International Environmental Modelling and Software Society (iEMSs)
2012 International Congress on Environmental Modelling and Software
Managing Resources of a Limited Planet, Sixth Biennial Meeting, Leipzig, Germany
R. Seppelt, A.A. Voinov, S. Lange, D. Bankamp (Eds.)
http://www.iemss.org/society/index.php/iemss-2012-proceedings

The Impact of Uncertain Ecological Knowledge on a Water Suitability Model of Riverine Vegetation

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Abstract: Freshwater aquatic ecosystems are increasingly under threat due to climate change and river regulation. Water management is considered important for maintaining and restoring freshwater aquatic ecosystems in Australia. A habitat model based on the water requirements of four riverine vegetation species was developed to assess the suitability of water regimes for the maintenance and regeneration of these species in the Namoi Catchment, Australia. This model identifies characteristics of flooding events (e.g. duration, timing and inter-flood dry period) from hydrological data or models, and generates suitability indices based on the species' water requirement preference curves. These preference curves are central to the model and were established based on expert knowledge. Two comprehensive sources are available on the water requirements of vegetation species in the Murray-Darling Basin, Australia: Rogers and Ralph [2010] and Roberts and Marston [2011]. Both of these sources are based on extensive review of studies on species' response to flooding in the Murray-Darling Basin. The water requirements proposed in these two sources differ due to differences in literature selection and interpretation of the literature by the authors. In this paper, we examine how these interpretations affect the outcomes of the Namoi ecological model. Two sets of preference curves are produced based on Rogers and Ralph [2010] and Roberts and Marston [2011], respectively, and the model outputs are compared. The goal is to understand the robustness of the model and how the model behaves in face of imperfect knowledge and information in ecosystem's response to water regime. Significant differences in model outputs were found for periods with large winter floods and for less commonly studied species such as water couch where there is higher uncertainty associated with water requirements. This understanding is critical to guide data collection and future model development.

Keywords*: ecological model; water suitability; preference curves; ecological knowledge uncertainty.*

1 INTRODUCTION

Riverine ecosystems rely on surface water and groundwater to maintain habitats, provide and transport energy and food sources, and support the growth of plants and animals. However, riverine ecosystems are increasingly under threat by drivers such as climate change and unsustainable land and water management such as over grazing and excessive groundwater pumping. Ecological models are useful tools for assessing the ecological impacts of these drivers, and assisting the development of adaptive management plans which can be vital to the protection of riverine ecosystems and their services.

An integrated assessment of the socio-economic and environmental impacts of climate change, technology and water policy drivers is being developed for the Namoi River Catchment [Ticehurst et al., In press]. A component of this integrated framework is an ecological mode that can be used to examine the ecological impacts of climate change and management scenarios. The ecological model uses an index-based approach to estimate the suitability of the combined surface water and groundwater regimes for the riverine ecosystems. These index type approaches were initially developed and applied to hydro-ecological models in Australia as part of the Murray Flow Assessment Tool [Young et al., 2003], and later applied in other modelling tools such as the Eco Modeller [Little et al., 2011]. The key to this approach is to convert flood attributes to water suitability indices, based on data, literature and/or expert opinions. The conversion is achieved through the use of preference curves which define the relationships between flood attributes and water suitability indices. However, our knowledge in riverine ecosystems is imperfect, which contributes to the uncertainty in the generation of preference curves.

In this paper, we use different preference curves in the ecological model to examine how knowledge uncertainty affects the model outcomes. The preference curves were generated from two most comprehensive and well-recognised reviews of literature on the water requirements of riverine vegetation in the Murray-Darling Basin, Australia: Rogers and Ralph [2010] and Roberts and Marston [2011]. These sources are both based on extensive review of previous studies on species' responses to flooding in the Murray-Darling Basin. However, different recommendations on water requirements are made due to differences in literature selection and the authors' interpretation of the literature.

