26th International Congress on Modelling and Simulation, Adelaide, SA, Australia, 30 Nov–4 Dec 2025
mssanz.org.au/modsim2025

Resolving the hydrodynamics of a coastal wetland in Moreton Bay

K Kurucz [a,b], **SG Escudero** [a,b], **MR Hipsey** [a,b]

[a] UWA School of Agriculture and Environmental Science, University of Western Australia, Crawley, Western Australia, [b] Centre for Water and Spatial Science, University of Western Australia, Crawley, Western Australia
Email: kamilla.kurucz@research.uwa.edu.au

Abstract: Coastal wetlands are complex ecosystems that support key ecosystem services however, they have been facing widespread degradation due to climate change and coastal development. In recognition of this, restoration efforts have been gaining momentum with the aim of improving their ecological function, which requires in-depth understanding of the current state of the system. In coastal wetlands, the dynamics of different hydrological processes serves as the primary driver that subsequently shapes biophysical, biogeochemical and ecological conditions. Process-based models that can resolve wetland ecohydrology and the dynamic changes over space and time can serve as a valuable tool supporting blue carbon studies and wetland adaptation and restoration planning.

Here we present a first step towards an integrated hydrodynamic-biogeochemical analysis, where we developed an unstructured hydrodynamic model for simulating the water height, salinity and temperature variations to gain insight into the location-specific interplay of hydrological processes. The focus site for the application is a mangrove creek on Woogoompah Island, an ecologically significant coastal wetland located in Moreton Bay. We used high-resolution LiDAR elevation data to inform detailed topography and vegetation canopy characteristics, and this was combined with maps of habitat zonation and a dynamic meteorological model for model forcing. The model was validated based on observations from a supporting field program that spanned different tide phases and seasons and included locations within the tidal creek and adjacent floodplain.

The model effectively captured inundation dynamics of the site but highlighted areas for improvement in representing biophysical variables and shed light on missing processes. The modelled water height agreed well with observations at both creek and floodplain locations over a full spring to neap tide cycle but was sensitive to assumptions about vegetation drag. The inundation dynamics demonstrated a clear spatial gradient over the year, and the resulting inundation signatures aligned well with the pattern of vegetation zonation across the site. The dilution effect of rainfall on salinity during a storm event was overestimated by the model, and creek water salinity took several tide cycles to return to pre-storm salinity levels, whereas observations demonstrated a faster recovery suggesting addition of a salt source from the high intertidal cells is needed to more accurately resolve the salt balance. Diurnal and seasonal variability in water temperatures was generally captured well by the model, however, the microclimate created by dense mangrove vegetation was affecting water temperatures at the shallow upstream creek location, which led to over-prediction of nighttime cooling. Building upon this model, next steps include incorporating improved parameterisation of the vegetation canopy microclimate to allow for refined surface heat fluxes able to capture wind-sheltering and solar shading, and coupling with a biogeochemical model in order to represent key aspects of carbon and nitrogen processing.

Keywords: *coastal wetland modelling, inundation dynamics, mangrove creek*

© MSSANZ and The Authors, CC-BY

1. INTRODUCTION

Coastal wetlands provide important ecosystem services such as flood and storm buffering, carbon sequestration and storage, nitrogen assimilation and diverse habitats for flora and fauna. However, these invaluable systems have been at the forefront of land use and climate change impacts, which resulted in widespread wetland degradation estimated to affect about half of the world's wetlands (Glamore et al. 2021). In recognition of the ecological and economic value of coastal wetlands, recent efforts have focused on restoring and conserving their ecological function and has endeavoured to maximise their carbon sequestration potential for climate change mitigation (Guo et al. 2025). This requires an in-depth understanding of the current state of the system, including the hydrological, biogeochemical, and ecological interactions between surface water, groundwater, soil, and vegetation, operating over a range of spatial and temporal scales.

