MODELLING OF NEARSHORE NOURISHMENTS IN THE MEDIUM-TERM

Ana Margarida Ferreira[1], Carlos Coelho[2] and Paulo A. Silva[3]

Nearshore nourishments are a common technique to artificially feed coastal zones. This approach involves introducing larger volumes of sediments in the submerged area of the coastal zone, creating an artificial sandbar. The performance and longevity of a nourishment depend on sediment transport processes that distribute the sediments alongshore and across the beach profile. Numerical modelling tools can assist in designing the nourishment interventions, but due to the complexity of describing multiple coastal processes across different time-scales, cross-shore and longshore sediment transport processes are often study and model separately. This study aimed to contribute to the numerical modeling of nearshore nourishments from a medium-term perspective (annual scale). To this end, a numerical model that combines both cross-shore and longshore sediment transport processes was developed and applied to study the impacts of nearshore nourishments on sediment dynamics and shoreline evolution, under different wave climate conditions. The proposed numerical model integrates the results of two existing numerical modes: LTC and CS-Model. Overall, the results emphasize the importance of combining sediment transport processes in medium-term numerical modelling. The model results help to understand sediment transport trends and predict the evolution of morphological parameters over time, such as shoreline position and sandbar volume, which can support experts in the design of nearshore nourishments, maximizing its cost-effectiveness.

Keywords: Sediment dynamics; Shoreline; Beach profile; LTC - Long Term Configuration; CS-Model

INTRODUCTION

Coastal managements practices over the last decades reveals an increasing tendency to implement sand nourishments as a measure to mitigate sediment deficits in coastal areas impacted by erosion. Analysis of nourishment projects datasets indicates that coastal erosion mitigation plans based on nourishments require regular interventions. Past nourishments practices show an exponential increased in the volume of sand placed and future projections suggest an even higher demand for nourishment volumes (Hanson *et al*., 2002; Pinto *et al*., 2020; de Schipper *et al*., 2021; Elko *et al*., 2021; Dan *et al*., 2023; Amrouni *et al*., 2024). The sediments availability is therefore a crucial factor, as it combines with the distance from the sand source to the project site to determine nourishment costs. Although several sand sources are identified, offshore borrow sites are often the preferred option due to the large volumes available and distance factors (French, 2001; Dean, 2002).

The nearshore nourishment approach involves introducing large volumes of sediments in the submerged area of the coastal domain, creating an artificial sandbar. This method is often preferred because it is generally less expensive than beach or dune nourishments. Based on the Dutch experience, Brand *et al.* (2022) report a cost of 3.5 €/m³ for nearshore nourishments, compared to 5.5 €/m³ for sand placement on emerged beach. Rosendahl & Halsnaes (2015) synthetize data from global nourishment projects, showing that unit costs for most projects range between 1 and 10€/m³. They further indicate nearshore nourishments based on sailing distances and project location, reporting sand costs for projects performed in Europe of approximately 5-6 €/m³ with a sailing distance of 15 km, with costs increasing by 0.2 €/m³/km for distances up to 25 km. In remote locations, costs can rise significantly, reaching up to 30 €/m³ for smaller projects where dredges are not nearby.

Nourished sediments are distributed within beach profiles and alongshore through water motion driven by hydrodynamic forces, such as waves, currents, and tides (Dean, 2002; Larson *et al*., 2016). The timescales of sediment transport processes and the resulting morphological response of the coastal systems span a wide range of space and time scales, varying from seconds to years (Larson *et al*., 2002; Larson, 2005). Morphologically, beach profile evolution towards equilibrium is generally linked to seasonal events, occurring over time scales of days to months, while shoreline evolution towards an equilibrium state evolves longer periods, ranging from years to decades. However, processes across different time and space scales interact. Larson *et al.* (2002) indicated that, over a year, the cumulative effects of small-scale sediment transport can contribute as much to regional morphological evolution (on a larger scale), as sediment transport occurring during storm events within the same period.

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[1] RISCO & Department of Civil Engineering, University of Aveiro, Campus Universitário de Santiago, Aveiro, 3810-193, Portugal

[2] RISCO & Department of Civil Engineering, University of Aveiro, Campus Universitário de Santiago, Aveiro, 3810-193, Portugal

[3] CESAM & Department of Physics, University of Aveiro, Campus Unirsitário de Santiago, Aveiro, 3810-193, Portugal

Schwarzer (2003), based on observations of morphological changes, states that short-term period events impose morphological variations that superpose seasonal effects, influencing the long-term processes.

To support coastal management that rely on nourishments interventions and optimize sand and economic resources, it is important to assess the interventions impact on shoreline evolution. Over the years, coastal researchers have focused efforts on developing numerical models to describe the interactions between the forcing sediment transport forces and morphological response of coastal systems. However, due to the complexity of describing all interactions and timescales involved, most models focus on specific processes (Capobianco *et al*., 2002; Larson, 2005; Hoagland *et al*., 2023). They are often categorized into cross-shore numerical models, which describe short- to medium-term events (days to months), and shoreline evolution models, which describe long-term morphological changes (years). Recently, the scientific community has concentrated efforts on propose numerical approaches focused on integrate cross-shore and longshore processes of sediment transport over medium- to long-term periods (Hoagland *et al*., 2023).

