Ecosystem Response Modelling in the Murray-Darling Basin: Better Use of Environmental Water

Waterview Conference Centre, Sydney Olympic Park
May 11-12th 2010

Australian Government

Department of the Environment, Water, Heritage and the Arts

Murray-Darling Basin Authority

National Water Commission

NSW GOVERNMENT | Environment, Climate Change & Water

NCCARF
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Cover Photographs

Clockwise starting from top left corner:
Newly-hatched freshwater turtles, Mercedes Swamp, Yanga National Park, photographer: Lisa Knowles (DECCW) , 2010; Richard Allman and Jordan Iles retrieving a fyke net from South Eulimbah, Lowbidgee, photographer: Jenny Spencer (DECCW) , 2009; Jennifer Spencer at Yanga National Park with fish net for fish surveys, photographer: Russell Cox (DECCW), 2009; Dried cracking clay in a swamp of the Lowbidgee, photographer: Rachael Thomas (DECCW), 2009; Frog on hand, Old Dromana, Gwydir wetlands, photographer: Sharon Bowen (DECCW), 2008; Bearded Dragon, Macquarie Marshes, photographer: Sharon Bowen (DECCW); Emus, Yanga Homestead, photographer: Russel Cox (DECCW); Yanga national park, photographer: Rachael Thomas (DECCW), 2009; Black Box at Sunset Macquarie Marshes, photographer: Sharon Bowen (DECCW); Cumbungi, Baroona Waterhole, Gwydir Wetlands, Photographer: Sharon Bowen (DECCW), 2008; Paroo Peery Lake, photographer: Alison Curtin (DECCW); Macquarie Marshes aerial, photographer: Rachael Thomas (DECCW), 2008.

Centre:
Macquarie Marshes aerial, photographer: Rachael Thomas (DECCW), 2008.

Ecosystem Response Modelling in the Murray-Darling Basin: *Better Use of Environmental Water*

Waterview Conference Centre, Sydney Olympic Park, Sydney
11 – 12th May 2010

Dear Delegates

On behalf of the NSW Department of Environment, Climate Change and Water, and the CSIRO Water for a Healthy Country Flagship, it is our pleasure to welcome you to the conference "*Ecosystem Response Modelling in the Murray-Darling Basin: Better Use of Environmental Water*".

The conference was prompted by the very positive feedback we received following the "*Ecosystem Response Modelling in the Murray-Darling Basin: Northern Basin Southern Basin*" conference at the same venue 18 months ago. During this conference we will launch the book "Ecosystem Response Modelling in the Murray-Darling Basin", the proceedings of the 2008 conference released this month through CSIRO Publishing. Thank you again to all of you who contributed papers and provided expert review.

There is clearly a need for an Australian conference dedicated to ecosystem response modelling for wetland and river health. Over the next two days more than 50 scientists will provide an up-to-date "snapshot" of the science that has contributed to improved ecological forecasting in the Murray-Darling Basin. Several major interdisciplinary science programs are reaching maturity, and the conference will feature work completed under the NWC-funded Ecological Outcomes of Flow Regimes and the NSW Rivers Environmental Restoration Program, funded under the Water for the Future program. On the eve of the release of the draft Murray-Darling Basin Plan, the conference will demonstrate the rigour of ecological work supporting water reform in Australia. However, there is still so much more to do.

From the outset we were determined to make the conference free to all delegates. This would not have been possible without the generous support of the conference sponsors. Gold level sponsorship was provided by the National Water Commission, the Murray-Darling Basin Authority and the Commonwealth Department of Environment, Water, Heritage and the Arts. Silver level sponsorship was provided by CSIRO, the NSW Office of Water and the National Climate Change Adaptation and Research Program. We should also acknowledge the in-kind contributions of the NSW Department of Environment, Climate Change and Water. The Society of Wetland Scientists has also provided considerable in-kind support and we would like to draw your attention to the benefits of joining the Australian Chapter (details are provided inside the program).

Finally, we would like to say a special thank you to Beth Alexander, who for the past 6 months has worked tirelessly to deliver a wonderful program at a great venue.

Enjoy the conference

Neil Saintilan
Head Rivers and Wetlands Unit
NSW DECCW

Ian Overton
Stream Leader Environmental Water
CSIRO Water for a Healthy County Flagship

National Water Commission
Driving water reform in Australia

Managing our water more effectively is one of the greatest challenges facing Australia. The National Water Commission is responsible for driving national water reform under the National Water Initiative - Australia's blueprint for how water will be managed into the future.

National imperatives for water management include more effective water planning to determine how we share valuable water resources between competing uses, protection of significant environmental assets, expansion of water markets, and improved security of water supplies and entitlements.

The Commision provides advice to the Council of Australian Governments (COAG) and the Australian Government on national water issues.

To advance its reform objectives, the Commission also reports regularly on specific aspects of water management such as the performance of urban water utilities and rural water service providers, the operation of Australian water markets, and the impacts of water trading.

Through its $250 million Raising National Water Standards Program, the Commisson invests in projects to advance water reform and improve water management.

The Commission also provides leadership by being a catalyst for water reform.

- Waterlines reports are regularly published to boost understanding and awareness of water management issues.
- Position statements are released to improve the quality of debate about water challenges and recommend actions vital to advance reform.

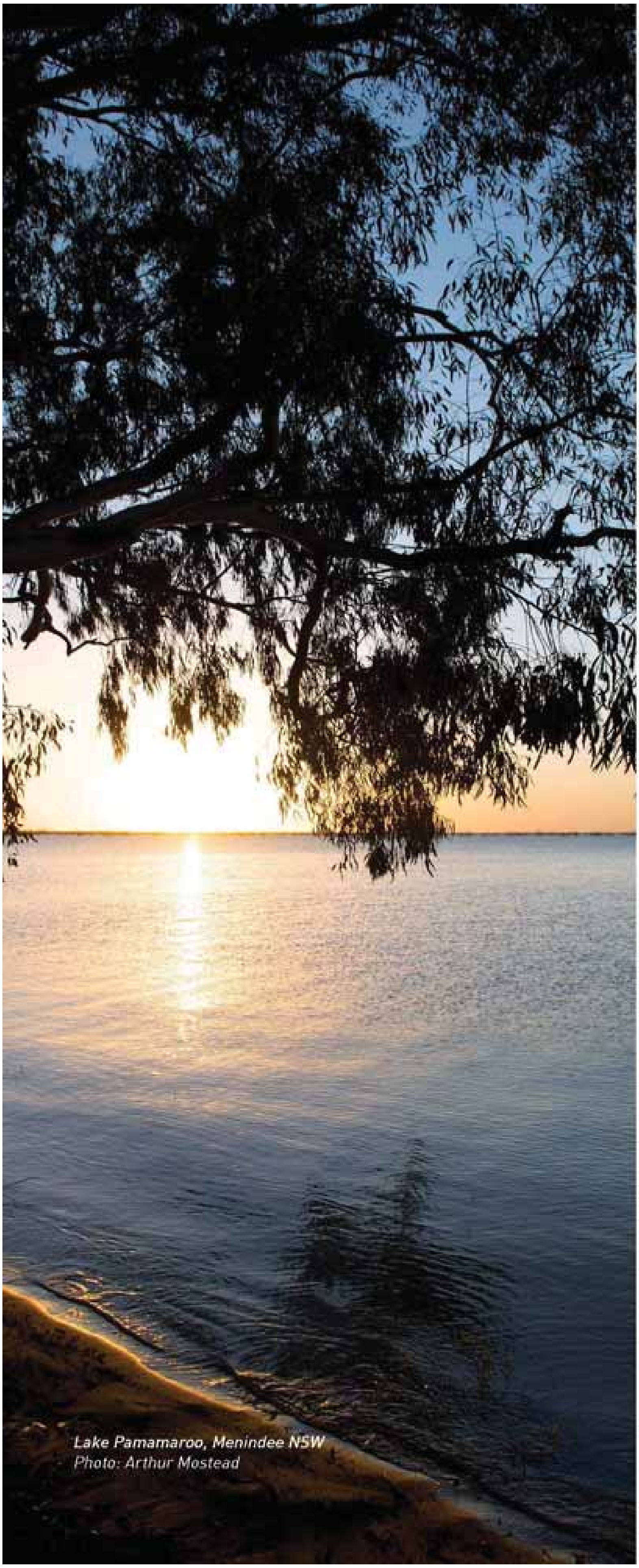
Through its biennial assessments, the Commission reports to COAG on progress towards implementing the commitments agreed by the Australian, state and territory governments under the National Water Initiative.

The Commission's recently published second biennial assessment found that despite some progress, the pace of water reform has slowed on almost every front.

In its recommendations to COAG, the Commisison has called on governments to commit to a renewed round of national water reform.

Australian Government
National Water Commission

More information about the Commission, the NWI, and our activities is available at www.nwc.gov.au.


Lake Pamamaroo, Menindee NSW
Photo: Arthur Mostead

Australian Government

Water for the Future

Preparing Australia for a future with less water

The Australian Government is getting on with the job of tackling water scarcity in the face of climate change through a comprehensive national response to meet water availability challenges in both rural and urban areas.

Water for the Future focuses on four national priorities:

- taking action on climate change
- using water wisely
- securing water supplies, and
- supporting healthy rivers.

These priorities will be delivered through strategic investment in irrigation infrastructure to help farmers adapt to a future with less water, as well as purchasing water for the environment, and a renewed commitment to water reform nationally.

A key part of future plans will be a scientifically-based cap on water use in the Murray-Darling Basin to ensure the sustainability of this critical resource.

Water for the Future provides $5.8 billion for improving rural water use and efficiency to help farmers and regional communities as well as protect food supplies.

To help restore the health of our vitally important rivers, wetlands and floodplains, *Water for the Future* has $3.1 billion to purchase water entitlements.

Other initiatives include securing water supplies for cities and towns through projects such as recycling, desalination, and stormwater harvesting.

For further information on *Water for the Future*
call 1800 218 478
or visit www.environment.gov.au/water

WATER for the FUTURE

The Society of Wetland Scientists (SWS), is an international organization of about 3,500 members dedicated to fostering sound wetland science, education, and management. The mission of the Society of Wetland Scientists is to promote understanding, scientifically based management, and sustainable use of wetlands. Our specific goals as outlined in the 2005-2010 strategic plan are to:

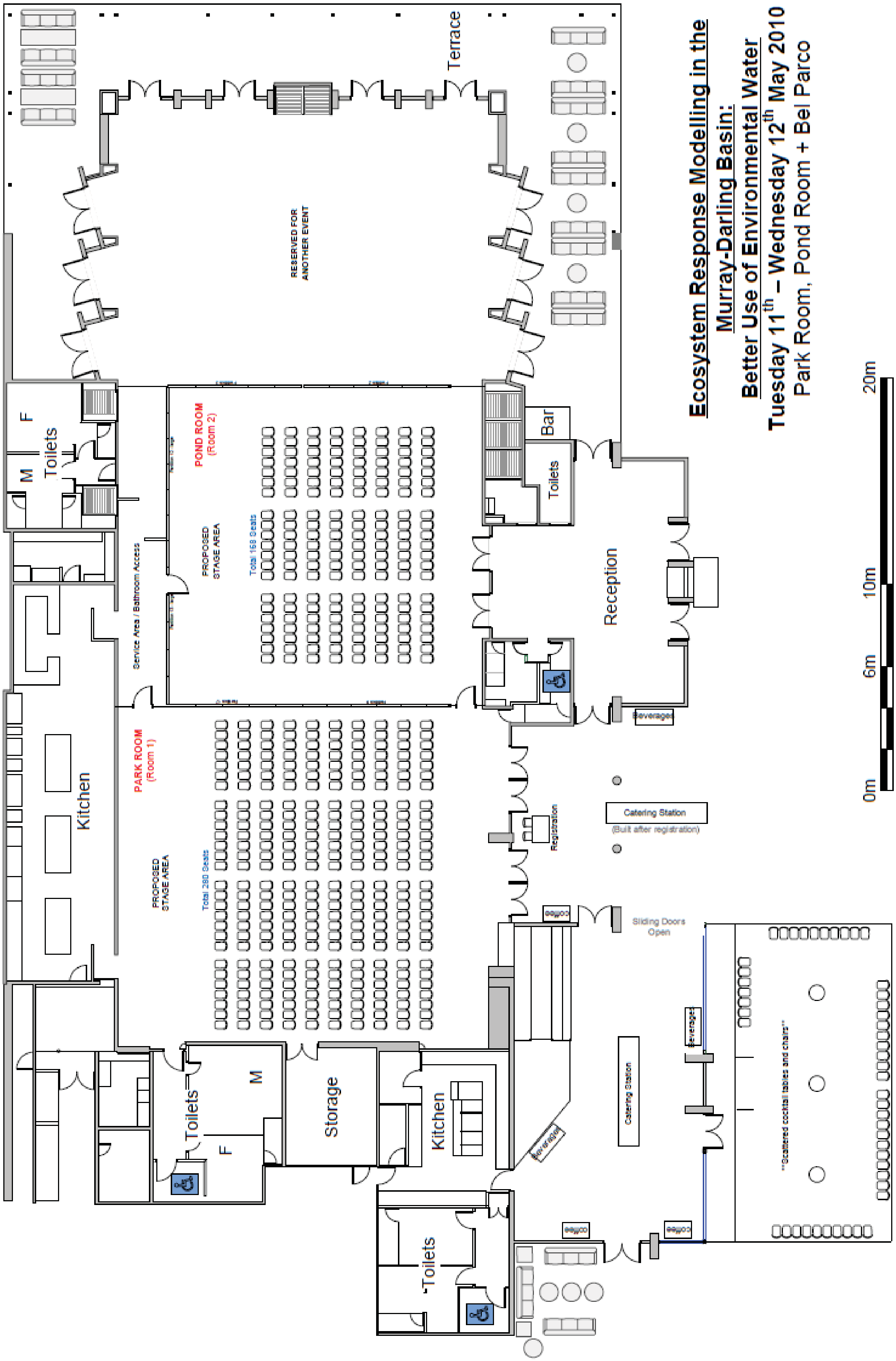
- Promote basic and applied wetland research of high quality
- Support wetland education and public awareness of wetlands
- Provide forums to disseminate the latest scientific results
- Promote science-based stewardship of wetlands
- Encourage incorporation of sound wetland science into policy
- Foster the international scope of wetland science and SWS

Benefits of membership include:

- Subscription to the quarterly journal ***Wetlands***
- Subscription to the quarterly bulletin ***Wetland Ecology and Practice***
- Membership of the active Australian Chapter- (we hosted the 2006 international meeting in Cairns)
- Opportunity to join one or more of several special interest groups, including Global Change Ecology, Women in Wetlands, Biogeochemistry
- Student prizes and travel awards
- Cheap registration (strong exchange rate) $80-$90, Student $30

Join on-line at

www.sws.org



WATERVIEW
IN BICENTENNIAL PARK

Tuesday 11th May 2010		
Room 1		
Opening	**Chair** Neil Saintilan	
9:00 – 9:15am	Stuart Bunn, Commissioner, National Water Commission	Opening Address
9:15 – 9:40am	Neil Saintilan, Head Rivers and Wetlands Unit D. Environment Climate Change and Water	Opening Comments
9:40 – 10:00am	Jody Swirepik, Executive Director, Natural Resource Management Murray-Darling Basin Authority	Murray-Darling Basin Authority Keynote Address
10:00 – 10:20am	Ian Robinson, Commonwealth Environmental Water Holder D. Environment, Water, Heritage and the Arts	Department of the Environment, Water, Heritage and the Arts Keynote Address
10:20 – 10:40am	Ken Matthews, Chair and Chief Executive Officer	National Water Commission Keynote Address and book launch: *Ecosystem Response Modelling in the Murray-Darling Basin,* Saintilan N. and Overton I. (Eds.), and the Science Report from the NWC Ecological Outcomes of Flow Regimes in the Murray-Darling Basin project

	National Water Commission				
10:40 – 11:05am	**Morning tea**				
Room 1			**Room 2**		
1. Ecosystem Response		**Chair** Neil Saintilan	*2. Hydrologic / hydrodynamic Modelling*		**Chair** Simon Williams
11:05 – 11:20am	Rachael Thomas DECCW	Spatial inundation patterns in floodplains wetland of semi-arid regions in the Murray-Darling Basin	11:05 – 11:20am	Tim Morrison DHI	Hydrodynamic Modelling of the Macquarie Marshes
11:25 – 11:40am	Sharon Bowen DECCW	What are we getting for our wetting? Measuring ecosystem responses - the role of monitoring change in extent and condition of vegetation communities in response to environmental water	11:25 – 11:40am	Steve Clarke Water Technology	RERP Gwydir wetland hydrodynamic model development
11:45 – 12:00pm	Jennifer Spencer DECCW	Monitoring the responses of waterbirds, fish and frogs to environmental flows in the Lowbidgee wetlands in 2008-10	11:45 – 12:00pm	Craig Mackay SKM	Hydrodynamic modelling of Yanga National Park and Lower Murrumbidgee River floodplain
12:05 – 12:20pm	Skye Wassens CSU	Evaluation of landscape and patch metrics to predict the response of frog populations following flooding	12:05 – 12:20pm	Rohan McDonald NSW Office of Water	Ecological modelling in IQQM-2. Gwydir Wetlands

12:25 – 12:40pm	Tim Ralph DECCW, MU	Species response to hydrological regimes and variability, and applications to ecosystem response modelling	12:25 – 12:40pm	Ilan Salbe NSW Office of Water	Incorporating water resource management rules into floodplain hydrological modelling with RiverManager
12:45 – 1:45pm	**Lunch** **Poster Session**				
Room 1			**Room 2**		
3. Ecosystem Response – trophic investigations		**Chair** Matt Collof	*4. Eco-hydrology*		**Chair** Skye Wassens
1:45 – 2:00pm	Michael Reid UNE	Establishing benchmarks and trajectories of change in the Lower Murrumbidgee floodplain	1:45 – 2:00pm	Geoff Vietz U. Melb	Slow flowing and shallow habitat: ecological importance and relationship to discharge
2:05 – 2:20pm	Simon Mitrovic UTS	Flow related saxitoxin producing cyanobacterial blooms in the Darling and Lower Darling River, Australia and use of environmental flows for suppression	2:05 – 2:20pm	Simon Linke ARI	Catering for multiple outcomes: a systematic approach to environmental water allocations
2:25 – 2:40pm	Jordan Iles DECCW	Environmental flow water and aquatic consumer food web structure: temporal aspects	2:25 – 2:40pm	Paul Frazier Eco Logical Aus	River habitat inundation patterns: high-resolution remote sensing tools and solutions
2:45 – 3:15pm	**Afternoon Tea**				