2 THE ECOLOGICAL MODEL

The ecological model has been developed for the Namoi River Catchment, located in north-western NSW, Australia, with an area of approximately 42,000 km^2 (Figure 1). The Namoi River is categorized as an anabranch and distributary river zone [Thoms et al., 1999] and losing-connected system [NSW Office of Water, 2011]. Much of the Namoi River Catchment has been cleared, except for corridors and patches of riverine vegetation which cover about 25% of the catchment area [Eco Logical, 2009]. The Namoi catchment has the highest groundwater use in the Murray-Darling Basin. In 2004/2005, groundwater extract in the Namoi was estimated to be 255 GL, accounting for 15.2% of groundwater use in the Murray-Darling Basin, within which 35% was from the Lower Namoi Alluvium Groundwater Management Unit [CSIRO, 2007].

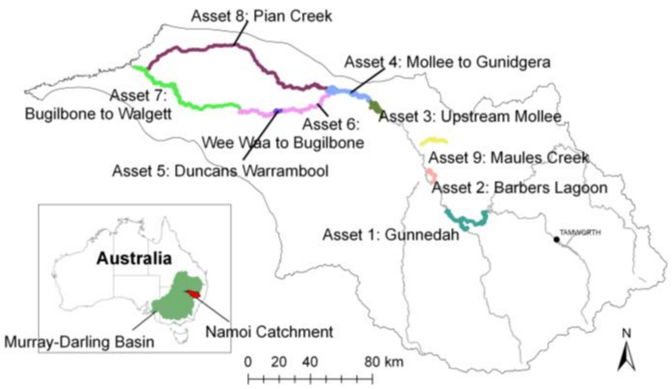


Figure 1. Modelled ecological assets in the Namoi River Catchment.

The ecological model for the Namoi focuses on healthy river function. This involves:

- a sustained level of base flow, which provides refuges during drought;
- regular flushing at various levels of benches and anabranches, in order to increase habitat areas and transport nutrients and carbon to the river system;

- regular flooding to sustain the growth of riverine vegetation and support regeneration;
- suitable groundwater and salinity levels to allow the access of water by riverine vegetation, particularly during drought.

The conceptual framework for the ecological model is illustrated in Figure 2. Inputs of the model are daily time series of surface flow, groundwater levels and groundwater salinity. These inputs can be derived from observations or from hydrological models. Outputs of the ecological model are aggregated annual time series of hydrological and ecological indicators. Nine ecological assets along the Namoi River are included in the model (Figure 1). Eight of these assets were selected based on work reported in [Barma Water Resources et al., 2012]. All assets are important river red gum corridors in the region. Some assets such as Barbers Lagoon (Asset 2 in Figure 1) and Duncans Warrambool (Asset 5) contain wetlands which are important waterbird and fish habitats. In addition, a river red gum corridor at Maules Creek was also included, which is considered as a reference site which has sustained little impact from groundwater extraction.

