

**Document Version**

Final published version

**Licence**

CC BY

**Citation (APA)**

Shafiei, H., Pearson, S. G., & Reniers, A. J. H. M. (2026). Analysis of Rip-Channel Formation at an Idealized Beach in the Framework of Coastal Sediment Connectivity. In C. Coelho, C. Hallin, F. Sancho, & P. A. Silva (Eds.), *Coastal Dynamics 2025: Volume 1* (Vol. 1, pp. 89-94). (Coastal Research Library; Vol. 41). Springer.  
[https://doi.org/10.1007/978-3-032-15473-6\\_14](https://doi.org/10.1007/978-3-032-15473-6_14)

**Important note**

To cite this publication, please use the final published version (if applicable).  
Please check the document version above.

**Copyright**

In case the licence states "Dutch Copyright Act (Article 25fa)", this publication was made available Green Open Access via the TU Delft Institutional Repository pursuant to Dutch Copyright Act (Article 25fa, the Taverne amendment). This provision does not affect copyright ownership.  
Unless copyright is transferred by contract or statute, it remains with the copyright holder.

**Sharing and reuse**

Other than for strictly personal use, it is not permitted to download, forward or distribute the text or part of it, without the consent of the author(s) and/or copyright holder(s), unless the work is under an open content license such as Creative Commons.

**Takedown policy**

Please contact us and provide details if you believe this document breaches copyrights.  
We will remove access to the work immediately and investigate your claim.



# Analysis of Rip-Channel Formation at an Idealized Beach in the Framework of Coastal Sediment Connectivity

H. Shafiei<sup>(✉)</sup>, Stuart G. Pearson, and A. J. H. M. Reniers

Department of Hydraulic Engineering, Delft University of Technology, Delft 2600GA,  
The Netherlands

[h.shafiei@tudelft.nl](mailto:h.shafiei@tudelft.nl)

**Abstract.** Tracking coastal sediments can provide useful information about coastal dynamics, thereby helping coastal management. However, the highly dynamic conditions of the coasts makes analyzing the trajectories of a huge number of particles challenging. To solve this limitation, the framework of coastal sediment connectivity is designed. In this framework, recent advances in graph theory are used to quantify coastal systems as complex networks. In this context, sediment sinks/sources and pathways represent the graphical nodes and links, respectively. In this work, we take the first step to evaluate the ability of this newly-developed framework in quantifying the basic processes on a sandy beach. Firstly, we used Delft3D to obtain the velocity field and bed-level changes. Then, the Eulerian results were fed into SedTRAILS to simulate the sediment pathways. We show that the current version of the model can correctly calculate the basic metrics of the sediment-connectivity network (e.g., network link strength which is a proxy for sediment fluxes). More specifically, we show that this framework is capable of exploring the initiation of the rip channel formation.

**Keywords:** Sediment Connectivity · Rip-channeled beach · Complex Networks

## 1 Introduction

Sediment dynamics of sandy beaches are highly variable both temporally and spatially. Understanding gross sediment transport (which indicates the sediment fluxes) can be calculated using Lagrangian models. It can provide a wide range of understandings about the dynamics of coastal systems, e.g., the source (destination) of the eroded (deposited) sediments, the sediment-mixing dynamics, and morphological hot spots. However, the large number of sediment trajectories impedes efficient analysis of the results and drawing solid conclusions. Therefore, development of a toolbox for analyzing the sediment pathways altogether is invaluable. Considering these sediment pathways as a complex network paves the way to take advantage of recent advancements in network sciences and quantify the practical characteristics of coastal sediment dynamics.

Coastal sediment connectivity is a recently-developed framework through which properties of sediment pathways are quantified to better understand sediment dynamics and help coastal management [1, 2]. To validate the simulated sediment pathways, the spatial distribution of their direction and strength can be compared to the short-term morphological changes. This comparison can give us insight into the interpretation of these connectivity metrics. Consequently, the main goal of this investigation is to evaluate the relevance of some basic connectivity metrics to sediment dynamics of a relatively well-studied environment, i.e., embayed rip-channelled beach [3].

