A framework for the ecogeomorphological modelling of the Macquarie Marshes, Australia

Jose Rodriguez(1), Manuel Seoane(1), Steven Sandi Rojas(1), Patricia Saco(1), Gerardo Riccardi(2), Neil Saintilan(3), Li Wen(3).

(1) School of Engineering, University of Newcastle, NSW, Australia

(2) Centre for Hydro-Environmental Research, University of Rosario, Santa Fe, Argentina

(3) Science Division, NSW Office of Environment and Heritage Sydney, Australia

1. Introduction

This research presents an eco-geomorphologic framework that combines hydrodynamic, vegetation and channel evolution modules. The framework uses hydrodynamic modelling in order to compute spatially distributed and time aggregated characteristics of the flow. These characteristics can be use for developing a vegetation model based on species preferences to hydraulic conditions. A model that contemplates sediment transport is also used to asses geomorphological changes. Updates of river network, floodplain surface elevations and vegetation coverage provide feedbacks to the hydrodynamic model. We performed preliminary tests and compared the results to existing data to assess the models capabilities and limitations.

2. Description

The Macquarie Marshes is a system of permanent and semi-permanent marshes, swamps and lagoons interconnected by braided channels. The Marshes are located in a semiarid region in south eastern Australia and is part of the of the Murray–Darling Basin (Figure 1).

Portions of marshes are listed as internationally important under the Ramsar Convention. Over the last few decades some of the ecological assets of the wetlands have undergone degradation, mainly attributed to water allocations and regulation at Burrendong Dam upstream of the marshes.

Channel breakdown and avulsion processes occur in the marshes. These are associated with decline of discharge in the downstream direction typical of dryland streams. Decrease in discharge leads to sediment deposition, reduction of the channel, vegetative invasion of the channel, overbank flows, and ultimately channel breakdown, marsh formation, avulsion and marsh abandonment. All the previous geomorphology evolution processes have an effect on the established ecosystem, which will produce feedbacks on the hydrodynamics of the system and thus affect the geomorphology.