The objective of this study is to provide contributions to the numerical modeling of nearshore nourishments from a medium-term perspective, discussing the impacts of these interventions on cross-shore and longshore sediment transport dynamics and shoreline evolution. To achieve the objective of the study, a numerical approach integrating cross-shore and longshore sediment transport processes of sediment transport over medium- to long-term periods is proposed and applied to study nearshore nourishments under different wave conditions. The proposed numerical methodology combines results from two simplified numerical models: the LTC - Long Term Configuration (Coelho, 2005), for simulating longshore processes, and CS-Model (Larson *et al*., 2016), for cross-shore processes. This integrated approach enables analysis of the impacts of different coastal sediment transport processes on the evolution of nearshore nourishments and their effects on shoreline position. These findings are valuable for supporting nearshore nourishment design and coastal management strategies.

METHODOLOGY

The study's methodology consisted of two main phases. Initially, the research focused on developing a numerical approach to integrate the effects of longshore and cross-shore sediment transport processes into shoreline evolution from a medium to long-term perspective. In the second phase, this numerical approach was applied to assess the impact of nearshore nourishments on the morphology of a coastal domain, in relation to nourishment volumes and wave heigh conditions.

The numerical approach developed to integrate cross-shore and longshore sediment transport processes over a medium- to long-term perspective is based on combining the results of two existing numerical models: LTC - Long Term Configuration (Coelho, 2005) and CS-Model (Larson *et al*., 2016). LTC, developed at the University of Aveiro, is a one-line model designed for sandy beaches, which applies the continuity equation to model shoreline position evolution over long-term scales (years). In this model, shoreline position is driven by gradients in longshore sediment transport resulting from waves action, water levels, and boundary conditions of the modelled domain (Coelho, 2005; Lima & Coelho, 2017; Ferreira & Coelho, 2021).

The CS-Model (Larson *et al*., 2016), developed at Lund University, is a cross-shore profile evolution model that considers different processes to compute sediment exchanges within the beach profile from a medium-term perspective. These include wave impact on the dune system (q_D), wind-blown sand transport (q_{WS}) and sandbar-berm sediment exchange (q_B). As illustrated in Figure 1, the model describes profile evolution through morphological parameters such as dune toes position (Y_L and Y_S), shoreline position (Y_G), berm crest position (Y_B), dune heigh (S), berm heigh (D_B), sandbar volume (V_B), depth of closure (D_C), dune face slopes (β_L and β_S) and berm slope (β_F). The cross-shore model is based on the assumption of mass conservation within the profile.

According to Larson *et al*. (2013), the CS-Model simulates sandbar evolution based on the concepts of equilibrium sandbar volume presented by Larson & Kraus (1989), and deviations from this equilibrium. At each time step, the model calculates the equilibrium sandbar volume and the evolution of the sandbar is dictated by the relationship between the actual sandbar volume and the equilibrium volume. If the sandbar volume is higher than the equilibrium volume the sediments are transported from the sandbar to the berm. Conversely, the sediments are transported from the berm to the sandbar (Larson *et al*., 2013). The equilibrium sandbar volume is a function of the dimensionless fall velocity, and deep-water wave parameters (wavelength, the wave height and wave period).

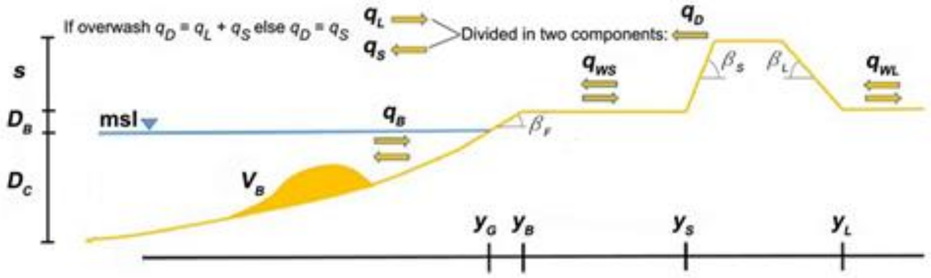


Figure 1. Scheme of the beach profile used by CS-Model: morphological parameters and sediment transport components - based on Larson *et al*. (2016)

The proposed model for integrating cross-shore and longshore sediment transport processes applies a cyclic structure, repeated over a user-defined number of time steps (NCAL). This number corresponds to the number of waves to be simulated. At each time step, for each cross-shore profile in the study area, the effects of longshore and cross-shore sediment transport processes are calculated (ΔQ), and the results are integrated to update beach morphology (ΔZ) by distributing sediment volumes across the active profiles width. Figure 2 provides a flowchart illustrating the workflow of this numerical approach.