The complexity of coastal wetlands systems stems from high landscape heterogeneity and highly dynamic environmental gradients. These ecosystems often feature several different habitat types including mangroves, saltmarshes, mudflats and riparian woodlands which are all hydrologically interconnected. Vegetation can strongly influence wind, shortwave radiation, and other factors, creating localised microclimates within coastal wetlands. Generally, coastal wetlands are flooded by tides on a regular basis, and while some wetland areas are inundated daily, other areas are only flooded during spring tides creating spatially varying wetting-drying conditions. Different hydrological components such as tidal forcing and freshwater inputs drive the inundation dynamics including the depth, frequency and duration of flooding which collectively define the hydroperiod (Vulliet et al. 2024). Tidal creeks link the wetland areas to open water and facilitate the constant exchange of solutes such as carbon and nutrients through incoming and outgoing tidal waters. Moreover, the strong dynamic interactions between surface water and groundwater inherent in these systems play a critical role in carbon and nutrient exchange (Wilson and Morris 2012). The interplay of these hydrological processes varies across sites and shapes habitat zonation, salinity and temperature variation and redox gradients in coastal domains.

Eco-hydrodynamic models have proven effective in simulating the inundation dynamics of coastal wetlands and have improved our understanding of the complex interactions inherent in these systems. Numerous approaches varying in spatial resolution and model complexity have been applied to explore key interactions such as the effect of vegetation on water flow (Temmerman et al 2005), the resilience of coastal wetlands to climate change impacts (Zhang et al. 2019) and porewater exchange between the wetland and tidal creek domains (Wilson and Morris 2012). Two- and three-dimensional (2D/3D) hydrodynamic models have the potential to capture the spatiotemporal variability within coastal wetland domains, as well as differences between sites driven by variations in tidal regime, climate, topography, and habitat distribution. To date however, there are a lack of integrated applications for the purpose of resolving inundation patterns, temperature and salinity over ecologically relevant timescales (e.g., seasonal to annual) that can be used as the basis for carbon and restoration studies.

Here we present the application of an unstructured hydrodynamic model for simulating the water height, salinity and temperature variations in an ecologically significant mangrove creek located in Moreton Bay. The current work focuses on improving our understanding of the location-specific hydrodynamic processes and underpins future coupling with a biogeochemical model for an integrated analysis of ecological function.

2. METHODS

2.1. Study site

Woogoompah Island is a tidal wetland system located in Moreton Bay, south-east Queensland, Australia. The island is part of the Southern Moreton Bay Island National Park, which is recognised for its ecological value for providing critical habitat for fish, birds, shellfish, dugong and turtles (Department of Environment and Science 2023). The Moreton Bay area experiences a sub-tropical climate and exhibits distinct seasonal patterns. The annual average rainfall is 1500 mm, which predominantly occurs in the summer months. The average daily air temperature varies between 13 to 29°C. The study area includes a mixture of different vegetation types including *Aegiceras cornicatum* and *Avicennia marina australasica* mangroves, *Sporobolus virginicus* saltmarsh, *Suaeda australis* saltbush and Melaluca/casuarina riparian woodlands (Lovelock et al. 2019). The distribution of the different land cover types is shown in Figure 1a. The site features a well-defined tidal creek that is connected to open water through a network of channels. The creek is well-mixed and includes no upstream freshwater inputs. The tidal regime is semi-diurnal, and the tidal elevation measured at Couran Cove Station ranged from a minimum of -0.65 mAHD and maximum of 1.43 mAHD during the simulation period.

