Incorporating Infrastructure and Vegetation Effects on Sea Level Rise Predictions in Low-Gradient Coastal Landscapes

Jose F. Rodriguez[1] ✉ , Steven Sandi[1], Franco Trivisonno, Patricia M. Saco[1], Gerardo Riccardi[2]

[1]Civil and Env. Eng. University of Newcastle, Callaghan, NSW 2308, Australia [2]Hydraulics Department, University of Rosario, Argentina

✉ Jose.Rodriguez@newcastle.edu.au

AGU FALL MEETING
San Francisco | 14 – 18 December 2015

1. Introduction

Models of vegetation evolution on coastal wetlands responding to expected sea-level rise scenarios are common in landscape simulation studies and coastal management plans[1]. These modelling tools consider that wetland vegetation depends on the prevailing hydrodynamic conditions based on empirical evidence collected both on saltmarsh[2] and mangrove studies[3]. Accordingly, vegetation will establish itself and migrate landwards following the rising water levels. Some models consider that geomorphology will also be affected by these changes, with increased flow promoting erosion on tidal channels , and vegetation producing soil accretion on the tidal flats.

Vegetation preference to hydrodynamic conditions has been described as a function of local values of depth below mean high tide (D), tidal range, hydroperiod or elevation with respect to the tidal frame[4,5]. Most of the relationships are site-specific and often times obtained via simplifications or proxies, so generalizations and extensions of the models outside of their validated domain generate great uncertainty. In addition, the hydrodynamic simulation of the flooding attenuation effects in current models is extremely simplified. A very common modelling simplification is to neglect flow attenuation mechanisms altogether by assuming that the water levels at a given time are the same over the entire wetland. Vegetation roughness in tidal flats reduces depth and maximum inundation extent but increases ponding, so it affects both inundation depth and hydroperiod. Local man-made flow restrictions in tidal flats and channels also contribute to flood attenuation in a similar way. Hydrodynamic attenuation effects due to levies, culverts and other man-made tidal modifications are not considered in any of the existing models.

2. Methods

Our simulation approach couples a hydrodynamic model with vegetation rules based on preference to hydrodynamic conditions. It also includes soil accretion in vegetated areas for the long-term simulations. The hydrodynamic model solves the flow equations of continuity and momentum or energy at every point in the wetland to provide a continuous simulation of water levels. The model incorporates attenuation effects due to vegetation resistance using Manning's n coefficient, and due to man-made restrictions using discharge coefficients. We then use the time series of local water levels to compute inundation depths and hydroperiods required by the vegetation rules. We define vegetation establishment rules based on spring tide conditions when inundation is more extreme. Hypoxia limits establishment for saltmarsh that has a typical height of 30 cm, so a maximum threshold value of 30 cm is set for D. For mangrove we specify a suitable hydroperiod range from 0.1 to 0.5 given by limitations on oxygen availability and accumulation of phytotoxins in soils , which was selected based on our data. Once the vegetation cover is determined by the rules, a new run of the hydrodynamic model is performed on the modified domain.