Room 1			Room 2		
5. Ecosystem Response		**Chair** Ben Gawne	*6. Incorporating climate change into ecosystem response models in aquatic systems*		**Chair** Sam Capon
3:15 – 3:30pm	Jonathan Marshall DERM	Waterhole sedimentation in a dryland river and the loss of drought refugia for fish	3:15 – 3:30pm	Fran Sheldon ARI	Approaches for predicting the impact of climate change on aquatic ecosystems
3:35 – 3:50pm	Elizabeth Heagney UNSW	The effect of flow on the growth and condition of two native fish species in the Gwydir wetlands	3:30 – 3:45pm	Bruce Chessman DECCW	Traits of increasing and declining freshwater taxa may indicate relative vulnerability to future climatic changes
3:55 – 4:10pm	Debashish Mazunder ANSTO	Isotopic and modelling studies of food web structure in wet and dry conditions, Yanga wetlands NSW, Australia	3:45 – 4:00pm	Nick Bond eWater CRC	Predicting the impacts of drought and climate change on freshwater fish distributions in Victoria using statistical modelling approaches: a summary of results and appraisal of the approach
4:15 – 4:30pm	Doug Westhorpe NSW Office of Water	Limitation of lowland riverine bacterioplankton by dissolved organic carbon and inorganic nutrients	4:00 – 4:30pm	Facilitated discussion	
4:45 – 5:45pm	**Conference Drinks**				

Wednesday 12th May 2010					
Room 1					
Opening		**Chair** Ian Overton			
9:00 – 9:15am	Kate Wilson D. Environment Climate Change and Water	Opening Address			
9:15 – 9:40am	Ian Overton CSIRO	Opening Comments			
9:40 – 10:00am	Patrick Driver NSW Office of Water	NSW Office of Water Keynote Address			
Room 1			**Room 2**		
7. Ecological Outcomes of Flow Regimes		**Chair** Ian Overton	*8. Decision Support Systems*		**Chair** Sue Cuddy
10:05 – 10:20am	Paul Wettin Consultant	Policy and management and the use of ecosystem response modelling	10:05 – 10:20am	Richard Norris UC, eWater CRC	Evidence-based decision making: using scientific literature for causal inference analysis in environmental assessment
10:25 – 10:40am	Brent Henderson CSIRO	Analysing ecological and flow relationships for ecological response modelling	10:25 – 10:40am	Angus Webb U. Melb	Evidence-based modelling of ecological responses to flow alteration: Towards an international standard for storing, sharing and synthesizing evidence from the literature

Room 1			Room 2		
10:45 – 11:00am	Stephen Mackay ARI	Drivers of macrophyte assemblage structure – the relative importance of hydrology, hydraulics and light	10:45 – 11:00am	James Grove U. Melb	High and Dry: An investigation using the Causal Criteria methodology to investigate the effects of regulation, and subsequent environmental flows, on floodplain geomorphology
11:05 – 11:20am	Matthew Colloff and Warren Jin CSIRO	Ecohydrological Classification for Ecosystem Response Modelling	11:05 – 11:20am	Morag Stewart UNE	Transforming stream biogeochemical data using digital elevation models
11:25 – 11:55pm	**Morning tea**				
Room 1			**Room 2**		
9. Ecological Outcomes of Flow Regimes		**Chair** Ian Overton	*10. Decision Support Systems*		**Chair** Nick Marsh
11:55 – 12:10pm	Ian Overton CSIRO	Ecohydrology of the Murray-Darling Basin to underpin basin-wide response models	11:55 – 12:10pm	Baihua Fu ANU	Evaluation of models within the Decision Support System, EXploring CLimAte Impacts on Management Ver. 2 (EXCLAIM2)
12:15 – 12:30pm	Michael Stewardson U. Melb	The effect of dams on channel morphology in Southeast Australia: a regional analysis	12:15 – 12:30pm	Carmel Pollino ANU	IBIS: An adaptive approach to Decision Support Systems for environmental flow planning
12:35 – 12:50pm	Neil Sims & Matt Colloff CSIRO	Measuring Ecosystem Function using Primary Productivity Estimates from Remote Sensing	12:35 – 12:50pm	Nick Marsh eWater CRC	Modelling the ecological response of adding water to the Lowbidgee

12:55 – 1:10pm	Tony Arthur CSIRO	Threshold flow requirements for the breeding of colonial nesting waterbirds	12:55 – 1:10pm	John Francis, Margie Parmenter, Ian Reid Murrumbidgee CMA, Parsons Brinckerhoff	Development of a wetlands database for the Murrumbidgee River Catchment
1:15 – 1:30pm	Ben Gawne MDFRC	A Bayesian approach to predicting native fish response to wetland inundation under different management scenarios	1:15 – 1:30pm	Rob Leslie Parsons Brinckerhoff for Lachlan CMA	Hydrodynamic Modelling of the Great Cumbung Swamp
1:35 – 2:45pm	**Lunch**				
Room 1			**Room 2**		
11. Ecosystem Response Modelling		**Chair** Tim Pritchard	*12. Management & Policy application of ecosystem response models*		**Chair** Mike Maher
2:45 – 3:00pm	Li Wen DECCW	Modelling the impacts of climate and hydrology on waterbird population trends in Lowbidgee Floodplain	2:45 – 3:00pm	Eren Turak DECCW	Spatial prioritisation for freshwater conservation in the Murrumbidgee Catchment
3:05 – 3:20pm	Peter Berney UNE	Modelling response of wetland plant communities to novel disturbance regimes: the comparative roles of flooding and competition.	3:05 – 3:20pm	Susan Nichols UC	An innovative approach to provide environmental flows and ecological outcomes for the lower Cotter River.

3:25 – 3:40pm	Michael Wilson MDBA	Availability of ecosystem data, reference condition and modelling from MDBA's Sustainable Rivers Audit	3:25 – 3:40pm	Ian Burns MDBA	Determining the Environmentally Sustainable Level of Take for the Basin Plan
3:45 – 4:00pm	Rebecca Lester Flinders U.	Outputs and uses of ecological response modelling in the Coorong	3:45 – 4:00pm	Yoshi Kobayashi DECCW	Modelling interactions among catchments, rivers, hydrology, human disturbance and climate change: qualitative implications from loop analyses
4:05 – 4:25pm	**Afternoon Tea**				
Room 1					
4:25 – 4:45pm Conference Wrap up	Richard Davis, National Water Commission				
4:45 – 5:00pm Discussion / Conference Close	Neil Saintilan (DECCW) & Ian Overton (CSIRO)				
Conference Close					

Abstracts Room 1

Progress towards the restoration of significant wetlands in NSW under the Rivers Environmental Restoration Program

Neil Saintilan[1] and Jeff Hillan[2]

[1]Rivers and Wetlands Unit, NSW Department of Environment Climate Change and Water
[2]Water for the Environment Branch, NSW Department of Environment Climate Change and Water

The significant wetlands of the northern Murray-Darling Basin have been in significant decline for several decades. The Narran Lakes, Macquarie Marshes, Lachlan Wetlands, Gwydir Wetlands and Lowbidgee floodplain have all experienced high mortality amongst wetland trees and the gradual reduction in the area of permanent wetland vegetation since the mid 1990's. Over the same period the East Australian Waterbird Survey has documented a consistent decline in the number of waterbirds within these and other important wetlands.

In response to the growing risk of ecological collapse in these critical wetlands, the NSW and Commonwealth governments jointly funded the $181 million Rivers Environmental Restoration Program (RERP) in 2007. RERP seeks to arrest the decline of significant wetlands through four interrelated subprograms:

- the purchase of water entitlements from willing sellers to add to the environmental water account;
- improvements to the scientific basis for environmental water management (the subject of this presentation);
- infrastructure works to assist in the delivery of environmental water and fish passage; and
- support to private landholders and Aboriginal communities relating to high conservation value/cultural significant wetlands on private land and complementary property purchase..

For example in the Gwydir, RERP funded the purchase of the largest Ramsar site in the Gwydir Wetlands (Old Dromana) in the heart of the Gwydir wetlands for $10m, and the water purchased by RERP and Commonwealth Environmental Water Holder more than triples water available to the environment (relative to the 45,000 ML Environmental Contingency allowance under the Water Sharing Plan).

The science subprogram of RERP (Subprogram II) improved the hydrological representation of these wetlands through the construction of hydrodynamic models, drawing upon improved elevation modelling (LiDAR), and soil survey. These models have already been used to design water management units and supporting structures in Yanga National Park. Further, hydrodynamic models have allowed for the first time the extension of IQQM into significant wetland mosaics, and the modelling of long-term hydrological scenarios throughout wetlands in terms meaningful to ecological response.

This conference will feature many of the ecosystem response models being developed in support of RERP. Many of these models take as drivers the outputs of our hydrological models: frequency and duration of flooding, inter-flood period, rate of recession and flood depth. The integration of hydrological models and ecosystem response models in wetland Decision Support Systems is an important step towards scientifically rigorous and transparent water planning. Our hope is that such models will find centre-stage in the adaptive management process, where the monitoring of flow events and regimes provides an on-going opportunity to test and improve our hydrological and ecological models over time.

Spatial inundation patterns in floodplains wetland of semi-arid regions in the Murray-Darling Basin

Rachael Thomas[1,2], Yi Lu[1], Steve Cox[1], and Simon Hunter[1]

[1]NSW Department of Environment, Climate Change and Water, PO Box A290 Sydney South NSW 1232
[2]Australian Wetlands and Rivers Centre, School of Biological, Earth & Environmental Sciences, University of New South Wales Sydney 2052 NSW, Australia

The floodplain wetlands of semi-arid regions are the most ecologically significant in the world supporting high abundance of biota and a diversity of habitats. Flow regimes drive the ecology of rivers and inundation patterns of associated floodplain wetlands, influencing species' distribution and composition. Water resource development has modified flow regimes and altered habitats affecting flooding and connectivity. Inundation is one of the most influential parameters that dictates the distribution and survival of flood dependent vegetation. Understanding the temporal and spatial variability of inundation patterns is critical for environmental flow management and the monitoring of inundation response in flood dependent vegetation. Satellite remote sensing, in particular the Landsat satellite, provides the opportunity to monitor historical inundation patterns and wetland system response over ecologically meaningful timescales and over large areas. We present these spatial patterns in some of the contrasting floodplain wetlands of the Murray Darling Basin. These patterns will form the basis for determining inundation responses in vegetation communities required to maintain wetland health and to further improve the adaptive management capacity of environmental watering.

What are we getting for our wetting? Measuring ecosystem responses - the role of monitoring change in extent and condition of vegetation communities in response to environmental water

Sharon Bowen and Shannon Simpson

NSW Department of Environment, Climate Change and Water

A large proportion of the flood dependant and amphibious wetland vegetation of the iconic inland floodplain wetlands of the Murray Darling Basin in south eastern Australia has been lost or is in decline through changing land use practices and continued reduction in inundation over the last 50 years. Over the last decade the remaining flood dependant vegetation communities have undergone a decline in

extent and condition due to changes in inundation patterns, exacerbated by long term drought and climate change.

The Macquarie Marshes, Gwydir Wetlands and the Lowbidgee Floodplain have been targeted as focus areas under the NSW Wetland Recovery Program (WRP) and the Rivers Environmental Restoration Programme (RERP). RERP is supported by the NSW Government and the Australian Government's Water for the Future - Water Smart Australia Program. RERP aims to arrest the decline of wetlands through water recovery, effective management of environmental water and the sustainable management of our wetlands. One of the key mechanisms to arrest the decline of wetlands is the purchase of water for the environment and effective, active management of this environmental water. In order to achieve the desired outcomes the State and Federal Governments require effective information to manage, monitor and report on these water investments.

Vegetation community health and distribution is an important indicator of ecosystem health. It is a key component of the monitoring of outcomes of management actions and can help to define the potential health of fauna populations, functioning of tropic pathways and levels of biodiversity. The monitoring of real outcomes of management actions is a key in the adaptive management process. Measuring the changes in the extent and condition of vegetation communities in response to environmental flows is one of the ways that ecosystem response models can be constructed and tested for a number of scenarios for water management.

This presentation outlines a number of case studies currently developing quantitative, robust monitoring techniques to measure flood dependant vegetation community change to targeted environmental flows. These studies are providing some of the required information for affective adaptive management of environmental water in NSW.

Monitoring the responses of waterbirds, fish and frogs to environmental flows in the Lowbidgee wetlands in 2008-10

Spencer, J.A.[1] and Wassens, S.[2]

[1]Rivers and Wetlands Unit, NSW Department of Environment, Climate Change and Water
[2]School of Environmental Sciences, Charles Sturt University

River regulation and catchment disturbance is a major threat to the health of riverine and floodplain biota. Reductions in flooding in the Murray-Darling Basin have contributed to the large-scale degradation of nationally important wetlands causing reductions in the frequency of waterbird breeding, increases in introduced fish populations and the near extinction of the endangered frog, *Litoria raniformis.* In response to widespread declines in the health of iconic wetlands in the Murray-Darling Basin, managed environmental flooding has been used to maintain wetland-dependant species, including waterbirds, native fish, frogs and wetland vegetation. Between 2008 and 2010, small amounts of environmental water were released in the Lowbidgee floodplain, south-western NSW, to maintain critical habitats for *L. raniformis,* and breeding and feeding habitat for waterbirds. We monitored the environmental outcomes of managed flows in the Lowbidgee floodplain over two

seasons from 2008-10 and investigated recruitment outcomes for, and interactions among waterbirds, fish and frogs across a range of wetland types. Responses to flooding varied with the timing of flooding, the volume of water entering the wetland, flooding history and wetland type. Waterbird numbers were very low during the 2008-09 season but their numbers increased in response to greater wetland area in 2009-10 and small numbers of egrets and cormorants bred successfully. Overall, nine native fish species were detected and larval stages were present for at least five species. The abundance of fish was higher in wetlands flooded in spring and summer compared with those flooded during winter, but fish numbers increased in these sites after spring top–up flows. Six frog species were detected and *L. raniformis* was present at four out of six watering sites. The initial response of frogs following winter flooding was limited but increased rapidly with increasing daytime temperatures and frog recruitment was highest at sites with low abundances of introduced fish. Environmental watering is an essential tool for maintaining endangered wetland species and there are significant follow-on benefits for other wetland taxa, however, successful management depends on greater understanding on how these taxa interact. Our monitoring provided real-time input into the management of environmental flows for key biota in the Lowbidgee system in 2008-10, however, further monitoring is required to provide ongoing input for optimising the delivery and outcomes of environmental water for the Lowbidgee system and other significant wetlands in the Murray-Darling Basin.

Evaluation of landscape and patch metrics to predict the response of frog populations following flooding

Wassens, S[1] and Healy, S[2].

[1] School of Environmental Sciences, Charles Sturt University
[2] Water for Environment Branch, NSW Department of Environment, Climate Change and Water

Identification of the key habitat characteristics which are strongly associated with the distribution of species and communities is essential when developing models to predict responses to flooding and to prioritise areas for conservation. Frogs are an important component of wetland ecosystems yet we currently have a poor understanding of the conservation status, distribution and habitat requirements of many key wetland species. We surveyed frog communities at 77 waterbodies across the mid and lower Murray floodplain between Hume Dam and Lake Victoria in order to develop habitat-based predictive models to describe the distribution patterns of frog species across the floodplain. A total of nine species were recorded. Of these *Crinia signifera, Crinia parinsignifera, Litoria peronii, Limnodynastes tasmaniensis* were widespread and occurred at more than 50% of sites, while *Neobatrachus sudelli, Limnodynastes fletcheri* and *Limnodynastes dumerili* were all locally common occurring at between 20 and 30% of sites, *Litoria raniformis, Litoria ewingi* and *Crinia sloanei* were rare occurring at less than 10% of sites. Non-metric Multidimensional Scaling was used to describe frog communities occurring in wetlands with differing hydrological classifications. Frog community composition differed significantly between the three broad hydrological classifications of rain fed temporary, seasonally flooded and permanent waterbodies, with seasonally flooded wetlands containing the greatest proportion of locally common and rare species

(ANOSIM Global R 0.247, p 0.004). Step-wise logistic regression models were then generated to select a subset of variables that could best predict occupancy by each species. Overall, models incorporating wetland hydrology and vegetation complexity were better predictors of species occupancy then those incorporating water quality or wetland context but these relationship varied considerably between species, with widespread species generally less sensitive to hydrological regime than locally common and rare species. This study also identified a strong link between the distribution of rare species and wetlands currently under active flooding management, which highlights the importance of environmental flooding for the conservation of rare and threatened species within the Murray River floodplain.

Species response to hydrological regimes and variability, and applications to ecosystem response modelling

Tim Ralph[1, 2], Kerrylee Rogers[2], Skye Wassens[3], Hugh Jones[4]

[1]Department of Environment and Geography, Macquarie University
[2]Rivers and Wetlands Unit, NSW Department of Environment, Climate Change and Water
[3]School of Environmental Sciences, Charles Sturt University
[4]Landscape Modelling and Decision Support Unit, NSW Department of Environment, Climate Change and Water

Climate variability and river hydrology drive inundation regimes in floodplain wetlands of the Murray-Darling Basin. The response of floodplain wetland ecosystems to these drivers has now become a common theme in ecosystem response modelling and requires information at a range of spatial and temporal scales. At the species scale, we reviewed the likely response of 49 plants, 51 waterbirds, 15 fish, 15 frogs and 17 molluscs and crustaceans to hydrological regimes and variability. Information was compiled in a database of the water requirements of floodplain wetland flora and fauna in the Murray-Darling Basin. This database is a useful tool for exploring the response of biota to climatic and hydrological variability. Understanding the cause-and-effect relationship between hydrological change and biota is essential for management of these large and complex floodplain wetlands and information from this database is now being applied to ecosystem response models within the Murray-Darling Basin.