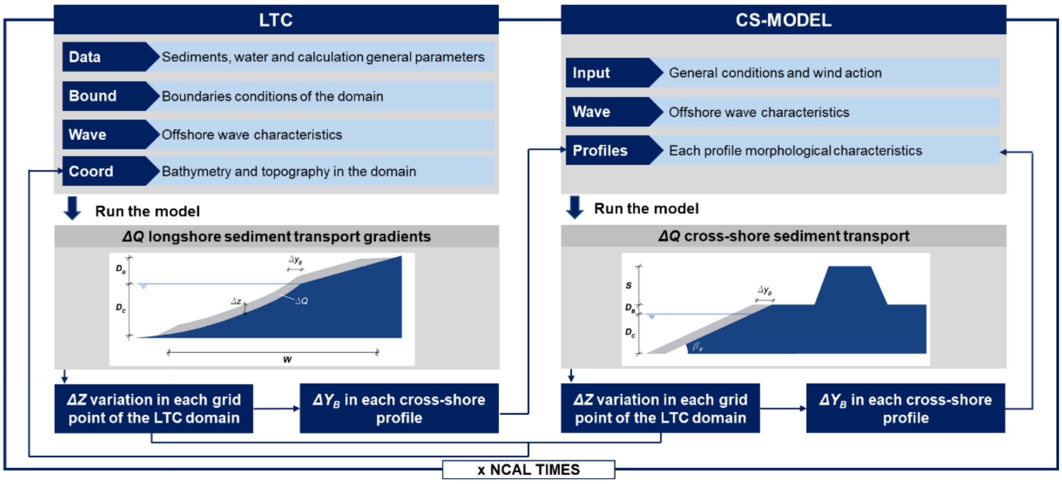


Figure 2. Flowchart of the model developed to integrate longshore and cross-shore sediment transport processes.

The cycle structure consists of five main phases:

1. The LTC is run and the longshore sediment transport gradients are obtained (ΔQ *longshore*) and used to update the bathymetry and topography of the numerical domain (ΔZ variation of the grid points in the active profile width of LTC), by distributing the longitudinal sediment transport gradients (ΔQ *longshore*) across the active width of the cross-shore profiles;
2. The cross-shore morphology of each cross-shore profile (berm crest position, Y_B) is updated to incorporate the effect induced by the littoral drift on the morphology of the profiles (ΔY_B);
3. The CS-Model is run, and the cross-shore sediment transport processes within each cross-shore profile of the numerical domain is obtained (ΔQ *cross-shore*);
4. The bathymetry of the LTC domain is updated to incorporate the cross-shore effects through the distribution of the cross-shore volumes in the active widths of the cross-shore profiles (ΔZ variation of the grid points in the active profile width of LTC);
5. The berm crest position of each cross-shore beach profile is updated to incorporate the effects induced by the cross-shore processes on the morphology of the beach profiles.

MODELING SETUP AND ASSESSED SCENARIOS

The developed model was used to assess nearshore nourishments and examine the influence of wave climate on their performance and longevity. This involved studying three distinct beach morphology scenarios under regular wave conditions. The numerical study was conducted on a generic study area with a regular and parallel bathymetry, consisting of 251 points in the West-Est direction, spaced 20 m, and 15 points (number of cross-shore profiles) in the North-South direction, spaced 10 m (Figure 3). Bathymetry was determined based on the Dean (1991) profile, where the sediment-depend scale parameter was set to 0.127, and the wave energy exposure parameter was set to 2/3. The topography features a 1.5% slope. The active beach profile was defined by a runup limit of +5 m (CD) and the closure depth of -15 m (CD). The boundary conditions of the numerical domain (North and South) were set to extrapolate sediment transport from neighboring areas at boundary limits. According to the LTC (Coelho, 2005) model assumptions, this means that the model calculates the sediment volumes entering or exiting in each boundary of the study area based on the average sediment transport volumes in the three profiles adjacent to the boundary.

A reference scenario (Scenario I) was defined, where all cross-shore profiles in the numerical domain had the same initial sandbar volume of 7.94 m^3/m, corresponding to the equilibrium sandbar volume for $H = 1$ m. Two additional scenarios (Scenario II and III) were defined, simulating nearshore nourishments at the center of the numerical domain. This was accomplished by varying the initial sandbar volume of cross-shore profiles P6 to P10 (Figure 3), and maintaining the cross-shore profiles P1 to P5 and P11 to P15 as those in Scenario I. In Scenario II, the nourished cross-shore profiles had an initial sandbar volume of 129.46 m^3/m, corresponding to the equilibrium sandbar volume for $H = 3$ m. In Scenario III, the sandbar volume of the nourished profiles was set at 498.05 m^3/m, corresponding to the equilibrium sandbar volume for $H = 5$ m. Each scenario was modeled for four constant wave heights, ranging from 1 to 4 m, over a 1-year time period (2920 time-steps, with a 3-hour interval). The wave direction (α) was fixed at 80° (counterclockwise from North, as shown in Figure 3) and the sediment D_{50} was set at 0.5 mm. In the model, the potential longshore sediment transport was calculated using the CERC (1984) formula and the calibration coefficient of the formula was defined equal to 0.01, which resulted in a longshore sediment transport of approximately 15x10^3 m^3 for $H = 1$ m, 82x10^3 m^3 for $H = 2$ m, 225x10^3 for $H = 3$ m and 460.08x10^3 m^3 for $H = 4$ m, by the end of the year of simulation.