© MSSANZ and The Authors, CC-BY

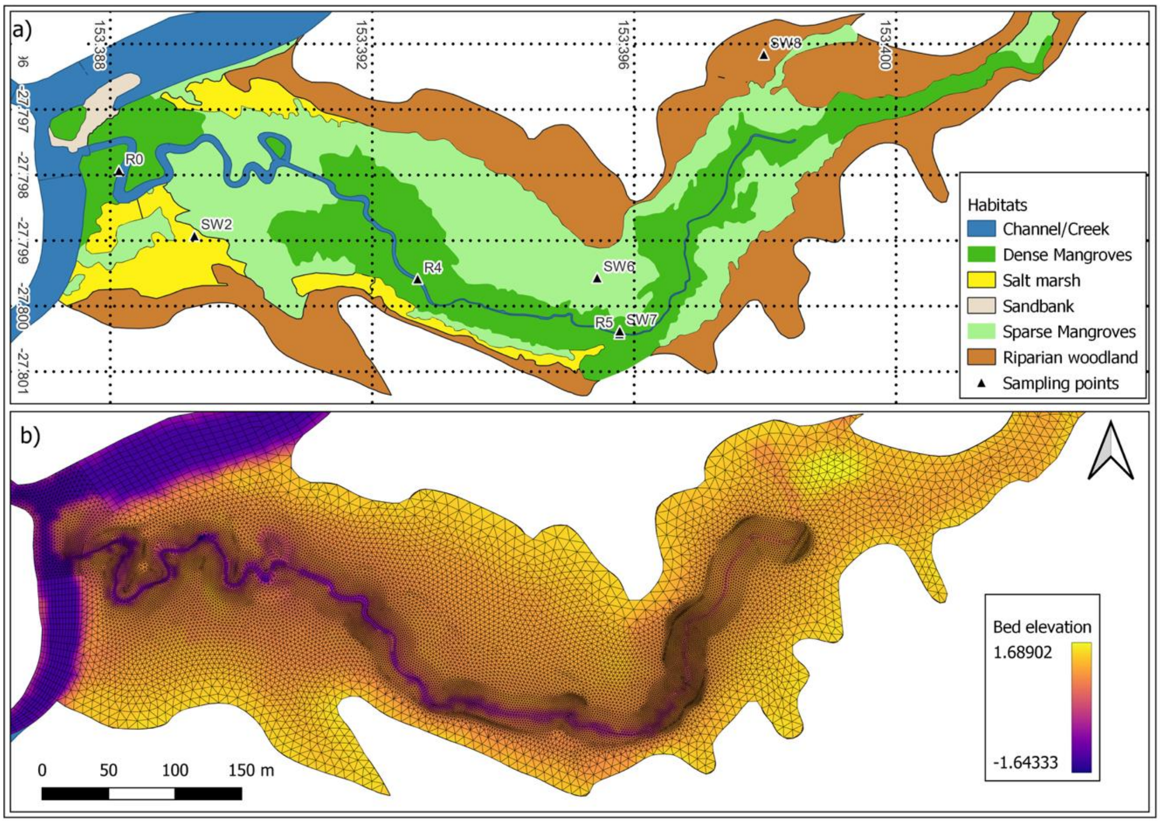

Figure 1 Habitat map of study domain including the location of the sampling points a) and bed elevation and mesh structure of the site b).

2.2. Field data collection

Water depth, salinity and temperature data were collected at different locations in the tidal creek; near the creek mouth (R0), and at two sites upstream (R4 and R5). At the creek mouth location, a Hydrolab HL4 was deployed on the creek bed for ~30 hours during both spring and neap tides, capturing all tidal stages within each phase. The data collection was repeated three times, in February, July and November 2023 to capture seasonal variation. At the upstream sites two YSI water quality probes were deployed from the 3 July to 11 July 2023 during the full spring to neap tide cycle. HOBO water level loggers were installed at four floodplain sites during the same spring to neap tide cycle to capture inundation dynamics. In the tidal creek, a FLUVIA electromagnetic water velocity meter was used to measure current velocity at the R4 creek location 10 cm off the riverbed for a ~24-hour period from 10 July 2023.

2.3. Modelling approach

The TUFLOW-FV hydrodynamic platform was used to simulate the hydro and thermodynamics of the focal site (BMT WBM 2019). TUFLOW-FV is a finite volume hydrodynamic model used for the prediction of water level, salinity, temperature, transportation and mixing dynamics in response to tidal forcing, inflows and surface thermodynamics. It employs a 2D/3D flexible mesh approach which encompasses both triangular and quadrilateral elements of different size, facilitating the simulation of sites with complex morphology. The model solves the nonlinear shallow water equations and is suitable for simulating the wetting and drying of cells using user-defined threshold values. The Smagorinsky scheme was applied in the horizontal plane to simulate turbulent mixing of momentum and scalars.