Establishing benchmarks and trajectories of change in the Lower Murrumbidgee Floodplain

Michael Reid

Riverine Landscapes Research Lab, Geography and Planning, University of New England

Our capacity to conserve and restore natural ecosystems is limited by a lack of baseline information and a limited understanding of long-term variability. The lower Murrumbidgee River and its floodplain have been affected by agriculture, flow regulation and invasive exotic species for more than a century. The combined impacts of these stressors have led to a decline in the condition of natural ecosystems in the region; however, the lack of good long-term ecological data

means that is it difficult to identify the proximate drivers of change and hence mitigate their effects.

This study presents palaeoenvironmental reconstructions for three sites within the Yanga National Park which are used to investigate the long-term ecological history of the lower Murrumbidgee River and its floodplain and hence contribute to improved understanding of the nature and drivers of recent ecosystem change.
Three sites were included in the study: Mercedes Swamp, Russell's Billabong and Lake Tala. Sedimentary sequences from each of these sites were examined for a range of physical and biological proxies while core chronologies were based on Pb210 and OSL dating and pollen stratigraphy.

The results suggest that, despite over 150 years of agriculture in the region, the contemporary vegetation of the Yanga floodplain is little changed from that of pre-European times, although there is evidence that river red gum is more abundant today than it was prior to European settlement. This finding is in accord with anecdotal accounts that river red gum has expanded in the recent past as a result of the active management of the floodplain to encourage red gum for timber harvesting.

In contrast, wetland environments examined appear to have undergone a greater degree of ecological change than the broader floodplain. For example, it is likely that the current dominance by *Eleocharis sphacelata* at Mercedes Swamp is a recent development, which may reflect hydrological changes associated with river regulation. The greatest change in the derived records occurs in the Russell's Billabong record, where a shift from macrophyte to phytoplankton-dominance associated with the introduction of European land use practices and river regulation appears to have occurred. Importantly, however, the loss of submerged macrophytes in billabongs is a widely observed phenomenon in lowland rivers of the southern Murray-Darling Basin and therefore is likely to have been a response to regional drivers rather than a reflection of local changes.

Flow related saxitoxin producing cyanobacterial blooms in the Darling and Lower Darling River, Australia and use of environmental flows for suppression

Simon Mitrovic

Department of Environmental Sciences, University of Technology, Sydney

Growth and dominance of the cyanobacterium Anabaena circinalis in weir pools of the Barwon–Darling River, Australia, and Lower darling River are related to persistent vertical thermal stratification between October and March, when discharge is low. We determined critical velocities and discharges required to suppress bloom formation at three sites, and modelled the occurrence of sub-critical discharges in order to predict the frequency of blooms under different management scenarios. Our model suggests that the frequency of blooms was about double that expected under near-natural flows (without major impoundment or water extraction) for 1990–2000. Flow management, through Environmental Water Provisions that limit water extraction when river levels are low, has been in place since July 2000. Our model suggests that these provisions are unlikely to have had an effect on bloom frequency for 2000–2003. In the longer term, however, they could reduce bloom frequency at

some sites by up to one-third. Releases from Menindee Lakes to the Lower darling are also examined for their ability to manage blooms.

Environmental flow water and aquatic consumer food web structure: temporal aspects

Jordan Iles[1], Tsuyoshi Kobayashi[1], Lisa Knowles[1], Neil Saintilan[1] and Debashish Mazumder[2],

[1] NSW Department of Environment, Climate Change and Water
[2]Australian Nuclear Science and Technology Organisation

We examined the structure of a consumer food web in a swamp on the Lowbidgee floodplain which was inundated by an environmental flow for nine months. The food web structure was measured as a two-dimensional space (polygon) formed by mean $\delta^{13}C$ and $\delta^{15}N$ values of consumer species. The change in the food web structure was assessed by examining the shape and area of polygons.
We found marked temporal changes in the consumer food web structure with the development of the swamp. The mean $\delta^{13}C$ value of the consumer population decreased within the swamp indicating a consumer shift to a more ^{13}C depleted food source. The amount of niche space occupied by the consumer population reduced although the nearest neighbour distance between species increased.
We conclude that floodplain habitats such as inundated swamps in the Lowbidgee provide a broader range of food items to consumer species for relatively longer periods of time, enabling the food web structure to develop following an environmental flow.

Waterhole sedimentation in a dryland river and the loss of drought refugia for fish

Jonathan Marshall[1,2], Jaye Lobegeiger[1,2], John Tibby[3], Theresa Myburgh[3], John Vitkovsky[1,2], Stephen Balcombe[1,4]

[1] eWater Cooperative Research Centre
[2] Department of Environment and Resource Management
[3] Geographical and Environmental Studies, University of Adelaide
[4] Australian Rivers Institute, Griffith University,

Waterholes are important refugia in dryland rivers and are essential for maintaining viable populations of fish during and after drought. In-channel waterholes play this role in the Moonie River (northern MDB in southern Queensland) where periods without flow are common and can last up to 700 days.

We determined the bathymetry of 15 waterholes and measured water loss to model waterhole persistence in the absence of flow and found maximum depth to be an accurate predictor of persistence. Because the Moonie catchment has been extensively cleared for grazing and cropping and there is prevalent gully erosion we were concerned waterholes were filling with deposited sediment. Sediment cores collected from waterholes revealed that over 2.3 m of fine sediment has been

deposited within the past 50 years. This time period corresponds with the commencement of broad-scale vegetation clearing in the catchment. Work is continuing to estimate contemporary and pre-European sedimentation rates and sources.

The implications of sedimentation for refuge function are serious. Our persistence model estimates a 2.3 m shallowing of individual waterholes would result in loss of over twelve months of water availability during drought. During the longest droughts known in the Moonie, this would dry many otherwise permanent waterholes. This is of even greater concern given climate change projections of more frequent and extreme droughts.

We expect that pool sedimentation will have adverse impacts upon fish assemblages across a range of spatial and temporal scales.
In individual waterholes, sedimentation will degrade refuge quality via reduced habitat complexity and other losses of habitat such as the provision of predator and prey refuges. This will alter trade-offs between foraging and predation.

At larger spatial scales (such as at the whole catchment scale), there will be reduced overall habitat availability and diversity, leading to lower productivity of fish prey and thus reduced fish distribution and abundance. During harsh times (such as droughts) sedimentation-induced loss of waterhole persistence will lead to more local extinctions and thus lower capacity for species to repopulate the system following drought (lower resilience). This effect will be exaggerated by infrastructure forming artificial barriers that reduce connectivity between waterholes and thus limit free migration of individuals throughout the catchment. These twin stressors work in unison to reduce both the rate and the likelihood of recolonisation following local extinction and may contribute to regional losses of fish populations.

The effect of flow on the growth and condition of two native fish species Gwydir wetlands

Elizabeth Heagney[12], Jennifer Spencer[2], Ash Fowler[3] & Rich Allman[12]

[1]University of NSW
[2] NSW Department of Environment, Climate Change and Water
[3] University of Technology, Sydney

In the northern Murray-Darling Basin, regulation of inflows has altered the timing, frequency and duration of flood events contributing to declines in water quality, health of wetland vegetation and the diversity and abundance of native fish species in the Gwydir wetlands. Efforts to manage native fish populations in this degraded wetland system are hampered by a lack of basic understanding of the biology of many freshwater fish species, and how flow characteristics may impact population processes. We use otolith growth increments to provide juvenile growth data for Australian smelt (*Retropinna semoni*) and bony bream (*Nematolosa erebi*) in the Gwydir wetlands, and to investigate links between flow characteristics and the growth and condition of these native fish species. Examination of daily growth rings of 200 juvenile smelt from 8 in-channel sites revealed significant geographic differences in growth and condition (ANCOVA; $p<0.001$). Smelt growth and

condition were negatively correlated with mean daily discharge recorded at each sample site, and particularly with discharge recorded during the spawning and hatch periods (Spearman's rho, $p = 0.028$ & $p = 0.002$ for growth and condition respectively). Examination of daily growth rings of 100 bony bream from 5 sample sites revealed a similar trend, with faster growth and better condition observed in fish from sites with lower flow volumes ($p<0.001$ & $p = 0.006$ for growth and condition respectively). Rapid juvenile growth has been linked to successful recruitment to adult populations for a variety of fish species, so the interaction between flow timing and volume and juvenile growth and condition observed in our study may help elucidate the mechanisms through which altered flow regimes can affect fish population dynamics and/or abundances. Otolith based indices of fish growth and condition can be used to monitor the impacts of altered flow regimes, and provide a quantified measure of the productivity of fish populations under a range of flow conditions, which can be input to ecosystem based models that aim to estimate the productivity of wetland and river ecosystems. Our preliminary analyses suggest that otolith based techniques may be suitable for use on a variety of fish species found in the Murray Darling Basin.

Isotopic and modelling studies of food web structure in wet and dry conditions, Yanga wetlands NSW, Australia

Debashish Mazumder[1], Mathew Johansen[1], Neil Saintilan[2] Jordan Iles[2], Lisa Knowles, Yoshi Kobayashi[2] and Li Wen[2]

[1]Australian Nuclear Science and Technology Organisation
[2]Department of Environment, Climate Change and Water,

Floodplain wetlands provide habitat for a diverse range of aquatic biota, as well as performing other important ecosystem functions such as transformation of nutrients, providing breeding and nursery grounds for numerous species. Overall productivity and biodiversity of floodplain wetlands are closely linked with water availability, and in particular to the reliable reoccurrence of water inflows. Alteration of wetland inflow and outflow regimes can greatly impact the functioning of food-webs through biodiversity loss, diversion of energy flow and ecosystem functionality.

In the present study stable isotope ratios ($\delta^{13}C$ and $\delta^{15}N$) of primary producers, sediment organic matter (SOM) and a variety of invertebrate and fish species are used to gain better understanding of the food-web relations at various waterholes in wetter and drier conditions in Yanga National Park, in the lower Murrumbidgee floodplain. Mass-balance mixing models were used to examine relative food source contributions to consumer diet. We also employed probabilistic simulation software to better understand trends of trophic positions, diet shifts and varying contributions from sources to consumers in waterholes of the Yanga wetlands.

We compared $\delta^{13}C$ and $\delta^{15}N$ data from wetter (greater surface water area and depth) conditions in February, with data from the drier (smaller surface water area and depth) conditions in August. The data indicated contraction in the trophic position of *Hypseleotris spp.* (carp guudgeon) in August consistent with shrinking waterholes where species were forced into competing for overlapping, and a more limited variety, of food sources. In particular the endemic *Hypseleotris spp.* appears to be forced into greater competition with the exotic *C. carpio* (carp).

Data also indicated that energy source of consumer species varied with changing water levels among all waterholes. The drier (August) $\delta^{13}C$ values for fish and insects were typically shifted ~1-3‰ lower than the corresponding wetter (February) values. These shifts appear to correspond to depletion in the $\delta^{13}C$ algal values, and appear to indicate a greater proportional contribution of $\delta^{13}C$ from algae to the $\delta^{13}C$ in consumers.
This study provides $\delta^{13}C$ and $\delta^{15}N$ values for endemic and exotic aquatic species in Australian semi-arid wetlands. It provides modelling results indicating shifts in energy source and trophic position relative to water fluctuations and indicates increased competition among similar species that may adversely impact endemic species populations.

Limitation of lowland riverine bacterioplankton by dissolved organic carbon and inorganic nutrients

Doug Westhorpe

WSP Science & Evaluation – North, NSW Office of Water

Flow regulation in lowland rivers has reduced the amount of allochthonous dissolved organic carbon (DOC) entering main channels through less frequent wetting of benches, flood runners and floodplains. The hypothesis tested was that lowland riverine bacterioplankton are DOC limited when flow events are absent and environmental flows increasing allochthonous DOC concentrations will lead to heterotrophic dominance. Experiments were performed in the Namoi River, a highly regulated lowland river in Australia. Specifically, in situ microcosms were used to examine the responses of bacterioplankton and phytoplankton to various additions of DOC as glucose or leaf leachates, with and without additions of inorganic nutrients. The results indicated that the bacterioplankton were limited by DOC for the three seasons examined. When DOC was added alone, dissolved oxygen concentrations decreased primarily as a result of increased bacterial respiration and bacterioplankton growth generally increased relative to controls. Additions of DOC alone led to a pattern of decreased chlorophyll a concentration relative to controls except for willow leachate. Additions of inorganic nutrients alone increased chlorophyll a concentrations above controls, indicating limitation of phytoplankton. Bacterioplankton growth generally remained similar to controls, indicating no limitation by phosphorus or nitrogen without the addition of DOC. These findings support the hypothesis. Based on the present results, environmental flows are thought to increase the duration of allochthonously driven heterotrophic dominance, thus rendering regulated lowland rivers to more natural (pre-regulation) conditions for greater periods of time.

Environmental Response Modelling - a New South Wales Office of Water perspective

Patrick Driver

Water Sharing Plan Science & Evaluation – North, New South Wales Office of Water (NOW)

The New South Wales Office of Water (NOW) performs environmental flow monitoring, modelling and reporting through numerous surface water and groundwater systems across upland and lowland New South Wales, including some estuary systems. Programs that assess the effectiveness of environmental flows (performance monitoring) are largely based on before–after intervention monitoring, and testing hypotheses about how hydrological change affects ecological function across water-sharing plan areas. This includes assessment of ecological response to environmental flow rules in the state's major regulated river systems, the Snowy, Hawkesbury-Nepean and Shoalhaven Rivers, the Greater Sydney Metropolitan Area and in unregulated river systems. This performance monitoring is complementary to the monitoring of the condition of water sources, which includes aiding the Sustainable Rivers Audit and reporting on NSW Government's state-wide river health targets. Development of flow rules across broader landscapes with even less ecological information relies on macroplanning instream value asset identification, assessment of hydrological stress, classification of water sources for different water sharing rules and a generic, precautionary approach. This presentation focuses on performance (not condition) monitoring and provides examples which give an indication of diversity of, and challenges associated with Ecosystem Response Modelling.

Ecological Outcomes of Flow Regimes
*National Water Commission sponsored session**

Policy and management and the use of ecosystem response modelling *

Paul Wettin

Consultant

As part of the National Water Commission funded 'Ecological Outcomes from Flow Regimes' project, a number of environmental water managers in the Murray-Darling were interviewed to establish the basis for ecological objectives and management hypotheses that link ecology and flow. The questions dealt with 3 categories of management namely; the ecological objectives applying to the management of environmental water, the targets of specific environmental water releases and the flow: ecology relationships which supported these actions. Key findings included:

Flow:ecology hypotheses are more implicit than explicit when environmental waterings occur. The availability of relevant, integrated and synthesised science to support environmental water management decisions is an important need. In some

cases formulation of water plans (particularly longer-term plans) has been supported by synthesised science on the flow requirements of key features of aquatic ecosystems. But this has not been the case for many situations. Technological improvements in decision support tools for environmental water management is growing rapidly. Hydrodynamic models are proving valuable for scenario testing of differing environmental watering options, consequently leading to more realistic and relevant objective setting and meeting of ecological outcomes.

The drought and low water availability in recent years has had a major impact and driven a need to re-evaluation environmental watering strategies. Discretionary environmental water has been very limited in volume due to low allocations, therefore prioritisation of the use of the limited volumes has become paramount to relieve or avoid ”catastrophic losses” for aquatic ecosystems.

The term ‘resilience’ is appearing as one of the key objectives for environmental water management and is a feature in several recent environmental water management strategies

Environmental watering plans are directed at the management of discretionary environmental water. This planning is appropriate, and mostly done in conjunction with the availability of non-discretionary environmental water. However, there are many rivers in the Basin that have no discretionary environmental water. It is not clear whether water plans for all rivers have optimised use of non-discretionary water for environmental benefits.

When using environmental water there were many considerations which need to be addressed additional to the ecological outcome. In some instances these considerations result in a decision for water use that may not have been optimal for achieving the primary ecological outcome. It is not clear whether the development of flow–ecology responses for environmental water management adequately address these ‘sub-optimal’ circumstances.

Ecological outcomes: analysing ecological and flow relationships for ecological response modelling*

Brent Henderson

Research Group Leader – Environmetrics, CSIRO Mathematics, Informatics and Statistics

The National Water Commission funded project ‘Ecological Outcomes from Flow Regimes in the Murray-Darling Basin’ has sought to identify existing ecological datasets in order to relate flow regime to biological and habitat responses, and through scientific analysis of these datasets provide empirical evidence to support the management of environmental flows.

The project identified 359 datasets constituting 577 individual sets of data that could be used to link an ecosystem outcome with a particular component of river flow. Of these, a subset was identified to proceed with statistical analysis, and used to test 11 key ecological response hypotheses related to biogeochemistry, plankton, invertebrates, native fish, waterbirds, aquatic plants, riparian vegetation, ecosystem function, geomorphology and the River Murray estuary.

The talk will discuss the analysis strategy adopted. In general this involved creating a suite of flow history characteristics (covariates) from antecedent conditions for each response time point. These covariates captured aspects of the magnitude, duration, frequency, timing, deviations from natural for that flow series. Inundation history and over ancillary characteristics such as landuse also played an important part.

A broad range of analysis techniques were adopted, largely reflecting the complexity of the data and interactions at play. Methods included linear and logistic regressions, generalised additive models, regression and classification trees, time series analysis and decomposition, multivariate analyses and ordination. Some of these methods played an important role in establishing response relationships given their comparative predictive power over some simpler analysis strategies.

Specific examples and findings from the analysis of riparian vegetation, macroinvertebrates and native fish will be discussed. Companion talks from this project will feature in this conference, and will focus on some other ecosystem components (e.g. waterbirds, geomorphology, ecosystem function)

Finally, this talk will summarise lessons gained from the analyses undertaken, and provide some key recommendations for future ecological response modelling and analyses in the Murray Darling Basin.

Drivers of macrophyte assemblage structure – the relative importance of hydrology, hydraulics and light*

Stephen Mackay

Australian Rivers Institute, Griffith University

The presentation will outline a NWC research project that is attempting to develop flow-ecology relationships for riparian vegetation, aquatic vegetation and fish for southeast Queensland rivers. Specifically, this project is testing the ELOHA principle that rivers with similar flow regimes will have similar biotic attributes. An existing conceptual model of aquatic macrophyte growth predicted that hydraulic features (particularly substrate stability) and riparian canopy cover would be more important to macrophyte assemblage structure than the flow regime.