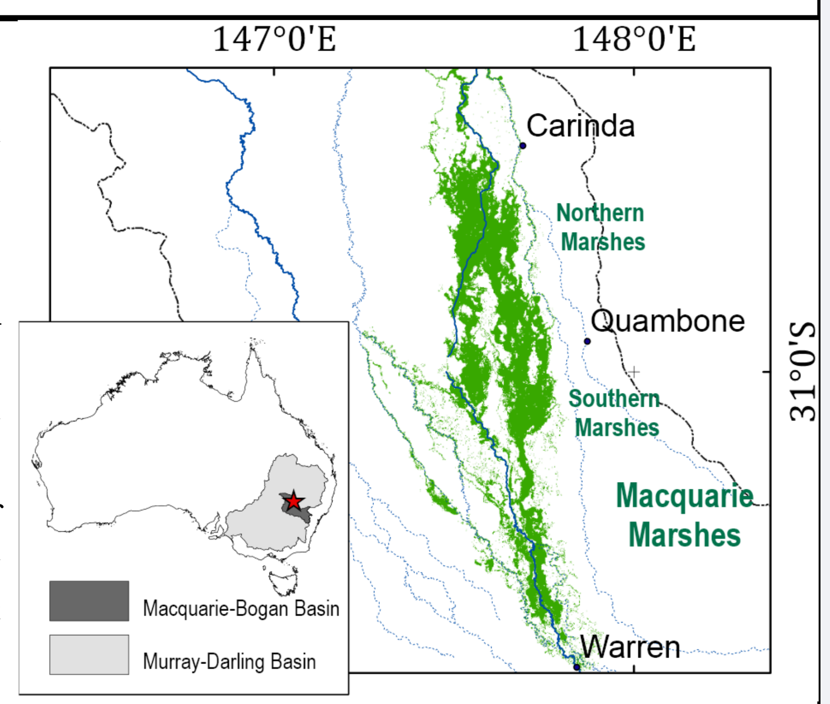

Figure 1. Location of the Macquarie Marshes

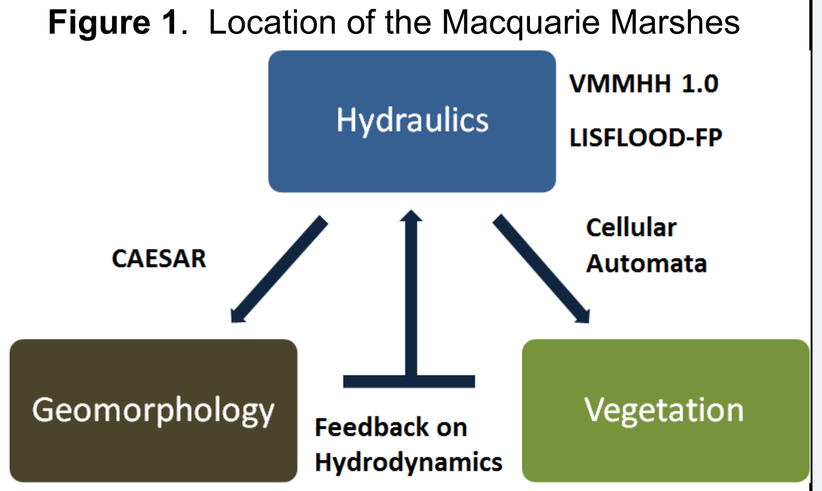

Figure 2. Ecogeomorphologic framework.

This research intends to incorporate these feedbacks to produce realistic predictions of wetland dynamics in an ecogeomorphologic framework (Figure 2). Different models are tested for representing the ecogeomorphologic processes of the Macquarie Marshes. The CAESAR-LISFLOOD (Coulthart et al. 2013) combined model was calibrated for determining floodplain surface evolution. The VMMHH 1.0 hydrodynamic model has also been used for simulating flooding of the Macquarie Marshes and a cellular automata model is under development for simulating vegetation changes. One of the challenges of this project is to link different models in order to incorporate feedbacks from vegetation and floodplain surface changes into flow processes.

3. Wetland flow modelling

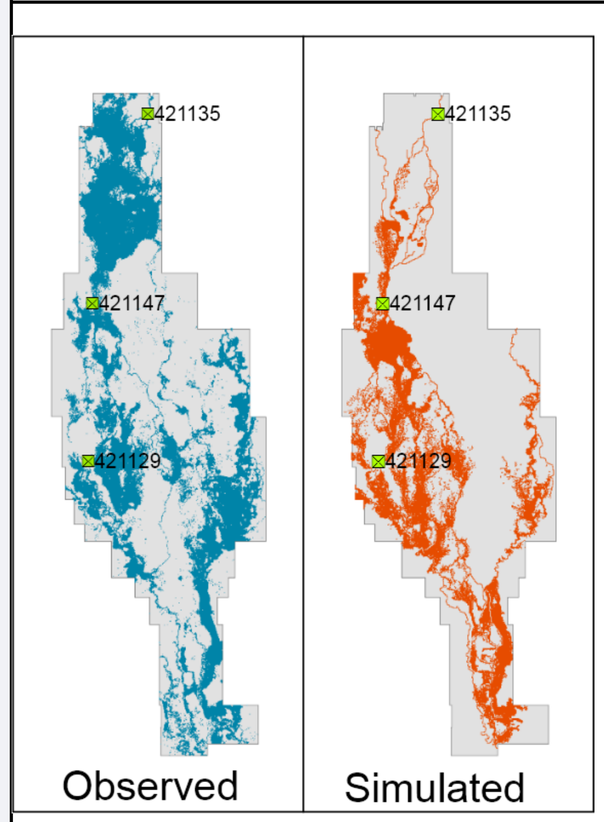

Figure 3. Inundation maps from a medium flow event.

The total area of the Macquarie Marshes is around 1700 Km^2. A cell based quasi-2D hydrodynamic model (VHHMM 1.0) was implemented in order to simulate flow dynamics of the whole wetland using a squared 90x90 m grid. 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. It includes cells that represent river reaches with sub grid parameterization.

Results were found to provide a good general representation of the inundation extent. Comparison of observed and simulated inundation maps and hydrographs are presented in Figures 3-5.

Even though the results obtained with the VMMHH 1.0 are acceptable for preliminary calibration, further work is needed for a better representation. This is specially true for the Northern Marshes, where inundation is greatly underestimated. Current work is focussed on improving simulations for this section of the marshes.

