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The development of interdisciplinary flow-ecology models for the wetlands of the northern Murray-Darling Basin

NEIL SAINTILAN, JOANNE LING & LI WEN

Rivers and Wetlands Unit, NSW Department of Environment and Climate Change, PO Box A290, Sydney South, New South Wales 1232, Australia

neil.saintilan@environment.nsw.gov.au

Abstract The purpose of eco-hydrological research within the Rivers Environmental Research Program is to inform decisions made about the application of environmental water over operation and planning timeframes within the northern segment of the Murray-Darling Basin, Australia. The Subprogram has acquired high resolution elevation data and inundation time-series to model the wetland hydraulic properties, and this modelling is forming the basis of wetland hydrological models being developed to link catchment inflows to wetland inundation over timescales ranging from the individual flow event to the 100-year planning horizon. Decision Support Systems are being developed which incorporate the hydrological and ecological response models to allow water resources planners and wetland managers to model the ecological outcomes of water resource planning and climate change scenarios.

Key words decision support; ecosystem response; modelling; wetlands; Australia

INTRODUCTION

The northern Murray-Darling Basin, Australia, supports three Ramsar-listed wetlands: the Narran Lakes, the Gwydir Wetlands, and the Macquarie Marshes. Historically, these wetlands would support near-annual breeding colonies of wading birds. However, a decline in flooding frequency has seen insufficient water within these wetlands to sustain a breeding event since 2001, with the exception of a large breeding colony of straw-necked ibis in the Narran Lakes in early 2008. Compared to more than 30 000 birds recorded for the Macquarie Marshes in the annual waterbird survey in the early 1980s, only 10 birds were observed from the air in the marshes in 2008 (Kingsford & Porter, 2008). The core club-rush (*Bolboschoenus medianus*) swamps of the Gwydir Wetlands have reduced in extent by >50% since 1996 (Bowen *et al.*, 2008). Recent vegetation mapping in the Macquarie Marshes has documented widespread dieback of River Red Gum (*Eucalyptus camaldulensis*) in the northern Nature Reserve and the conversion of permanent marshland to chenopod shrubland (Thomas *et al.*, 2008).

The water planning framework in the regulated rivers of the northern Murray-Darling Basin was largely in place by the turn of the century. These plans were negotiated using hydrology as a common language at a time when environmental needs had not been clearly articulated in hydrological terms. Further, the circumstances of the current protracted drought had not been anticipated. The uniquely dry condition of the past eight years has brought into sharp focus the over-allocation of water in the basin and the vulnerability of rivers and wetlands to ecological collapse.

In this context the strategy of the State and Commonwealth governments has been to enter the water market to establish a reserve of strategic environmental water. This water could be used to supplement water made available under the Water Sharing Plans without the compulsory re-acquisition of entitlements. Funding the acquisition of entitlements from willing sellers is the main purpose of the AU$171 million Rivers Environmental Restoration Program (RERP).

The RERP was jointly funded by the NSW government (AUS$101 million) and the Commonwealth government (AUS$71 million) under the Water Smart Australia program, commencing in 2007. The programme has the overarching objective of improving the ecological conditions of significant ecological assets in five valleys: the Macquarie, the Gwydir, the Narran, the Lachlan and the lower Murrumbidgee (Fig. 1). This is achieved through four subprograms, comprising the four key components of management intervention:

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– Subprogram I – acquisition and management of water for environmental purposes in NSW river valleys, the primary activity of the RERP;
– Subprogram II – better use of environmental water (science);
– Subprogram III – better delivery of environmental water (infrastructure);
– Subprogram IV – benefits of environmental water on private land (community engagement).

