COMPUTATIONAL MODELLING OF THE IMPACT OF SALT MARSH MANAGEMENT INTERVENTIONS ON COASTAL FLOODING

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ABSTRACT

Coastal management strategies in the UK are coming under increasing scrutiny, due to the declaration of a climate emergency, and the governments commitments towards it. Thus, there is additional pressure to consider more sustainable coastal management options, which involve the natural environment. In this study, a coupled Delft3D FLOW-WAVE-Vegetation model of the macrotidal Taf estuary in South West Wales, UK is used to investigate the role of salt marsh management on coastal flooding. The function mitigation function of saltmarshes within this estuary was modelled under two contrasting storm conditions, and with three management interventions implemented for comparison with the current condition 'no-intervention' scenario. Certain saltmarsh management interventions are shown to have widespread impacts on estuarine hydrodynamics. The effect of extensive salt marsh grazing by livestock caused an increase in wave height over the marsh areas, while tidal currents within the estuary were also found to have increased as a result of managed realignment of the marsh area. Thus, it is important to understand the impact of the management interventions considering the context in which they are implemented.

Keywords: Delft3D, Vegetation, Coastal Flooding, Coastal Management

1. INTRODUCTION

Salt marshes can act as natural buffer zones against coastal erosion and flooding, providing protection from storm waves (Temmerman et al., 2013). Marshes have been demonstrated to be effective in attenuating wave energy at barrier marshes along open coastlines that typify marshes on the eastern coasts of the UK (e.g. Möller et al., 2014). Their coastal defence function is less well defined for smaller, more sheltered bar built estuaries which characterize much of west coast of Wales (Manning & Whitehouse, 2012). These sheltered estuaries are inherently lower energy environments than open coastlines (Davis & Fitzgerald, 2019) which may alter the relationship between salt marshes and the role of wave dampening for flood mitigation (Möller et al., 2014). Similarly, grazing of saltmarsh vegetation is a popular practice within livestock farming communities. Grazing reduces the marsh vegetation height, and subsequently the resistance to flow and waves, and can impact the hydrodynamics on the marsh, thus potentially impairing the coastal protection function of the marsh (Davidson et al., 2017).

Current environmental policy stresses the need to maintain no net loss in coastal habitat areas, adding pressure on coastal managers to consider approaches beyond traditional hard coastal defences. Managed realignment is increasingly used worldwide as a sustainable coastal defence measure, creating new intertidal areas from former flood defended areas of coastal land, as well as providing additional valuable coastal habitat. Due to the large context dependency in the effects of saltmarshes on coastal protection, there is much discussion over the impacts and the necessity of additional coastal defence interventions.

2. STUDY SITE – TAF ESTUARY, WALES, UK

The Taf (Figure 1) represents a typical Welsh estuary in terms of size, tidal characteristics and morphodynamic features. It is a small estuary (8.65 km^2) within Carmarthen Bay in the South West of Wales. The estuary is macro-tidal with a mean spring tidal range of 7.5 m, a neap tidal range of 3.7 m (Ishak, 1997) and a tidal prism of 17.7 × 106 m3 (Bristow & Pile, 2003). It is a funnel shaped sinuous estuary (Cousins et al., 2008), with peak tidal currents reaching 2.2 m/s (Ishak, 1997). The river Taf has an average daily freshwater discharge of 7.0 m^3/s with an extreme high of 60 m^3/s during winter and extreme low of 0.6 m^3/s occurring during summer (Halcrow, 2012). Because of the low freshwater influx and large tidal range, the estuary consists of intertidal flat with saltmarshes and mudflats intertwined by shallow drainage channels (Ishak, 1997). Swell wave penetration into the estuary is limited by the orientation of the estuary mouth (Pye & Blott, 2009). However, locally generated wind waves within the estuary can be significant and have a wider array of directions. The saltmarshes occupy a total area of 279 ha (Bristow & Pile, 2003). The marshes fringing the Taf estuary are characterised by the woody shrub *Atriplex portulacoides* which dominates much of the marsh. The historic village Laugharne, located at the fringe of one of the largest marshes of the estuary and regularly floods during winter storms, attracts the attention of policy makers and coastal managers as there is an urgent need to implement a sustainable solution to protect the village. The current management policy in the Taf estuary is to allow natural development of undefended shores, and reduce the risk of flooding and erosion (Halcrow, 2012). This creates a number of differing policies depending on the assets at risk, and the time frame considered.