Flow regime types within southeast Queensland were identified by model based clustering of hydrologic metrics calculated for 46 stream gauges. Clustering identified five flow regime classes. Three surveys of macrophytes at sites within each flow class have been conducted. These sites are distributed over hydrologic gradients represented by discharge magnitude and discharge variability. Hydraulic measurements and cross-sectional channel surveys were used to calculate substrate stability. Hierarchical partitioning was used to identify hydrologic and hydraulic parameters that explained significant independent variation in macrophyte assemblage attributes.

Substrate stability and bankfull shear stress were found to explain greater variation in macrophyte assemblage metrics than flow metrics. Sites where bankfull shear stress exceeded the critical shear stress required for substrate mobilisation had lower macrophyte cover than sites where the bankfull shear stress was lower than the critical shear stress. Sites with low substrate stability (i.e. substrates easily entrained at relatively low water velocities) supported extensive macrophyte growth, provided flood frequency was very low. Channel morphology and site position in catchment (particularly elevation) were also important factors in structuring macrophyte assemblages.

We conclude that hydraulic measures are more important predictors of macrophyte assemblage structure than flow regime metrics. The importance of substrate stability in comparison to flow metrics demonstrates the importance of site-specific habitat conditions (channel morphology, bed slope, substrate composition, riparian canopy cover) to assemblage structure. We discuss the implications of our results for development of flow-ecology relationships.

Ecohydrological classification for ecosystem response modelling*

Matthew Colloff and Warren Jin

CSIRO Entomology

An ecohydrological classification has been developed for 44 floodplains within the Murray-Darling Basin. The classification incorporates differences in flow characteristics between modelled pre-regulation conditions with no water resources development and historic climate ('historic') and contemporary conditions with water resources development ('current'). The classification forms a basis for predicting the major characteristics of ecological responses to geographical differences in flow regimes and changes over time. In other words, it helps ensure the ecological comparison of like-with-like. We used Bayesian mixture modelling to cluster floodplains into groups and estimate the membership of each cluster, and to develop a classification using Classification and Regression Trees (CART). The results of the cluster analysis show relatively good geographical grouping. Classes 1-3 represent predominantly the floodplains of the Northern Basin, plus the Goulburn-Broken, Wimmera and Eastern Mt Lofty regions, and Classes 4-6 consist predominantly of Murray and Murrumbidgee floodplains. The relatively high number of floodplains in Class 1 includes those which are characterized as having relatively low mean annual flow and/or a high coefficient of variation of flows. This includes two major geographical groups, those of the northern regions of the Murray-Darling Basin and some of the smaller southern tributaries flowing into the Victorian and South Australian Murray. Similarly, those floodplains in Classes 4-6 under both scenarios are in regions mainly within the Murray and Murrumbidgee regions that have relatively high mean annual flow and a low coefficient of variation of flows. Those floodplains that underwent a shift in their classification from historical to current modelled scenarios are also predominantly located within the Murray and the Murrumbidgee and are likely to be associated with moderate or poor hydrological condition, as defined by the Sustainable Rivers Audit criteria. It is anticipate that further refinements of the model will provide a basis for combining an iterative, predictive classification with planning, prioritisation and risk management of environmental water allocations to floodplains.

Ecohydrology of the Murray-Darling Basin to underpin basin-wide response models*

Ian Overton, Juan-Pablo Guerschman, Tanya Doody, Garth Watson, Daniel Pollock, Neil Sims, Warren Jin and Sue Cuddy

Water for a Healthy Country, CSIRO Land and Water

The Ecological Outcomes of Flow Regimes project was funded by the National Water Commission. It has provided a number of key findings in regards to data availability to test ecological flow responses, as well, issues of ecological monitoring to support environmental flow management. A number of ecology flow relationships were analysed using previously collected data, however, the project has identified a number of issues in using existing data collected for other purposes in identifying ecology flow relationships. The project will be introduced and findings outlined as an introduction to following presentations. The project collated databases of ecology flow hypotheses, ecological data and management objectives. Key areas of the project developed a floodplain inundation model and a wetland classification.

The ecology of the Murray-Darling Basin is driven by ephemeral flooding connecting channel, floodplains and wetlands throughout the system. River regulation, water resource development and climate change have reduced flow regimes and consequently the frequency and magnitude of flood events. A Murray-Darling Basin Floodplain Inundation Model (MDB-FIM) has been developed to describe the changes in floodplain and wetland connectivity over the whole of the Murray-Darling Basin. The model was developed using remote sensing techniques by collating 8 day composites over the last 10 years. The model also compiled existing flood mapping and modelling and linked inundation extents to river flows in separate zones in the Basin. The flood extent was then mapped for specific flood return intervals within historic, current and future scenarios. The MDB-FIM has been used to show that floodplain inundation extents in the last 10 years have been approximately 25% of the maximum area of inundation recorded during 1983-1993. Wetland connectivity and changes to the extent of the floodplain areas within the Basin can be predicted from changes in flow regimes.

The presentation will include how the findings of the Ecological Outcomes of Flow Regimes project can support ecosystem response models in the Basin.

The effect of dams on channel morphology in southeast Australia: A regional analysis*

Michael Stewardson,[1] Huidong Jin[2] and Brent Henderson[2]

[1] Melbourne School of Engineering, The University of Melbourne
[2] CSIRO Mathematics, Informatics and Statistics

Dams alter both the flow and sediment regime of the downstream rivers. This can lead to changes in channel size, shape and variability with consequences for physical habitats, biota and ecosystem processes. This paper provides a conceptual model of these effects. A statistical test is performed on hypothesised dam effects

using channel surveys in 73 river reaches across Victoria, including both regulated and unregulated rivers.
In this analysis, dams are characterised by surrogate measures of altered sediment load and sediment transport capacity. We also allow for lag effects and spatial buffering of responses by representing the time since dam construction and distance downstream of the dam. A set of channel metrics is selected to represent morphologic responses.

We compare three statistical modelling approaches which would be applicable to ecosystem response modelling for a broad range of ecological responses: (i) multiple linear regression using data from all sites; (ii) multiple linear regression using data for sites downstream of dams only, but referencing channel metrics to a modelled natural state; and (iii) GAM modelling to allow for non-linear affects. General comments are made on the usefulness of these approaches for broader application in modelling ecosystem responses to dams.
We report many statistically significant relations between channel metrics and the surrogate measures of altered flow and sediment regime. The results are discussed in terms of their contribution as evidence of a causal link between dams and a geomorphic response. There is evidence of widespread impacts of dams on channel morphology. We use spatial datasets to examine the magnitude and extent of geomorphic changes produced by dams across the Murray-Darling Basin.

The use of the resulting statistical models to predict consequences of flow alteration and environmental water delivery is critically examined. This work is part of a broader review and data mining effort to develop models of ecosystem response to flow alteration in the Murray Darling Basin for the National Water Commission.

Measuring ecosystem function using primary productivity estimates from remote sensing*

[1]Neil. C. Sims, [2]Matthew Colloff

[1]Remote Sensing Research Scientist, CSIRO Sustainable Ecosystems, Ian Wark Laboratory
[2]Senior Research Scientist, Project leader, Floodplain Ecosystem Function, CSIRO Entomology

This study measures plant growth vigour and biomass throughout the entire Murray Darling Basin from a time series of MODIS satellite images captured almost every day between 18 February 2000 and 18 July 2009. These images were used to interpret the integrity and functioning of vegetation ecosystems within hydrological zones in the MDB. A comparison of trends in plant biomass and vigour between hydrological zones indicates differences in the recovery of vegetation biomass from severe climatic perturbations, which may be correlated with the magnitude of change in runoff, rainfall and water use activities between zones. This study indicates broad geographical patterns in the level of vegetation biomass and vigour throughout the MDB and their variability over time. It also indicates a geographic association with patterns of vegetation condition decline. This presentation also points to a possible method for minimising the influence of climatic and seasonal influences on the interpretation of plant response to environmental flows. With further development, this method might be used to indicate differences in the duration of wetland response

to floods of different magnitude or duration, or to assess plant growth responses to environmental flows in terms of kg increase in biomass per ML of water. This information could be used to more accurately prescribe the magnitude and character of environmental flow events required to sustain individual floodplain and wetland ecosystems throughout the MDB.

Threshold flow requirements for the breeding of colonial nesting waterbirds*

Tony Arthur[1], Julian Reid[2], Heather McGinness[1] and Keith Ward[3].

[1]CSIRO Sustainable Ecosystems
[2]The Fenner School of Environment and Society, Australian National University
[3]Goulburn Broken CMA

Large breeding events by tens of thousands to hundreds of thousands of colonial nesting waterbirds have been associated with flooding events on wetlands throughout the MDB. We currently have a general understanding of the characteristics of floods required for successful breeding. We used data from three sites within the MDB, Barmah-Millewa, Lake Merriti and the Macquarie Marshes to address the following questions: (1) Is there a threshold for the commencement of colonial nesting waterbird breeding? (2) Does this threshold vary by species? (3) Does it vary by location? Breeding data were obtained from published and unpublished sources and included any evidence of attempted breeding ranging from nest construction through to successful fledging. Flow characteristics were based on data from gauges upstream of the site. Hydrographs were used to determine (1) whether a flow threshold was associated with breeding attempts and (2) whether the number of days a threshold was exceeded was associated with breeding attempts.

Results were consistent with the hypothesis that there are threshold periods of inundation required to induce attempted breeding by colonial nesting waterbirds. Our results indicate that the threshold period is related to the number of days between July or August and December when a flow threshold in the river feeding the floodplain is exceeded, particularly for largely shedding floodplains. For Barmah-Millewa (15,000 ML/day at Yarrawonga) and the Macquarie Marshes (1500 ML/day at Oxley) there was a high probability that Egrets, Glossy Ibis and Nankeen Night Heron attempted to breed if the flow threshold was exceeded for more than 50 days. For Barmah-Millewa the same period was associated with attempted breeding of Straw-necked and Australian White Ibis, but for the Macquarie Marshes the period was 25-30 days, consistent with the hypotheses that the northern system may generate food resources for breeding more rapidly than the southern system. For Lake Merriti results suggested that attempted breeding by Straw-necked and Australian White Ibis is related to a flow threshold in the river being exceeded (25,000–35,000 ML/day) - this probably relates to the lake being filled, consistent with this being a non-shedding system that once filled retains water for an extended period. It is important to note that our results indicate flows and thresholds for which breeding was attempted and it would be necessary to extend the period of any breeding event to allow for laying, hatching and fledging (i.e. by a further 2.5 - 3.5 months).

A Bayesian approach to predicting native fish response to wetland inundation under different management scenarios*

Gawne B[1], Meredith S[3], Beesley L[2], King A[2], Koehn J[2], Nielsen D[1], Price A[1].

[1]Murray-Darling Freshwater Research Centre: A joint venture between La Trobe University, CSIRO and the MDBA.
[2]Arthur Rylah Institute for Environmental Research
[3]Swan River Trust

Floodplain wetlands are utilised by many of the fish species that inhabit the Murray-Darling Basin, and are believed to play an important role in their spawning, feeding, habitat, growth, and recruitment. However, there is limited information available on the relationships between characteristics of inundation (or watering) of these wetlands and their benefits to fish. The National Water Commission funded '*Optimising Environmental Watering Protocols to Benefit Native Fish Populations*' project aims to redress this imbalance by providing critical information to water managers on how to make best use of environmental water to benefit native fish populations. A survey of wetland managers found that the primary objective of most environmental watering plans for wetlands in the MDB was to ensure the survival or maintenance of native plant communities particularly riparian vegetation. The survey identified that although determination of the 'optimum' wetland inundation protocol for native fish may be of considerable scientific interest, such a protocol would seldom be able to be implemented because of the physical and legislative constraints imposed on wetland managers. In response to this, a key component of the project is the development of predictive Bayesian models which will assist water managers to make informed decisions regarding which wetland to water and how, in order to maximise benefits to native fish communities in river-floodplain ecosystems.

The models are driven by a series of management levers which include timing, duration and depth of inundation, method of water delivery and the presence of carp screens. These management levers interact with wetland variables such as size, depth, nutrient status and presence of acid-sulphate soils to drive a series of mechanistic ecological relationships related to spawning, recruitment, mortality and immigration/emigration of different life-stages, which in turn, predict three key indicators of fish population health - abundance, population structure and fish condition. Bayesian models are being developed to predict fish response for four species which commonly utilise wetlands, Australian smelt, carp gudgeons, golden perch and common carp. In addition to predicting fish response, the models will also allow managers to determine which management decisions are most important in driving response in an individual wetland.

Modelling the impacts of climate and hydrology on waterbird population trends in Lowbidgee Floodplain

Li Wen, Kerrylee Rogers, Neil Saintilan and Joanne Ling

Rivers and Wetlands Unit, NSW Department of Environment, Climate Change and Water

Restoration of waterbird diversity and abundance is a key objective of river system management in Australia. Therefore, understanding the effects of climatic and hydrological variables on waterbird population dynamics is fundamental for successful restoration programs. We investigated the population dynamics of total waterbirds and seven functional waterbird groups in the floodplains of lower Murrumbidgee River, and found a general declining trend from 1983 to 2007 except for the deep water foragers. The relative contribution of the climatic and hydrological variables to waterbird population decrease was modelled using the generalized additive model (GAM) framework after identifying the negative binomial distribution. Of the seven functional groups, only dabbling ducks and large waders were positively related to both annual rainfall and water volume defined as the total water volume intercepted by the river reach, and the models indicated equivalent importance of the two variables. Furthermore, the population sizes of deep water foragers and small waders were positively related to water volume while the population sizes of fish eaters and shoreline foragers were positively affected by rainfall. Temperature also played a role in waterbird population variation: the maximum summer temperature negatively influenced the population size of dabbling ducks, shoreline foragers and fish eaters, while the minimum winter temperature positively affected the dabbling ducks and shoreline foragers. Overall, our results support the practice of providing environmental water for sustaining waterbird populations. However, environmental water provision is likely to be most effective when timed to coincide with antecedent rainfall.

Modelling response of wetland plant communities to novel disturbance regimes: the comparative roles of flooding and competition.

Berney, P.J[1]., Price, J.N[1]., Ryder, D.S[1]., Whalley, R.D.B[2]., Wilson, G.G[1]., Gross, C.L.[1]

[1]Ecosystem Management, University of New England
[2]Botany, University of New England

Modeling ecosystem responses to disturbance regimes is reliant upon knowledge of how individual species respond to both biotic and abiotic factors. In the Murray-Darling Basin, changes to the historical water regime through water resources development has been associated with the proliferation of introduced species, notably lippia (*Phyla canescens*), in many floodplain wetland systems. However, reinstating a more 'natural' water regime may not necessarily restore native dominance as this will be governed by interactions with other competing species and other disturbance agents such as grazing livestock. The success of such a restoration measure will depend on whether the action either causes mortality of the invader or whether vigour of the native species is sufficiently increased to enable it to outcompete the invader.

This study investigated the competitive interactions between water couch (*Paspalum distichum*) and lippia when both species were subject to different watering/inundation regimes to determine the potential of restoring native dominance through manipulating flood regimes. In the glasshouse, we examined intra- and inter-specific competition (9 planting densities) and inundation (4 watering treatments) in a factorial design. We also monitored spatial distribution patterns of each species in

the field before and after an environmental flow. The glasshouse study showed maximum growth in both species was achieved under conditions of saturated soil and that both species experience reductions in growth when grown in higher density mixes, that is, effects of intra- and inter-specific competition. Importantly, both lippia and water couch had similar competitive effects on each other. Lippia growth was strongly inhibited by inundation and remained dormant, whereas water couch continued to grow under all watering treatments. In the field, water couch cover expanded immediately following flooding, but this was only temporary, with lippia cover increasing rapidly once flooding receded. Over the duration of this field study GPS trackers attached to cattle recorded their position allowing analysis of grazing patterns. Results indicated that grazing pressure was greatest on the water couch plant community.

In concert, these results indicate that it is unlikely that changes to the water regime alone in these agricultural landscapes will be sufficient to eliminate lippia. At present, we have limited understanding of how such modified communities respond spatially and temporally to flooding regimes but it will be important in the future if response models are going to be used in water allocation decisions where promotion of native dominance is a goal.

Availability of ecosystem data, reference condition and modelling from MDBA's Sustainable Rivers Audit

Michael Wilson

Murray-Darling Basin Authority

MDBA's Sustainable Rivers Audit (SRA) collects data, analyses and reports on the condition of five themes across the Murray-Darling Basin: fish, macroinvertebrates, hydrology, physical form and vegetation. All data are available and many data recipients are attempting to model ecosystem responses. Field sampling, remote sensing and modelling are used to determine current condition. Modelling, historical evidence and expert judgment are used to determine reference condition. Expert rules are used to integrate indicators. The presentation will outline the data and information that are available from MDBA and explore modelling approaches that have been trialled and used in development and roll out of the SRA. Some of the fruitful and barren paths that have been attempted using SRA data for ecological response modelling will be outlined.

Outputs and uses of ecological response modelling in the Coorong

Rebecca E Lester and Peter G Fairweather

School of Biological Sciences, Flinders University

We adapted alternative stable state theory to develop an ecosystem state model for the Coorong, the estuary for the Murray-Darling Basin, to model ecological responses. This model identified eight suites of biota that occurred together in space and time, and the physico-chemical conditions that were associated with their presence (together constituting 'ecosystem states'). These states described

relatively-healthy through to relatively-degraded assemblages for both tidally-influenced and tidally-independent regions. The physico-chemical parameters distinguishing amongst ecosystem states were various combinations of the degree of tidal influence, the maximum number of days since flow from the River, the average water level, the average water level from the previous year, and the average salinity at each location.

We then used this model to assess the likely response of the Coorong to a range of management scenarios under several different climatic projections. The scenarios included proposed and current management interventions (e.g. dredging of the Murray Mouth or diverting additional fresh water from southeastern South Australia to the Coorong), as well as changes to environmental flow allocations (e.g. via The Living Murray initiative). These were investigated under current climatic conditions, as well as median and dry projections of climate for the future, and under various levels of sea-level rise. This breadth of scenarios provides managers with an understanding of the extremes in response that should be expected within the Coorong under a variety of management options.