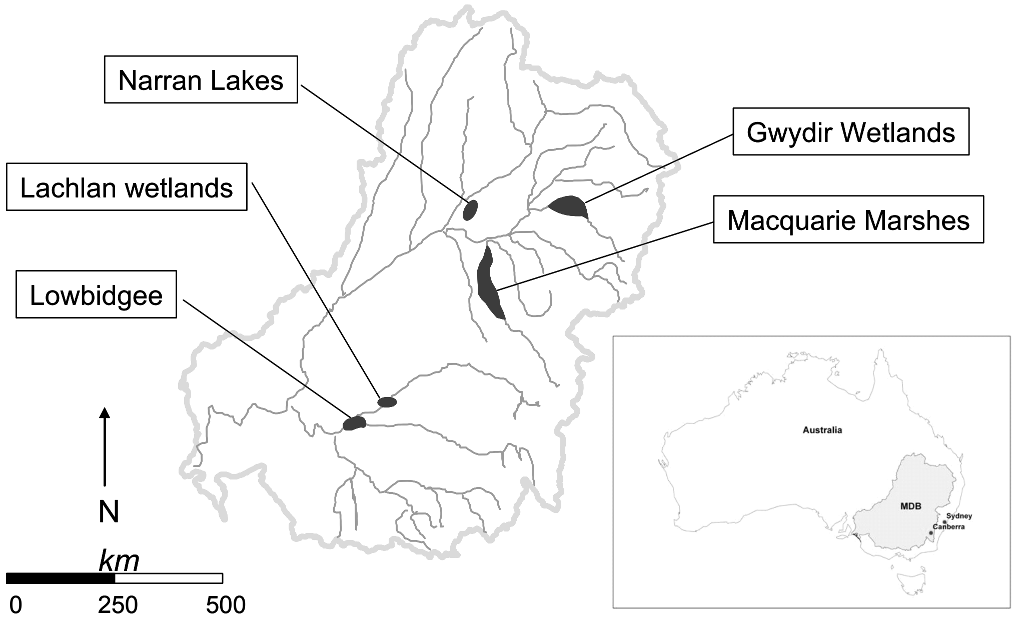

Fig. 1 Location of wetlands targeted by the Rivers Environmental Restoration Program.

This paper describes the work within Subprogram II, which seeks to guide the better use of environmental water through a better understanding of the ecological character of the key wetlands, specifically the relationships between ecological attributes and flow regimes.

CONCEPTUAL FRAMEWORK

Decisions concerning the optimal application of environmental water are made over two timescales. Over an operational timeframe, water is managed on an event-by-event basis. Operational decisions are made within the constraints of a fixed allocation of water and a particular set of antecedent conditions that will determine the extent of inundation and the water demands of the wetland. Over broader timescales, planning decisions are made concerning the water regime to be imposed on the wetland, and scope exists to inform the rules governing the allocation of water. Of relevance over the broader planning timescales are the responses of components of the wetland to water regimes. The trajectory of the condition in the wetland components that define ecological character can be modelled through a time series of hydrological inputs. In this way, scenarios of climate change impacts and water resource scenarios can be modelled (Fig. 2).

Projects within Subprogram II therefore fall into one of four categories:

– Physical components: the physical template of the wetlands incorporating elevation models, vegetation structure and soil properties which influence both the progression of water through the wetland and the response of biological components.
– Hydrological Drivers: considered the principal driver of change within flood plain wetlands, and also the driver most relevant to the overarching objectives of the RERP.

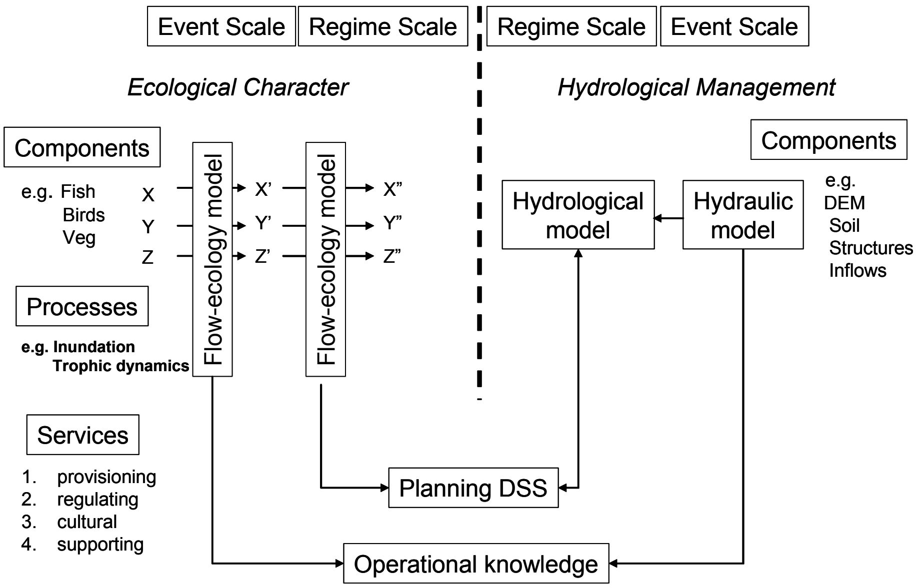

Fig. 2 Conceptual framework of Subprogram II, prepared in co-operation with the Science Technical Reference Committee of Subprogram II.