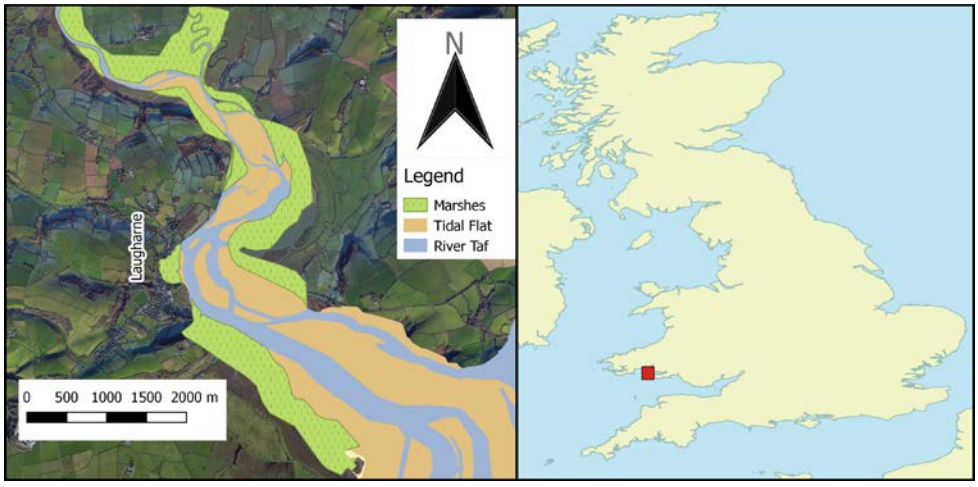

Figure 1. The Taf estuary (left) and its location within the UK (right - red box)

3. METHODOLOGY

3.1 Storm boundary conditions

To investigate the impacts of different estuary management intervention scenarios on hydrodynamics of the Taf estuary during extreme events through computational modelling, it is necessary to derive storms that may have significant implications on the estuary and the surroundings. Here, storm conditions are defined by extreme wave, wind and water levels (tides and storm surge). A range of statistically significant storm conditions were determined using hindcast wave and wind data available for this region, to encompass the diverse nature of storm events that can occur in the south-west Wales.

3.2 Modelling approach

The computational coastal model Delft3D (Lesser et al., 2004) was used to investigate changes in estuary hydrodynamics due to differing coastal management scenarios. Delft3D allows for the implementation of various features, including vegetation characteristics, differing sediments, and hard defences, which are key to accurately capturing the Taf estuary. The model provides the waves and hydrodynamics of the estuary and captures the impacts of river flow, salt marsh ecology and wave-current interactions on hydrodynamics. Encompassing the majority of the Taf estuary, the domain extends out into Carmarthen bay to a depth of 22m, to capture undisturbed water levels and waves. Three computational domains are combined using domain decomposition in order to allow local refinement to capture greater details within the Taf, and near the village of Laugharne. Grid cells gradually refine from approximately 200m x 400m at the model boundary to 10m x 10m over the marsh areas. Salt marsh vegetation is modelled with plant geometry simplified as rigid cylinders that are parameterized by plant height h_v, stem diameter b_v and plant density n_v (Dalrymple et al., 1984). The stem diameter reduces in upward stem direction. The validity of these assumption builds on the woody stems of *Atriplex portulacoides* and its successful application in prior numerical modelling studies that included salt marshes (e.g. Ashall et al., 2016).