Results of these scenario analyses indicated that current water extraction levels had a much greater impact on the ecosystem states of the Coorong than was predicted under a median or dry future climate. The combined effects of current extraction levels and median climate change were not worse than current conditions in the region but, under current extraction levels and a dry future climate, the current situation was much more common throughout the 114 year sequence. In addition, extensive analysis of engineering solutions for the region or diverting additional water from elsewhere failed to find any interventions that resulted in a mix of ecosystem states comparable to that resulted from average freshwater flows from the River Murray.

Thus, we conclude that securing adequate freshwater flows must be the priority for long-term management of the Coorong. The small impact of climate change, compared with extraction levels, suggests that achieving such flows is possible. However, political will is needed to ensure that extraction policies are modified to secure sufficient freshwater for environmental flows to the Coorong.

Abstracts Room 2

Hydrodynamic modelling of the Macquarie Marshes

Craig Allery, Tim Morrison, Md Atiquzzaman

DHI Water and Environment Pty Ltd

Understanding the movement of water through the complex system of channels and across floodplain areas in the Macquarie Marshes plays an important role in devising appropriate management strategies that maximise the ecological benefit of available environmental water releases. Hydrodynamic modelling is a powerful tool for providing detailed information on the spatial and temporal variations for channel and floodplain flows.

DHI has developed a MIKE FLOOD hydrodynamic model of the whole Macquarie Marshes. The model represents major channels with 1D cross-sections, while the floodplain is represented with a 2D grid. Dynamic coupling is provided between the 1D and 2D components. Cross-sections for the 1D model were obtained from LiDAR data with a horizontal resolution of 1m, supplemented with ground survey. Hydraulic control structures, such as weirs, culverts, bridges and gates, were included in the 1D network. The 2D model used the same 1m LiDAR data to generate a 90m grid of the floodplain. The coupled model has been calibrated and validated for low, medium and high flows using data on stream flows and depths from the PINNEENA database and maps of inundation extent derived from satellite images.

The model now provides a detailed representation of the hydraulic behaviour of the Macquarie Marshes. The results from the modelling have been used in the identification of water management areas (WMAs). The WMAs have been defined as units that may be separated from surrounding areas by consideration of hydraulic characteristics, such filling and emptying independently from other areas. The designation of the WMAs has been modified to ensure that they also represent units of ecological significance. Results from the hydraulic model have been processed to provide data on the hydraulic characteristics of the WMAs, including inflows, area inundated, volume of inundation, depth of inundation and outflows. These data have been derived for a range of flow conditions from low flows to high flows, based on the real historic events used for calibration of the model.

The data from the hydraulic model form the basis of a hydrological model of the marshes that will be used to test a range of water delivery scenarios, including the effects of climate change and revision to water sharing rules. The results from the hydrologic model will ultimately form part of a decision-support system for management of the marshes that integrates an ecosystem response model with the hydrologic model data to determine potential ecological outcomes from different management decisions.

Rivers Environmental Restoration Program (RERP) Gwydir wetland hydrodynamic model development

Steve Clark[1] and Warwick Bishop [2]

[1] Director, Water Technology Pty Ltd, West End QLD
[2] Director, Water Technology Pty Ltd, Notting Hill VIC

The Department of Environment and Climate Change (DECC) is currently in the process of developing hydrodynamic models for the Gwydir wetlands, the Macquarie Marshes and Yanga National Park as part of the science component of the Rivers Environmental Restoration Programme (RERP). A key objective of the RERP is to maximise the benefit of environmental water through improved scientific understanding of major wetland systems in NSW.

The convergence of a number of critical technologies has occurred in recent years that have enabled the development of tools to accurately represent the hydraulics of large floodplain systems. Chief among these has been the development of coupled one-dimensional and two-dimensional hydraulic modelling software packages. When combined with large-scale aerial terrain data collection, this software can provide a practical tool for modelling complex floodplain areas.

Outputs from hydrodynamic modelling of these wetland systems, in conjunction with ecological models, will form the basis for examining the ecological effect of individual flow events delivered to these wetlands. Over longer timescales (up to 100 year periods), the IQQM synthesis of the 2D models coupled with the valley scale IQQM model will be employed to examine the effect of different water sharing scenarios and climate change on the volumes of water delivered to wetlands and the optimal fate of water within the wetlands. Decision Support Systems (DSSs) are also being developed to integrate the various datasets and models to aid management of these systems.

This paper provides an overview of the Gwydir wetlands hydrodynamic model construction, calibration and relevant outputs for DSS construction.

Hydrodynamic modelling of Yanga National Park and Lower Murrumbidgee River floodplain

Craig MacKay

Sinclair Knight Merz

Hydrodynamic models are widely used in floodplain management, water quality and sediment transport modelling. However their application in environmental water management has been limited until now due to the complexity of the physical interactions and a lack of detailed datasets. DECCW has now commissioned development of a hydrodynamic model of Yanga National Park, at the western end of the Murrumbidgee Valley.

Yanga National Park covers much of the southern floodplain of the Murrumbidgee River between the Lachlan River confluence and Balranald. Prior to becoming a

National park the land was managed for river red gum harvesting and pastoral agriculture and this was reflected in the way water was managed on the property. In particular, a number of embankments were constructed across the floodplain to control and distribute flow to maximise the distribution of water across the property. Understanding how water moves across the park is essential if the best use is to be made of scarce environmental water volumes. In the past the landowner was able to observe the effect of varying sizes of flow diversions and floods, and adjust the management and layout of embankments by trial and error. In the absence of recurrent large flows into the park, a hydrodynamic model can provide valuable insight into the behaviour of the floodplain, and how embankments and regulators affect this.

A detailed two-dimensional hydrodynamic model of Yanga National Park and the adjacent northern floodplain of the Murrumbidgee River has been developed. Development of a hydrodynamic model has been possible in the Lowbidgee because of extensive data collection, including LiDAR data, satellite based historical flood inundation mapping, soil infiltration surveys, vegetation mapping, and embankment and regulator topographic survey. The model is currently being used to develop a Decision Support System for environmental flow management. The model will be also help park managers make decisions about how to modify embankments and regulators in the park, by allowing them to add and remove features from the model and look at the resulting changes in flow distribution across the park.

This presentation describes the model development process, the steps in the production of a full working model, and presents some simulation results and demonstrations. This includes wetland filling with environmental flows through regulator structures, and uncontrolled overbank flood inundation from the Murrumbidgee Channel.

Wetland Modelling in IQQM

Rohan Macdonald[1], Tahir Hameed[1], Li Wen[2] and Stephen Roberts[1]

[1] Water Management Division, Office of Water, NSW Department of Environment, Climate Change and Water
[2] Rivers and Wetlands Unit, Scientific Services Division, NSW Department of Environment, Climate Change and Water

The NSW Rivers Environmental Restoration Programme (RERP) has been set up to improve the health of some of the most threatened nationally and internationally significant wetlands of the Murray Darling Basin. Under RERP, projects have been initiated to develop Decision Support Systems (DSS) for the provision of environmental flows to various wetland areas in the Basin such as the Gwydir wetlands, the Macquarie Marshes and the Lower Murrumbidgee wetlands. The key purpose of each DSS is to assist the environmental managers to achieve the optimum utilisation of the scarce environmental water allocations. The DSS will make it possible to compare scenarios relating water delivery to ecological outcomes in order to provide a transparent and scientifically rigorous decision-making process.

To incorporate the high variability of Australian climatic conditions into planning decisions, long-term (more than 100 years) simulation data such as flows and area of

inundation are required. Due to the enormous computations involved, hydrodynamics models are generally only considered feasible for the simulation of shorter durations (up to six months). Furthermore, hydrodynamics models do not represent other important river system processes such as water accounts, irrigation and other consumptive demands. On the other hand, hydrology models do not simulate two dimensional flows and cannot be adequately developed if there is insufficient stream gauging data available within wetlands. It was therefore decided that hydrodynamics models would be developed for the wetlands and used to simulate individual flow sequences of various magnitudes in each system. The information from the hydrodynamics models (flows, volumes, inundation areas, etc.) would then be used to develop detailed hydrology models. The hydrodynamics models were based on the inundation maps and LIDAR surveys completed over the last year for the Gwydir, Macquarie and Lower Murrumbidgee wetlands.

Over the past 20 years, the NSW Office of Water has developed a planning model known as IQQM (Integrated Quantity Quality Model). IQQM has been extensively used for the development of Water Sharing Plans for the regulated NSW river systems and was therefore adopted as the hydrology model for this project. Based on historical ecological information and the inundation patterns, the ecologically important wetlands and their locations were identified. Those wetlands were then modelled within IQQM using outputs and information extracted from the hydrodynamics models. The calibrated IQQM model then provided the water delivery information, such as volumes and inundation areas, required by the DSS.

This paper provides an overview of the process of the implicit linking of hydrodynamics and hydrology models with particular reference to the Gwydir system. Preliminary results of the hydrological modelling are discussed along with the assumptions and shortcomings in the model. Potential implementation of the IQQM-DSS is also discussed.

Incorporating water resource management rules into floodplain hydrological modelling with RiverManager

Ilan Salbe[1], Li Wen[2]

[1] Water Management Division, Office of Water, NSW Department of Environment, Climate Change and Water
[2] Rivers and Wetlands Unit, Scientific Services Division, NSW Department of Environment, Climate Change and Water

The Lowbidgee Flood Control and Irrigation District (LFCID) is within an extensive floodplain located at the lower end of the Murrumbidgee River around its confluence with the Lachlan River. It encompasses an area of approximately 158,000 hectares, comprising productive agricultural land and extensive areas of native, particularly wetland vegetation, playing a critical role in maintaining biodiversity in the region. The NSW Department of Environment, Climate Change and Water (DECCW) is responsible for identifying and managing the ecological assets within the LFCID. To ensure the long-term ecological integrity of the region, management strategies are required to optimise the use of scarce environmental water resources in situations where the future water availability is unclear, except in a long term probabilistic sense. Through comprehensive consultations, 38 ecological assets were identified

within Lowbidgee. Using the RiverManager framework, the Lowbidgee floodplain hydrological model was built to simulate long-term daily time series of inundation extent and depth for each of the key assets under different climatic and management scenarios, providing the hydrological inputs for the ecological response models. By evaluating the ecological outcomes of different hydrological regimes, managers could make science-based decisions.

Building the hydrological model has been more challenging because of the lack of historical flow measurement and to a lesser extent level measurement with the floodplain. Remote sensing satellite imagery and LiDAR derived topography in conjunction with the hydrodynamic models provided the means to overcome this measurement deficiency. The assembled 1D and more complex 2D hydrodynamic models provided a mathematical description of how water moves along the floodplain. This understanding has been encapsulated into the hydrological model, which is more suited for long term simulation. The hydrological model also provides a means of simulating the operation of regulators within the LFCID by coding the water management rules using the transparent expressions. We calibrated and validated hydrological model against satellite imagery of inundation extent and also against the knowledge of the State Water operator in LCFID. The hydrological model will receive input flows from the whole Murrumbidgee Valley water supply IQQM model, allowing for a full integration of all current and proposed water sharing rules. This multi-model, remote sensing approach is fairly novel to DECCW and is expected, with future refinement, to provide DECCW with improved ways to manage its ecological assets.

Slow flowing and shallow habitat: ecological importance and relationship to discharge

Geoff Vietz

University of Melbourne

It has long been known that species assemblages are linked to the hydraulics of habitat. Slow flowing and shallow flowing habitat, commonly termed slackwaters, provide important refuge from flow and are associated with a number of ecological processes. Slackwaters have been shown to play a key role in the ecology of lowland rivers, specifically reducing mortality for fish larvae and more generally supporting the full life cycle requirements of fish, a range of invertebrates and aquatic plants. Indeed, up to an order of magnitude more fish and shrimp have been found in slackwaters compared with faster flowing or deeper habitats. Slackwaters are common within lowland river channels throughout the Murray Darling Basin, yet, the abundance has been reduced by regulation.

The aim of this research is to improve our understanding of the effects of flow manipulation on slackwater habitats and the ecological processes they support. The focus catchment for this research is the Broken River, a tributary of the Goulburn River in north central Victoria. This paper presents a review of literature on the ecological importance of slackwaters, proposes a hydraulic characterisation of slackwaters and demonstrates the relationship between slackwater abundance and discharge. The latter is achieved through two-dimensional hydrodynamic modelling of a lowland site on the Broken River. Quantification of the variation in abundance of slackwater habitat with discharge is linked to field based evidence of ecological

requirements for slackwaters. We conclude that regulated flow releases during the irrigation season impact on the abundance of slackwater habitat and this has implications for the ecology of lowland streams.

The specific and initial research outcomes addressed in this paper form part of a wider research project aimed at optimising water use for agriculture and the environment. The Farms Rivers and Markets Project is an initiative of Uniwater and funded by the National Water Commission, the Victorian Water Trust, The Tallis Trust and The University of Melbourne. The project is supported by the Departments of Sustainability and Environment and Primary Industry, the Goulburn Broken Catchment Management Authority and Goulburn-Murray Water.

Catering for multiple outcomes: a systematic approach to environmental water allocations

Simon Linke[1], Eren Turak[2], Jeanne Nel[3]

[1]*Australian Rivers Institute, Griffith University*
[2]*NSW Department of Environment & Climate Change*
[3]*CSIR, South Africa*

Systematic approaches have been used for conservation and restoration planning activities worldwide, including in high profile projects such as the Cape Floristic Region Conservation plan and the rezoning of the Great Barrier Reef Marine Park. A key principle behind these approaches is to state clear objectives at the beginning and then find a plan that fulfils the objectives in the most effective way, thus reducing social and economic impact on other stakeholders.
Our approach will combine these principles from systematic conservation planning with environmental flow science to develop a systems view of environmental water allocations. The principle of complementarity – describing how optimal allocation of resources can meet multiple objectives at the same time and thus reduce impact on stakeholders – does not have to be applied to static, land-based problems. It is also highly relevant when applied to environmental water allocations, answering two key questions:

1. For a given number of ecological assets with their respective target levels, what is the least amount of water that can fulfil all asset watering requirements?
2. Given a certain amount of environmental water, what is the most efficient allocation that fulfils the highest number (and potentially highest diversity) of assets.

To resolve these questions, we are proposing five steps

1. Identification and mapping of assets, including species, ecosystems, habitats and ecosystem function. This includes – but is not restricted to – the assets in the MDBA's asset register.
2. Setting targets or benefit functions for assets. This is important in case not all assets can be fulfilled and ensures that diversity of assets is maximised (ie, not only wetlands or not only fish spawning sites are prioritised for).
3. Characterisation of flow regimes in the system, including natural flows, current flows and watering options
4. Development of ecosystem response models for all assets

5. Prioritisation of water allocations to fulfil the asset targets. This uses a complementarity-based algorithm to allocate environmental water, while fulfilling multiple objectives.

This paper will present a pilot study to develop priority maps, that include a range of prescribed flow schedules under different allocation scenarios as well as allocation irreplaceability for certain assets. We will also determine how much water is needed to satisfy a range of pre-defined objectives (and when it should be allocated). Analysis will be conducted a a range of target levels.

River habitat inundation patterns: high-resolution remote sensing tools and solutions

Paul Frazier[1,2], Darren Ryder[2], Emma Macintyre[1]

[1]Eco Logical Australia
[2]University of New England

Optimal delivery of environmental water requires detailed understanding of riverine habitat location, extent and inundation level. In most rivers of the MDB we simply do not have this information at a scale fine enough to inform delivery patterns for environmental water. This project focussed on the development and verification of techniques to map riverine habitats at sub-reach scale in the lower Namoi River (near Wee Waa).

High resolution airborne digital imagery and full wave form Lidar data were processed using object oriented (OO) and data segmentation approaches to map key riverine habitats. The 3-d habitat map was then linked to historical flow records to develop a 3-d reach inundation model to analyse the frequency, period and duration of habitat feature inundation over a 30 year period.

Riverine habitat mapping was conducted in four main stages: Lidar segmentation of channel and non-channel areas; elevation and slope-based topographic feature mapping; OO spectral image bare area mapping; and foliar density determination. The channel bank was identified and mapped using a slope layer to determine regions of high slope and a fill function to produce a smoothed bank boundary. The in-channel environments (bars, benches and banks) were then mapped based on a combination of elevation and slope characteristics. OO techniques were applied to the digital imagery to map bare soil areas on the floodplain and a Lidar-based analysis was conducted to provide foliar cover from the tree canopy. These separate layers of information were then combined to create a single 3-d riverine habitat layer.

The3-d habitat map was then linked to historical river flow stage to enable the development of a flow stage-habitat inundation model. This process will assist environmental water delivery through identifying key habitat inundation patterns at relevant spatial scales.

Incorporating climate change into ecosystem response models in aquatic systems
*National Climate Change Adaptation Research Facility Facilitated Session**

Approaches for predicting the impact of climate change on aquatic ecosystems*

Fran Sheldon and Mark Kennard

Australian Rivers Institute, Griffith University, Nathan, QLD 4111

The ecological sustainability of river-floodplain ecosystems in Australia is seriously threatened by the pervasive effects of hydrological alteration, agricultural and urban land-use, and invasive species. Climate change is an added stress, with critical implications for the long-term integrity of aquatic biodiversity and productivity. The prospect of dramatic environmental changes over the next century underscores the need for innovative science and new decision-support tools for efficiently managing and conserving freshwater ecosystems. Our current understanding of the likely environmental controls of freshwater biodiversity and potential responses to changing environmental conditions need to be advanced and quantified. This will enhance the capacity of natural resource managers to implement effective mitigation and adaptation programs. Unfortunately however, scientists and natural resource managers in Australia currently do not have the knowledge required to achieve this goal. Innovative and scientifically robust approaches are urgently needed to ensure the long term sustainability of Australia's unique freshwater biodiversity.

Projected changes to the Australian climate are likely to directly affect freshwater biodiversity, through losses of coastal freshwater habitats from saline intrusion due to rising sea level and increased storm surge, increased water temperatures, and increased variability and severity of extreme hydrological events (i.e. floods and droughts). In regions with high levels of consumptive water use, decreased water availability due to climate change is likely to impact disproportionately on the environmental share of surface water. These issues are important biodiversity conservation challenges for scientists and managers in Australia. The ability to forecast impacts on aquatic ecosystems under future environment and management scenarios is not well advanced in Australia, except in a conceptual and speculative context. This has precluded the capacity to quantitatively predict the consequences of future catchment management or flow alteration scenarios for freshwater biodiversity. This paper will explore the approaches used for predicting the impact of climate change on aquatic ecosystems.