- Ecological Responses: covering the identified ecological assets of each of the target wetland systems, including vegetation, invertebrate, fish, amphibian and avian responses at the scale of the individual flow, and integrated over the scale of multiple flows.
- Knowledge exchange: components of Subprogram II which facilitate the integration and application of knowledge (Decision Support Tools) and the sharing of knowledge with government and community stakeholders.

CONSTITUENT PROJECTS

Physical components

The primary aim of the physical suite of projects is to characterise the physical characteristics of the Macquarie Marshes, Gwydir Wetlands and Lowbidgee Wetlands sufficiently to build a detailed wetland hydraulic model. Specifically, physical component projects contributing to this modelling include:

- an accurate digital elevation model (derived from LiDAR) of the Macquarie Marshes, Gwydir, and Lowbidgee Wetlands;
- an assessment of soil textural and structural properties across the wetlands including variation in hydraulic conductivity (Jenkins & James, 2009; EA Systems, 2008); and
- maps of historical and current vegetation structure across the wetlands.

Hydrological drivers

The wetland hydrology models being developed incorporate the insights of a number of projects, primarily the inundation mapping projects, and are refined and tested by hydrodynamic modelling. They will be designed to allow inputs from catchment-scale models such as IQQM, the Integrated Quality/Quantity model developed by the New South Wales Department of Water and Energy, for scenario analysis such as changes in Water Sharing Plans.

Because wetlands are low-gradient environments, their hydrology is complex. There are a number of factors which influence the flow of water through a wetland, including the rate of water delivery, the elevation characteristics of the wetlands, sources of water loss (including evaporation and infiltration), and resistance to flow from structures in the path of water, including vegetation.

In spite of this complexity, several advances have made possible the modelling of wetland hydraulic characteristics. These include improvements in computer software and hardware, and access to detailed elevation models. Wetland hydrodynamic models have now been successfully developed for Narran Lakes (Thoms *et al.*, 2007), and several of the Murray River icon sites.

These models are computationally demanding, and a single model run may take several weeks, even on a powerful computer. Given this limitation, it is not possible to derive a hydrological model (covering several months or years) using repeated runs of a hydrodynamic model. The common practice, advocated in this programme, is to use the key learnings from a few hydraulic model runs to inform the development of a "simplified" wetland hydrology model which can then be used to model wetland hydrological characteristics over the longer term. These models are calibrated using a combination of real time flow monitoring, and the archive of historic flows made available from the Landsat satellite.

Components of the hydrological suite of projects include:

- Hydraulic modelling of the Macquarie Marshes, Gwydir Wetlands and Lowbidgee Wetlands (DHI, 2008; WMA, Water 2008; Sinclair Knight Mertz, 2008);
- Hydrological modelling of the Macquarie Marshes, Gwydir Wetlands and Lowbidgee Wetlands;
- Historic inundation mapping from the Landsat archive (Thomas *et al.*, 2008);
- Investigation of groundwater–surface water interactions (Hollins *et al.*, 2009);
- Trial application of Synthetic Aperture Radar in the identification of flooded extent (Milne *et al.*, 2009).

Case Study: Inundation Mapping from the Landsat archive. Few data exist for the flood plain wetlands of NSW by which hydraulic and hydrological models might be calibrated. The gauging network maintained by the NSW Department of Water and Energy rarely extends into wetlands. An alternative means of model calibration is to map the extent and duration of flood plain inundation using the Landsat archive (Thoms *et al.*, 2007).

Thomas *et al.* (2008) used the 30-year Landsat satellite archive to map the monthly sequence of inundation over the a range of flow events in the Macquarie Marshes, Gwydir Wetlands, Lowbidgee Wetlands and the Great Cumbung Swamp in the Lower Lachlan River. This allowed distributional patterns and flood durations to be determined and changes to these patterns and flood frequencies to be analysed. A consistent pattern of decline in the frequency of inundation for small to moderate floods has been documented in this research.

These data are being used to calibrate hydraulic and hydrological models, but also to develop an understanding of the flooding requirements of key components of the wetland, including significant vegetation and colonially-nesting waterbirds. The temporal sequence provides a context for the interpretation of trends in condition of key ecological assets (Kingsford *et al.*, 2009).