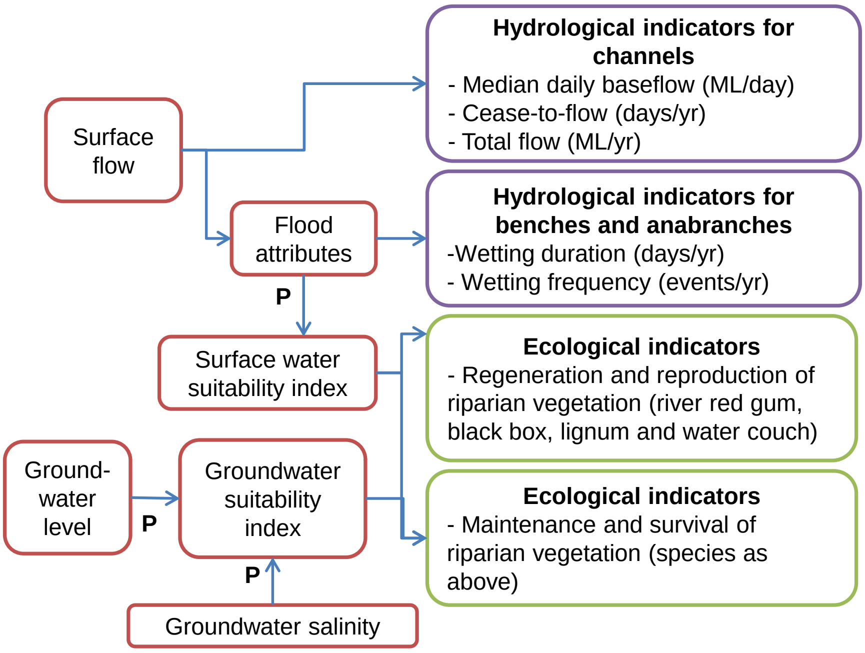


Figure 2. Conceptual framework of Namoi ecological model. P represents the use of preference curves.

The model inputs are i) daily surface flow at river flow gauges associated with respective ecological assets and ii) groundwater levels and salinity at the assets Baseflow was derived from surface flow through baseflow separation using a minimum filter with a half width of 5 time steps. Daily surface flow and baseflow data was then summarised to provide annual hydrological indicators for channels. The hydrological indicators for benches and anabranches were estimated through the identification of flooding or wetting events using commence-to-flow (CTF) levels. CTF levels for each modelled assets were identified through field inspection and remote sensing [Foster, 1999; Sue Powell, per comm, 2011]. Flood attributes (e.g. duration, timing, inter-flood dry period) were used to generate surface water suitability index for the ecological indicators.

The ecological indicators were estimated using preference curves. The water suitability index is modelled for four riverine vegetation species: *Eucalyptus camaldulensis* (river red gum), *Eucalyptus largiflorens* (black box), *Muehlenbeckia florulenta* (lignum) and *Paspalum distichum* (water couch). These species were selected because they are the most commonly distributed riverine vegetation species identified at the modelled areas. In addition, knowledge of water requirements is given by both Rogers and Ralph [2010] and Roberts and Marston [2011], which allows to the development of preference curves for the model.

The surface water suitability index is modelled in three steps (Figure 2):

1. Critical flood attributes were generated from surface flow time series based on the definition of a flood event. The attributes are flood duration, flood timing and inter-flood dry period. By default, it was assumed that the minimum number of days in each flood event window is 3 day, and the minimum number of days that can separate events is 2 days. These two parameters are arbitrary and can be modified for each species.
2. For each species, the suitability index of each flood attribute was estimated using preference curves. The preference curves were based on the water requirements for each flood attribute reported in Rogers and Ralph [2010] or Roberts and Marston [2011].
3. For each species, the surface water suitability index was estimated using weighted sum of the suitability index of each flood attribute. Weights were assigned based on Rogers and Ralph [2010] or Roberts and Marston [2011].

Groundwater suitability index was derived based on the suitability of the groundwater level (the groundwater level index) adjusted by groundwater salinity. The groundwater level index was generated from preference curves. If the groundwater salinity level is higher than the salt tolerance threshold for a given species, the groundwater suitability index is reduced to 0; otherwise, the groundwater suitability index is equal to the groundwater level index.

Finally the water suitability index was estimated using weighted sum of the surface water suitability and groundwater suitability indices. It is assumed that the weights for groundwater and surface water indices are 0.2 and 0.8, respectively. The annual water suitability index is the sum of the daily water suitability index in a calendar year.

3 METHODS

In this paper, we describe the methods and results for Asset 2, Barbers Lagoon. Two periods are selected: a wet period (1975 – 1980) and a dry period (2005 – 2010). The wet period has a mean annual flow of about 1102 GL at Boggabri (Gauge 419012, the gauge near Barbers Lagoon) compared with 363 GL during the dry period.