Traits of increasing and declining freshwater taxa may indicate relative vulnerability to future climatic changes*

Bruce Chessman

Principal Research Scientist, Climate Change Science, NSW Department of Environment, Climate Change and Water

Projections of increasing temperatures in south-eastern Australia and changes in the annual volumes, seasonal timing and extremes of rainfall and river flow suggest that some freshwater species will suffer population declines and contractions of geographic ranges while others may expand their distributions and increase in abundance. The identification of vulnerable species should assist in conservation planning to sustain freshwater biodiversity in the face of climatic changes. Various traits have been proposed as potentially associated with vulnerability to projected climatic changes, and evidence of association between particular traits and trends in distribution, abundance or occurrence could help to confirm the value of traits as predictors of responses to such changes. I used multiple logistic regression analysis to show that many families of freshwater macroinvertebrates had significantly increasing or declining trends of probability of detection in bioassessment samples collected from streams throughout New South Wales over the period from 1994 to 2007, when air and water temperatures increased while rainfall and river flows declined. Analysis of relative preferences and tolerances showed that families were more likely to have declined if they favoured cooler waters and habitats with faster currents. Correlations between various traits and population or biogeographic trends could help to identify vulnerable species across a wide range of freshwater organisms.

Predicting the impacts of drought and climate change on freshwater fish distributions in Victoria using statistical modelling approaches: a summary of results and appraisal of the approach*

Nick Bond[1], Paul Reich[2], Jim Thomson[3], Darren Giling[3] and Janet Stein[4]

[1]Senior Research Fellow, School of Biological Sciences & eWater CRC, Monash University
[2]Arthur Rylah Institute, Department of Sustainability and Environment, Victoria
[3]School of Biological Sciences, Monash University
[4]Senior Research Fellow, The Fenner School of Environment and Society, Australian National University, Canberra

In southern eastern Australia, the predicted increase in temperature and decrease in rainfall associated with climate change will likely impact on the hydrology of many streams and rivers, reducing mean annual flow, altering flood frequency and increasing the duration of cease to flow periods. Together with climatic influences, such changes in hydrology have the potential to impact strongly on the distribution and abundance of aquatic biota. We used statistical modelling approaches (boosted regression trees) to link existing datasets on the distribution of freshwater biota to a suite of climatic, hydrologic and catchment physiographic variables, and then used these models to explore the potential impacts of several climate change scenarios. In the case of fish, which we focus on here, the results forecast widespread distributional shifts and some species losses at landscape and regional scales. Species showing notable declines included river blackfish and southern pygmy perch. A number of species showed opposite trends, including the highly invasive *Gambusia holbooki*, highlighting the potential for indirect effects of climate change on biotic interactions.

Evaluation of a scenario based on the drought conditions experienced over the last 13 years also forecast widespread species deletions. Validation of the drought scenario against empirical datasets collected from a number of sites across Victoria supports predictions for several, but not all species. Improvements in model predictions would likely benefit from inclusion of additional predictor variables that were not included in our models due to a lack of suitable datasets. In particular information on groundwater levels, geomorphic disturbances such as sand-slugs, and data on anthropogenic drivers of water stress (e.g. farm dams) may address some of the limitations of the current models. Predicted patterns of current and future species distributions are now being used in conjunction with conservation planning approaches and software to identify critical areas required to maintain species diversity at catchment scales and which may become a priority for protection and restoration by waterway managers. Here we present a summary of the work and directions for this research for the future

Evidence-based decision making: using scientific literature for causal inference analysis in environmental assessment

Richard Norris, S. Nichols, M. Stewardson, A. Webb and E. Harrison

Institute for Applied Ecology, University of Canberra and eWater CRC
University of Canberra ACT

Rivers are often exposed to a range of stressors, both natural and human, which can impair the health and fitness of aquatic biota. These stressors may act independently, antagonistically, or synergistically and biotic responses are the integrated outcomes. Management decisions regarding stressor and ecological effects can be made confidently when the quality of the information on which they are based is understood. A robust (e.g. BACI design) local study may answer relevant questions of cause and effect, however, such studies are often not possible because the putative causes have already occurred and treatments usually cannot be replicated. Also, the results of local studies are unlikely to be generally applicable and would need to be undertaken at each new site to improve the confidence in reaching a similar conclusion at other locations. If powerful studies are not possible and results from them not generally applicable, more types of evidence are needed. Methods for testing causal relationships using the existing scientific literature and considering the quality of individual studies have been widely accepted in epidemiology for more than 50 yrs. This paper demonstrates the application of causal inference using published literature for an environmental problem of fine sediment addition to rivers. These methods could also be used to develop generalised models that describe causal links between flow alteration and ecosystem responses in the Murray-Darling Basin.

Evidence-based modelling of ecological responses to flow alteration: Towards an international standard for storing, sharing and synthesizing evidence from the literature

J. Angus Webb[1,4], Michael J. Stewardson[2,4], Richard H. Norris[3,4], Stephen R. Wealands[1,4], C. Richard Ziegler[5], Susan J. Nichols[3,4], Andreas Melcher[6], Susan B. Norton[5], Kate Schofield[5], Elizabeth M. Wallis[2], Joe Greet[1]

[1] Department of Resource Management and Geography, The University of Melbourne, Victoria, 3010,
[2] Department of Civil and Environmental Engineering, The University of Melbourne, Victoria 3010
[3] Institute for Applied Ecology, The University of Canberra, ACT 2601
[4] eWater Cooperative Research Centre
[5] National Center for Environmental Assessment, Office of Research and Development, United States Environmental Protection Agency, Washington, DC 20460, USA
[6] University of Natural Resources and Applied Life Sciences, Vienna 1180, Austria

Australia is embarking on a multi-billion dollar effort to return water to the environment. Agencies investing in this initiative are required to provide evidence of the ecological benefits of environmental flows. Ecological response models are a key part of this evaluation. However, it will be some time before these models are able to represent ecological responses to flow alteration with confidence, particularly because we are still unsure of the causal pathways in many systems.

There is an immediate need to support model development by synthesising evidence of ecological responses from the hundreds of relevant studies published in the scientific literature. Such a synthesis can provide clear statements of the known effects of flow alteration and where there is a need for further research. This will allow environmental water managers to move from expert-based to evidence-based approaches in environmental flows, and to use the best available knowledge in making decisions.

In this presentation, we introduce the method of causal criteria analysis and argue that this approach can be used to strengthen the evidence basis of models of ecological response to flow alteration. Such rigour of models will become increasingly important as environmental watering decisions become increasingly contested by affected water users.

We will also outline a number of case studies where the approach is being used in the Murray-Darling Basin. These studies are helping to further develop the method, and have found mixed results concerning the amount of evidence in favour of various causal pathways. They have also demonstrated the significant amount of work that is required to manually extract evidence from the literature.

Lastly, we will describe an emerging international partnership that seeks to create an international database of ecological evidence. In a remarkable case of parallel evolution of scientific methods, individual research efforts in Australia, the USA and Europe have developed databases of ecological responses to various anthropogenic influences (including flow regulation). Recently, these groups have agreed to merge these efforts, immediately tripling the amount of evidence available to any researcher. We will describe our aspirations for the international database, particularly how we may reduce the burden of evidence extraction described above.

This includes moving towards an open-source, peer-production model for extraction and sharing of evidence, and the possibility of using natural language processing tools to semi-automate evidence extraction.

High and dry: an investigation using the Causal Criteria methodology to investigate the effects of regulation, and subsequent environmental flows, on floodplain geomorphology

James R. Grove[1,3], Philip M. Marren[1,3], Michael J. Stewardson[2,3] and J. Angus Webb[1,3]

[1]Department of Resource Management and Geography, The University of Melbourne, Parkville, Victoria, 3010, Australia
[2]Department of Civil and Environmental Engineering, The University of Melbourne, Victoria 3010, Australia
[3]eWater Cooperative Research Centre, The University of Melbourne, Parkville, Victoria, 3010, Australia

Traditionally geomorphology has been a descriptive science, observing landscape processes and form. The prediction of environmental flow effects on fluvial geomorphology has been strongly influenced by engineering, or simply ignored and the relationship between flow and flora/fauna used instead. To aid the change from a descriptive to a prescriptive science, a causal criteria analysis was used to assess how regulation affects floodplain geomorphology.

We initially created a conceptual model using a traditional literature review approach. This was then used to investigate which linkages were supported by evidence. The terms in the eWater CRC's Causal Criteria Evidence Database (CCED) were then adapted so that evidence of *Cause* and *Effect* from relevant literature could be entered. Once papers had been added into the database the evidence was interrogated using eWater's Causal Criteria Analysis Software (CCAS).
It was immediately apparent that the geomorphology literature lacked evidence with the same rigour of experimental design compared to the ecological literature. This was dealt with by adjusting the scoring system in CCAS so the highest scores were adjusted to levels appropriate for the best quality designs possible in the field of geomorphology. However, even after these adjustments, there was still insufficient evidence to make a strong argument for causality for individual pathways within the conceptual model. This lack of causal evidence was dealt with by reducing the number of terms in the analysis through aggregation of individual causes and effects to higher levels within the conceptual model. Despite these adjustments, there was still insufficient evidence available to answer the posed question. One of the reasons for this was because it is not a question that has been currently asked in the literature.

Our results show that geomorphological literature frequently looks to explain process and form, and that this may be elucidated by a conventional reviewing approach. Separating this into *Cause* and *Effect* pairings is not easily achieved. Evidence tends to be less rigorous than biological studies in terms of study design and statistical analysis due to the limitations of scale inherent in geomorphological investigations. However, the conceptual model can still be used to identify where evidence is available and where there are knowledge gaps. The CCAS can also be used to pose a question by entering a *Cause* term and ALL the *Effects* in the system. This does not restrict the reviewer in the same way as following citations in a traditional literature review.

Transforming stream biogeochemical data using digital elevation models

Morag Stewart and Darren Ryder

Ecosystem management, University of New England

The use of geographic information systems (GIS) within environmental research has become an important tool, allowing researchers to visualize and spatially locate areas of interest, as well as being able to derive useful physical data. Our current project is investigating the effects of riparian vegetation on in-stream biological processes, such as ecosystem metabolism, and organic matter and nutrient dynamics, within primary tributaries of the Gwydir river. The Gwydir river catchment is located in the northeastern corner of New South Wales and forms part of the upper Murray-Darling Basin. Although the main body of the project relies on field sampling and laboratory techniques to obtain the biological data, GIS has proven to be helpful in selecting the sites and the analysis and transformation of the data into standardized measurements. Catchment data such as drainage area, stream length, and land-use or vegetation cover are some of the common parameters included in study area or site descriptions, while physical data at the reach level usually includes stream gradient, discharge, bank height and in-stream features such as pools, riffles and coarse woody debris. Using surveying equipment we obtained a large number of coordinates, which were then used to develop a high resolution digital elevation model (DEM) of these important parameters and features. The construction of DEMs also allows for biological data such as nutrient concentrations or organic matter inputs initially taken as point concentrations or weight measures, to be transformed into loads, which facilitates data comparison among rivers. Loads can be interpreted as the total imported and exported amounts of a particular element, allowing researchers to see how much of the element is being transported through the ecosystem. To calculate the data as loads, it is essential to know the cross-sectional area or volume of the reach and the flow rate, which can be easily derived from the DEM model. The DEM model can also assist in explaining data and resolving unexpected results by presenting potential physical influences. Creating a DEM for fieldwork sites can produce accurate biological data that has the potential for comparison with other creeks and rivers of the Murray-Darling Basin, which is essential in understanding the physical movement of nutrients and organic matter and how this affects ecosystem processes.

Evaluation of models within the Decision Support System, EXploring CLimAte Impacts on Management Ver. 2 (EXCLAIM2)

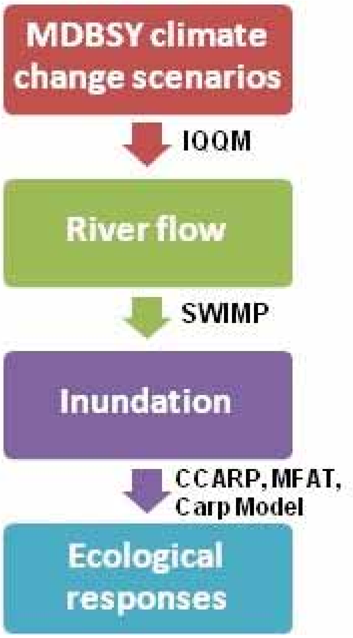
Baihua Fu, Carmel Pollino and Felix Andrews

Integrated Catchment Assessment and Management Centre (iCAM), The Fenner School of Environment and Society, The Australian National University, Canberra

EXCLAIM2 (EXploring CLimAte Impacts on Management, Version 2) is a Decision Support System (DSS) that has been constructed to explore the potential impacts of climate change on the ecological health of the Macquarie River and Marshes (NSW).

The DSS contains four linked component models, being climate, river flow, inundation and ecology. Climate change scenarios are based on CSIRO Murray-Darling Basin Sustainable Yields (MDBSY) Project (CSIRO, 2008). The major outputs of EXCLAIM2 are habitat conditions for a range of vegetation, fish and waterbird species. The ecological models are constructed using existing models and knowledge of biota responses. The vegetation and waterbird models are linked to the inundation model, and based on the database constructed for the Climate Change Adaptation Research Project (CCARP) (Rogers et al., 2009). The native fish model is linked to the river flow models, and was based on the Murray Flow Assessment Tool (MFAT) (Young et al., 2003) and a purpose built model for carp (Cyprinus carpio).

To evaluate model performance, we examined the following aspects of the ecological models in EXCLAIM2:
1. sensitivity of the model outputs to climate change scenarios;
2. sensitivity of vegetation and waterbird habitat conditions to flood regimes; and
3. visual 'sanity-checking' of the ecological response model output against monitoring data.



Test 1:
Other than the fish model, model outputs were generally not sensitive to climate change scenarios. Overall, we found that the predicted impacts of climate change in the Macquarie Marshes were less than the impacts of river regulation (considering the current Water Sharing Plan). This finding is consistent with CSIRO (2008) report.

Test 2:
The most sensitive variable to ecological response was flood duration. This aspect of the inundation regime was found to be critical for quantifying suitable habitat for the maintenance of nearly half of the 18 vegetation species, and for the breeding habitat of 16 waterbird species. For regeneration of vegetation species, the flood timing variable was the most sensitive for nine of the 18 vegetation species.

Test 3:
Model predictions for waterbird breeding habitat were visually compared with available monitored waterbird nest counts (1986 – 2000) published by Kingsford and Auld (2005). Of the 7 species tested, reasonable to good agreements were found between model outputs on the waterbird breeding habitat conditions and their observed nest counts.

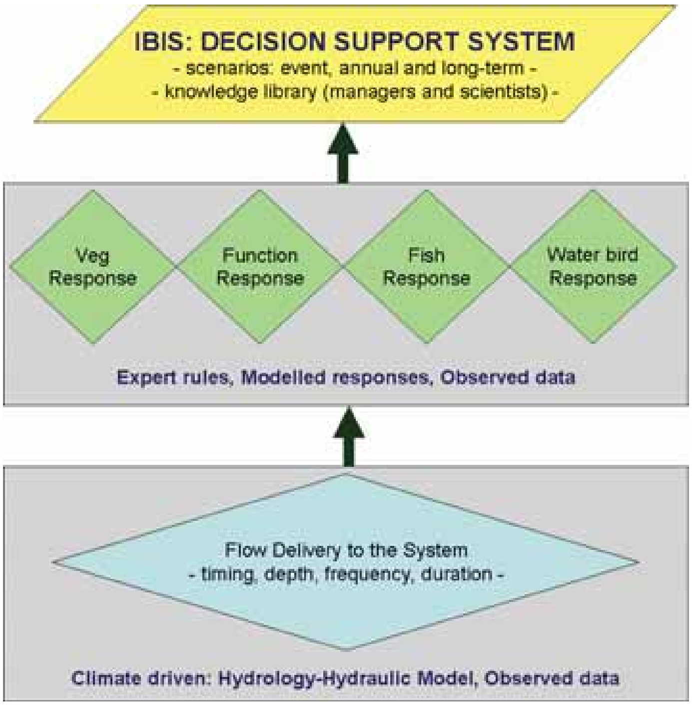
In summary, EXCLAIM2 provides a good foundation for linking climate, hydrology and ecological response models, and is a useful tool to explore climate change impacts on river/wetland health, and to identify critical knowledge gaps and research needs.

IBIS: An adaptive approach to Decision Support Systems for environmental flow planning

Carmel A. Pollino, Wendy Merritt, Baihua Fu

Integrated Catchment Assessment and Management centre (iCAM), The Fenner School of Environment and Society, The Australian National University,

Environmental flow planning is a complex and interdisciplinary task, involving hydrological, hydraulic and ecological expertise. Environmental flow planners and managers are required to collect, understand and link these knowledge sources in order to make salient decisions on how best to deliver water to achieve a stated set of objectives. Clearly, this is a challenging task, particularly as new knowledge from recent events and investments in science is obtained. To assist decision makers in environmental flow planning, the NSW Dept. of Environment, Climate Change and Water has commissioned the development of Decision Support Systems (DSS) for key inland wetlands. This paper will introduce the DSS framework, referred to as IBIS, which is in development for the Narran Lakes, Macquarie Marshes and the Gwydir Wetlands.



The DSS is built on a software platform, which can contain system information such as maps and other documentation, models and their associated documentation, scenario construction tools, model modification tools and report building functions. The IBIS DSS framework 'talks to' external hydrology and hydraulic models (the IBIS DSS currently interacts with IQQM, but it can accept data from any linked hydrology-hydraulic model) with purpose built ecological response models[1] in development for ecological function, fish, birds and vegetation. The DSS is being constructed to consider three flow planning time frames (event, annual, decadal), where ecological responses can be modelled spatially across wetlands and dynamically over time. The DSS framework is updateable, allowing models and other information to be updated, allowing for a more adaptive approach to decision making.

