

ESTUARY RESPONSE TO EXTREME RIVER DISCHARGE EVENTS AFTER DREDGING OPERATIONS

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INTRODUCTION

Growing concern about the effects of dredging in certain nearshore areas has led to the development of complex tools to analyze the effects of bathymetric changes on estuarine dynamics. Changes occur not only for average conditions, but also in the response to extreme river discharge events and storm surges (Hoagland et al., 2020), both of which affect salinity distribution. This study aims to develop a simplified numerical tool to formulate a behavioral model that approximates the salt transport response to extreme river discharge events in real dredged estuaries. The results are highly relevant for basin management to improve salinity control and to adjust river discharge to avoid the consequences of excessive salt intrusion.

PHYSICAL SCENARIOS

The physical domain in which the numerical model is implemented represents an idealized estuary. Consequently, the width distribution along the channel follows a biparametric negative exponential function depending on the mouth width (B_0) and the convergence length (b). In this study, we used an estuary geometry previously used to analyze the role of convergence and short river discharge pulses on salinity distribution in alluvial estuaries (Martín-Llanes & López-Ruiz, 2023). In order to explore the estuary response and salinity distribution after extreme river discharge events in dredged estuaries, twelve different scenarios were formulated. These scenarios result from the combination of 3 depth increments above the initial mouth depth ($\Delta H = 15, 30, 40\%$) and 4 dredging extents (Figure 1) which, in turn, are defined as a fraction of the maximum salt intrusion in the original estuary ($d/X_{\max,0} = 0.35, 0.7, 1, 1.35$).

NUMERICAL MODELLING

The hydrodynamics and salinity distribution in the estuary are obtained through a three-dimensional model in Delft3D, since the large number of processes that can be included makes this high-resolution model suitable for a wide range of nearshore areas under different coastal situations (Lesser et al., 2004). The numerical domain consists of a regular grid encompassing both the channel and the shelf, divided into rectangular cells aligned with the along-channel axis. The σ -scheme consists of 10 vertical layers whose thickness adjusts to 5% and 11.25% of local depth considering, respectively, the extreme and intermediate layers. Boundary conditions are imposed in four different open boundaries. In the offshore boundary, an astronomical water level condition is considered. This includes two tidal harmonics, M2 and S2, whose

prescribed amplitudes and phase lags are 1.00 m, 0.25 m and $180^\circ, 90^\circ$, respectively. At the lateral cross-shore boundaries, a Neumann-type condition with zero alongshore gradient for the water level is imposed. For the transport conditions in these three boundaries, a constant salt concentration equal to the ocean salinity (36 psu) is imposed. Finally, a total discharge boundary condition with uniform vertical velocities is considered in the upstream section. In this case, the salt concentration for the transport conditions is set to zero for the entire simulation period.

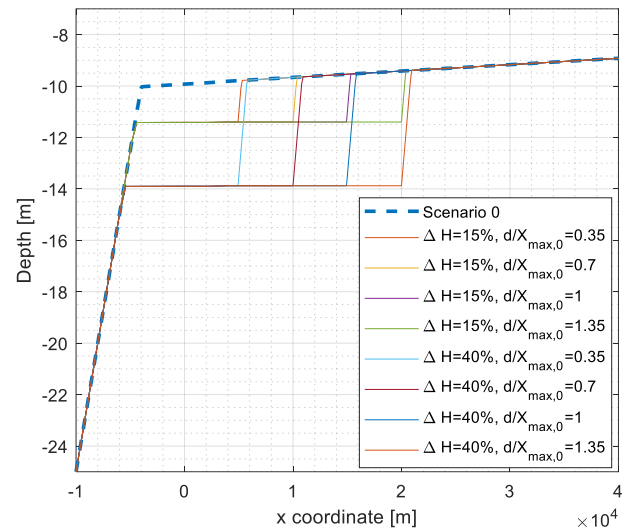


Figure 1 - Detail of the dredged along-channel profiles for the minimum and maximum depth increases. The unaltered bathymetry is represented with dashed lines.

NUMERICAL EXPERIMENTS

In order to identify the impact of the dredging operations on the estuary response, the same boundary conditions and river discharge event are considered in each physical scenario. Consequently, the 12 numerical experiments result from the prescription of the same external forcing on each of the formulated bathymetries. The time series flow conditions for the transient river discharge are defined as a transformed nondimensional SCS hydrograph. Concretely, a peak discharge of $Q_p = 1500 \text{ m}^3\text{s}^{-1}$ was considered, which implies an increase of $\Delta Q = 1350 \text{ m}^3\text{s}^{-1}$ over a background value of $Q_{bg} = 150 \text{ m}^3\text{s}^{-1}$. For the definition of the peak time, the approach of López-Ruiz et al. (2020) was followed. The resulting river discharge distribution was set to start at the beginning of the simulation and its duration is close to the semidiurnal tidal period. The initial conditions for each

scenario were obtained from previous simulations the low-flow regime (i.e., with constant river discharge equal to the background value), which allowed to obtain the steady hydrodynamic and transport conditions. The time frame covers 10 days, which is sufficient to reproduce the salt wedge displacement and the post-flood recovery process.