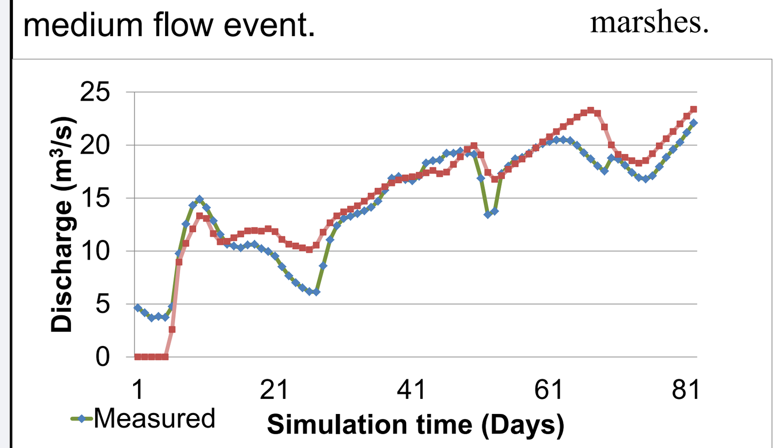

Figure 4. Simulation results for measuring station No.421147.

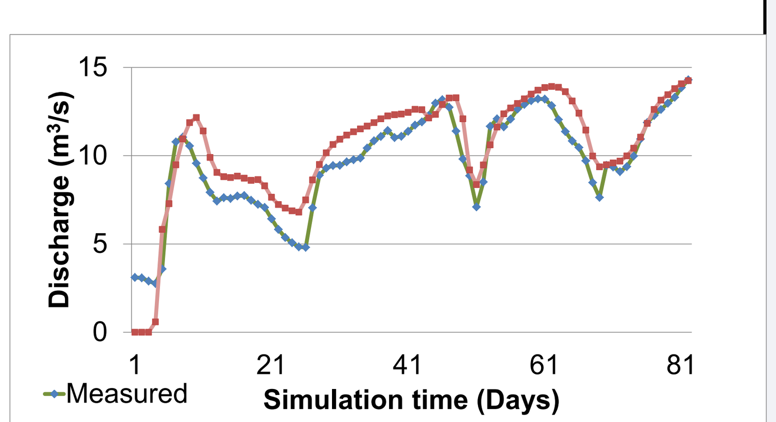

Figure 5. Simulation results for measuring station No.421129.

4. Conceptual Vegetation Evolution Model

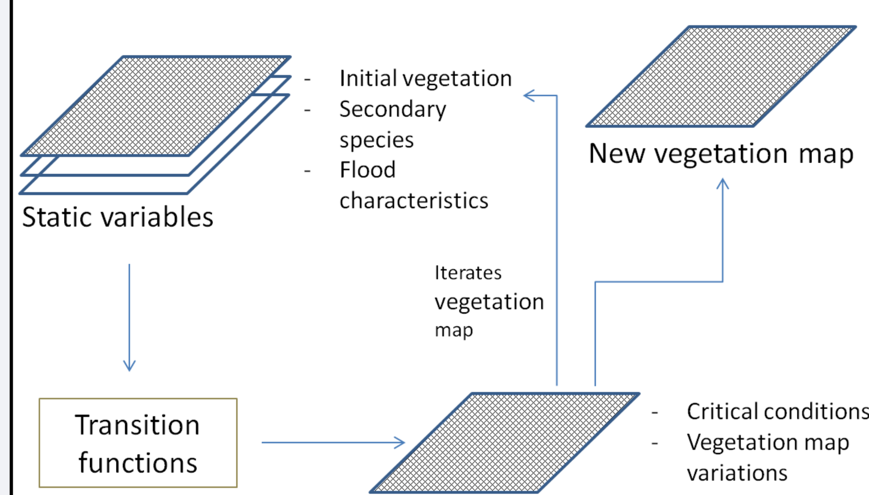

Figure 6. Conceptual vegetation model.

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 they can be used as deterministic transition functions in a cellular automata model for vegetation evolution (Figure 6).

The concept of the model is to use the hydrodynamic simulations 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 7).

