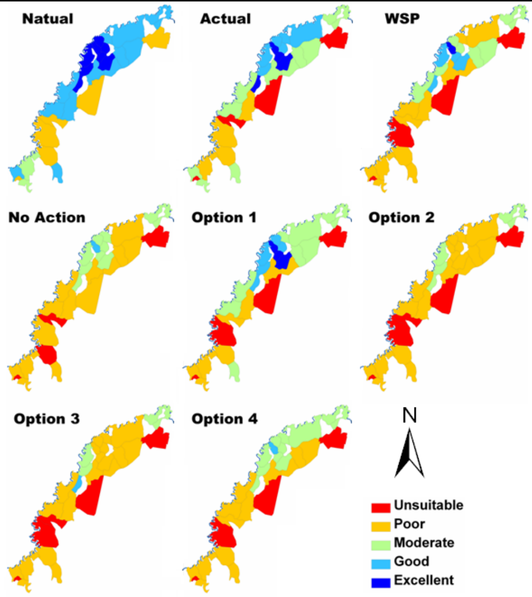

Fig. 6 Spatial variation of habitat quality for the maintenance and survival of river red gum

Winter-spring environmental watering can avoid the large-scale habitat degradation modelled under the no-action and current WSP scenarios, especially for the northern wetlands. Under option 1, 18 of the 30 modelled wetlands were in moderate or better classes.

4. CONCLUSIONS

In this study, we applied modelled hydrological sequences to LYNC, a decision support system built within Eco Modeller, to investigate the ecological outcomes of eight water management scenarios. In particular, we compared the ecological outcomes of water provision options with the reference (natural) condition and the worst scenario (no water allocation). The results for river red gum forests were presented. Major findings from the study include: 1) providing environmental water is necessary to avoid the large scale habitat degradation under current water resource management policy (i.e. no dramatic reduction in water extraction and diversion upstream); 2) none of the investigated scenarios can reproduced the temporal and spatial dynamics of habitat quality under natural condition; however, 3) additional environmental water allocation can achieve tangible ecological benefits compared to the current water plan, especially when the environmental water is delivered in the winter-spring season; 4) with the constraint of environmental water availability, winter-spring delivery is clearly the best option; 5) if winter-spring delivery of all the environmental water entitlement is not possible due to operational constraints, two-stage application is still a better option than summer delivery.

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