RESULTS

The impact of changes in channel bathymetry due to the dredging operations is assessed using three different parameters: (1) the salt wedge displacement or change in salt intrusion (defined as the landward limit for the 1psu isohaline) ΔX , (2) the adjustment time (T_{adj}) and (3) the recovery time (T_{rec}). The salt wedge displacement is defined as the difference between the initial salt intrusion and the minimum value obtained after the peak discharge. This quantity is scaled by the salt intrusion range X_R which is defined as the difference between the maximum and minimum salt intrusion at low river flow conditions. The adjustment time (Biemond et al., 2022) is defined as the time when the 90% of the total salt wedge displacement has already been achieved. Finally, the recovery time (Biemond et al., 2022) is considered the time when the estuary has almost reached its initial steady state, with only 10% remaining.

Preliminary results for these three parameters are shown in Figure 2. Increasing channel depth reduces the effect of bottom friction (Ralston et al., 2019), which alters the interaction between tidal processes and river discharge, and consequently the response of the estuary in terms of salinity.

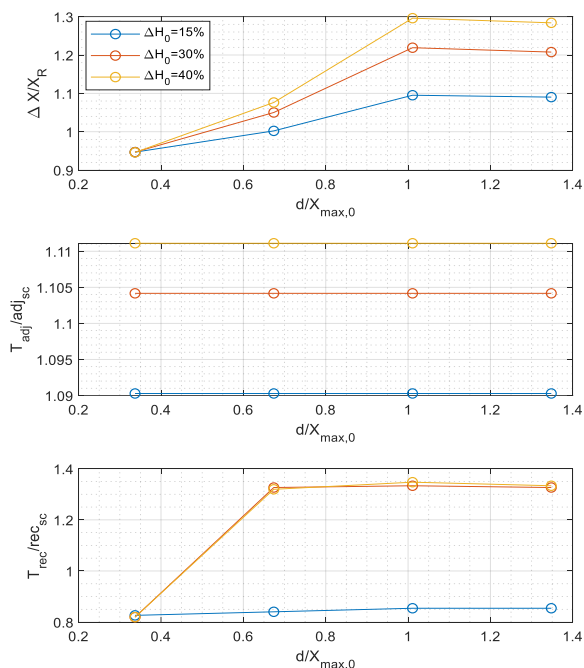


Figure 2 - (a) Scaled salt wedge displacement. (b) Scaled adjustment time. (c) Scaled recovery time. Each curve represents a different channel depth after the dredging operation. The same legend is used for the three panels.

Figure 2a shows the salt wedge displacement scaled

with the salt intrusion range as a function of the dredging extent (d). As can be seen, the potential salt wedge displacement achieved after the river flood increases linearly with the channel depth. Specifically, a maximum difference of 17% is observed when comparing depth increases of $\Delta H = 15, 40\%$. However, a different trend is obtained when comparing the different dredging extents. Figure 2a shows that the maximum salt wedge displacement related to the salt intrusion range is achieved when the estuary is dredged landward up to the maximum salt intrusion limit for the unaltered bathymetry ($X_{max,0}$). The singularity of this point is due to the value of the salt intrusion range: although the salt wedge displacement increases with d , the reduction of X_R for $d=X_{max,0}$ results in a local maximum.

On the other hand, the adjustment time barely depends on the channel depth or the dredging extent (Figure 2b) and it is close to the advective timescale ($T_{adj}/adj_{sc} \cong 1$). This implies that the dominant process for the adjustment is the export of salt by the river flow, as found by Biemond et al. (2022). Finally, the results obtained for the recovery time (Figure 2c) show a weak dependence on channel depth and the dredging extent. The differences between the curve for $\Delta H = 15\%$ and those for $\Delta H = 30, 40\%$ are related to the phase lag between the advective flow and the tide, which causes that the minimum salt intrusion is obtained in a different tidal cycle.

CONCLUSIONS

The preliminary results presented in this abstract demonstrate the utility of using numerical models based on idealized estuaries as a predictive tool for Coastal Engineering. In other words, the validation of this tool would improve the measurement of the impact of human activities (e.g. river regulation, land reclamation, dredging) and rationalize the necessary solutions. A more in-depth analysis of the results and a discussion of their implications for basin management will be presented at the ICCE.

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