## 2 Methodology

In the first step, an Eulerian hydro-morphodynamic model (Delft3D, here) is set up to simulate the effects of forcings on bed-level changes and obtain the intermediate bathymetries. Then, those intermediate bathymetries are used as the initial bed level in the Eulerian morpho-static model while the other settings are kept the same as in the morphodynamic model. In the third and final step, the simulations in the second step are fed into the SedTRAILS model to be used as the initial conditions as well as the particle drivers. Then, SedTRAILS tracks the seeded sediments following the approach of Soulsby et. al. [4] and calculates the connectivity metrics using the toolkit of Rubinov and Sporns [5].

SedTRAILS (Sediment TRANsport vIsualization & Lagrangian Simulator) is a newly-developed model adapted to calculate, visualize, and analyse the sediment connectivity network [1]. In the current version, it assumes a morpho-static bed, and the particles are seeded as the initial conditions. The main outputs are the trajectories of each seeded particle until the end of the simulation and the respective 2D adjacency matrix. In this matrix, each row and column represents one of the nodes and each cell indicates whether its respective row and column are connected or not.

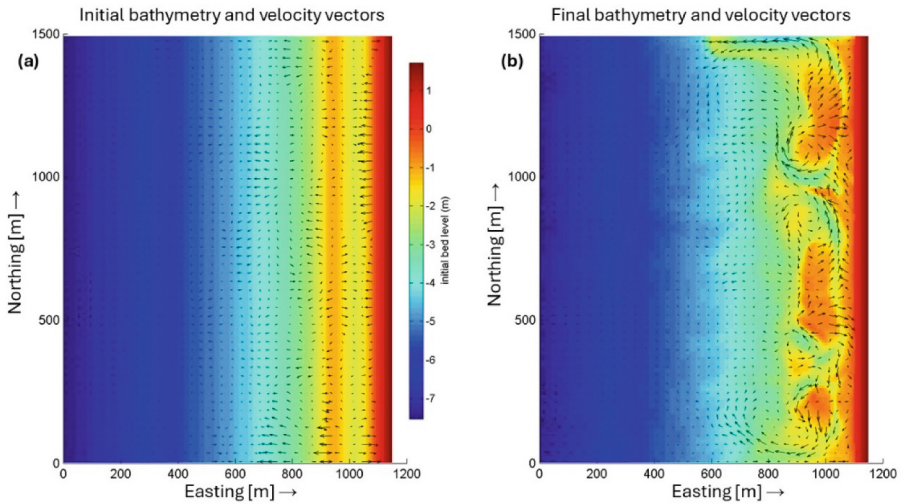
Once the sediment pathways have been compiled as a complex network, a suite of toolboxes and methodologies are available to quantify the properties of the resultant network [1, 2]. In this work, we focus on node strength which is a basic network metric. In the context of graph theory, the metric strength is the sum of the weights of all the links connected to a given node. Furthermore, in-strength and out-strength focus on the total weight of incoming and outgoing links, respectively. In the context of sediment transport, strength represents the amount of sediment exchanged between a given node with its neighbors. The spatial distribution of the net strength (i.e., out-strength minus in-strength) is expected to be similar to the maps of initial erosion/sedimentation. It should be noted that, in this manuscript, absolute strength is used interchangeably with strength to emphasize that the sign of the strength values is not taken into account.

## 3 Results

### 3.1 Delft3D

The Delft3D model settings are the same as Reniers et al. [3]. It simulates the morphological evolution of an idealized, embayed sandy beach with grain size of 0.22 mm under wave group forcing. Root-mean-squared wave height and directional spreading are 1 m

and  $12.2^\circ$ , respectively. Therefore, the waves are erosive and alongshore variable while the initial bathymetry is an alongshore-uniform bar profile (see Fig. 1(a)). Besides, the hydrodynamic model simulates 8 h with morphological factor of 12. Figure 1(b) illustrates the final bed level and velocity field in which rip channels and currents are fully developed. However, in this paper, we focus only on the initial time steps during which the formation of the rip channel is initiated. Consequently, the morpho-static Delft3D model is set up using the alongshore-uniform bar and 1 h simulation period. A 30 min spin-up period is considered and therefore not included in the output. Although other aspects of the model configuration are kept as in the morphodynamic model, the outputs, which will be used in the SedTRAILS model, are written in small time steps (i.e., 4.8 s).