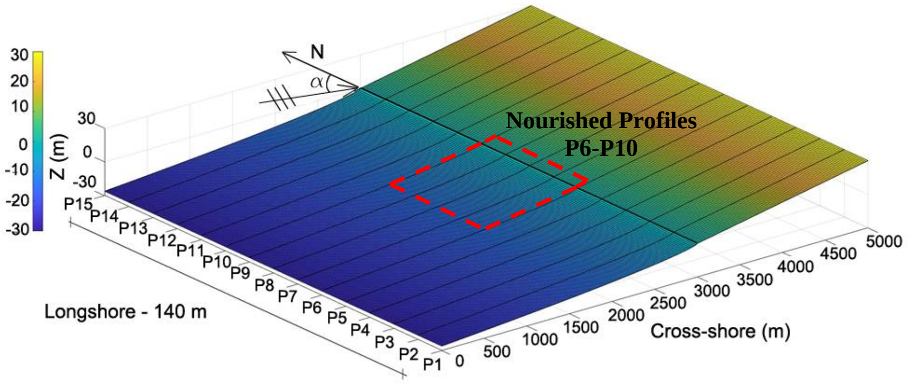


Figure 3. Numerical domain with identification of the cross-shore beach profiles.

Table 1 presents the values adopted to define the initial morphology of the cross-shore profiles. The wind-blown sand transport parameter was set to zero to eliminate the influence of sediment transport induced by the wind. Additionally, the beach berm width was set larger enough to avoid interactions between the berm and the dune.

Table 1. Cross-shore morphology of the CS-Model cross-shore beach profiles (see also Figure 1).

Y_L	Y_S	Y_G	Y_B	S	S_{max}	D_B	β_L	β_S	β_F	D_C
(m)	(m)	(m)	(m)	(m)	(m)	(m)	(rad)	(rad)	(rad)	(m)
1600	1800	3000	3042.79	6.5	6.5	3	0.31	0.16	0.07	15

RESULTS

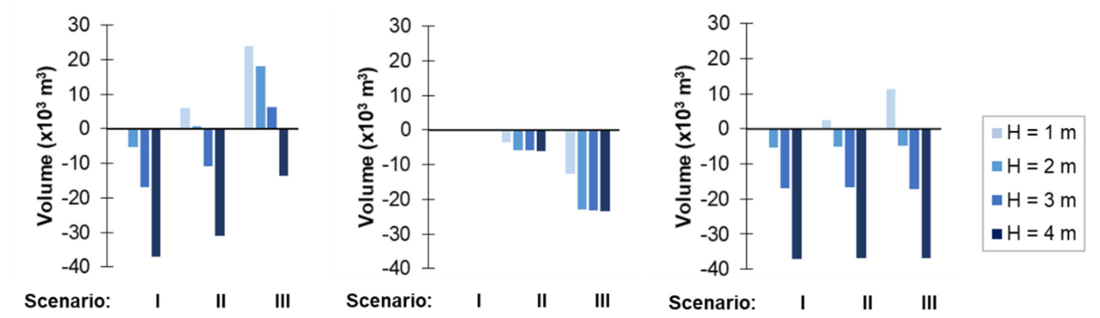
Table 2 and Figure 4 summarize and compare the sediment balance within the numerical domain for the three assessed scenarios in function of the wave height. The results compare the variation of sediments volume induced by longshore processes ($\Delta Vlong$) and by cross-shore processes related to sandbar-berm dynamics ($\Delta Vcross$). Regarding the cross-shore processes, the results are presented in terms of the cross-shore impact induced in the sum of all the nourished profiles ($\Delta VcrossNP$) and in the sum of all the non-nourished profiles ($\Delta VcrossNNP$). Additionally, the table provides the sediment volume going in and out the numerical domain through its boundaries (Qin and $Qout$, respectively). Based on these results, in Scenario I, the coastal domain´s morphological evolution is governed by cross-shore processes. However, in scenarios involving nearshore nourishments, both sediment transport components significantly impact the sediment balance of the numerical domain. The sediment balance of the beach berm ($\Delta Vberm$) is determined by the combined effects of both sediment transport components.

Table 2. Summary of the sediment balance within the numerical domain for the assessed scenarios (x10^3 m^3).

	Scenario I				**Scenario II**				**Scenario III**			
H (m)	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**
Qin	14.60	81.76	224.84	458.44	13.44	79.60	221.84	455.88	8.54	70.77	213.00	447.73
Qout	14.60	81.76	224.84	458.44	16.96	85.32	227.71	461.89	21.12	93.63	236.30	471.06
ΔVlong	0.00	0.00	0.00	0.00	-3.52	-5.72	-5.87	-6.01	-12.58	-22.86	-23.29	-23.34
ΔVcrossNP*	0.00	-1.90	-6.05	-13.19	5.99	4.03	0.00	-7.14	23.80	21.47	17.12	10.17
ΔVcrossNNP*	0.00	-3.42	-10.90	-23.75	0.00	-3.42	-10.90	-23.75	0.00	-3.42	-10.90	-23.75
ΔVcross*	0.00	-5.31	-16.95	-36.94	5.99	0.61	-10.90	-30.89	23.80	18.05	6.22	-13.58
ΔVberm**	0.00	-5.31	-16.95	-36.94	2.47	-5.10	-16.77	-36.90	11.22	-4.80	-17.07	-36.92

*Negative values indicate sediment transfer from the beach berm to the sandbar and positive values represent the opposite trend.