3. Results and Conclusions

3.1 Initial conditions

We use as case study the sub-tropical coastal wetland located in the Hunter estuary of SE Australia presented in Fig. 1a,b. The wetland flow is heavily controlled by infrastructure, which includes 10 active culverts and bridges over an area of 1.2 km[2]. Vegetation comprises mudflats, tidal pools, *A. marina* mangroves, *S. virginicus – S. quinqueflora* mixed saltmarsh and some remnants of pasture on the periphery (Fig. 1c). We compare the results of our model and an approach that does not consider flow attenuation in Figs 1d,e,f (full attenuation effects) and Figs 1g,h,I (no attenuation effects). We use as tidal input the 2004 hourly tidal records at a nearby gauging station.
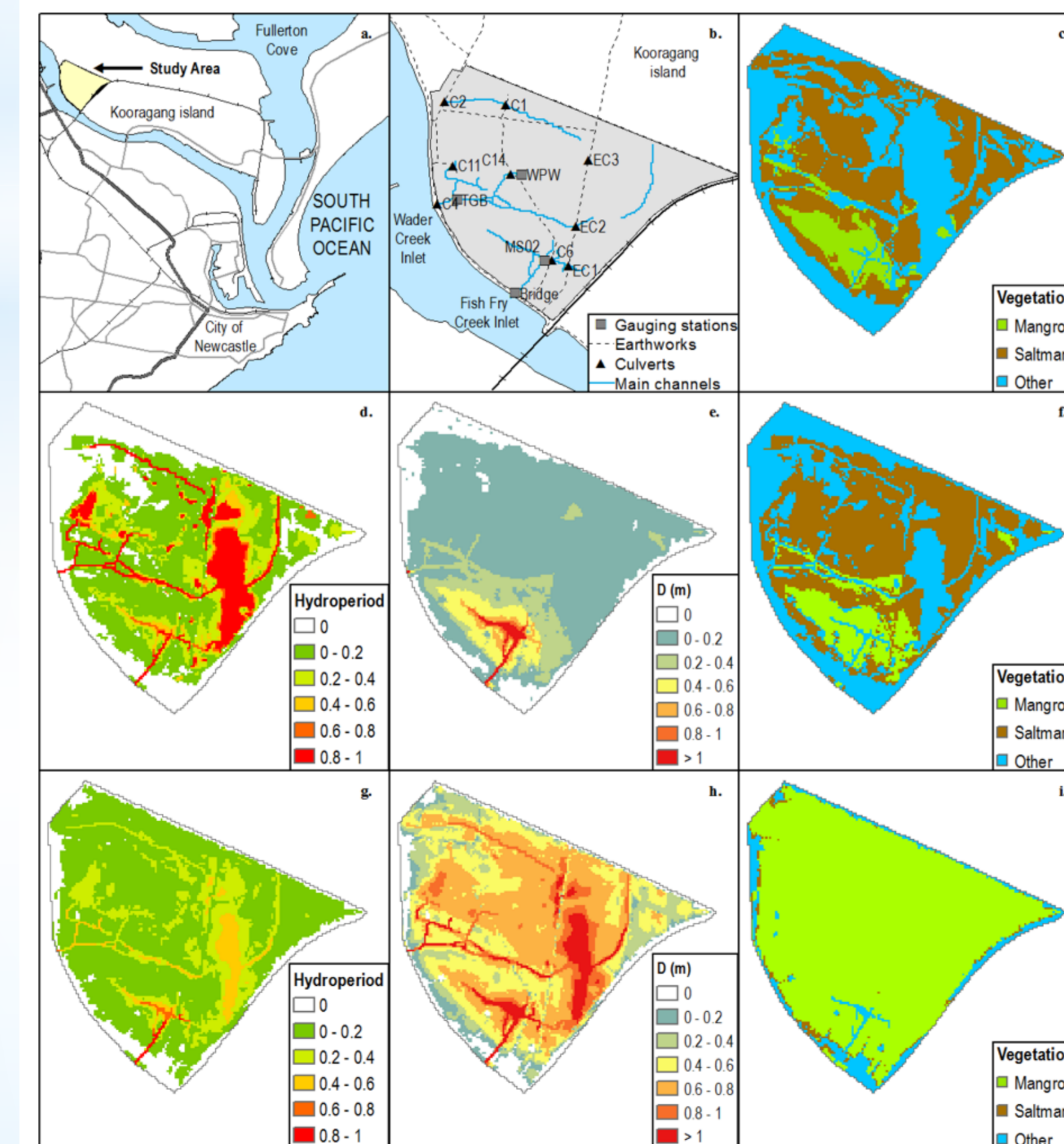

Figure 1: Modelling initial conditions in a sub-tropical tidal wetland

The approach without considering the attenuation effects of infrastructure and vegetation is unable to reproduce the initial vegetation distribution. Our approach correctly predicts mangrove and saltmarsh extent.