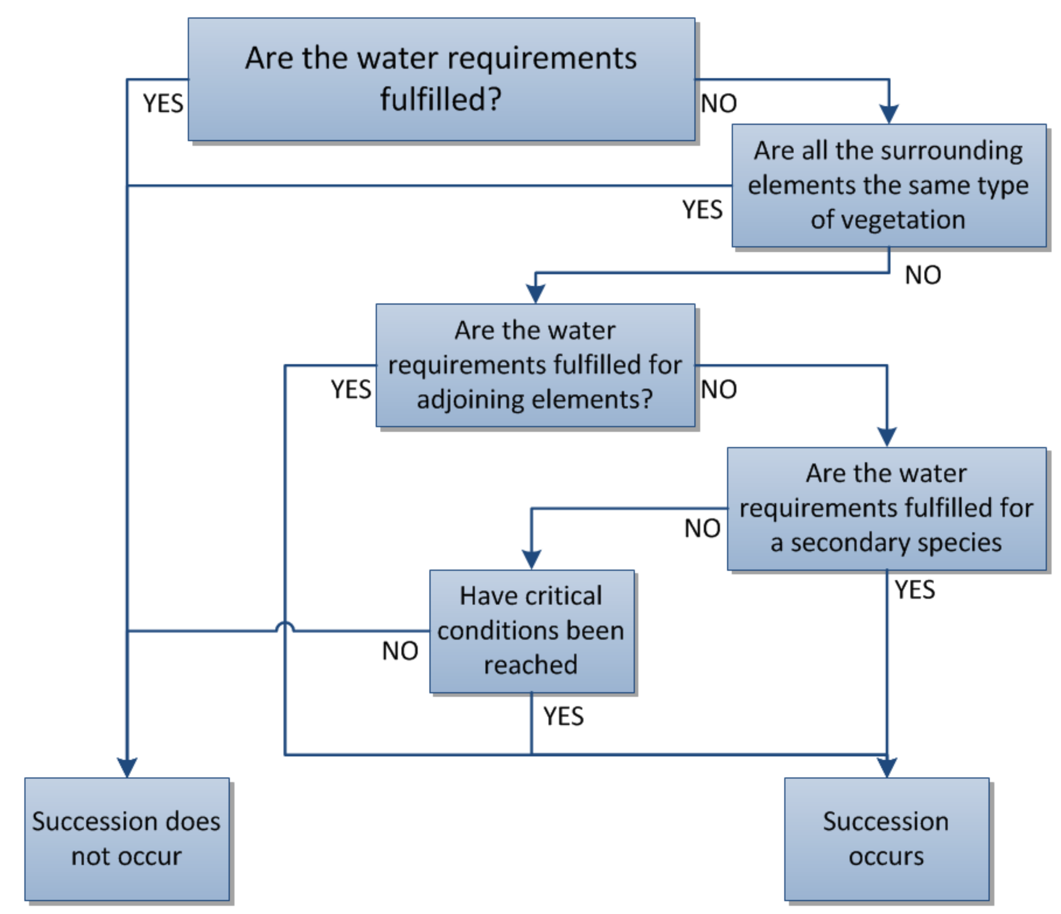

Figure 7. Iteration loop for vegetation.

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

5. Northern Marshes Modelling

A cellular-automata landscape evolution model (LEM) was used for preliminary assessment of geomorphological dynamics 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.

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 densely braided region.

Calibration results show an improvement in the preliminary results from the VHHMM 1.0 (as seen on Figures 3 and 8). 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 9).