Ecological responses

At the heart of the decision support capability within Subprogam II are Ecosystem Response Models for each wetland which integrate the perspectives of the hydrological models and ecological studies. The Ecosystem Response Model predicts the response of the wetland to watering, using quantitative relationships between inundation and wetland health and function. Modelling ecological responses to flow requires a thorough literature review and ecological investigations where the literature is lacking. Though generalisations can be made, the response of species to flow may vary from site to site, and Subprogram II will investigate the fundamental ecological processes at each of the wetlands concerned. The intention of this is to target the delivery of water to those places with the greatest ecological benefit, while preserving the identified values of each site.

A thorough literature review of the water requirements of biota has been conducted (Rogers *et al.*, 2009) and provided a firm basis for the assessment of knowledge gaps. While these studies provided guidelines about optimal flooding frequencies for a range of flora and fauna, an understanding of the interactive effects of predator-prey and competitive relationships was lacking, as was a detailed understanding of the way in which flooding and land-use history has contributed to the current state of each of the wetlands. Ecological response projects funded under RERP were targeted at these knowledge gaps, and corresponded to core assets within the target wetlands. These are described in Tables 1–4 by wetland.

Table 1 Ecological Response Projects, Gwydir Wetlands.

Project	Reference
Survey of fish and waterbird habitats for distribution and abundance	(Spencer *et al.*, 2008)
Trophic ecology of aquatic biota in the three watercourses (Gingham, Mehi and Gwydir channels), including response to environmental flow	(Kellaway *et al.*, 2009)
Productivity of response of flood plain soil under incubation, stratified by inundation history	(Kobayashi *et al.*, 2009)
Time series (inter-decadal) mapping of vegetation community extent	(Bowen *et al.,* 2008; McCosker, 2008)
Assessment of vegetation responses to flooding	(Thomas *et al.*, 2008)

Table 2 Ecological Response Projects, Macquarie Marshes.

Project	Reference
Assessment of limits to fish passage under a range of hydrological thresholds	(Raynor *et al.*, 2008a)
Relationships between fish and habitat type	(Raynor *et al.*, 2008b)
Trophic ecology of aquatic organisms in drought refugia	(Kobayashi *et al.*, 2009)
Time series (inter-decadal) mapping of vegetation community extent	(Bowen *et al.*, 2009)
Assessment of vegetation responses to flooding	(Thomas *et al.*, 2008)

Table 3 Ecological Response Projects, Lowbidgee Wetlands.

Project	Reference
Survey of fish and waterbird habitats for distribution and abundance	(Spencer & Allman, 2009)
Trophic ecology of aquatic biota in flooded wetlands including response to environmental flow	(Kobayashi *et al.*, in prep.)
Productivity of response of flood plain soil under incubation, stratified by inundation history (a component of the trophic ecology project)	(Kobayashi *et al.*, in prep.)
Time series (inter-decadal) mapping of vegetation community extent	(McCosker, 2008)
Analysis of changing vegetation extent and condition in response to flooding history	(Wen *et al.*, 2009)
Response of the Southern Bell-frog (*Litoria raniformis*) to environmental flows, and relationships with predation	(Wassens, 2009)
The effect of land-use history on flood plain response to flooding, both in terms of seedbank responses, and the quality of food made available following inundation	(Capon *et al.*, in prep.)
A thorough review of the distribution and known ecological attributes of the wetlands of Lowbidgee	(Wen, 2009)

Table 4 Ecological Response Projects, Lower Lachlan Wetlands.

Project	Reference
A thorough review of the distribution and known ecological attributes of the wetlands of the Lower Lachlan	(Capon *et al.*, 2009)
Survey of the potential productivity response to inundation at Lake Ita	(Kobayashi *et al.*, in prep.)

Case Study: Classification and regression tree (CART) analysis of inundation and vegetation condition in Yanga National Park. Wen *et al.* (2009) demonstrate how CART analysis can be used to model critical thresholds relevant to the conditions of River Red Gum community types. This work related the overbank flow history (frequency and duration, modelled by Wen, 2008) and local climate conditions (rainfall and maximum summer temperature) at Yanga National Park in the Lowbidgee to the River Red Gum community type and condition categories identified and mapped by McCosker (2008). Not only can survival thresholds be identified but the flooding frequency and duration required to sustain River Red Gum in better condition can be defined.