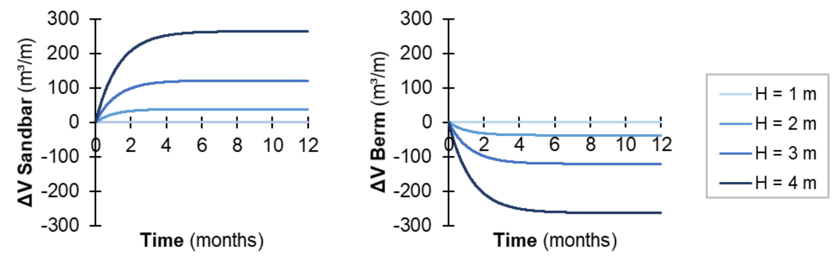
**Negative values represent sediment loss on the beach berm, while positive values indicate sediment gain.



a) $\Delta Vcross$ b) $\Delta Vlong$ c) $\Delta Vberm$

Figure 4. Comparison of sediment volumes induced by cross-shore (*ΔVcross*) and longshore (*ΔVlong*) sediment transport processes, along with the overall sediment balance (*ΔVberm*) within the numerical domain, for each assessed scenario.

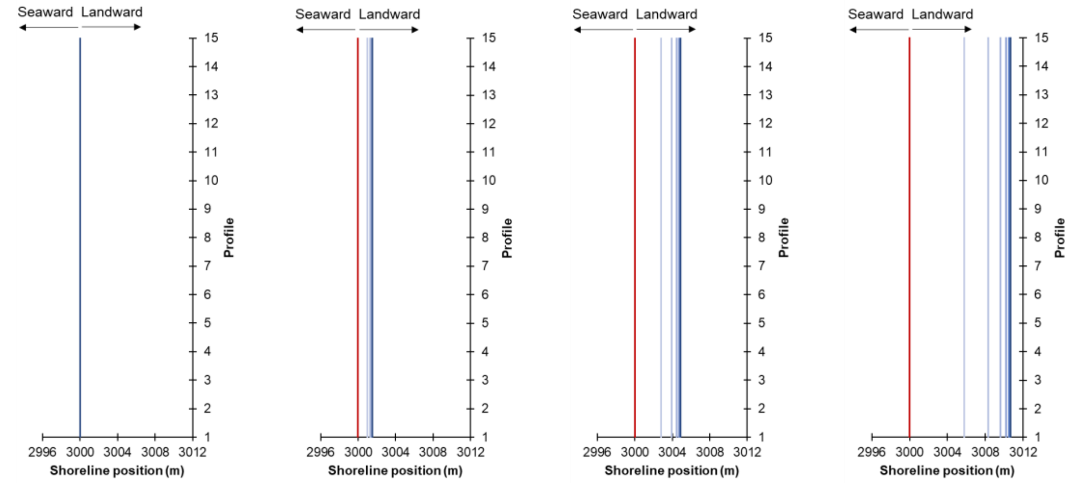
The difference in the impact of sediment transport components between the non-nourished scenario and nourished scenarios is linked to cross-shore displacements along the coastal domain. The results show that sandbar volume of the cross-shore profiles tends to an equilibrium configuration, resulting in sediment exchanges with the beach berm. In Scenario I, since all cross-shore profiles start with the same initial sandbar volume, they exhibit the same shoreline displacement, and consequently, no longshore sediment transport gradients occur. Thus, the morphology evolution of the coastal domain is driven by sediment exchanges between the sandbar and the berm that occurs until the sandbar reaches its equilibrium volume, which is dependent on the wave climate. Figure 5 compares the sediment exchange between the sandbar and berm as a function of wave height. When H = 1 m the cross-shore processes have no impact on the sediment balance because the sandbar matches the equilibrium sandbar volume, meaning that the coastal domain is in equilibrium. For more energetic wave climates, the cross-shore processes move sediments to deeper areas in the numerical domain. Since the initial sandbar volume is lower than the equilibrium volume, sediments are transferred from the berm to the sandbar. Higher wave heights result in a greater amount of sediments being transferred.



a) ΔV Sandbar b) ΔV Berm

Figure 5. Evolution of sandbar and berm volume variations in Scenario I as a function of wave height.

Figure 6 compares the monthly shoreline position in Scenario I for different wave heights. When H = 1 m, the shoreline maintains its initial position. In more energetic wave climates, the transfer of sediments from the berm to the sandbar causes shoreline retreat. The time required to cross-shore profiles reach the equilibrium sandbar volume depends on the wave climate and it is visible by the convergence of the shoreline position to the final position.



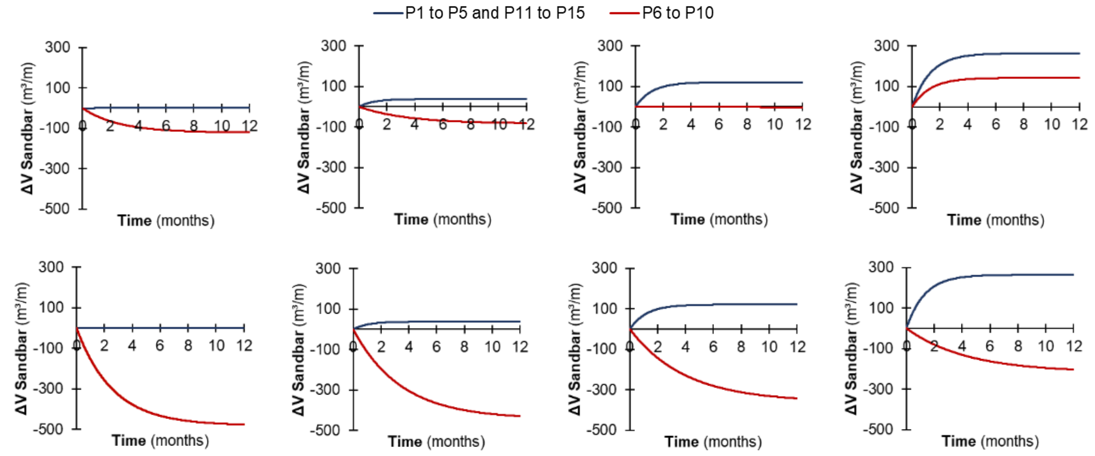
a) H = 1 m b) H = 2 m c) H = 3 m d) H = 4 m