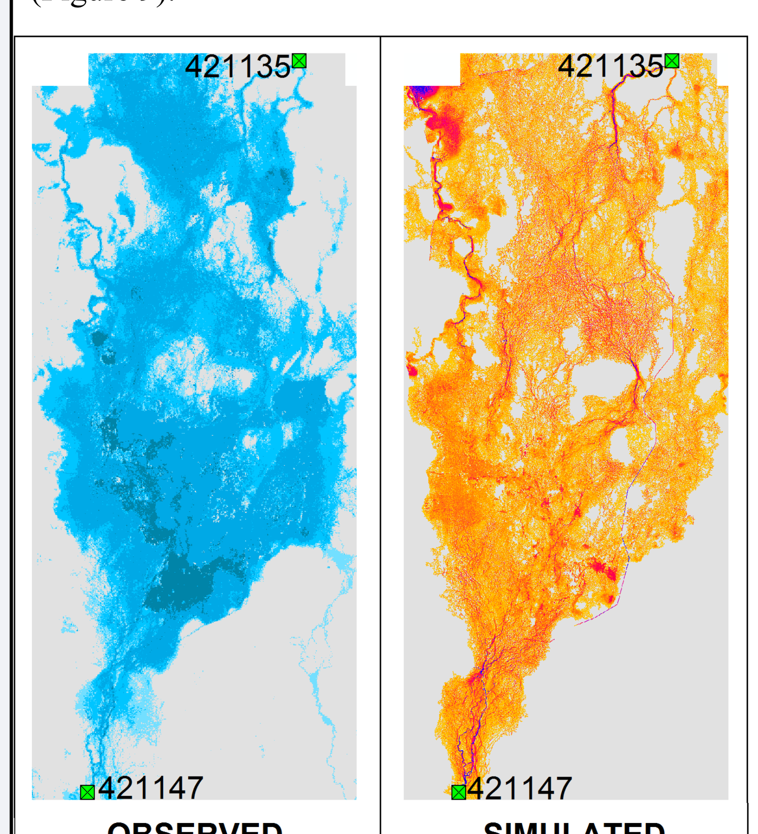

Figure 8. Observed and simulated inundation maps from the same medium flow event.

One of the drawbacks of implementing this model is the long computational time (approximately 15 days to model 150 days). The use of larger cells will speed up computations, but it will require sub gridding parameterization due to the reduced width of the streams. This issue is currently under implementation.

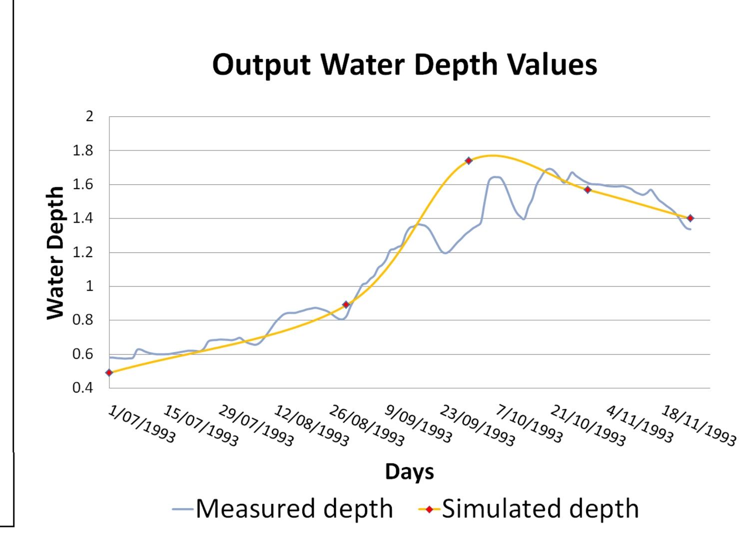

Figure 9. Simulation results at output station No.421135.

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 long time scales (decennial to centennial), but they originate from small scale sediment transport and deposition processes intracting with vegetative invasion or abandoning.

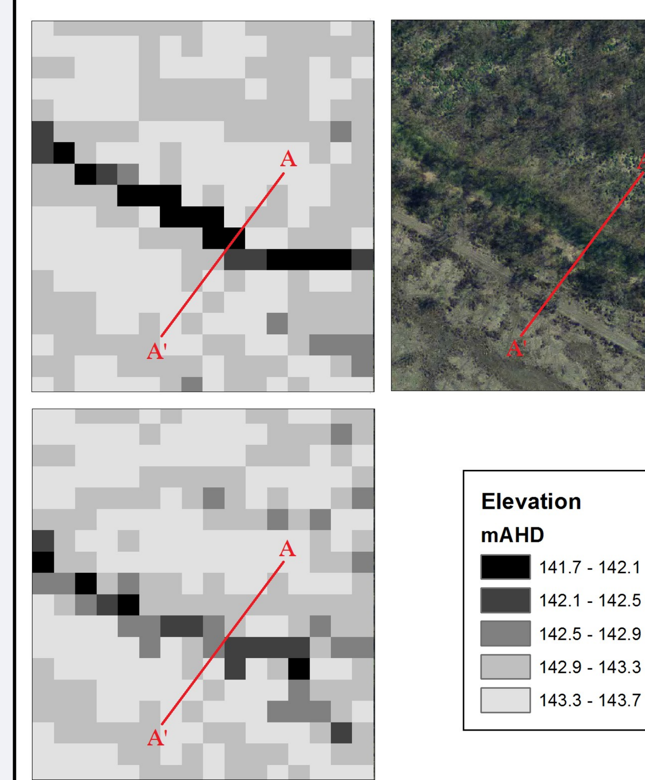

Figure 10. Aggradation of the main channel. Top and bottom left show topography at the beginning and end of simulation respectively.