Knowledge exchange

Computer-based Decision Support Systems (DSSs) are an increasing popular means of integrating the findings of interdisciplinary research in a form adoptable in a planning and management context (McIntosh *et al.*, 2008). The key purpose of DSSs in planning for environmental water is to compare scenarios relating water delivery (volume and timing) to ecological outcomes in order to assist a transparent and scientifically rigorous decision-making process. Several DSSs have been applied in recent years to manage environmental water in the Murray-Darling basin, including the Murray Flow Assessment Tool (MFAT – Young *et al.*, 2003) and the Water Allocation Decision Support System (Letcher, 2005). In this volume, Merritt *et al.* (2009) outline the IBIS DSS which, as applied to the Gwydir Wetlands, integrates a water balance model of the Gwydir Wetlands (Powell *et al.*, 2008) with models of vegetation and fish response to flow.

This question of response to water arises primarily in a planning context. We envisage two planning timescales of relevance to the development of DSSs, the first and most significant of which is the multi-decadal timescale. Water sharing plans will be revised prior to 2014, coinciding with a greater role for the Commonwealth in reviewing the adequacy of water sharing arrangements throughout the basin. The new round of water sharing plans will require endorsement from the Commonwealth, a process which will most probably require demonstration of the modelled ecological outcomes. The DSSs for the Gwydir Wetlands, the Macquarie Marshes, the Lowbidgee Wetlands and Narran Lakes will represent the principal mechanism whereby the ecological outcomes of proposed water sharing arrangements can be modelled.

This is done by using long-term (100-year sequence) model runs on the basis of potential hydrological inputs. These inputs include, *inter alia*, a comparison of pre-development hydrological inputs, proposed water sharing plan inputs if the ensuing 100 years corresponds to the previous 100-year rainfall conditions, and proposed water sharing plan inputs under regional climate change models. Model outputs include metrics such as the probability of survival of different vegetation communities in geographical components of the wetland under each scenario, and the number of significant bird breeding events and the proportion of events leading to successful fledging. These analyses will be performed as a partnership between expert scientists and regional wetland and water managers.

Secondly, over a shorter time-scale, there is a role for ecosystem response modelling in helping to define the use of the environmental water account defined under annual water sharing plans. Relevant considerations include the volume of water in the account and potentially available (through tributary inflows, etc.), the recent history of watering within the wetland (which sets up water demands from components of the system), and the overarching goals of water management within the wetland (the setting of which may be assisted by the application of longer time series model runs).

CONCLUSIONS

The hydrological modelling of large flood plain wetlands in inland Australia is providing an important tool for wetland managers and water planners. In particular, the coupling of wetland hydrology models with catchment hydrology models allows for the modelling of longer time series of hydrological inputs into wetlands and the propagation of these effects through a wetland. Ecosystem response modelling can then provide insights into likely ecological consequences of decisions relating to water use at catchment and wetland scales.

However, the outputs of models are only ever as good as the quality of information entering a model, and the nature of climatic and hydrological variability within the catchments of the Murray-Darling basin remains poorly understood. Recent attempts have sought to downscale global climate change models to catchments (CSIRO, 2008) with resulting forecasts estimating a decline of up to 15% in rainfall in southern sections of the Murray-Darling Basin. These projections have contributed to a pervading pessimism concerning the possibility of providing quantities of water sufficient to sustain the ecological character of important wetlands.

Our knowledge of the drivers of inter-annual and inter-decadal variability in climate is rudimentary. Inter-annual variation in rainfall within the Murray-Darling Basin is influenced by the El Niño-Southern Oscillation (ENSO), and relationships between the phases of ENSO (around 3–8 years) and the inter-decadal Pacific Oscillation may control the frequency of flooding over large sections of the basin (Verdon *et al.*, 2004, 2006). More recently, Thoms *et al.* (2007) demonstrated a relationship between the Madden-Julian Oscillation (intra-seasonal oscillation that is partly linked to the ENSO cycle) and hydrological variability in the northern Murray-Darling Basin. A challenge for hydrological modelling over timeframes useful for management (years to decades) is to reconcile the outputs of global climate models with the drivers of regional climate variability over the same timescales.

A final challenge to the management of wetlands within many of the catchments of the Murray-Darling Basin is to balance the water requirements of large iconic wetlands with the myriad of smaller wetlands within catchments. There is still a large task in mapping the distribution of these wetlands and documenting their ecological character to an extent that would inform valley-wide watering plans. The optimal use of environmental water in the landscape must be considered at the broader scale of the catchment and the basin.

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