Two ecological indicators are analysed: water suitability for the maintenance of i) river red gum, and ii) water couch. The preference curves for flood attributes and the weights given to the different flood attributes were defined based on Rogers and Ralph [2010] and again using Roberts and Marston [2011]. The two sets of preference curves and weights obtained using these sources are detailed below.

3.1 Preference Curves

Preference curves are key parameters used to convert water regime into water suitability indices. Generation of preference curves were based on Rogers and Ralph [2010] or Roberts and Marston [2011]. The recommendations of the two sources and the preference curves derived from these recommendations are provided in Tables 1 and 2 for river red gum and water couch, respectively.

One set of groundwater level preference curves (Figure 3) and salinity thresholds are defined based on expert opinion and literature [O'Grady et al., 2006; Roberts and Marston, 2011; Rogers and Ralph, 2010] . Salinity thresholds for river red gum and water couch are 25600 ppm and 10000 ppm respectively [Roberts and Marston, 2011; Rogers and Ralph, 2010].

Table 1. Water requirements of river red gum and their preference curves

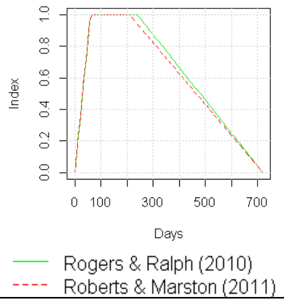
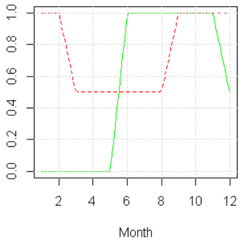
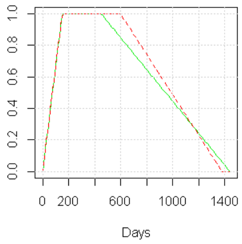
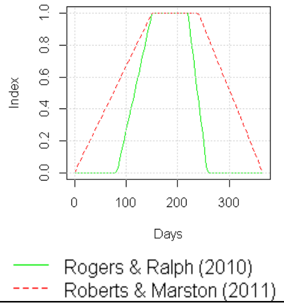
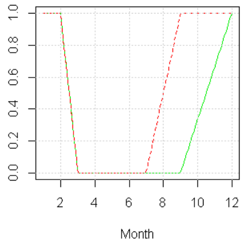
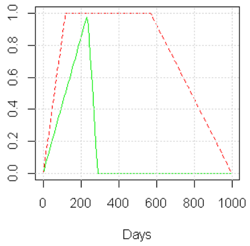
	Flood duration	Flood timing	Inter-flood dry period
Rogers and Ralph (2010)	Ideal flood duration is 2-8 months. Maximum flood duration is 24 months.	Ideal flood timing is winter to spring. Maximum flood timing is winter to early summer.	Ideal inter-flood dry period is 5-15 months. Maximum inter-flood dry period is 36-48 months.
Roberts and Marston (2011)	5-7 months for forests, 2-4 months for woodlands. Continuous Inundation of 2-4 years has been tolerated at a diverse site (Barmah Forest).	Start of flooding is not critical, but more growth is achieved if flooded during spring-summer.	NA (Defined based on information on flood frequency and flood duration.)
Preference curves			

Table 2. Water requirements of water couch and their preference curves

	Flood duration	Flood timing	Inter-flood dry period
Rogers and Ralph (2010)	Ideal flood duration is 1-2 months or 299-440 days/2 years. Maximum duration 163-513 days/2 years.	Ideal flood timing is summer. Maximum flood timing is spring to summer.	Ideal dry period is 236 days. Maximum dry period is 290 days.
Roberts and Marston (2011)	5-8 months.	Late winter or spring. Flooding is needed over summer.	NA (Defined based on information on flood frequency and flood duration.)
Preference curves			

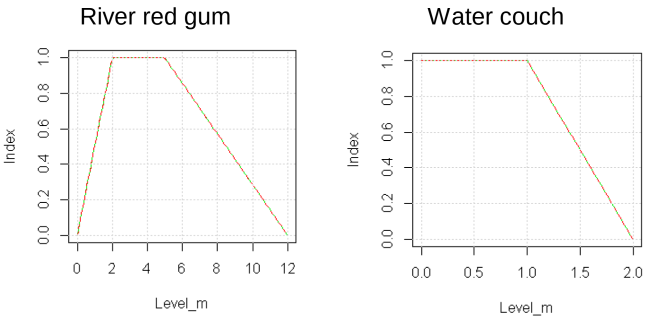


Figure 3. Groundwater level (meter below ground) preference curves for river red gum and water couch.