4. RESULTS

In order to compare changes in hydrodynamic behaviour of the Taf estuary as a result of flood management interventions against its current 'no-intervention' configuration, several potential flood alleviation interventions were introduced to the saltmarsh areas of the estuary in the computational model. These interventions reflect both 'hard' and 'soft' engineering options, as well as changes in land use and environment: (i) hard coastal defence in front of the marsh; (ii) grazing by livestock; and (ii) management re-alignment of the marsh.

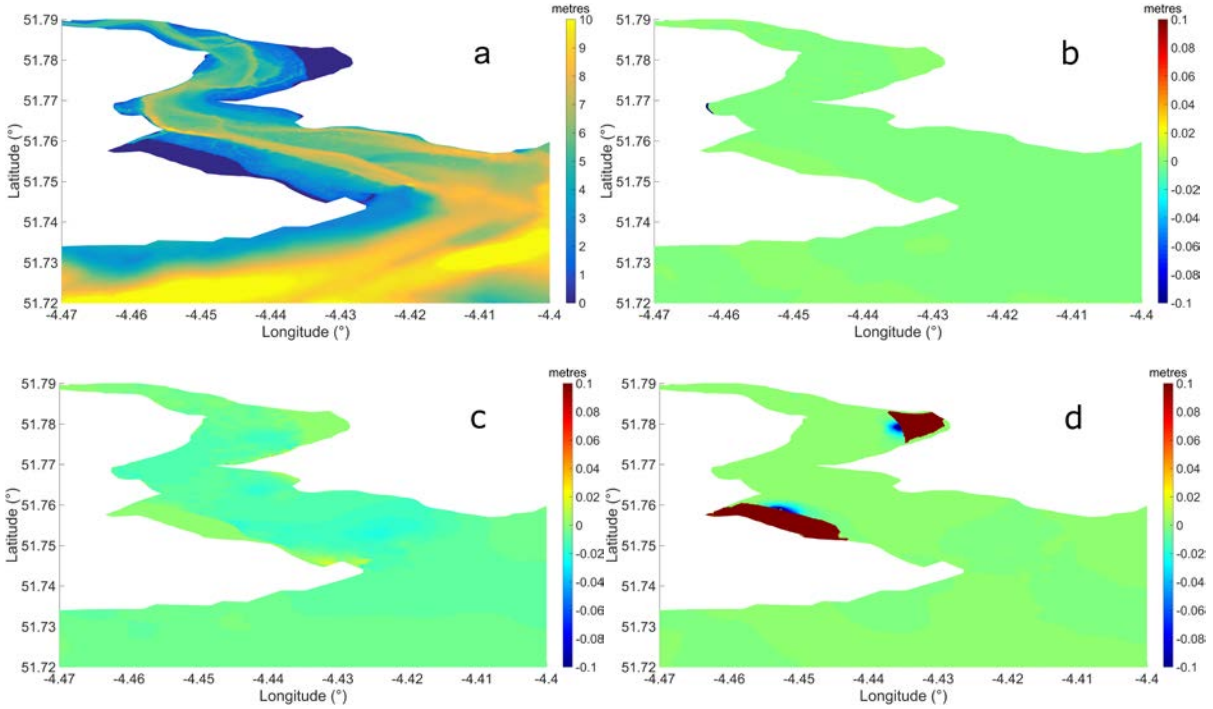

Figure 2. Comparison of Peak Storm Water Depths at the Taf estuary under the selected intervention scenarios during 1:50 year South Westerly storm. a) Current condition, b) difference between defended and current c) difference between grazed and current d) difference between managed realignment and current.

