# Co-evolution of hydrodynamics, vegetation and channel evolution in in wetlands of a semi-arid floodplain

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## 1. Introduction

This research presents an update in the development of an eco-geomorphologic framework that combines hydrodynamic, vegetation and channel evolution modules. The hydrodynamic simulation provides spatially distributed values of inundation extent, duration, depth and recurrence to drive a vegetation model based on species preference to hydraulic conditions. It also provides velocities and shear stresses to asses geomorphological changes. Regular updates of stream network, floodplain surface elevation and vegetation coverage provide feedbacks to the hydrodynamic model. We continue the exploitation of the different modules of the model based on preliminary tests and development of conceptual model elements

## 2. Site description

The Macquarie Marshes are located in the semi-arid region in north western NSW, Australia, and constitute part of the northern Murray–Darling Basin (Figure 1). The Marshes are comprised of a system of permanent and semi-permanent marshes, swamps and lagoons interconnected by braided channels (Ralph, 2011). The wetland complex serves as nesting place and habitat for many species of water birds, fish, frogs and crustaceans, and portions of the Marshes is listed as internationally important under the Ramsar Convention.

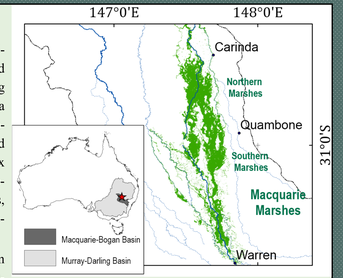


**Figure 1**. Location of the Macquarie Marshes

Some of the wetlands have undergone degradation over the last four decades, which has been attributed to changes in flow management upstream of the marshes (Wen et al., 2013). Among the many characteristics that make this wetland system unique is the occurrence of channel breakdown and channel avulsion, which are associated with decline of river flow in the downstream direction typical of dryland streams. Decrease in river flow can lead to sediment deposition, decrease in channel capacity, vegetative invasion of the channel, overbank flows, and ultimately result in channel breakdown and changes in marsh formation. A similar process on established marshes may also lead to channel avulsion and marsh abandonment, with the subsequent invasion of terrestrial vegetation. All the previous geomorphological evolution processes have an effect on the established ecosystem, which will produce feedbacks on the hydrodynamics of the system and affect the geomorphology in return.

## 3. Methods

This research intends incorporate feedbacks between hydraulics, surface evolution and vegetation in order to produce realistic predictions of wetland dynamics in an ecogeomorphologic framework (Figure 2).

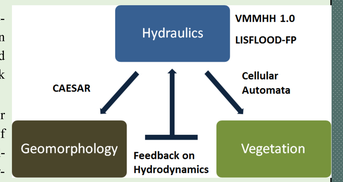


**Figure 2**. Ecogeomorphologic framework.

So far we have implemented different models for simulating the ecogeomorphologic processes of the Macquarie Marshes. The CAESAR-LISFLOOD paired model was calibrated for determining floodplain surface evolution. A quasi-2D hydrodynamic model (VMMHH 1.0) has been accustomed used for simulating flooding of the Macquarie Marshes.

The vegetation model is under development as a cellular automata model. One of the greatest challenges of this project in to link the use of the different models in a way the feedbacks from the different fields can be incorporated.

## 4. Wetland flow modelling

A first approach to the hydrodynamic simulation o the Macquarie Marshes used a domain of around 1700 $Km^2$ set in a squared 90x90 m grid. The VHHMM 1.0 hydrodynamic model (Riccardi, 2000) was implemented and preliminary results were presented by Sandi-Rojas et al. (2014). This model incorporates simplified versions of the mass and momentum conservation differential equations and uses a fast algorithm for its solution.

Results were found to provide a good general representation of the inundation extent. Comparison of observed and simulated inundation maps are presented in Figure 3. Hydrograph comparison revealed that the model has an satisfactory performance in terms of discharge prediction; however, improvements are clearly necessary. This lead us to concentrate our work in the Northern Marshes, where inundation area is greatly underestimated in the model. Current work is focussed on improving flow simulations for this section of the marshes.

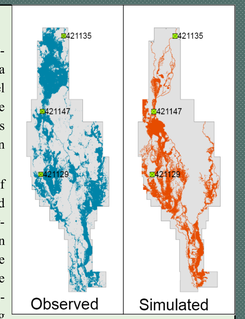


**Figure 3**. Inundation maps from a medium flow event.

## 6. Northern Marshes Modelling

A cellular-automaton based landscape evolution model (LEM) was used for preliminary assessment of geomorphological modelling of the marshes. The CAESAR-LISFLOOD combines the capabilities of a long scale LEM (CAESAR) with a simplified 2D flow model (LISFLOOD), allowing faster simulation times and better physically-based results (Van De Wiel et al., 2007; Coulthard et al., 2013).

The simulated domain of the Northern Marshes has area of around 260 $Km^2$ The area was defined as a squared 15x15 m grid, resulting in a domain comprised of approximately 1.2 million cells. The high resolution increases the computation times considerably, but this is compensated by highly detailed results that allow for a deeper analysis of the evolution processes occurring in this heavily braided region.

Calibration results have shown an improvement in the preliminary results from the VHHMM 1.0 (as seen on Figures 3 and 4). Only one gauging station was used for calibration (No. 421135). Water depths produced at the downstream boundary close to the control station show an acceptable fit with the observed data (Figure 5).

One of the drawbacks of implementing this model is the long computational time (approximately 15 days to model 150 days). Initially, it was proposed the use of larger cells, but the discretization was limited by the width of the streams. It is necessary to address this issue for future works.