[1] Models are in development by iCAM and in cooperation with project partners from UNE, Griffith University and UNSW

Modelling the ecological response of adding water to the Lowbidgee

Nick Marsh[1] and Ian Varley[2]

[1]eWater CRC.
[2] Sinclair Knight Merz (SKM)

Together with DECCW, SKM and the eWater CRC are creating an ecological modelling tool to predict temporal and spatial habitat availability for key species of the Lowbidgee Wetlands under different water use scenarios. As input to the tool a detailed hydraulic model of the Lowbidgee wetlands is being used to allow the conversion of main channel flow and within-wetland hydraulic structure management options to produce time series of water availability across more than 20 distinct areas in the wetland. These time series will include daily representations of the area of inundation and water depth for each of the management areas. This hydraulic and hydrologic modelling activity is being jointly conducted by SKM and the NSW office of water.

Whilst the hydraulic and hydrologic modelling is being conducted, descriptions of the key water requirements for several important species is being collated. These water requirements are being represented as habitat suitability models for each of the species. The description of the habitat suitability is based on the life history stages of each species and are described in terms of continuous functions relating to the depth or area of inundation time series which indicate a preferred wetting regime based on the:

- Magnitude – e.g. a preferred depth range.
- Duration – e.g. a preferred length of inundation for say germination to occur.
- Timing – e.g. a preferred time of year for germination to be successful.
- inter-annual frequency – e.g. a maximum time between successful wetting events so that vegetation does not die.
- rate of change – e.g. maximum daily change in water level to prevent nest abandonment.

The tool will allow the updating or addition of habitat preference models as well as allow the addition of new flow scenario data. The tool allows the subsequent overall reporting by species as well as reporting by the spatial units on the long term habitat availability for each of the key species. This long term habitat availability for each reporting area can then be further scrutinised to give a year by year analysis of habitat suitability.

In our presentation we will describe the species based modelling approach and demonstrate the output from the prototype tool.

Development of a wetlands database for the Murrumbidgee River Catchment

Margie Parmenter[1], Ian Reid[1] and John Francisght[2]

[1]Parsons Brinckerhoff
[2]Murrumbidgee Catchment Management Authority

Parsons Brinckerhoff and the Murrumbidgee CMA will present and demonstrate the practical capabilities of the Murrumbidgee Wetlands Decision Support Tool in assisting environmental water managers make decisions regarding the use of limited environmental water across the entire Murrumbidgee River Catchment.
Under the Murrumbidgee *RiverReach* program, the Murrumbidgee CMA is responsible for managing environmental water and directing its use for the best ecological outcomes. Knowledge of the distribution, size, biodiversity and hydrology of wetlands for the whole Murrumbidgee Floodplain is vital for making these decisions.

The Murrumbidgee CMA and PB are developing a GIS-based decision support tool that can test various scenarios and help make decisions about how to use limited environmental water allocations to water wetlands that will lead to the best ecological outcomes. It provides a central repository for data and information regarding wetlands in the Murrumbidgee including information about when to water wetlands, when a wetland was last watered, what wetlands can be reached under what flows, the expected ecological outcomes from watering, ecosystem responses from past watering events, operational delivery constraints and opportunities for the integrated management of environmental and consumptive water.

The system will allow the Murrumbidgee CMA and other environmental water managers to identify and rank wetlands that can be watered under various river flow conditions and promote transparent decision making based on rigorous results. It is also a tool that can assist in the “coordinated” use and management of environmental water either held or managed by various other organisations in the Murrumbidgee River Catchment, including planned environmental water and water entitlements held by the Commonwealth Environmental Water Holder (CHEW) and NSW Government for environmental purposes.

The tool will also be valuable for demonstrating compliance with requirements for state water resource management plans in terms of the use and management of environmental water.

The results and lessons from this innovative program can be spread throughout the Murray Darling Basin to help establish environmental water markets and develop and implement environmental watering plans at the local, state and MDBA levels including the Environmental Watering Plan currently being developed by the MDBA as a key component of the Basin Plan

Hydrodynamic Modelling of the Great Cumbung Swamp

[1]Michelle Jefferies, [2]Rob Leslie

[1]Lachlan Catchment Management Authority
[2]Parsons Brinckerhoff

The Great Cumbung Swamp comprises an area of 50,000 Ha and is listed on the Register of the National Estate as a Significant Wetland. It is described as a terminal drainage swamp of the Lachlan River located south west of Oxley and is known to support large numbers of waterbirds, with widespread breeding events of many species occurring after flood events. The swamp also provides a drought refuge when other wetlands are dry. It has been identified as a key environmental asset within the Murray Darling Basin.

Lachlan CMA is undertaking a number of projects to develop a better understanding of the Swamp ecology and the response of the ecology to rainfall and inflow. The overall objective is to obtain information that will be used to supplement decision support systems developed by the Lachlan Riverine Working Group to identify best use of Adaptive Environmental Water Allocations and direct on ground investment.

Ecologically significant wetland processes often occur in small and specific locations within the Swamp, which in some cases are hydraulically linked via minor channels or flood runners. The natural flooding regime has been considerably modified by the presence of constructed levees and channels. These processes and features highlight the need to develop a better understanding of the flow distribution under various hydrologic conditions, which will assist in investigating options to maximise the use of available environmental water.

Lachlan CMA has commissioned this hydrodynamic modelling study of the Swamp to develop an understanding of flow distribution. The study is utilising LiDAR data to provide the DTM platform for the model. The model is developed using the MIKE FLOOD software which allows integrated 1 and 2-dimensional modelling of river and floodplain systems.

The Swamp area is relatively flat, with ground levels ranging from 71 to72 mAHD. The relatively small range in level means that there is no well defined topographic boundary to the Swamp to identify the limits of the model and potential flood extents. Therefore, it is essential that the model makes allowance for losses as flow is distributed across the Swamp to avoid overestimating the flow distribution and extent of flooding.

This paper describes the method used to model the flow distribution within the Swamp taking into account key losses of evaporation and groundwater seepage. The paper will describe the conceptual model for the losses and the approach to including the key losses within the model. Key sources of information in developing the loss models are the existing IQQM model of the Lachlan and the Water Balance Assessment of the Swamp undertaken by NSW DIPNR.

Spatial prioritisation for freshwater conservation in the Murrumbidgee Catchment

Eren Turak[1], Greg Summerell, Glenn Manion and Michael Drielsma

[1]Department of Environment, Climate Change and Water

Broad-scale spatial prioritisations for conservation actions in NSW have until now rarely incorporated freshwater biodiversity. We recently developed a tool to prioritise small sub-catchments across large regions for conservation and restoration actions using estimates of the integrity of biological assemblages in rivers and catchment disturbance.

Using this tool, we determined the irrepleceability of each of 15000 sub-catchments within the Murrumbidgee catchment based on classifications of rivers and wetlands. The model uses recent data on land use and changes to natural flow regimes and generates maps that show spatial priorities across the catchment for the restoration of natural flows, catchment protection, catchment restoration and actions focussed on specific river reaches and wetlands to protect aquatic biodiversity. We discuss the benefits for regional freshwater biodiversity, of implementing alternative management scenarios involving multiple, spatially explicit management actions. The first attempt at applying this tool was based on coarse data inputs but promising results were achieved. We aim in future applications to improve the data sources to create a more refined model. Issues of data improvement, and the importance of training data sets will be discussed.

An innovative approach to provide environmental flows and ecological outcomes for the lower Cotter River

Susan Nichols and Richard Norris

Institute for Applied Ecology, University of Canberra

Abstract: The Cotter River is a tributary of the Murrumbidgee River in the upper region of the Murray-Darling Basin. A project is underway to enlarge the capacity of the existing Cotter reservoir from 4 GL 78 GL for Canberra's domestic water supply. The ability to release environmental flows from the reservoir to the lower Cotter River will be restricted during the construction of the enlarged Cotter Dam (ECD). The Murrumbidgee to Cotter pumping augmentation (M2C) project will provide an environmental flow transfer capability for the Cotter River reach below Cotter Dam by pumping water from Murrumbidgee River. Post-ECD construction, the M2C transfer system may continue to provide the majority of environmental flows with only large, flushing-flows to be provided by Cotter Dam releases, if and when required. This study is designed to assess the in-stream ecological responses and the ability of specified flow releases to achieve desired ecological outcomes. The results of this M2C water transfer study will improve predictive ability and the understanding of processes in the affected river reaches. Management operations can then evolve to bring the lower Cotter River reach to the optimal ecological condition possible within the constraints of infrastructure and river management.

Determining the environmentally sustainable level of take for the Basin Plan

Ian Burns

Director Environmental Water Requirements, Murray Darling Basin Authority

The Murray-Darling Basin Authority (MDBA) has been charged with developing a Basin Plan which will establish and enforce environmentally sustainable limits on the taking of water (surface and ground water) across the whole Murray-Darling Basin. The Water Act 2007 specifies that the environmentally sustainable level of take (ESLT) should not compromise key environmental assets, ecosystem functions, environmental outcomes or the productive base.

Conceptually the task of determining the ESLT seems straightforward:

1. Identify the key environmental assets, ecosystem functions, environmental outcomes and productive base;
2. Identify their environmental water requirements and the associated ESLT;
3. Consider climate change implications;
4. Assess socio-economic impacts; and
5. Optimise to minimise the socio-economic impacts whilst not compromising the key environmental assets, ecosystem functions, environmental outcomes and productive base.

However, for example, there are potentially thousands of key environmental assets. For many of these, little is known about their environmental water requirements, and it would be impossible to determine their water requirements within the timeframe required to develop the Basin Plan.
The MDBA is determining the ESLT for the Basin Plan using a process that combines:

- An assessment of the surface water requirements of 18 'indicator' key environmental assets (IKEAs)
- An assessment of the surface water requirements of key ecosystem functions
- A groundwater recharge risk assessment

The focus of this presentation will be the surface water assessments. The two surface water components integrate to provide a basin wide assessment of environmental water requirements. The 18 IKEAs typically require high flows (bankfull and overbank). Given that high flows provide a relatively large contribution to the volume of available water, the 18 IKEAs have the biggest influence on the ESLT. The key ecosystem functions assessment provides information on low flow environmental water requirements (relatively small impact on ESLT) and a mechanism to check the impact of the 18 IKEAs on flow regimes across the entire basin.

The assessments undertaken by the MDBA have relied heavily upon previous environmental flows assessments and ecosystem response modelling across the basin. The presentation will briefly describe the overall approach and the individual components, how they integrate, the various data inputs (including ecosystem response modelling), and provide some recommendation for future research and analysis.

Modelling interactions among catchments, rivers, hydrology, human disturbance and climate change: qualitative implications from loop analyses

Tsuyoshi Kobayashi[1] and Darren S Ryder[2]

[1]NSW Department of Environment, Climate Change and Water
[2]Ecosystem Management, University of New England

Ecosystem components interact in a complex way. Although the magnitude of interactions is usually unknown, the directions of change are often obvious and intuitive. Qualitative modelling of the interactions among the physical attributes of rivers, their hydrology and human-induced disturbance can predict how the system will respond to perturbation.

We constructed loop models to identify the direction of interactions that link the qualitative effects (positive, negative, no effect) between catchments, rivers, environmental flows, floodplains, human activities and climate change. Qualitative model outputs were used to investigate the stability of river-floodplain systems and their resilience to disturbances under increasing environmental flows.

Scenario-based modelling showed that establishing or restoring positive ecological feedback between river-floodplain systems enhances the ecological states of rivers and floodplains without negatively affecting human activities. An increase in human activities does not negatively affect the ecological states of river-floodplain systems, if environmental waters are provided independent of human activities. Climate change has an overarching effect on all local model components.

We believe that a qualitative modelling approach such as loop analysis can depict cascading interactive effects despite some of its inherent limitations (e.g. qualitative stability provides no insight into the stable structure of quantitative domain of the system).

Abstracts Posters

Do environmental flows promote the germination and establishment of aquatic plants? Assessing the evidence via causal criteria analysis

Elizabeth M. Wallis[1], J. Angus Webb[2,3] and Michael J. Stewardson[1]

[1]Department of Civil and Environmental Engineering, The University of Melbourne, Victoria 3010
[2]Department of Resource Management and Geography, The University of Melbourne, Victoria, 3010
[3]eWater Cooperative Research Centre

Environmental flow allocations are expected to deliver many environmental benefits to Victorian riverine ecosystems, including stimulating the germination and establishment of wetland plants. The Victorian Environmental Flows Monitoring and Assessment Program (VEFMAP) was established to provide a rigorous scientific assessment of the effectiveness of environmental flows in delivering ecological benefits. As part of this program, we conducted a systematic review of the literature and used causal criteria analysis to evaluate the strength of evidence for a causal link between inundation events of varying duration and frequency and the germination and establishment of wetland plants. Causal criteria analysis provides a way to systematically evaluate different pieces of evidence from the literature, which may collectively infer causality. The causal criteria approach was originally developed for studies in epidemiology, where limited replication and randomisation of treatments can result in a limited ability to draw inferences about causality. Because there are similar challenges in ecology, there is currently growing interest in applying causal criteria techniques to ecological questions. Our review found evidence to support a causal link between flood timing and the diversity of wetland plants and also a negative association between depth of inundation and the growth of wetland plants. However, we found insufficient evidence in the literature to infer causality between many aspects of environmental flows and plant responses. Evidence of causal links between environmental flows and ecological outcomes will improve ecological response models and help to justify allocation of increasingly scarce water resources to the environment.

Phosphorus budget in ephemeral wetland ecosystem after receiving environmental water

Lisa Knowles, Jordan Iles, Yoshi Kobayashi, Yi Lu, Li Wen

NSW Department of Environment, Climate Change and Water

In the summer of 2007/2008, the Avenue, a Southern Bell Frog habitat in Yanga National Park received around 2 GL of environmental water. The area is located at the lowland floodplain of the regulated Murrumbidgee River and has been dry for the last five years. The watering event inundated 412 ha of shallow swamp and River Red Gum woodland. As part of a larger floodplain trophic study, we estimated the total phosphorus (TP) budget in the wetland by combining a wetland water balance model and the concentrations of TP measured from river and floodplain water

samples and those released from floodplain sediments. Wetland water balance model was constructed using Digital Elevation Model (DEM) derived from 1 m LiDAR data (with vertical accuracy of ± 15cm) together with the water levels recorded continuously from a logger installed at the lowest point of the wetland. Upon receiving environmental water, 366.6 kg of TP was mobilised in the floodplain (242.4 kg from 368.4 ha of woodland and 124.2 kg from 43.6 ha of swamp and floodplain channels). This fraction of TP was released from top soil/sediment, litter (exclusion of large falling branches) and animal wastes accumulated in the system during dry period. In addition, 178.4 kg of TP was delivered to the system with the environmental water, giving a TP budget of 545.1 kg in the wetland. Our results show that the majority of TP (67%) was endogenous and differ from other studies reporting that flood water is the main P source.

Responses to Responses - interactions between environmental and anthropogenic impacts on the River Red Gum (RRG) Forests of the Mid Murray.

Peter Bacon

Woodlots and Wetlands Pty Ltd

The existence of RRG (*Eucalyptus camaldulensis)* forests in a semi arid environment is due to relatively frequent overtopping of the banks of rhe Murray River and its distributary channels (floodrunners). Flooding replenishes soils moisture. Trees within 10 to 15m of floodrunners can tap directly into this water. Late season floods supply water during a normally hot dry period. Trees further away rely on shallow aquifers. These aquifers are recharged during floods. The combined network of flood runners and aquifers created a mosaic of moisture availability.

The availability of the external water supplies plays critical determining roles in the germination, establishment, growth rate, morphology and ultimate size of River Red Gums (RRG) (Chesterfield, 1986).

Anthropogenic impacts

Regeneration is mostly dependent on canopy disturbance. The 1880s regeneration resulted from heavy logging/clearing. Even-aged stands since then have resulted from wildfire plus favourable soil conditions in the mid 1950s and 1970s.

Development of upstream water storages and diversions has markedly changed water availability to the RRG forest (Dexter, 1967, 1970, Dexter et al, 1988, Bren, 1987, 1988 a, b, Bren and Gibbs, 1986, Bren et al, 1987 and 1988). Drought since 2000 has reduced the total volume available.

Other key anthropogenic impacts include:

- Creation of ‘open’ woodlands. Aborigines apparently burned the forest to facilitate hunting and to stimulate grass growth (Sturt, cited by Hibbins, 1978).
- Total removal of forest and creation of farmlands and flood levees on the drier margins of the forest
- Logging.
- Grazing, especially cattle.
- Introduction of weeds and pastures species as part of grazing
- Development and some implementation of Environmental Flows.

Ecological responses to a changing environment include

- Slowing RRG growth due to reduced water supply
- Increased reliance of RRG on groundwater
- Less recruitment of young RRG
- Increased dominance of the forest floor with exotic ground covers
- Invasion of previously swampy areas by RRG.
- Death of individual trees on drier portions of the forest.

Anthropogenic responses to the changing ecosystem include:

- Ramsar nomination of portions of the RRG forest
- Increased call for environmental flows
- Changing in logging practices
- Reduction in logging intensity to reflect conservation concerns and reflect 'sustainable' yield rate
- Active management of forest flooding
- National park creation

This paper will explore the use of models and data to identify the extent to which the anthropogenic responses can achieve the outcomes desired by a range of stakeholders.

