A HOLISTIC MODEL TO SIMULATE LONG-TERM EVOLUTION OF CATCHMENT-ESTUARY-COASTAL SYSTEMS

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INTRODUCTION

Long-term (i.e., multi-decadal to century periods) evolution of inlet-interrupted coasts can be assessed in relation to the variation of sediment volume exchange between the inlet-estuary system and its adjacent coastal zone (Ranasinghe et al., 2013; Bamunawala et al., 2020a). The oceanic (e.g., sea-level-rise) and terrestrial processes (e.g., change in fluvial sediment supply) contribute to the long-term evolution of inlet-interrupted coasts. These contributing processes are affected by climate-change-driven impacts and anthropogenic activities. Thus, it is necessary to consider the holistic behaviour of Catchment-Estuary-Coastal (CEC) systems when assessing the evolution of inlet-interrupted coasts under the impacts of projected climate change and increasing pressures due to anthropogenic activities. Such a holistic assessment of the long-term evolution of CEC systems can be achieved via reduced-complexity modelling techniques, which also ably quantify the uncertainties associated with the projections due to their lower simulation times (Bamunawala et al., 2020b; Ranasinghe, 2020). The Generalised Scale-aggregated Model for Inlet-interrupted Coasts (i.e., G-SMIC) presented by Bamunawala et al. (2020b) is one such model that can probabilistically assess the long-term evolution of inlet-interrupted coasts while considering the holistic behaviour of Catchment-Estuary-Coastal systems. However, G-SMIC does not consider the presence of ebb-delta systems when considering the sediment budget at tidal inlets. Here, we present an improved version of G-SMIC by incorporating the ebb-delta dynamics into its computations. The updated model is piloted at two selected case study sites in Vietnam and United Kingdom, and the preliminary results are presented, along with the overall modelling concept.

THE MODEL

The sediment budget that governs the long-term evolution of inlet-interrupted coasts at the vicinity of ebb-deltas comprises three main components: (1) sediment volume exchanged between the inlet-interrupted coasts and its inlet-estuary system (ΔV_{T}), (2) sediment dynamics of ebb-delta system, and (3) capacity of the littoral drift (LST). The probabilistic assessment of ΔV_{T} is described by Bamunawala et al. (2020b). Here, we use the sediment reservoir aggregated concept presented by Kraus (2000) to incorporate the ebb-delta dynamics into the computation of ΔV_{T}. This model was successfully used in the CASCADE model by Larson et al. (2003) to simulate sediment dynamics between bee-shoal, attachment bars, and barrier islands (Larson et al., 2007, 2016; Palalane et al., 2016; Palalane and Larson, 2019).

Following the assumption of estuarine sediment requirements (i.e., ΔV_{T}) governs the overall evolution of its inlet-interrupted coastline, we present the inclusion of ebb-delta dynamics into ΔV_{T} computations under three categories: (1) sediment exporting systems, where inlet-estuary system exports sediment to its adjacent coastal zone, (2) Type 1 sediment importing systems, where inlet-estuary system imports sediment from its adjacent coasts with its magnitude (ΔV_{T}) is less than LST, and (3) Type 2 sediment importing systems, where inlet-estuary system imports sediment from its adjacent coasts with its magnitude (ΔV_{T}) is greater than LST.

EBB-DELTA DYNAMICS

According to Kraus (2000), the rate of sediment leaving the ebb-delta system (Q_{out} in m^3/yr) is expressed as [1].

$$Q_{out} = \left(\frac{V}{V_{\mathrm{eq}}}\right) Q_{\mathrm{in}} \qquad [1]$$

where V is the ebb-delta volume and V_{eq} is the equilibrium volume of the ebb-delta system (in m^3). The volume of the ebb-delta system is calculated as [2].

$$V = V_{\mathrm{eq}}(1 - e^{-\alpha t}) \qquad [2]$$

where $\alpha = \frac{Q_{\mathrm{in}}}{V_{\mathrm{eq}}}$ and t is the simulation time step in years.