The model was forced with tidal height time series data measured at Couran Cove Station (-27.82433°, 153.40827°; data source: Maritime Safety Queensland). The temperature and salinity of the tidal input was informed by field observations in Southern Bay (site: E00106) which is the nearest Ecosystem Health Monitoring Program (EHMP) site to Woogoompah Island. The temperature and salinity data were interpolated to 15-minute temporal resolution to match tide height input data and was used in conjunction with salinity and temperature measured at the creek mouth at high tide to inform input values. Temperature of the tidal inflow varied with season ranging from 17 to 30°C. Tidal inflow salinity generally exhibited seawater conditions (~35 psu) during the simulation period, except for January - February 2024 when salinity dropped to ~20-25 psu

© MSSANZ and The Authors, CC-BY

due to storms and flooding in the Moreton Bay area. The model was forced with meteorological data from different sources. Gridded meteorological conditions were extracted from the Weather Research and Forecasting Model (WRF; Powers et al. 2017) with 0.125 degrees spatial resolution and hourly temporal resolution including longwave and shortwave radiation, wind speed and direction and air temperature data. Relative humidity time series data were sourced from the Gold Coast Seaway Station (data source: Bureau of Meteorology). Rainfall data were sourced from the WRF model output, the Gold Coast Seaway BOM Station and from an on-site weather station fitted with the Davis 0.2 mm rain gauge located at SW6 (Figure 1a). In the final model, the HOBO weather station data was complemented with BOM and WRF rainfall data when unavailable.

The mesh geometry was created with Aquevo's SMS software, which incorporated 1-m resolution Light Detection and Ranging (LiDAR) topographic data of the site (Figure 1b). The LIDAR data along with 0.29 m resolution NearMap satellite imagery were used in an image classification workflow to delineate seven habitat zones characterising the focus site (Figure 1a). The habitat zones included sparse mangroves, dense mangroves, the main channel, the tidal creek, sandbanks, saltmarsh, and riparian woodland, which were assigned different Manning's roughness coefficients to simulate the effect of vegetation and morphology on drag. The model was run from 2023-01-01 to 2024-02-28 and was implemented in a two-dimensional (2D) depth-averaged configuration as the creek and floodplain exhibit well-mixed conditions.

3. RESULTS

3.1. Water level validation

The model was able to simulate the inundation dynamics of the site including the depth and timing of flooding over a complete spring-neap tidal cycle (Figure 2). At spring tide, the inundation depth on the floodplain reached around 0.6 m near the creek and in low-lying areas (SW2, SW7), while higher elevation floodplain sites experienced inundation depths of 0.3-0.4 m (SW6, SW8). Notably, floodplain inundation depths may be slightly lower during other spring tides, as this tide coincided with a significant rainfall event. As the tidal cycle