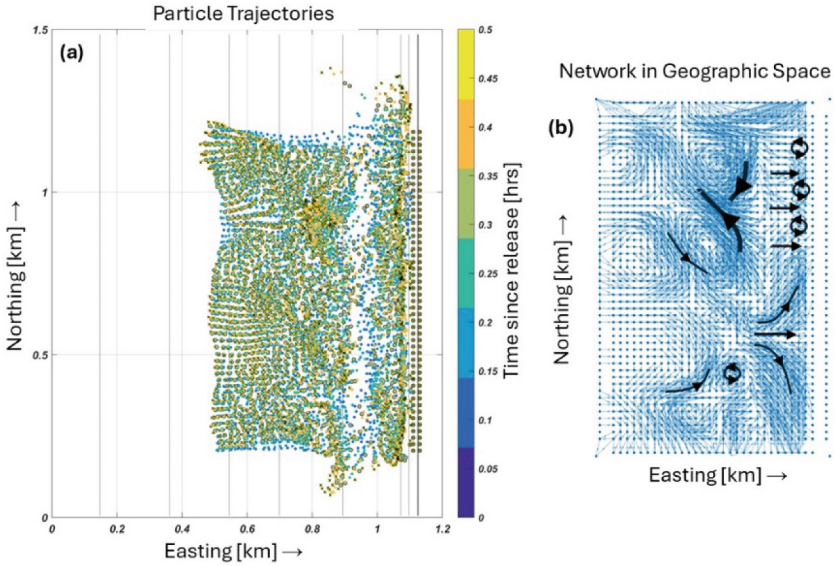
**Fig. 1.** Delft3D morphodynamic model results. (a) the initial bar is along-shore uniform while the velocity field is not uniform due to wave group forcing. (b) the rip currents and channels are fully developed after four days of morphological simulation.

### 3.2 SedTRAILS

In our SedTRAILS model, the particles are seeded uniformly within the central section of the surf zone as initial conditions. The distance between each particle is 20 m and additional particles are not introduced during the simulation. The sand properties and simulation timeframe are the same as the morpho-static Delft3D model.

Various plots can be obtained using the post-processing tool implemented into SedTRAILS. For example, particles can be illustrated at every given time step and setting their colors according to their age since their release (see Fig. 2(a)). The main observations from this figure are (I) the particles over the bar become scattered around the bar (II) the largest sediment accumulation occurs at around  $(x, y) \sim (800, 900)$ . This is consistent with the location of the rip-shoal system in Fig. 2(b). Furthermore, the resultant network of sediment nodes/sinks and pathways can be plotted in geographic space. As highlighted in Fig. 2(b), it reveals the main sediment pathways. We can conclude

that the initial bar migrates non-uniformly in both longshore and cross-shore directions. Visually, the areas with the densest pathways can be considered as the most persistent transport patterns. Consistently, the persistent offshore- and onshore-directed sediment pathways are located around the main rip channel and shoal (compare Fig. 2(b) with Fig. 1(b)).