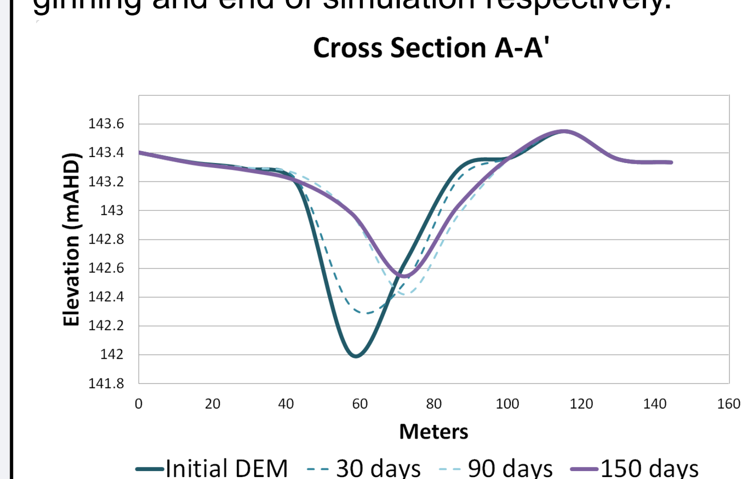

Figure 11. Deposition of sediment in the main channel.

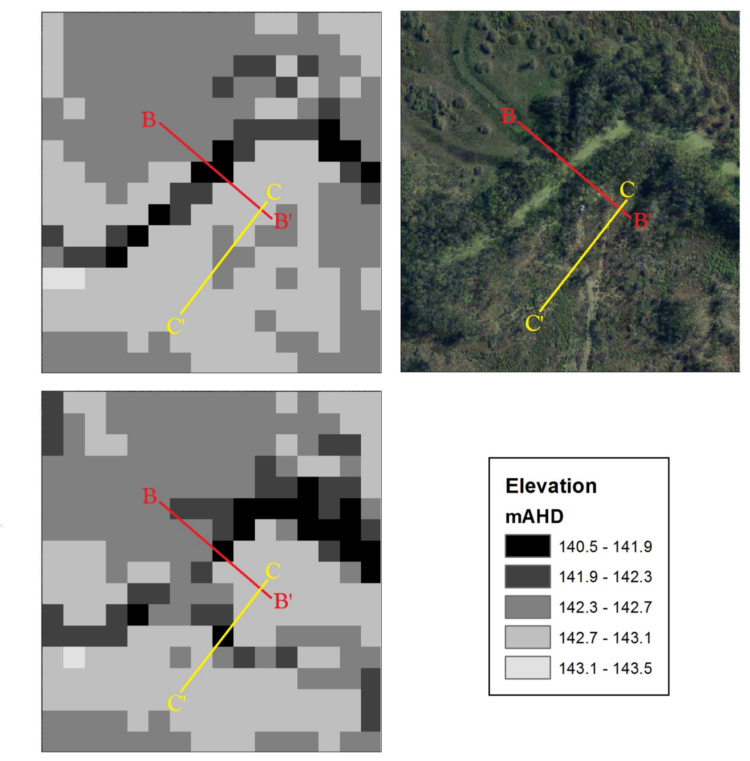

Figure 12. Channel formation. Top and bottom left show topography at the beginning and end of simulation respectively.

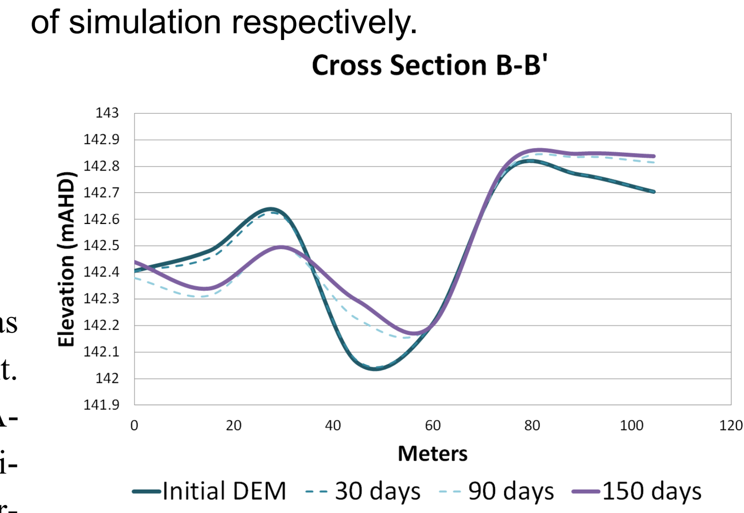

Figure 13. Partial filling of the main channel.