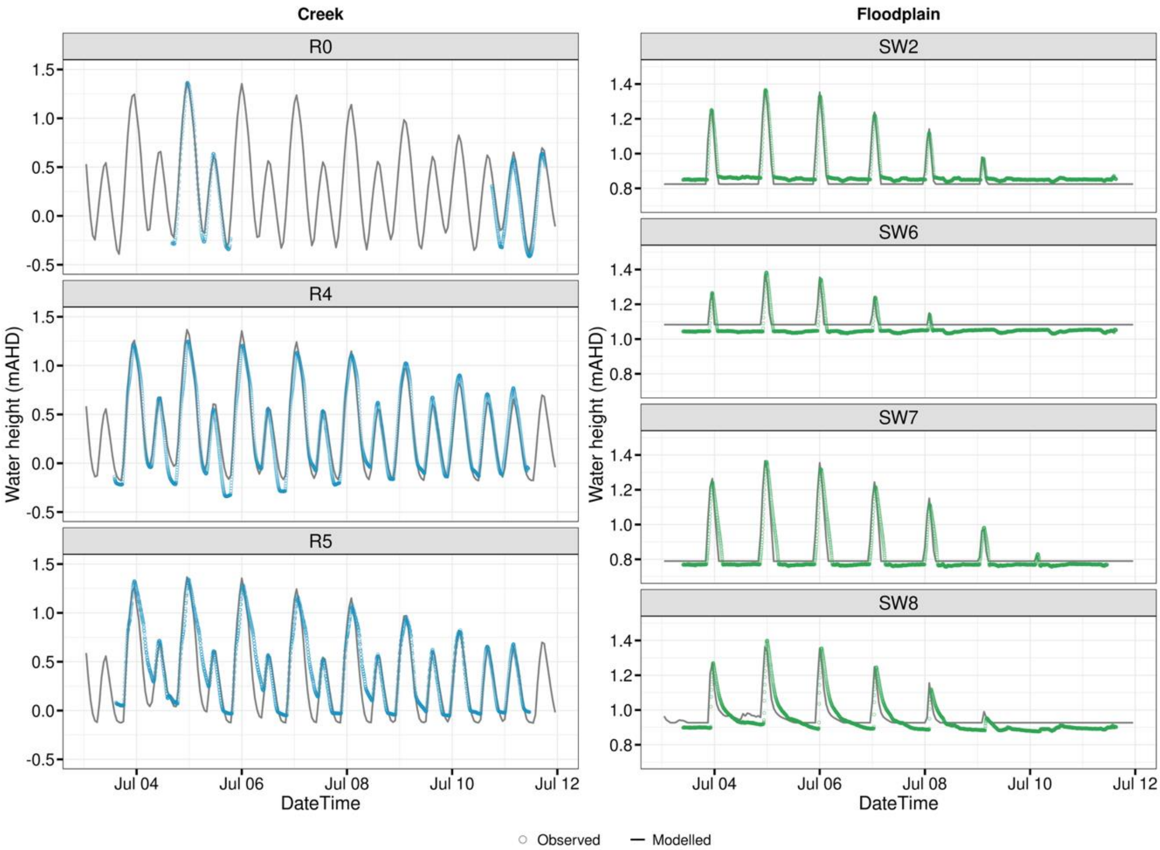

Figure 2 Observed versus modelled water height at three creek sites and four floodplain sites over a complete spring-neap cycle. The location of the sites within the study area are shown in Figure 1a.

© MSSANZ and The Authors, CC-BY

progressed from spring to neap, floodplain inundation gradually decreased, and by neap tide, only the creek bank was flooded, while the floodplain remained dry. The modelled water height at the creek sites agreed well with observations, and the model was able to capture the peak water height in the creek. At the upstream site (R5), the model underestimated water levels by ~0.25 m as it drained more water than observed during ebb tide, though this improved as the tidal cycle shifted to neap.

3.2. Salinity and temperature validation

The dilution effect of rainfall on salinity was overestimated in our model (Figure 3a). On 4 July, a rainfall event of approximately 30 mm occurred which resulted in the dilution of creek water salinity. While the dilution effect of rain is also demonstrated by the observed salinity data both at the creek mouth location (R0) and at the upstream creek location (R4), following the rain event the model took considerably longer than observed to return to seawater salinity levels in the creek. This model behaviour likely results from the vertically averaged model mixing rainfall uniformly through the water column, whereas in reality, freshwater from rain tends to remain as a surface layer above denser saline creek water. Moreover, in dry wetland areas some of the rainwater infiltrates into the soil and does not contribute to runoff that reaches the tidal creek. To account for the effect of infiltration, the rain forcing data was scaled down by 20% in our simulation. Additionally, another process affecting salinity at the study site is the dissolution of surface salts from the floodplain during inundation, which are transported back to the tidal creek on the ebb tide. This effect is enhanced during spring tides that flood areas dried long enough for evaporation to concentrate salts. However, this process is generally not represented in hydrodynamic models, as it would require tracking evaporation in ‘dry cells’ along with surface salt concentrations and subsequent dissolution when the cells become submerged again. Moreover, saline porewater has been found to also increase tidal creek water salinity which was not accounted for in our model.