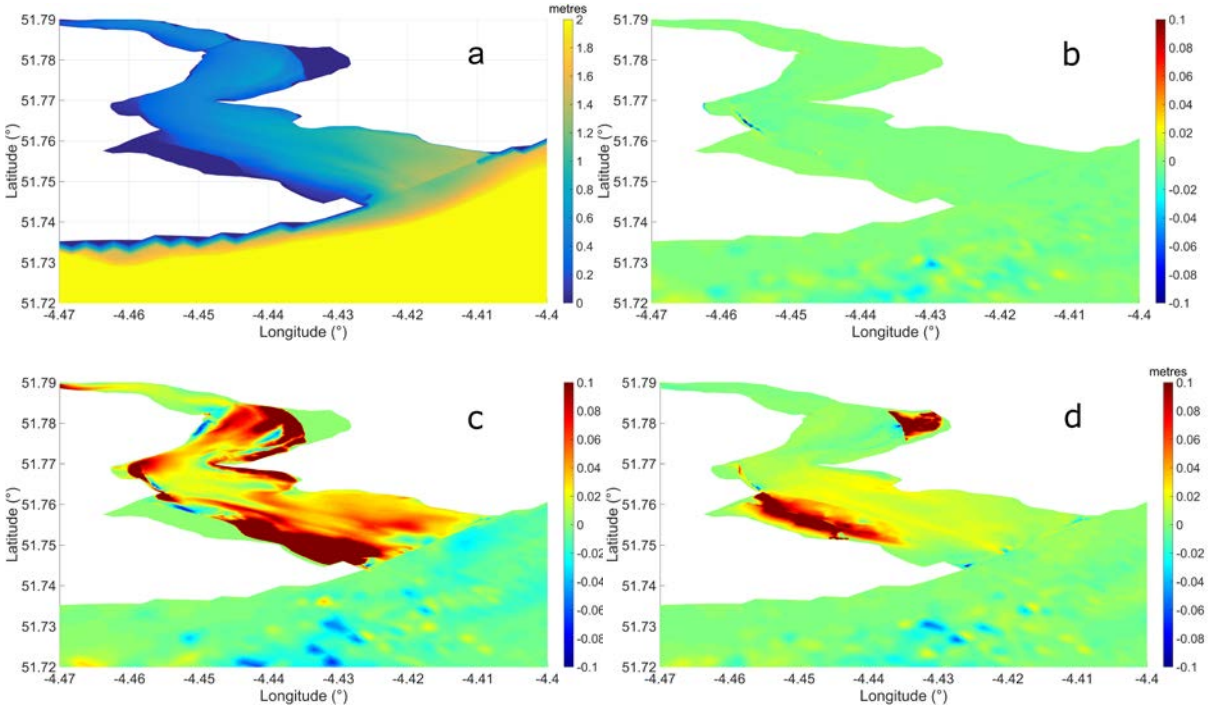

Figure 3. Comparison of Peak Storm Wave Height at the Taf estuary under the selected intervention scenarios during 1:50 year South Westerly storm. a) Current condition, b) difference between defended and current c) difference between grazed and current d) difference between managed realignment and current.

The storm water level in the Taf estuary and the water level differences due to the selected management intervention scenarios during the peak of the south-westerly storm are shown in Figure 2. In the current undisturbed state of Taf estuary, tidal extent during the peak of the storm reaches the landward edges of the marshes, with water depths in the range 1-2 m. With the introduction of a hard coastal defence to protect the

village of Laugharne, did not significantly change the peak storm water level of the estuary. Behind the structure there is no water, as expected, but beyond this also there are no noticeable changes. The change in water level due to marsh grazing is the almost insignificant. While obviously the water level difference between undisturbed and managed realigned sites is large, there is no noticeable water level difference seen outside of the marsh areas of the estuary.

A comparison of change in wave height in the estuary as a result of interventions are shown in Figure 3. In the current situation, the largest wave heights are seen in the areas around the mouth of the estuary (1.2-1.4m). At the edges of the marshes, close to the tidal channel location, wave heights reach 0.6-0.7m, while those on the marshes reduce to less than 0.2m (Fig. 3a). The hard defence at the landward edge of Laugharne marsh causes very small changes in wave height coincident with the channel at the seaward boundary of the marsh. With the reduction in wave attenuation due to the lack of vegetation as a result of grazing, the wave heights within the estuary are increased with a maximum of 0.1 m at some locations. As with grazing, managed realignment causes a general increase in wave height throughout the estuary. These increases may be significant in terms of flooding and marsh erosion.