3.2 Weighting

A weighting approach is used to combine the flood attributes into a single measure of surface water suitability for the reproduction and regeneration of riparian vegetation. In combining the flood attributes, we used the weighting approach. Weights were assigned to each flood attributes based on information provided in Rogers and Ralph [2010] or Roberts and Marston [2011]. For river red gum, Rogers and Ralph [2010] suggested that frequency, duration and timing all have significant influence on the growth of river red gum. Therefore, the weights for duration, timing and inter-flood dry period are 0.4, 0.4 and 0.2, respectively. In contrast, Roberts and Marston [2011] believes flood timing is not critical for the growth of river red gum. As a result, more weight was given to flood duration (Table 3). In terms of water couch, both sources acknowledge that flood timing is most critical [Roberts and Marston, 2011; Rogers and Ralph, 2010]. Therefore, more weights were given to flood timing (Table 3).

Table 3. Weighting flood attributes for river red gum and water couch

Species	Reference	Flood duration	Flood timing	Inter-flood dry period
River red gum	Rogers and Ralph (2010)	0.4	0.4	0.2
	Roberts and Marston (2011)	0.5	0.2	0.3
Water couch	Rogers and Ralph (2010)	0.25	0.5	0.25
	Roberts and Marston (2011)	0.25	0.5	0.25

4 RESULTS

The results for Asset 2, Barbers Lagoon, are illustrated in Figure 4. In general, water regime (including surface and groundwater) is in favour of the growth of river red gum more than for water couch. This is consistent with the site condition where river red gum is much more widespread than water couch which only exists in patches. Unsurprisingly, significantly higher water suitability indices are reported during the wet period for both species, especially for the river red gum. This is because apart from longer and more frequent flooding events during the wet period, shallower groundwater levels (average 8.6m below ground, SD=0.4) also sustains the growth of river red gum. In contrast, the average groundwater level dropped to 11.9m (SD=1.0) below ground during the dry period.

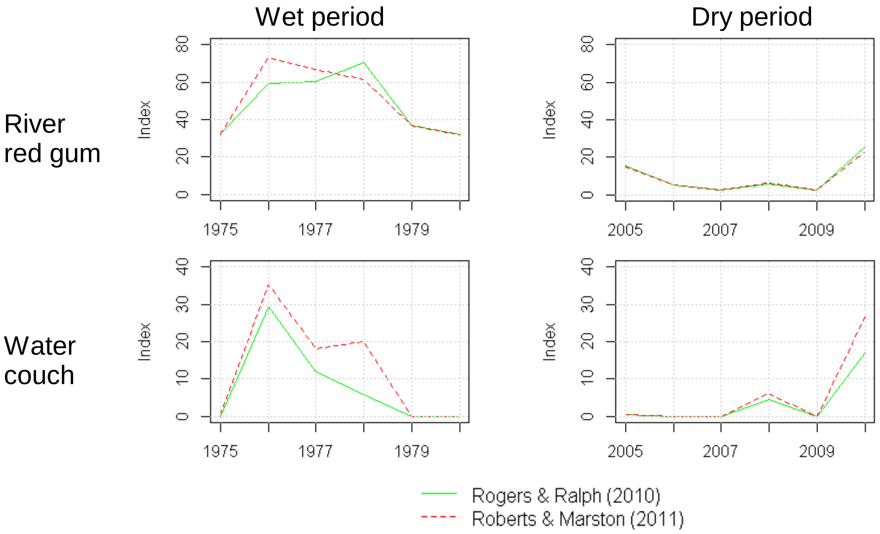


Figure 4. Annual water suitability index for river red gum and water couch at wet (1975-1980) and dry (2005-2010) periods at Barbers Lagoon, Namoi.