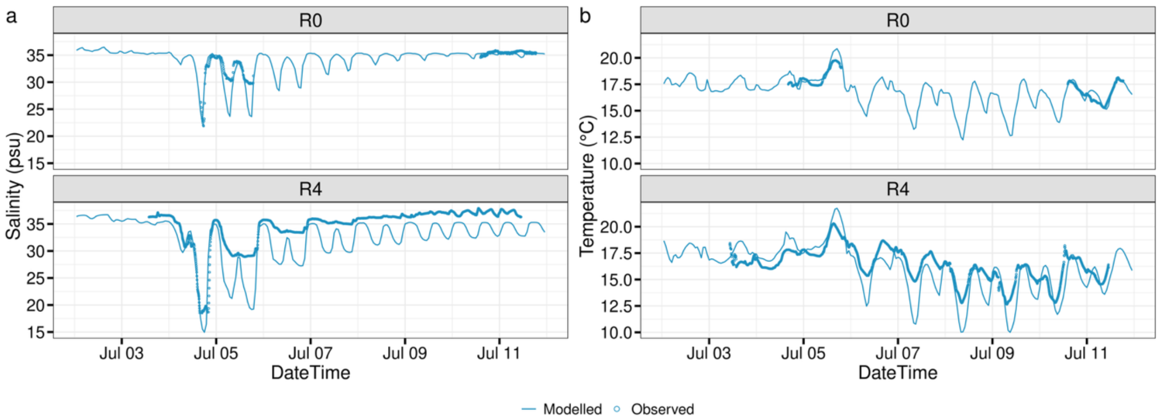

Figure 3 Observed versus modelled salinity a), and temperature b) at R0 during spring and neap tide and at R4 over a complete spring to neap tide cycle.

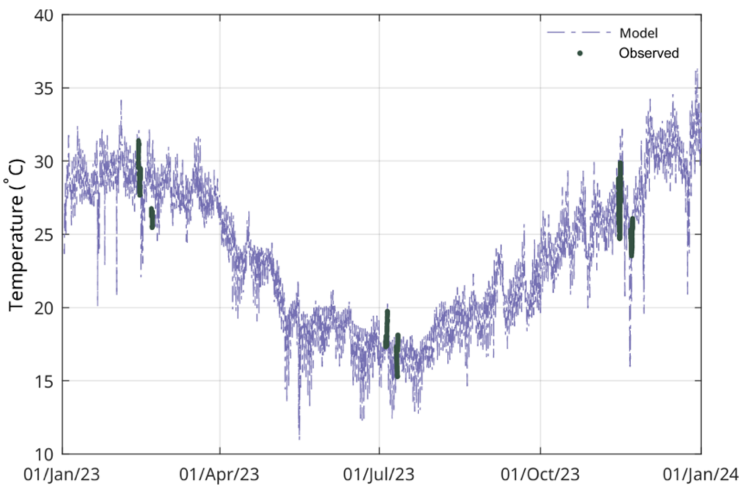

Figure 4 Observed versus modelled temperature in 2023 at the creek mouth location (R0).

© MSSANZ and The Authors, CC-BY

The seasonality of water temperature was captured well by the model (Figure 4). The model fit was better at the creek mouth location (R0) than the upstream creek location (R4; Figure 3b). Mangrove forests create distinct microclimates within coastal wetlands by providing shading that reduces daytime temperatures and by retaining heat and moisture, which moderates nighttime cooling compared to adjacent open habitats such as saltmarshes. The model overestimated nighttime cooling of water temperature, likely due to the meteorological forcing data not accounting for the moderating effect of the mangrove microclimate. The upstream creek site is located within and dense mangrove area and additionally shallow water depths of the upstream part of the creek make water temperatures highly sensitive to air temperature fluctuations.