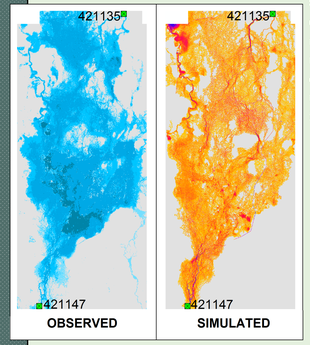


**Figure 4**. Observed and simulated inundation maps from the same medium flow event.

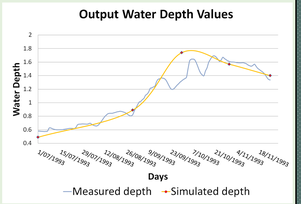


**Figure 5**. Simulation results at output station No.421135.

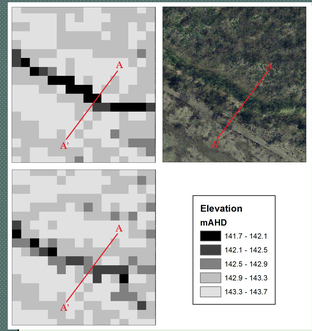


**Figure 6**. Aggradation of the main channel. Top and bottom left show topography at the beginning and end of simulation respectively.

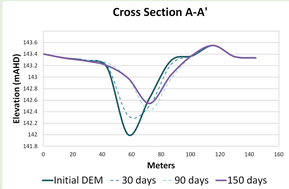


**Figure 7**. Deposition of sediment in the main channel.

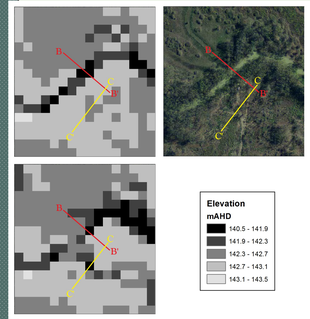


**Figure 8**. Channel formation. Top and bottom left show topography at the beginning and end of simulation respectively.

## 6. Geomorphologic processes modelling

A few cross sections across the Northern marshes were selected in order to analyse the capabilities of the CAESAR-LISFLOOD model for representing the geomorphological processes.

Aggradation and avulsion processes usually occur over large time scale periods (decennial to centennial), but they originate from the interaction of smaller scale sediment transport and deposition sub processes, altogether with vegetative invasion or abandoning (Hajek and Wolinsky, 2012).

Due to its computational cost, this preliminary study has been limited to simulation of a 150 days flood event. Figures 6-7 show a reduction of cross section A-A' area after the flood due to sediment deposition.

In a similar way, Figure 8 shows the channel formation process. Flow overtops the main stream bank and then erodes the floodplain in cross section C-C' (Figure 10). At the same time flow deviated from the main channel promotes deposition and it is partially filled (Figure 9). This incision of the floodplain does not guarantee an avulsion, but it suggests that for future long term simulations the model will be able to reproduce such process.

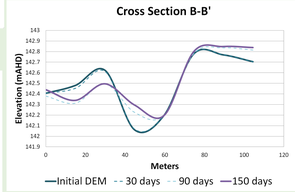


**Figure 9**. Partial filling of the main channel.

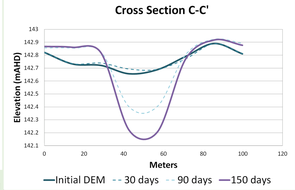


**Figure 10**. Erosion of the floodplain creating a new channel.

## 4. Conceptual Vegetation Evolution Model

Vegetation species in the Macquarie Marshes are known to be flood dependant; thus time aggregated characteristics such as flooding frequency, timing, duration and water depth are essential requirements for vegetation survival. These characteristics have been reported for some of the plant species of the Macquarie Marshes and grouped by eco-tones (Table 1). This characteristics can be used as deterministic transition functions in a cellular automata model for vegetation evolution (Figure 11).

The concept of the model is to use the hydrodynamic model to determine flow characteristics over a period of one to five years. Once this simulation is completed the vegetation model can recalculate changes in the vegetation for each cell by considering water requirements, vegetation in the previous timestep, existing secondary species in the cell and critical conditions for the species. The set of transitional functions will determine the occurrence of vegetation successions (Figure 12).

Changes in the vegetation will be reintroduced in the hydrodynamic model as a variation of the Manning roughness according to each plant species.

| Eco-tone | Flooding frequency | Timing | Flood duration | Water depth |
|---|---|---|---|---|
| Black Box woodland | 1 in 10 years | Summer to autumn | 2 months | - |
| River Red Gum woodland | 1 in 3-5 years | Spring to summer | 2-4 months | - |
| River Red Gum forest | 1 in 3 years | Spring to summer | 2-6 months | - |
| Lignum shrubland | 3- 10 years | Spring to summer | 1-6 months | 60 cm |
| Water couch | Annual | Spring to summer | 2-3 months | 30 - 60 cm |
| Reed aggrupation | Annual | Spring to summer | 6 months | 30 cm |
| Mixed marsh | Annual | Spring to summer | 9-12 months | 0-200 cm |
| Cultivated | - | - | - | - |

**Table 1.** Water requirements for different eco-tone levels.
Note: Adapted from Rogers (2011)

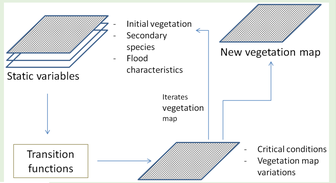


**Figure 11.** Conceptual vegetation model.

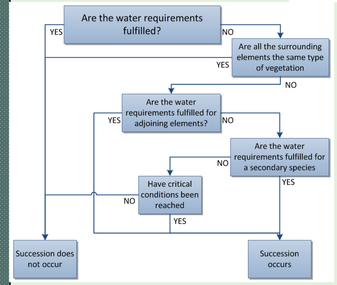


**Figure 12**. Iteration loop for vegetation.

## 7. References

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