SEDIMENT EXPORTING SYSTEMS

Here, Q_{in} (in m^3/yr) is calculated as [3], accounting for the sediment volume exported by the inlet-estuary system.

$$Q_{\mathrm{in}} = LST + V_{\mathrm{T}} \qquad [3]$$

In these systems, the sediment volume exchange does not affect the up-drift coast. Depending on the magnitude of Q_{out} and LST, the down-drift coast may prograde when $Q_{\mathrm{out}} > LST$ or erode when $Q_{\mathrm{out}} < LST$ by a volume V_{dd} [4].

$$V_{\mathrm{dd}} = |Q_{\mathrm{out}} - LST| \qquad [4]$$

TYPE 1 SEDIMENT IMPORTING SYSTEMS

Here, Q_{in} to ebb-delta system is reduced to cater for the estuarine sediment demand, thus, it is calculated as [5].

$$Q_{\mathrm{in}} = LST - V_{\mathrm{T}} \qquad [5]$$

The up- and down-drift coasts behave similarly to that of sediment exporting systems.

TYPE 2 SEDIMENT IMPORTING SYSTEMS

For this type of system, estuarine sediment demand (V_{T}) is fulfilled by a combination of LST, ebb-delta volume (V), and up-drift coast erosion volume (V_{ud}).It is assumed that a larger fraction of LST (β) contributes to fulfilling the estuarine sediment demand, while the rest is supplied to the ebb-delta system as Q_{in} [6], with $0 < \beta < 1$.

$$Q_{\mathrm{in}} = (1 - \beta).LST \qquad [6]$$

The rest of the V_{T} is fulfilled by eroding the ebb-delta system. In situations where V_{T} cannot be fulfilled by the ebb-delta system, the remaining sediment volume will be supplied by eroding the up-drift coast by a volume V_{ud} [7].

$$V_{\mathrm{ud}} = V_{\mathrm{T}} - [\beta . LST + V] \quad [4]$$

In addition to the above sediment volume-driven shoreline variations, up- and down-drift coasts will retreat under rising sea levels (i.e., the Bruun effect, (Bruun, 1962)).

PRELIMINARY RESULTS

The improved model was applied at Thu Bon estuary, Vietnam and Mawddach estuary, Wales, UK, to assess its capabilities. Here, the projections are made over the 2031 - 2100 period under four Shared Socio-economic Pathways (SSPs) of IPCC's sixth Assessment Report (i.e., SSP1-2.6, SSP2-4.5, SSP3-7.0, and SSP5-8.5) using CMIP6 projections and the results are presented for the Mawddach estuary system.

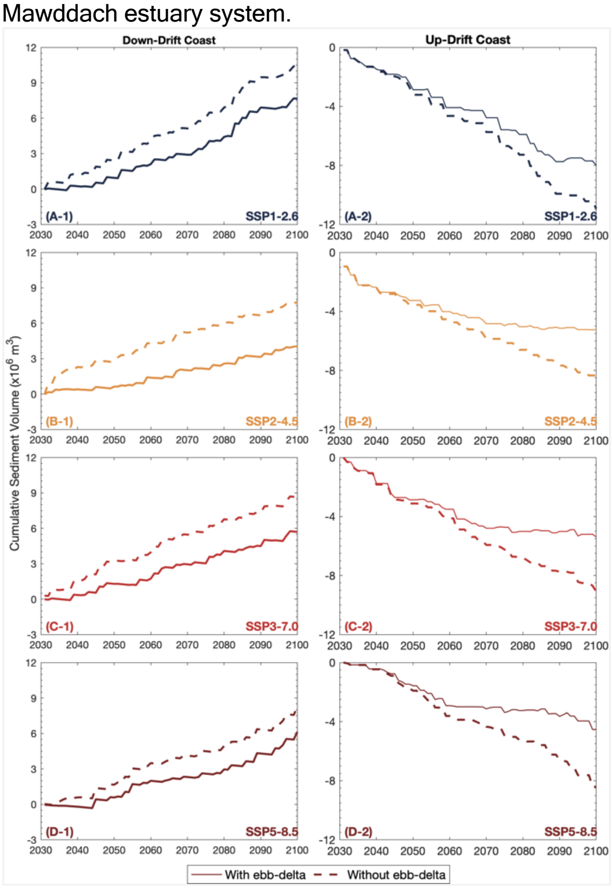

Figure 1 - Projected median (50th percentile) cumulative sediment volume change along the down-drift (left column) and up-drift (right column) coast of Mawddach estuary, UK, over the 21st century. The negative values indicate shoreline erosion.

The ebb-delta dynamics have reduced the erosion volume along the up-drift coast by ~4 MCM under SSP3-7.0 and SSP5-8.5 (compared to projections without ebb-delta dynamics) by the end of the 21st century. Further, the accretion volume along the down-drift coast is also projected to be reduced by ~ 4 MCM under SSP2-4.5 by 2100, highlighting the importance of considering the ebb-delta dynamics in assessing sediment budget at tidal inlets.

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