3.3. Current velocity validation

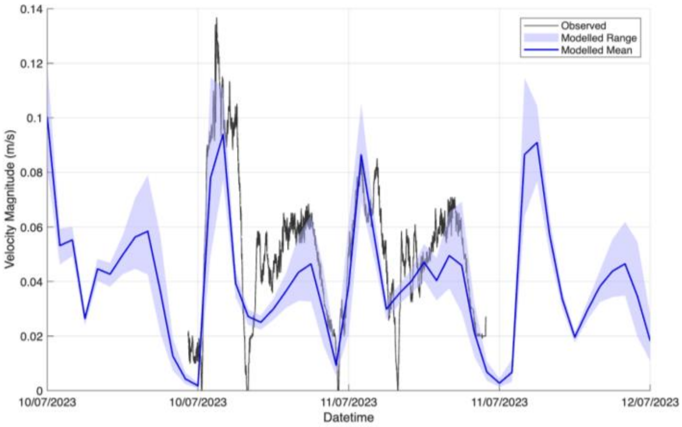

Figure 5 Observed versus modelled current velocity at the R4 location. The modelled range includes values from cells surrounding the R4 location.

The current velocity magnitude and patterns at the upstream creek location during neap tide were captured well by the model (Figure 5). The model generally reproduced the observed high velocities well, however it failed to capture periods of slack water, when tidal flow naturally stops before reversing. The model results are averaged for the water column whereas the flow was measured at 10 cm height above the seabed. Small deviations in the timing of tidal water flows from real-time conditions may occur as the model was forced with tide data recorded at Couran Cove Station located approximately 2.5 km away from the boundary of the study domain.

3.4. Annual inundation dynamics

The inundation map shows a clear spatial gradient in the annual inundation fraction across different wetland areas (Figure 6). Spring tides inundate most of the wetland area, with the exception of some fringing upland zones. Most of the wetland area is inundated for less than 20% of the year, while the tidal creek and its bank experience inundation between 50% and 100% of the year, depending on elevation and proximity to the creek mouth. The wetland areas that are inundated between 10%-20% of the year generally coincide with the dense mangrove forest habitats while the areas that are inundated less than 10% of the time are generally sparse mangroves, saltmarsh and riparian woodland habitats.

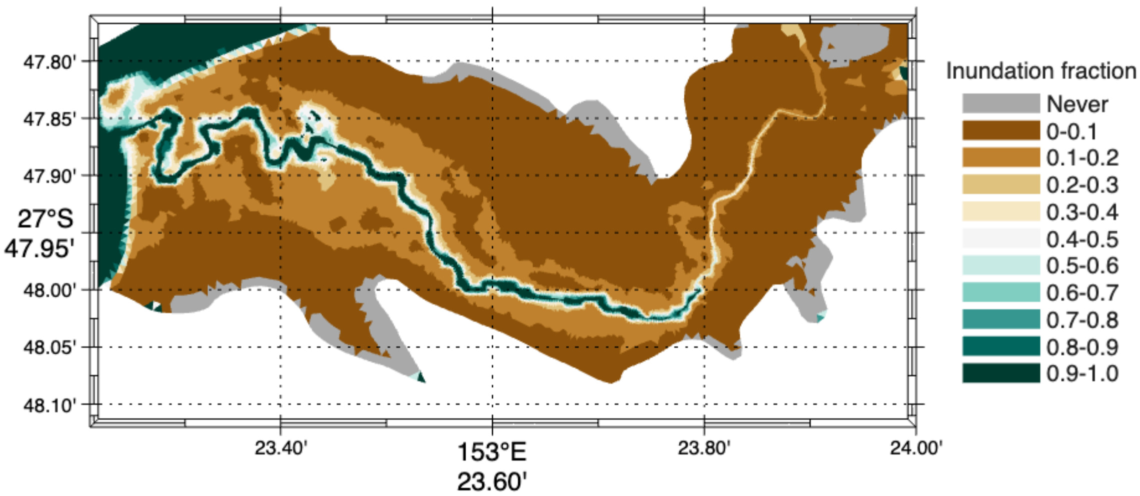

Figure 6 The annual inundation fraction of the study domain.