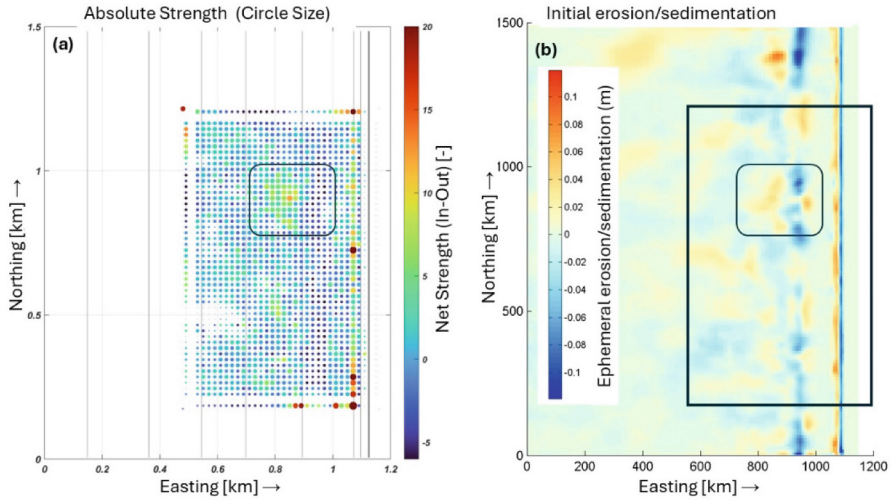


**Fig. 2.** Tracking the particles using SedTRAILS. (a) each particle is shown at different time steps and colored according to their age since release. (b) initial particle position and their respective pathways till the end of the simulation reveal the main sediment pathways.

### 3.3 Sediment Connectivity

In this manuscript, as presented in Fig. 3(a), the absolute and net values of strength of the nodes are chosen as proxies to sediment fluxes and erosion/sedimentation, respectively.

To verify the observed spatial patterns of these parameters, the initial sediment erosion/deposition during the first 30 min of the simulation is shown in Fig. 3(b). At this stage, it is important to predict the formation of the initial rip channel. This can be done by identifying the highest positive values of net strength (i.e., in-strength minus out-strength), which is consistent with Fig. 3 and is located at around  $(x, y) \sim (800 \text{ m}, 900 \text{ m})$ .



**Fig. 3.** Exploring the formation of a rip channel using SedTRAILS (a) Considering net and absolute values of node strength as a proxy for initial erosion and sedimentation. (b) spatial distribution of initial erosion and sedimentation in the first 30 min of the Delft3D morphodynamic simulation. The black boxes highlight the location of rip-channel formation.

## 4 Conclusions and Discussion

In this work, we evaluate the conceptual framework of coastal sediment connectivity to explore the formation of a rip channel at a sandy beach. SedTRAILS, as the main toolbox in this framework, simulates the sediment pathways and their respective connectivity network within the timeframe of 30 min. During this time, the wave group forcing entrains and transports all the particles on the sandbar towards various directions. The persistent patterns of sediment pathways trigger the formation of the first rip channel. Distribution of the particles at the end of the simulation and the node strength as the proxy for sediment fluxes are consistent in identifying the location where the formation of the first rip channel is initiated. Future work will focus on further development of network-based metrics for quantifying sediment pathways on evolving beaches.

## References

1. Pearson SG, et al (2021) Lagrangian sediment transport modelling as a tool for investigating coastal connectivity. In: Proceedings, Coastal Dynamics Conference (2021)
2. Pearson SG, van Prooijen BC, Elias EP, Vitousek S, Wang ZB (2020) Sediment connectivity: a framework for analyzing coastal sediment transport pathways. *J Geophys Res Earth Surface* **125**(10), e2020JF005595 (2020)
3. Reniers AJ, Roelvink JA, Thornton EB (2004) Morphodynamic modeling of an embayed beach under wave group forcing. *J Geophys Res Oceans* **109**(C1) (2004)

4. Soulsby RL, Mead CT, Wild BR, Wood MJ (2011) Lagrangian model for simulating the dispersal of sand-sized particles in coastal waters. *J Waterw Port Coast Ocean Eng* 137(3):123–131
5. Rubinov M, Sporns O (2010) Complex network measures of brain connectivity: uses and interpretations. *Neuroimage* 52(3):1059–1069

**Open Access** This chapter is licensed under the terms of the Creative Commons Attribution 4.0 International License (<http://creativecommons.org/licenses/by/4.0/>), which permits use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons license and indicate if changes were made.

The images or other third party material in this chapter are included in the chapter's Creative Commons license, unless indicated otherwise in a credit line to the material. If material is not included in the chapter's Creative Commons license and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder.