Figure 6. Scenario I - Monthly shoreline position (red line: initial shoreline; blue lines: monthly shorelines over time, gradually darkening towards the end of the simulation)

In the scenarios involving nearshore nourishments (Scenario II and Scenario III), the results indicate that variations in sandbar volume along the longshore dimension of the study area led to different cross-shore behaviors, between nourished and non-nourished cross-shore profiles. This difference is due to the convergence of the sandbar volume of the cross-shore profiles towards the equilibrium volume. The different cross-shore displacements between profiles changes the shoreline orientation, which consequently generates longshore sediment transport gradients. Thus, in these scenarios, both cross-shore and longshore sediment transport components impact the sediment balance in the numerical domain and, therefore, influence shoreline evolution.

In both nourished scenarios, longshore sediment transport has a negative impact on the sediment balance of the numerical domain. This effect arises from the evolution of shoreline orientation. Based on the analysis of the results, it is concluded that the shoreline orientation in the northern boundary (P15) reduces southward transport (Qin), while in the southern profiles (P1), the shoreline orientation increases southward transport ($Qout$). As a result, the volume of sediment entering the calculation domain is lower than the volume leaving, leading to a loss of sediment volume within the domain compared to the initial volume (*ΔVlong*). Greater sediment losses due to longshore effects are observed in the scenario with the higher nourished volume (Scenario III), and with larger wave heigh, Furthermore, similar impacts are observed for higher wave heights (2, 3, and 4 m).

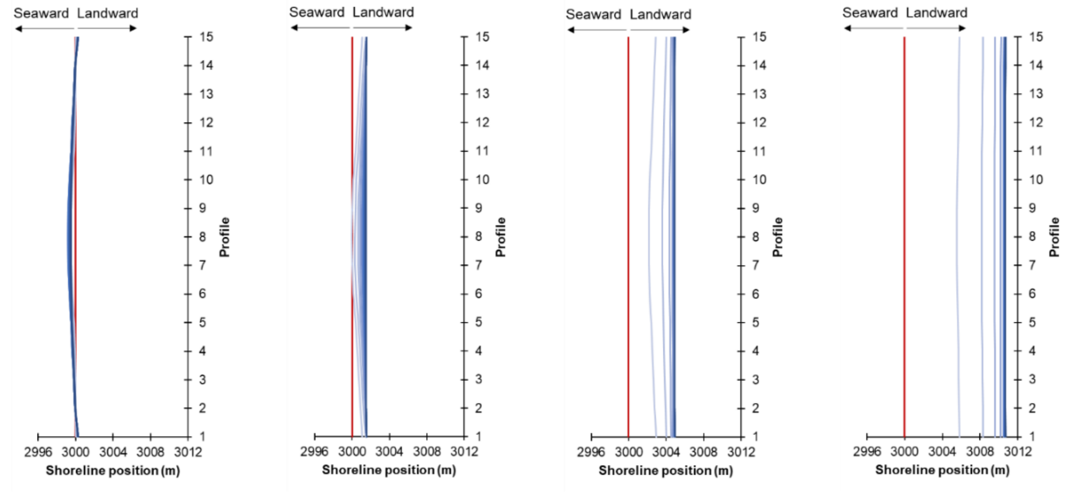
Figure 7 shows the evolution of sandbar volume variation of the cross-shore profiles within the numerical domain, resulting from cross-shore processes related to sandbar-berm dynamics. In terms of cross-shore processes, as observed in non-nourished profiles (P1 to P5 and P11 to P15), when wave heigh is H = 1 m, the sandbar volume in these cross-shore profiles remains stable over time. However, for higher waves, the sandbar volume in the cross-shore profiles increase, indicating sediment transfer from the berm to the sandbar. In the nourished profiles (P6 to P10), the sandbar-berm dynamics depend on the relationship between the initial sandbar volume and the equilibrium sandbar volume. In Scenario II, when the wave heigh is below 3 m, the sandbar volume of the cross-shore profiles decreases over time, indicating sediment transfer from the sandbar to the berm. In Scenario III, with a higher nourished volume, sediment transfer to the berm occurs in all wave climates.