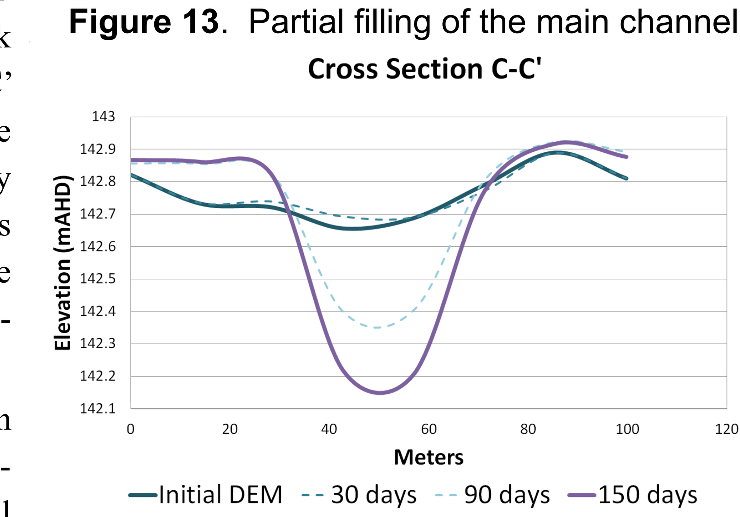

Figure 14. Erosion of the floodplain creating a new channel.

Due to its computational cost, this preliminary study has been limited to simulation of a 150 days flood event. Figures 10-11 show how a reduction of cross section A-A' area after the flood occurs due to sediment deposition. In a similar way, Figure 12 shows the channel formation process. Flow overtops the main stream bank and then erodes the floodplain in cross section C-C' (Figure 14). At the same time flow deviated from the main channel promotes deposition and it is partially filled (Figure 13). 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.

Overall, simulation results show that erosion-deposition processes are being simulated in a reasonable way. Formal comparison with observed geomorphological changes is being implemented.

7. References

- Coulthard, T. J., Neal, J. C., Bates, P. D., Ramirez, J., de Almeida, G. A. M. and Hancock, G. R. (2013) "Integrating the LISFLOOD-FP 2D hydrodynamic model with the CAESAR model: implications for modelling landscape evolution." Earth Surf. Process. Landforms, 38: 1897–1906.
- Hajek, E. A. and M. A. Wolinsky (2012). "Simplified process modeling of river avulsion and alluvial architecture: Connecting models and field data." Sedimentary Geology 257–260(0): 1-30.
- Ralph, T. J., Kobayashi, T., Garcia, A., Hesse, P. P., Yonge, D., Bleakley, N. & Ingleton, T. (2011) "Paleoecological responses to avulsion and floodplain evolution in a semiarid Australian freshwater wetland." Australian Journal of Earth Sciences 58(1): 75-91.
- Riccardi, G., (2000). "A cell model for hydrological-hydraulic modeling." Journal of Environmental Hydrology, 8.
- Sandi Rojas, S. G., Rodriguez, J. F., Saco, P. M., Riccardi, G., Wen, L., Saintilan, N., Stenta H, Trivisonno F, Basile, P. (2014). Macquarie river floodplain flow modeling: Implications for ecogeomorphology. River Flow 2014: Proceedings of the 7th International Congress of Fluvial Hydraulics. CRC Press: 2347-2355.
- van de Wiel, M. J., Coulthard, T. J., Macklin, M. G., Lewis, J. (2007) "Embedding reach-scale fluvial dynamics within the CAESAR cellular automaton landscape evolution model." Geomorphology 90(3–4): 283-301.
- Wen, L., Macdonald, R., Morrison, T., Hameed, T., Saintilan, N., Ling, J. (2013). "From hydrodynamic to hydrological modelling: Investigating long-term hydrological regimes of key wetlands in the Macquarie Marshes, a semi-arid lowland floodplain in Australia." Journal of Hydrology 500 (0): 45-61.