3.2 Predictions under sea level rise

In order to assess sea level rise effects, we run continuous simulations for 60 years with both models. We incorporate 2 mm/year of wetland surface elevation gain, due to the capability of vegetation communities to build up their own soil by trapping sediments or by accumulating organic matter[6]. We consider a sea-level rise rate of 8 mm/year that corresponds to the upper end of IPCC AR4 scenario SRES A1B projections adjusted for regional variability.
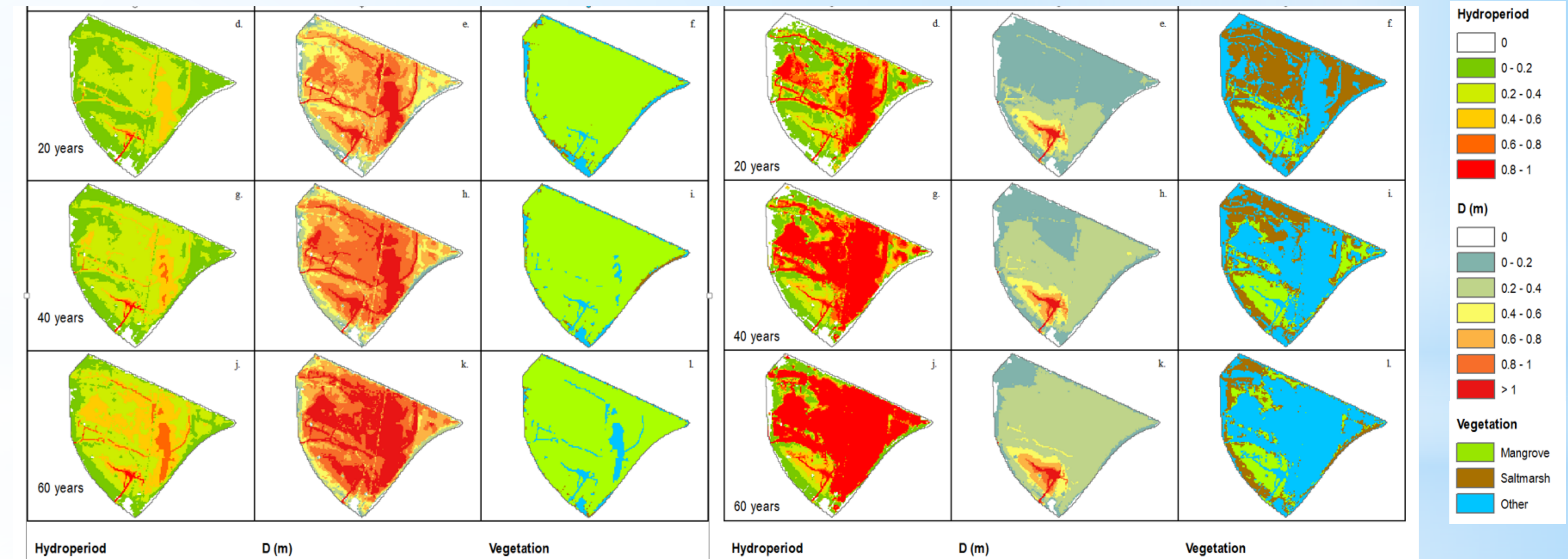

Figure 2: Predictions without infrastructure and vegetation effects

Figure 3: Predictions with infrastructure and vegetation effects

The model without attenuation effects predicts an initial vegetation distribution over most of the wetland dominated by mangrove (Fig 1i), with subsequent changes in hydroperiod and D that are gradual and follow the net difference between sea-level rise and accretion. That gradual change during the first 20 years produces conditions for mangrove establishment that squeezes saltmarsh into the high elevation areas (Fig.2f). After 40 years some mangrove areas in the lowest parts of the wetlands start to transition into mudflats and tidal pools due to increasing hydroperiods (Figs 2 i-l). When attenuation effects are considered the long term wetland evolution is totally different. Attenuation causes the uncoupling of the values of hydroperiod and D, which are noticeably correlated when the no attenuation approach is used. As a result of sea level rise, mangrove is adversely affected by the increasing hydroperiods, while saltmarsh is displaced by mangrove and by the increasing depths. During the first 20 years there is a minor migration to higher ground in both mangrove and saltmarsh communities as a result of increasing depths and hydroperiods (Fig 3d,e,f), which compensates vegetation losses due to the increase in the size of tidal pools. The next two snapshots at 40 and 60 years show more pronounced vegetation losses due to an increase in permanently inundated areas that have long hydroperiods (Fig 3h,k) and are also becoming deeper (Fig.3g,j). The distribution of vegetation consists of mangroves fringing a large central tidal pool with remnant saltmarsh in the periphery, which agrees with the typical pattern observed in sub-tropical wetlands.

References
1. Kirwan, M. & Megonigal, J. Tidal wetland stability in the face of human impacts and sea-level rise. Nature 504, 53-60 (2013).
2. Morris, J., Sundareshwar, P., Nietch, C., Kjerfve, B. & Cahoon, D. Responses of Coastal Wetlands to Rising Sea Level. Ecology 83, 2869 (2002).
3. Crase, B., et al. Hydroperiod is the main driver of the spatial pattern of dominance in mangrove communities. Global Ecology and Biogeography 22, 806-817 (2013).
4. Kirwan, M. et al. Limits on the adaptability of coastal marshes to rising sea level. GRL 37, (2010).
5. D'Alpaos, A., et al. Landscape evolution in tidal embayments: Modeling the interplay of erosion, sedimentation, and vegetation dynamics. J. Geophys. Res. 112, (2007).
6. Howe, A., Rodríguez, J.F. & Saco, P. Surface evolution and carbon sequestration in disturbed and undisturbed wetland soils of the Hunter estuary, southeast Australia. Estuarine, Coastal and Shelf Science 84, 75-83 (2009).