In general, greater differences are found for the wet period when using different sets of preference curves. This is because the wetter climate generates large and more frequent events, accumulatively resulting in greater differences in model outcomes. The differences in model outputs for river red gum are smaller than those for water couch, primarily because the preference curves generated for river red gum are more consistent between the two sources. In Australia, the ecology of river red gum has been studied more than water couch, and hence the water requirements of river red gum are better understood and well documented. In contrast, there is a greater uncertainty in the water requirements of water couch, leading to greater disagreement in preference curves and model outputs.

For river red gum, highest water suitability index is estimated in 1976 using the preference curves from Roberts and Marston [2011], while 1978 is estimated to be the best year when using preference curves from Rogers and Ralph [2010]. This is mainly caused by differences in flood timing. The total flow in 1976 and 1978 is 1875 and 1310 GL, respectively. In 1976 most floods occurred from late January to early March, while in 1978 most floods occurred in July and then in September. The different opinions in preferred flood timing for the growth of river red gum contribute to the differences in water suitability outcomes.

In terms of water couch, the model outputs using preference curves from Roberts and Marston [2011] are consistently higher than from Rogers and Ralph [2010]. In 1978, the estimated annual water suitability index using Roberts and Marston [2011] is more than three times as much as that from Rogers and Ralph [2010]. This may be because the preference curves from Roberts and Marston [2011] cover greater ranges in all flood attributes (duration, timing inter-flood dry period) than those from Rogers and Ralph [2010], particularly in the preference of winter-spring floods. Interestingly, the references used in Rogers and Ralph [2010] to inform water requirements of water couch are mostly taken directly from Blanch et al. [1999], which is based on an once-off survey at the lower Murray, the southern end of the Murray-Darling Basin. In contrast, Roberts and Marston [2011] attempted to generalise water requirements based on longer term (several years) studies and observations, mostly at the Gwydir Wetlands, which are located at the north of the Namoi River Catchment.

5 CONCLUSIONS

Preference curves are an effective way to estimate water suitability for the riverine ecosystems. Two of the most comprehensive and published reviews of water requirements of riverine vegetation in the Murray-Darling Basin are provided in Rogers and Ralph [2010] and Roberts and Marston [2011]. The variation in recommended water requirements between these sources reflects uncertainty in our ecological knowledge. This study shows that this uncertainty can have significant impacts on estimated ecological outcomes (e.g. in 1978). The impacts vary depending on species and water regime. In general, water requirements of water couch is much less studied than river red gum, which is reflected in the lesser level of consistency in the preference curves and model outcomes. In terms of water regime, requirement for flood timing is most uncertain for both species and is contributing to the variation in model outcomes.

The ecological model has been designed to evaluate ecological impacts of climate change and management. This will be achieved through the integration of hydrology and ecological models. For the larger Namoi project, the surface flow and groundwater levels will be derived from IHACRES_GW [Blakers et al., 2011], a surface-groundwater hydrological model being developed at the Australian National University. The implication of ecological uncertainty to modelling and subsequently management evaluation will be further assessed through the comparison of model outcomes for different scenarios. An integrated model will also allow comparison of the impacts of hydrological uncertainties and ecological uncertainties on a same scale. Such analyses will provide valuable insights into the significance of ecological knowledge uncertainty in the integrated hydro-ecological model.

ACKNOWLEDGEMENTS

This work was funded by the Australian National Centre for Groundwater Research and Training (NCGRT), and the Cotton Catchment Communities Cooperative Research Centre. Thanks to Jane Roberts and Sue Powell for their valuable advice.

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