5. CONCLUSIONS

The effects of several management interventions as a means of increased flood and coastal erosion protection at a small macrotidal Taf estuary are studied, providing insights into the role of saltmarshes in Welsh estuaries in flood risk management. Those interventions seem to have significant estuary-wide impacts on the estuarine hydrodynamics, with potential for changes to intertidal morphology, at least in small tide-dominated estuaries. It is important to take a 'whole system' approach when planning and designing salt marsh management.

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REFERENCES

Ashall, L. M., Mulligan, R. P., Van Proosdij, D., & Poirier, E. (2016). Application and validation of a three-dimensional hydrodynamic model of a macrotidal salt marsh. *Coastal Engineering*, *114*, 35–46. https://doi.org/10.1016/j.coastaleng.2016.04.005

Bristow, C., & Pile, J. (2003). *Aberoedd De Cymru Bae Caerfyrddin: Esblygiad Morffoleg Aberol ac Effaith hynny ar Reolaeth ACA South Wales Estuaries Camarthen Bay: Evolution of Estuarine Morphology and Consequences for SAC Management*.

Cousins, N., Chung, P., Coutts, H., Doody, P., & McCue, J. (2008). *Identifying Biodiversity Opportunities to Inform the Shoreline Management Review (SMP2) –Carmarthen Bay Estuaries*.

Dalrymple, R. A., Kirby, T., & Hwang, P. A. (1984). Wave Diffraction Due to Areas of Energy Dissipation. *Journal of Waterway, Port, Coastal and Ocean Engineering*, 67–79. https://doi.org/10.1061/(ASCE)0733-950X(1984)110

Davidson, K. E., Fowler, M. S., Skov, M. W., Doerr, S. H., Beaumont, N., & Griffin, J. N. (2017). Livestock grazing alters multiple ecosystem properties and services in salt marshes: a meta-analysis. *Journal of Applied Ecology*, *54*(5), 1395–1405. https://doi.org/10.1111/1365-2664.12892

Davis, R. A., & Fitzgerald, D. M. (2019). *Beaches and Coasts* (2nd ed.). Wiley.

Halcrow. (2012). *Lavernock Point to St.Ann's Head Shoreline Management Plan SMP2*.

Ishak, A. K. Bin. (1997). *Suspended Sediment Dynamics and Flux in the Macrotidal Taf Estuary, South Wales*.

Lesser, G. R., Roelvink, J. a., van Kester, J. a. T. M., & Stelling, G. S. (2004). Development and validation of a three-dimensional morphological model. *Coastal Engineering*, *51*(8–9), 883–915. https://doi.org/10.1016/j.coastaleng.2004.07.014

Manning, A. J., & Whitehouse, R. J. S. (2012). *TR167 - Enhanced UK Estuaries database : explanatory notes and metadata (SiTE P1). Development of estuary morphological models.* Retrieved from http://eprints.hrwallingford.co.uk/650/

Möller, I., Kudella, M., Rupprecht, F., Spencer, T., Paul, M., Van Wesenbeeck, B. K., … Schimmels, S. (2014). Wave attenuation over coastal salt marshes under storm surge conditions. *Nature Geoscience*. https://doi.org/10.1038/NGEO2251

Pye, K., & Blott, S. J. (2009). *Coastal processes and shoreline behaviour of estuary dominated systems in Swansea Bay and Carmarthen Bay Report prepared for Halcrow Group Ltd*.

Temmerman, S., Meire, P., Bouma, T. J., Herman, P. M. J., Ysebaert, T., & De Vriend, H. J. (2013). Ecosystem-based coastal defence in the face of global change. *Nature*, *504*(7478), 79–83. https://doi.org/10.1038/nature12859