Name	Last name	Affiliation	Email
Maree	Abood	Office of the Hawkesbury-Nepean	Maree.Abood@ohn.nsw.gov.au
Neal	Albert	NSW Dept. Environment, Climate Change & Water	Neal.Albert@environment.nsw.gov.au
Bethany	Alexander	NSW Dept. Environment, Climate Change & Water	beth.alexander@environment.nsw.gov.au
Craig	Allery	DHI Water and Environment	cal@dhigroup.com
Angela	Arthington	Griffith University	a.arthington@griffith.edu.au
Tony	Arthur	Commonwealth Scientific and Industrial Research Organisation (CSIRO)	tony.arthur@csiro.au
Peter	Bacon	Woodlots & Wetlands Pty Ltd	woodlots@optusnet.com.au
Emily	Barbour	Australian National University	emily.barbour@csiro.au
David	Bell	The Murray-Darling Basin Authority	david.bell@mdba.gov.au
Paul	Bendeich	NSW Dept. Environment, Climate Change & Water	Paul.Bendeich@environment.nsw.gov.au
Peter	Berney	University of New England	pberney@une.edu.au
Warwick	Bishop	Water Technology	wab@watech.com.au
Rachel	Blakey	NSW Dept. Environment, Climate Change & Water	rachel.blakey@environment.nsw.gov.au
Stephen	Blockwell	Sydney Water Corporation	steveblockwell@sydneywater.com.au
Christopher	Bobbi	Dept Primary Industries, Parks Water and Environment	chris.bobbi@dpipwe.tas.gov.au
Nick	Bond	Monash University	nick.bond@sci.monash.edu.au
Sharon	Bowen	NSW Dept. Environment, Climate Change & Water	sharon.bowen@environment.nsw.gov.au
Craig	Boys	Dept. of Industry and Investment	craig.boys@industry.nsw.gov.au
Anne	Brady	Dept. of the Environment, Water, Heritage and the Arts	anne.brady@environment.gov.au
Anthea	Brecknell	National Water Commission	anthea.brecknell@nwc.gov.au
Ryan	Breen	Dept. of the Environment, Water, Heritage and the Arts	ryan.breen@environment.gov.au

Name	Last name	Affiliation	Email
Jane	Brennan	University of Technology, Sydney	jane.brennan@uts.edu.au
Andrew	Brown	NSW Office of Water	andrew.brown@dnr.nsw.gov.au
Stuart	Bunn	National Water Commission	Peta.Mannix@nwc.gov.au
Ian	Burns	The Murray-Darling Basin Authority	ian.burns@mdba.gov.au
Chiara	Callipari	Parsons Brinckerhoff	ccallipari@pb.com.au
Samantha	Capon	NNCARF Water Network	s.capon@griffith.edu.au
Susy	Cenedese	NSW Dept. Environment, Climate Change & Water	susy.cenedese@environment.nsw.gov.au
Yun	Chen	Commonwealth Scientific and Industrial Research Organisation (CSIRO)	yun.chen@csiro.au
Bruce	Chessman	NSW Dept. Environment, Climate Change & Water	Bruce.Chessman@environment.nsw.gov.au
Stuart	Chilcott	Inland Fisheries Service	chilcott@ifs.tas.gov.au
Paul	Childs	DECCW	paul.childs@environment.nsw.gov.au
Shahadat	Chowdhury	NSW Office of Water	shahadat.chowdhury@dnr.nsw.gov.au
Tony	Church	Environemtal consultant	tchurch@skm.com.au
Steve	Clark	Water Technology	steve.clark@watech.com.au
Matthew	Colloff	Commonwealth Scientific and Industrial Research Organisation (CSIRO)	Matt.Colloff@csiro.au
Anne	Colville	University of Technology, Sydney	Anne.Colville@uts.edu.au
Di	Conrick	Dept. of the Environment, Water, Heritage and the Arts	di.conrick@environment.gov.au
Bruce	Cooper	NSW Office of Water	Bruce.Cooper@dnr.nsw.gov.au
Stephen	Cox	NSW Dept. Environment, Climate Change & Water	Steve.cox@environment.nsw.gov.au
Bob	Creese	Dept. of Industry and Investment	bob.creese@industry.nsw.gov.au
Susan	Cuddy	Commonwealth Scientific and Industrial Research Organisation (CSIRO)	susan.cuddy@csiro.au
Alison	Curtin	NSW Dept. Environment, Climate Change & Water	alison.curtin@environment.nsw.gov.au

Name	Last name	Affiliation	Email
Clare	D'Arcy	NSW Dept. Environment, Climate Change & Water	clare.darcy@environment.nsw.gov.au
Alec	Davie	University of Technology, Sydney	alec.davie@uts.edu.au
Richard	Davis	National Water Commission	Richard.Davis@nwc.gov.au
David	Deane	SA Dept of Water, Land and Biodiversity Conservation	david.deane@sa.gov.au
Matt	Dell	Myriax Software	mattd@myriax.com
Tanya	Doody	Commonwealth Scientific and Industrial Research Organisation (CSIRO)	tanya.doody@csiro.au
Susan	Drane	Catchment Management Authority Central West	susan.drane@cma.nsw.gov.au
Patrick	Driver	NSW Office of Water	patrick.driver@dnr.nsw.gov.au
Hiep	Duc	NSW Dept. Environment, Climate Change & Water	hiep.duc@environment.nsw.gov.au
Gillian	Dunkerley	NSW Dept. Environment, Climate Change & Water	gillian.dunkerley@environment.nsw.gov.au
Elysha	Dunlop	National Water Commission	elysha.dunlop@nwc.gov.au
Steve	Dwight	Dept. of the Environment, Water, Heritage and the Arts	stephen.dwight@environment.gov.au
Colin	Field	University of Technology, Sydney	cdf1@ozemail.com.au
Wilfred	Finn	National Water Commission	wilf.finn@nwc.gov.au
John	Floyd	NSW Dept. Environment, Climate Change & Water	john.floyd@environment.nsw.gov.au
Neal	Foster	NSW Office of Water	neal.foster@water.nsw.gov.au
Ashley	Fowler	University of Technology Sydney	ashley.m.fowler@student.uts.edu.au
John	Francis	Catchment Management Authority Murrumbidgee	john.francis@cma.nsw.gov.au
Paul	Frazier	Private	paulf@ecoaus.com.au
Baihua	Fu	Australian National University	baihua.fu@anu.edu.au
Ben	Gawne	Murray-Darling Freshwater Research Centre	B.Gawne@latrobe.edu.au
Chris	Gouramanis	Dept. of the Environment, Water, Heritage and the Arts	chris.gouramanis@environment.gov.au
Megan	Graham	NSW Dept. Environment, Climate Change & Water	megan.graham@environment.nsw.gov.au

Name	Last name	Affiliation	Email
Layna	Groen	University of Technology, Sydney	Layna.Groen@uts.edu.au
James	Grove	Melbourne University	jgrove@unimelb.edu.au
Tahir	Hameed	NSW Office of Water	tahir.hameed@dnr.nsw.gov.au
Scott	Hardie	Department of Primary Industries, Parks, Water and Environment	Scott.Hardie@dpipwe.tas.gov.au
Barry	Hart	The Murray-Darling Basin Authority	barry.hart@waterscience.com.au
Harry	He	NSW Office of Water	Harry.He@dnr.nsw.gov.au
Elizabeth	Heagney	University of NSW	e.heagney@unsw.edu.au
Brent	Henderson	Commonwealth Scientific and Industrial Research Organisation (CSIRO)	Brent.Henderson@csiro.au
Jeff	Hillan	NSW Dept. Environment, Climate Change & Water	jeff.hillan@environment.nsw.gov.au
James	Hitchcock	University of Technology, Sydney	james.hitchcock@student.uts.edu.au
Kate	Holland	Commonwealth Scientific and Industrial Research Organisation (CSIRO)	kate.holland@csiro.au
Linda	Holz	eWater	linda.holz@gmail.com
Tim	Hosking	NSW Dept. Environment, Climate Change & Water	tim.hosking@environment.nsw.gov.au
Jane	Humphries	NSW Dept. Environment, Climate Change & Water	Jane.Humphries@environment.nsw.gov.au
Simon	Hunter	NSW Dept. Environment, Climate Change & Water	simon.hunter@environment.nsw.gov.au
Jordan	Iles	NSW Dept. Environment, Climate Change & Water	jordan.iles@environment.nsw.gov.au
Sarah	Imgraben	NSW Dept. Environment, Climate Change & Water	sarah.imgraben@environment.nsw.gov.au
Tariful	Islam	NSW Dept. Environment, Climate Change & Water	tariful.islam@environment.nsw.gov.au
Michelle	Jefferies	Catchment Management Authority Lachlan	michelle.jefferies@cma.nsw.gov.au
Mat	Johansen	Australian Nuclear Science and Technology Org	matjohansen@ansto.gov.au
Rebecca	Johnston	Dept Environment and Resource Management (QLD)	rebecca.johnston@derm.qld.gov.au
Hugh	Jones	NSW Dept. Environment, Climate Change & Water	hugh.jones@environment.nsw.gov.au

Name	Last name	Affiliation	Email
Jamie	Kaye	Water Technology	jamie.kaye@watech.com.au
Helen	Keenan	Office of the Hawkesbury-Nepean	Helen.Keenan@ohn.nsw.gov.au
Jeff	Kelleway	former employee NSW DECCW	j.kelleway@gmail.com
Ailsa	Kerswell	Private	ailsak@ecoaus.com.au
Kyuho	Kim	The University of Melbourne	kimkh@unimelb.edu.au
Lisa	Knowles	NSW Dept. Environment, Climate Change & Water	lisa.knowles@environment.nsw.gov.au
Yoshi	Kobayashi	NSW Dept. Environment, Climate Change & Water	Yoshi.Kobayashi@environment.nsw.gov.au
John	Koehn	DSE vic	john.koehn@dse.vic.gov.au
Klaus	Koop	NSW Dept. Environment, Climate Change & Water	klaus.koop@environment.nsw.gov.au
Eric	Lam	Parsons Brinckerhoff	elam@pb.com.au
Rob	Leslie	Parsons Brinckerhoff	roleslie@pb.com.au
Rebecca	Lester	Flinders University	rebecca.lester@flinders.edu.au
Joanne	Ling	NSW Dept. Environment, Climate Change & Water	joanne.ling@environment.nsw.gov.au
Simon	Linke	Griffith University	simon.linke@gmail.com
Stuart	Little	The Murray-Darling Basin Authority	stuart.little@mdba.gov.au
Peter	Lloyd-Jones	NSW Dept. Environment, Climate Change & Water	peter.lloydjones@environment.nsw.gov.au
Debbie	Love	NSW Dept. Environment, Climate Change & Water	debbie.love@environment.nsw.gov.au
Yi	Lu	NSW Dept. Environment, Climate Change & Water	yi.lu@environment.gov.nsw.au
Qunying	Luo	University of Technology, Sydney	qunying.luo@uts.edu.au
Scott	Macaulay	Dept. of the Environment, Water, Heritage and the Arts	scott.macaulay@environment.gov.au
Rohan	Macdonald	NSW Office of Water	rohan.macdonald@dnr.nsw.gov.au
Jane	Macfarlane	Cotton Catchment Communities CRC	jane.macfarlane@csiro.au
Craig	Mackay	Sinclair Knight Merz	cmackay@skm.com.au

Name	Last name	Affiliation	Email
Stephen	Mackay	Griffith Univrsity	s.mackay@griffith.edu.au
James	Maguire	NSW Dept. Environment, Climate Change & Water	james.maguire@environment.nsw.gov.au
Michael	Maher	NSW Dept. Environment, Climate Change & Water	mike.maher@environment.nsw.gov.au
Jon	Marshall	Department of Environment and Resource Management	marshallj@derm.qld.gov.au
Owen	Martin	Dept. of the Environment, Water, Heritage and the Arts	owen.martin@environment.gov.au
Jennifer	Martin	Dept. of the Environment, Water, Heritage and the Arts	jennifer.martin@environment.gov.au
Ken	Matthews	National Water Commission	peta.mannix@nwc.gov.au
Dan	Mawer	NSW Dept. Environment, Climate Change & Water	Dan.Mawer@environment.nsw.gov.au
Debashish	Mazumder	Australian Nuclear Science and Technology Organisation (ANSTO)	debashish.mazumder@ansto.gov.au
Heather	McGinness	Commonwealth Scientific and Industrial Research Organisation (CSIRO)	Heather.McGinness@csiro.au
Rachel	Melrose	NSW Dept. Environment, Climate Change & Water	rachel.melrose@environment.nsw.gov.au
Simon	Mitrovic	NSW Office of Water	simon.mitrovic@dnr.nsw.gov.au
Tim	Morrison	DHI Group	tmo@dhigroup.com
Susan	Nichols	University of Canberra	sue.nichols@canberra.edu.au
Richard	Norris	University of Canberra	richard.norris@canberra.edu.au
Joanne	Ocock	University of NSW	joanne.ocock@unsw.edu.au
Ralph	Ogden	eWater CRC	ralph.ogden@ewatercrc.com.au
Ian	Overton	Commonwealth Scientific and Industrial Research Organisation (CSIRO)	ian.overton@csiro.au
Paul	Packard	NSW Dept. Environment, Climate Change & Water	paul.packard@environment.nsw.gov.au
Margie	Parmenter	Parsons Brinckerhoff	mparmenter@pb.com.au
Neville	Pavan	NSW Dept. Environment, Climate Change & Water	Neville.Pavan@environment.nsw.gov.au
Natalia	Perera	NSW Dept. Environment, Climate Change & Water	natalia.perera@environment.nsw.gov.au

Name	Last name	Affiliation	Email
Carmel	Pollino	The Australian National University	carmel.pollino@anu.edu.au
Megan	Powell	NSW Dept. Environment, Climate Change & Water	megpowell2002@yahoo.com
Tim	Pritchard	NSW Dept. Environment, Climate Change & Water	tim.pritchard@environment.nsw.gov.au
Ian	Prosser	Commonwealth Scientific and Industrial Research Organisation (CSIRO)	Ian.Prosser@csiro.au
Allan	Raine	NSW Office of Water	allan.raine@water.nsw.gov.au
Tim	Ralph	Macquarie University	tralph@science.mq.edu.au
Tom	Rayner	Australian Wetlands and Rivers Centre, UNSW	thomas.rayner@unsw.edu.au
Michael	Reid	University of New England	mreid24@une.edu.au
Stephen	Roberts	NSW Office of Water	stephen.m.roberts@water.nsw.gov.au
Ian	Robinson	Dept. of the Environment, Water, Heritage and the Arts	ian.robinson@environment.gov.au
Kerrylee	Rogers	NSW Dept. Environment, Climate Change & Water	kerrylee.rogers@environment.nsw.gov.au
Chris	Rush	NSW Dept. Environment, Climate Change & Water	chris.rush@environment.nsw.gov.au
David	Ryan	NSW Office of Water	david.ryan@dnr.nsw.gov.au
Darren	Ryder	University of New England	dryder2@une.edu.au
Neil	Saintilan	NSW Dept. Environment, Climate Change & Water	Neil.Saintilan@environment.nsw.gov.au
Zafer	Sarac	Queensland Government	zafer.sarac@deedi.qld.gov.au
Peter	Scanes	NSW Dept. Environment, Climate Change & Water	peter.scanes@environment.nsw.gov.au
Justin	Seymour	University of Technology, Sydney	Justin.Seymour@uts.edu.au
Ian	Shannon	NSW Dept. Environment, Climate Change & Water	Ian.Shannon@environment.nsw.gov.au
Fran	Sheldon	Griffith University	f.sheldon@griffith.ed.au
Cybele	Shorter	University of Techology, Sydney	cybele.shorter-1@uts.edu.au
Justen	Simpson	NSW Dept. Environment, Climate Change & Water	justen.simpson@environment.nsw,gov.au

Name	Last name	Affiliation	Email
Shannon	Simpson	NSW Dept. Environment, Climate Change & Water	shannon.simpson@environment.nsw.gov.au
Neil	Sims	Commonwealth Scientific and Industrial Research Organisation (CSIRO)	Neil.Sims@csiro.au
Marina	Sivkova	NSW Office of Water	Marina.Sivkova@dnr.nsw.gov.au
Peter	Sobinoff	NSW Dept. Environment, Climate Change & Water	Peter.Sobinoff@environment.nsw.gov.au
Jennifer	Spencer	NSW Dept. Environment, Climate Change & Water	jennifer.spencer@environment.nsw.gov.au
Celine	Steinfeld	University of NSW	celine.steinfeld@unsw.edu.au
Michael	Stewardson	The University of Melbourne	mjstew@unimelb.edu.au
Morag	Stewart	University of New England	mstewa28@une.edu.au
Paul	Swapan	Sydney Olympic Park Authority	swapan.paul@sopa.nsw.gov.au
Peter	Tate	Sydney Water Corporation	peter.tate@sydneywater.com.au
Ben	Tate	Water Technology	bt@watech.com.au
Peter	Terrill	NSW Dept. Environment, Climate Change & Water	peter.terrill@environment.nsw.gov.au
Rachael	Thomas	NSW Dept. Environment, Climate Change & Water	rachael.thomas@environment.nsw.gov.au
Chris	Togher	NSW Dept. Environment, Climate Change & Water	chris.togher@environment.nsw.gov.au
Laura	Torrible	IRPEC Pty Ltd	laura.torrible@irpec.com.au
Simon	Treadwell	Sinclair Knight Merz	streadwell@skm.com.au
Eren	Turak	NSW Dept. Environment, Climate Change & Water	eren.turak@environment.nsw.gov.au
Alistair	Usher	National Water Commission	alistair.usher@nwc.gov.au
Geoff	Vietz	The University of Melbourne	g.vietz@unimelb.edu.au
John	Wadsworth	NSW Dept. Environment, Climate Change & Water	john.wadsworth@environment.nsw.gov.au
Elizabeth	Wallis	University of Melbourne	ewallis@unimelb.edu.au
Andrew	Warden	The Department of the Environment, Water, Heritage and the Arts	andrew.warden@environment.gov.au

Name	Last name	Affiliation	Email
Skye	Wassens	Charles Sturt Univeristy	swassens@csu.edu.au
Robyn	Watts	Charles Sturt University	rwatts@csu.edu.au
Angus	Webb	University of Melbourne	angus.webb@unimelb.edu.au
Li	Wen	NSW Dept. Environment, Climate Change & Water	li.wen@environment.nsw.gov.au
Camilla	West	Santos Water	camilla.west@santos.com
Douglas	Westhorpe	NSW Office of Water	Doug.Westhorpe@dnr.nsw.gov.au
Paul	Wettin	Consultant	paulwettin@optusnet.com.au
Andrew	Whitford	EcoLogical Australia	andreww@ecoaus.com.au
Michael	Wilson	The Murray-Darling Basin Authority	michael.wilson@mdba.gov.au
Kate	Wilson	NSW Dept. Environment, Climate Change & Water	kate.wilson@environment.nsw.gov.au
Marion	Winkler	NSW Dept. Environment, Climate Change & Water	marion.winkler@environment.nsw.gov.au
Xihua	Yang	NSW Dept. Environment, Climate Change & Water	xihua.yang@environment.nsw.gov.au