© MSSANZ and The Authors, CC-BY

4. CONCLUSION AND NEXT STEPS

In this study, we applied an unstructured hydrodynamic model to a coastal wetland in Moreton Bay to simulate water level, salinity and temperature variations. Overall, the hydrodynamic model was able to capture the observed inundation patterns and changes in salinity and temperature in response to tidal and meteorological forcing however, the model application revealed the importance of key processes at the site that were not incorporated into the model. The model agreed well with the observed water height at both creek and floodplain locations over a full spring to neap tide cycle. The inundation dynamics showed a clear spatial gradient over the year, which resulted in hydrodynamic zones that coincided with the distribution of different vegetation types across the site. The dilution effect of rainfall on salinity was overestimated by the model, and creek water salinity took several tide cycles to bounce back to seawater salinity levels, whereas observations demonstrated a faster recovery. Therefore, to accurately resolve the wetland salt balance, a salt source needs to be incorporated to represent the soil salt store and local dissolution driven by inundation. The water temperature was captured well by the model at the creek mouth however, the effect of the mangrove microclimate was significantly affecting water temperatures at the shallow upstream creek location, resulting in the overestimation of nighttime cooling by the model.

Building upon this model, next steps include incorporating a vegetation model to our simulation to help refine local microclimate in the mangrove forest including wind sheltering, rain loss and solar shading. Since hydrodynamic processes underpin variations in redox conditions and vegetation zonation, the model provides a foundation for future biogeochemical analyses, and for predicting ecosystem responses to climate change, land use changes and restoration efforts.

ACKNOWLEDGMENTS

We acknowledge the TUFLOW software team for support and provision of the TUFLOW-FV model, and Health Land and Water (Qld) for provision of the LiDAR data. The field data collection study was supported by the Southern Cross University Centre for Coastal Biogeochemistry, and funding for the study provided by the Australian Research Council project LP200200910.

REFERENCES

BMT WBM. (2019) TUFLOW FV Science manual. BMT WBM, Brisbane Australia.

Department of Environment and Science (2023) Southern Moreton Bay Islands National Park. Department of Environment and Science, Brisbane, Australia.

Glamore W, Rayner D, Ruprecht J, Sadat-Noori M, Khojasteh D (2021) Eco-hydrology as a driver for tidal restoration Observations from a Ramsar wetland in eastern Australia. PLoS ONE 16, e0254701

Guo X, Liu Y, Xie T, Li Y, Liu H, Wang Q (2025) Impact of ecological restoration on carbon sink function in coastal wetlands A review. Water 17(4), 488. https://doi.org/10.3390/w17040488

Lovelock C, Accad A, Dowling R, Duke N, Lee SY, Ronan M (2019) Mangroves and saltmarshes of Moreton Bay. In: Tibbetts IR, Rothlisberg PC, Neil DT, Homburg TA, Brewer DT, Arthington AH (eds) Moreton Bay Quandamooka & Catchment Past present and future. The Moreton Bay Foundation, Brisbane, Australia. Available from: https://moretonbayfoundation.org/

Powers JG, Klemp JB, Skamarock WC, Davis CA, Dudhia J, Gill DO, et al. (2017) The Weather Research and Forecasting (WRF) model Overview system efforts and future directions. Bulletin of the American Meteorological Society 98(8), 1717–1737. https://doi.org/10.1175/bams-d-15-00308.1

Temmerman S, Bouma TJ, Govers G, Wang ZB, De Vries MB, Herman PMJ (2005) Impact of vegetation on flow routing and sedimentation patterns: Three-dimensional modeling for a tidal marsh. Journal of Geophysical Research Earth Surface 110(F4). https://doi.org/10.1029/2005jf000301

Vulliet C, Koci J, Jarihani B, Sheaves M, Waltham N (2024) Assessing tidal hydrodynamics in a tropical seascape using structure-from-motion photogrammetry and 2D flow modelling. Estuaries and Coasts 47(2), 352–375. https://doi.org/10.1007/s12237-023-01288-6

Wilson AM, Morris JT (2012) The influence of tidal forcing on groundwater flow and nutrient exchange in a salt marsh-dominated estuary. Biogeochemistry 108(1–3), 27–38. https://doi.org/10.1007/s10533-010-9570-y

Zhang Y, Li W, Sun G, King JS (2019) Coastal wetland resilience to climate variability: A hydrologic perspective. Journal of Hydrology 568, 275–284. https://doi.org/10.1016/j.jhydrol.2018.10.048

© MSSANZ and The Authors, CC-BY