a) H = 1 m b) H = 2 m c) H = 3 m d) H = 4 m

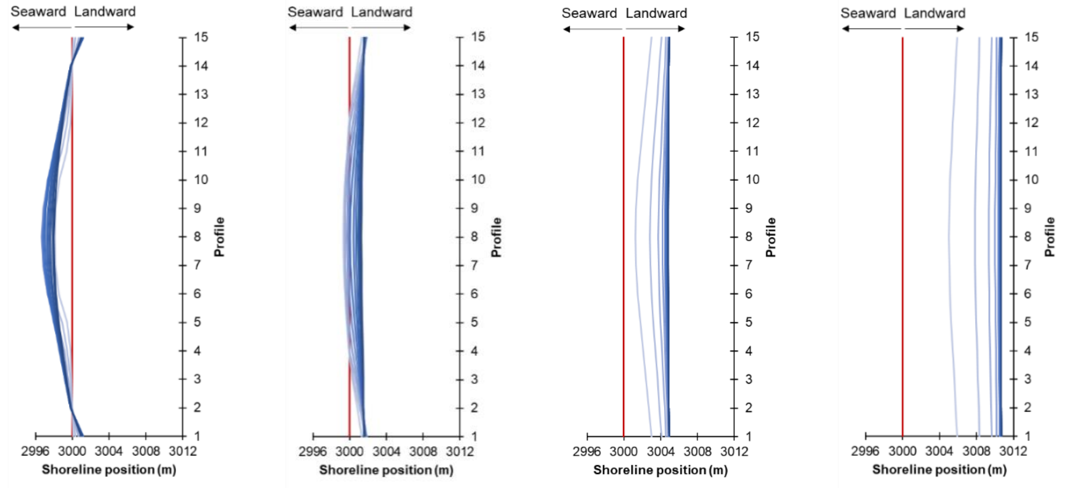
Figure 7. Evolution of the sandbar volume variation in the cross-shore profiles of the numerical domain: upper line - results for Scenario II; lower line - results for Scenario III

The shoreline configuration and its evolution results from the balance between the longshore and cross-shore sediment transport processes. Figure 8 and Figure 9 shows the monthly shoreline position in Scenarios II and III, respectively.



a) H = 1 m b) H = 2 m c) H = 3 m d) H = 4 m

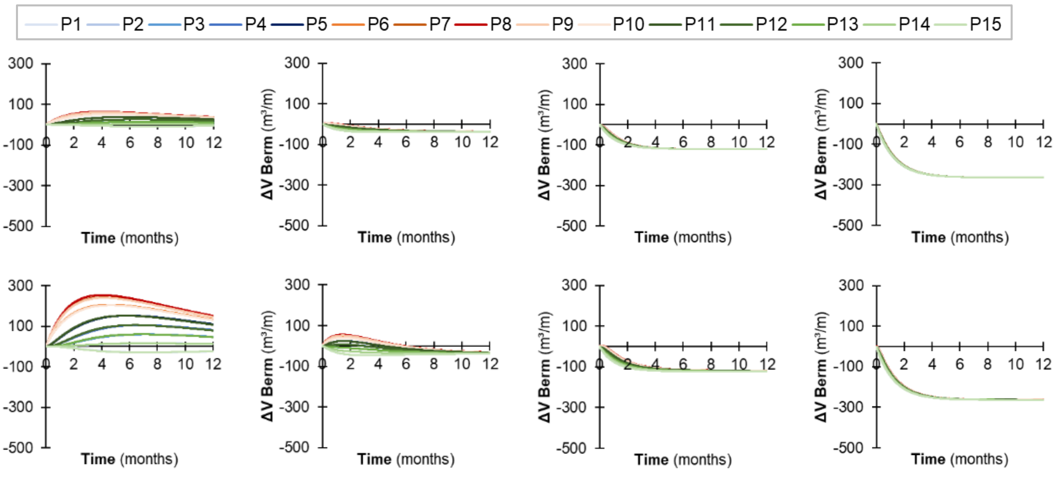
Figure 8. Scenario II - Monthly shoreline position (red line: initial shoreline; blue lines: monthly shorelines over time, gradually darkening towards the end of the simulation)



a) H = 1 m b) H = 2 m c) H = 3 m d) H = 4 m

Figure 9. Scenario III - Monthly shoreline position (red line: initial shoreline; blue lines: monthly shorelines over time, gradually darkening towards the end of the simulation)

Based on shoreline configuration, it is observed that nearshore nourishments cause the shoreline to adopt a concave shape, which is more pronounced in the scenario with a higher nourishment volume and/or less energetic wave climates. In less energetic wave climates, the shoreline configuration and the evolution of berm volume variation of the cross-shore profiles (Figure 10), highlights the positive impact of nearshore nourishment in terms of seaward shoreline advance and shoreline retreat mitigation. This advance is most pronounced in front of the nourished profiles. However, the evolution of the berm volume variation (Figure 10) shows that the benefits of nourishment extend to the non-nourished profiles due to the longshore sediment transport, causing the shoreline position to shift seaward compared to the position in Scenario I (which does not include nearshore nourishment). In more energetic wave climates, the shoreline curvature is observed in the initial phases of the numerical simulation. By the end of the one-year period, the shoreline assumes a more linear configuration, as the perturbation induced by cross-shore sediment transport on the shoreline position disappears.



a) H = 1 m b) H = 2 m c) H = 3 m d) H = 4 m

Figure 10. Evolution of the berm volume variation in the cross-shore profiles of the numerical domain: upper line - results considering Scenario II; lower line - results considering Scenario III

DISCUSSION AND CONCLUSION

The increasing demand for sand to implement beach nourishments highlights the importance of optimizing sand nourishments to ensure the viability of future coastal erosion mitigation plans based on these interventions (de Schipper *et al*., 2021). The design and evolution of nourishments depends on various design parameters and site-specific aspects (Dean, 2002; Pais-Barbosa *et al*., 2023). Among these, the placement site within the beach profile is a key parameter, as different locations to deposit the sediments involve different workflows and costs. The benefits of artificial nourishments include the improved safety for beach users, preservation of the beach for recreational purposes, maintenance of the dune system to mitigate overtopping events, which are closely linked to design considerations related to the placement location (Houston, 2018; Taal *et al*., 2016; Teixeira, 2016; Coelho *et al*., 2020, 2024). From a cost perspective, sediment deposition in the submerged area of the coastal domain is often the most economical option (Dean, 2002; Brand *et al*., 2022). However, the impacts of these interventions on shoreline evolution are not immediately and depend on sediment distribution within the beach profile and alongshore (Larson *et al*., 2016; Luijendijk *et al*., 2017). Numerical models are tools that can support the design of such interventions, enhancing their cost-effectiveness and addressing uncertainties (Capobianco *et al*., 2002; Hamm *et al*., 2002).

This study aims to provide a numerical approach to evaluate the evolution of nearshore nourishments from a medium- to-long term perspective. It focuses on developing a numerical model and applying it to assess the impacts of nearshore nourishments on shoreline evolution under different wave climates. The proposed model combines longshore and cross-shore sediment transport processes by integrating the results of two existing simplified numerical models: LTC, which simulates longshore processes and CS-Model, which simulates cross-shore processes.

The new proposed model relies in the main assumption of existing numerical models of coastal zones evolution that, according Roelvink & Reniers (2011), consist of morphodynamic loops that are repeated over a number of time steps and in each step, the morphology is updated based on the calculation of hydrodynamics forces and sediment transport volumes. However, by applying two simplified numerical models, the proposed approach enables medium- to long-term analysis with reduced computational effort, thus overcoming numerical limitations associated with combining coastal processes that act across different spatial and temporal scales. This numerical approach aligns with recommendations from researchers such as Hamm *et al.* (2002) and Hanson *et al.* (2003), who suggested that coupling longshore and cross-shore numerical models can be a promising way to overcome numerical limitations related to processing time and the need for extensive calibration parameters. These are key aspects when implementing models for coastal evolution studies on medium- to long-term timescales (years) and regional scales. Additionally, both models selected for integration have already been applied to medium- to long-term studies in both conceptual and real-world scenarios, demonstrating their suitability for coastal studies (Palalane *et al*., 2016; Kato & Udo, 2020; Coelho *et al*., 2022; Ferreira *et al*., 2023; Pais-Barbosa *et al*., 2023).

The numerical results show that nourishments induce changes within the coastal domain, with both longshore and cross-shore sediment transport processes impacting sediment distribution and, consequently, shoreline evolution. This finding aligns with Dean (2002) and Larson *et al.* (2016), who emphasize that nourishment evolution depends on sediment distribution, influenced by both cross-shore and longshore distribution. Based on the numerical results, the impact of cross-shore processes is associated with the sandbar volume in the cross-shore profiles, which evolves toward an equilibrium volume over time. Longshore effects result from sediment transport gradients induced by changes in shoreline orientation, due to different cross-shore displacements between nourished and non-nourished profiles. The shoreline evolution demonstrates that longshore effects cause the shoreline to adopt a concave shape, dispersing nourished sediments into non-nourished areas of the coastal domain. This process leads to a seaward advancement of the shoreline position when compared to non-nourished scenarios. These findings are consistent with monitoring works focused on observe and describe the effects of nearshore nourishments on shoreline evolution, which generally indicate that nourished sediments spread both alongshore and cross-shore, with longshore sediment transport processes extending the benefits of the nourishment to surrounding areas, thereby mitigating shoreline retreat (McGill *et al*., 2022; Pinto *et al*., 2022).

The results highlight the performance of nearshore nourishments under different wave climates, which represent different sediment balances in the numerical domain. The sediment balance results from the relationship between the effects of longshore sediment transport gradients and the cross-shore processes. For the assessed scenarios, it was observed that longshore effects have a negative impact on the sediment balance. Furthermore, in the most energetic wave climates, the total sediment volume induced by cross-shore processes also lead to sediment losses on the berm of the beach. These aspect are valuable for nearshore nourishment design because it is important to address existing research gaps in understanding the performance and longevity of such interventions in high-energy wave climates with chronic coastal erosion problems (Pinto *et al.*, 2022; Ferreira *et al.*, 2023). To address these questions and achieve more precise conclusions about nourishments performance under energetic wave climates, it is important to develop future numerical studies that considered real wave data series, including its seasonality effects.

The proposed model and the obtained results show potential for supporting nourishments design and therefore, coastal management and planning. The results provide insights into shoreline evolution, a key parameter for coastal management purposes. The model can simulate real wave data series, a site-specific factor, which enables the inclusion of seasonal effects related to wave climate in numerical simulations and facilitates real-world case studies. Additionally, as highlighted by Ferreira *et al.* (2024), the proposed numerical approach, based on combine the results of the simplified numerical models LTC and CS-Model, allows for the integration of coastal processes occurring in both the submerged and emerged areas of the coastal domain. This enables future studies to assess other design option for nourishment interventions, particularly those related to sand deposition locations (submerged area, subaerial profile or dune reinforcement), compare results, and support the design and evaluation of various nourishment options while optimizing resources.

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