

Document Version

Final published version

Licence

CC BY

Citation (APA)

Marijnissen, R., Schrijvershof, R., van Weerdenburg, R., & van Maren, B. (2026). A 21st Century Projection of Sediment Management Strategies as Nature-Based Solutions in the Ems Estuary. In C. Coelho, C. Hallin, F. Sancho, & P. A. Silva (Eds.), *Coastal Dynamics 2025* (Vol. 2, pp. 548-555). (Coastal Research Library; Vol. 42). Springer.
https://doi.org/10.1007/978-3-032-15477-4_83

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.



A 21st Century Projection of Sediment Management Strategies as Nature-Based Solutions in the Ems Estuary

Richard Marijnissen¹ (✉), Reinier Schrijvershof^{1,2}, Roy van Weerdenburg^{1,3},
and Bas van Maren^{1,3}

¹ Deltares, Boussinesqweg 1, 2629 HV Delft, The Netherlands
richard.marijnissen@wsp.com, {reinier.schrijvershof,
Roy.vanWeerdenburg,bas.vanmaren}@deltares.nl

² Wageningen University & Research, Environmental Sciences Group, Droevendaalsesteeg 3a,
6708 PB Wageningen, The Netherlands

³ Faculty of Civil Engineering and Geosciences, Delft University of Technology, Stevinweg 1,
2628 CN Delft, The Netherlands

Abstract. The Ems estuary faces rising turbidity and increased flood risk due to sea-level rise. We investigated three Nature-based Solutions (NbS) through hydro-morphological modeling to address these issues by 2100: converting a polder to wetland, facilitating salt marsh growth with brushwood groynes, and re-using dredged sediment. Without NbS, turbidity is projected to increase, especially with sea-level rise. Reconnecting a polder can help reduce turbidity in the Dollard while expanding facilitating new wetland, but may not fully counteract the increased sediment import projected with sea-level rise. Extracting mud from the Delfzijl harbour is the most effective measure in reducing turbidity, while marsh expansion with brushwood groynes does not significantly affect turbidity. Nevertheless, groynes facilitate both marsh expansion as well as significant local flood risk reduction.

Keywords: Nature-based solutions · Sea-level rise · Flood risk · Turbidity · Sediment management

1 Introduction

Located within the Wadden Sea along the border between the Netherlands and Germany, the Ems estuary has undergone substantial transformations due to natural processes and human interventions. Centuries of land reclamation and maintenance dredging from the latter half of the 20th century onwards for shipping are believed to be responsible for the current turbid state of the estuary [1]. The abundance of fine particles in the water limits light penetration for phytoplankton growth, severely restricting primary production [2]. Additionally, sea-level rise increases the risk of flooding and saltwater intrusion into the surrounding low-lying, subsiding polders.

Sediment management strategies as part of a Nature-based Solution (NbS) could provide solutions for these challenges. Fostering the deposition of suspended sediments is expected to reduce turbidity while restoring and creating new habitats. As part of the EmsDollard2050 program, various pilots are being conducted. These initiatives aim to mitigate current issues and provide a blueprint for sustainable estuary management in the future. The main goal of this study is to develop a long-term morphological process-based model and predict how the proposed sediment management strategies in the EmsDollard2050 programme will contribute to biodiversity and ecosystem services in the estuary on the long-term.

2 Methods

2.1 Hydro-Morphological Model

We developed a set of three nested Delft3D – Flexible Mesh models to predict the impact of sediment management strategies and sea-level rise. The largest model, the Dutch Continental Shelf Model (DCSM) [3], is used for a hydrodynamic hindcast of the year 2018. This hindcast provides synthetic hydrodynamic boundary conditions for a representative spring-neap period, following the procedure developed by Schrijvershof et al. [4]. The intermediate model covers the Ems estuary and includes the Wadden Sea from the islands of Norderney to Ameland. The wave- and wind climate were schematised from a nearby observation buoy into 12 representative wave-wind classes following the procedure described by Walstra et al. [5].

A smaller model that simulates sediment dynamics and morphodynamic evolution is nested inside the intermediate model, with a seaward boundary at Eemshaven and a landward boundary at the lock near Herbrum (Germany). This smaller model is forced with the tides and waves that are propagating through the mouth of the Ems estuary from the intermediate model. Additionally, for each wave- and wind climate class the expected non-tidal residual from 10 years of observations is imposed on the model boundaries.

The morphodynamic sediment transport model only accounts for muddy sediment because for two reasons. First, the focus on Nature-based Solutions (NbS) for restoring muddy intertidal flats and reducing turbidity. Second, the predominantly sandy features, such as tidal channels, will not change significantly up to 2100 while morphological predictions of such features are prone to errors (such as artificial deepening). Such errors would strongly influence the impact of the interventions.

Vegetation is included in the model simulations by exerting resistance to flows [6] and attenuating wave action [7] where marshes are present. The vegetation coverage is updated every five simulated years, according to simple ecotope rules from Bouma et al. [8].

After calibration, the model reproduces the general pattern of suspended sediment concentration in the Ems estuary and Dollard, increasing from Eemshaven into the Dollard, matching observations by Brinkman et al. [9]. Major sediment pathways, such as circulation across the Geise dam observed by van Maren et al. [10], are accurately reproduced, and sediment accumulation in marshes is well captured. Large spikes in suspended sediment and fluxes upstream from Emden and up to the Ems River are underestimated due to the absence of vertical transport gradients in the 2D-model and

omitted processes like fluid mud formation. Despite these limitations, we consider the model suitable for studying the effect of sediment management scenarios.

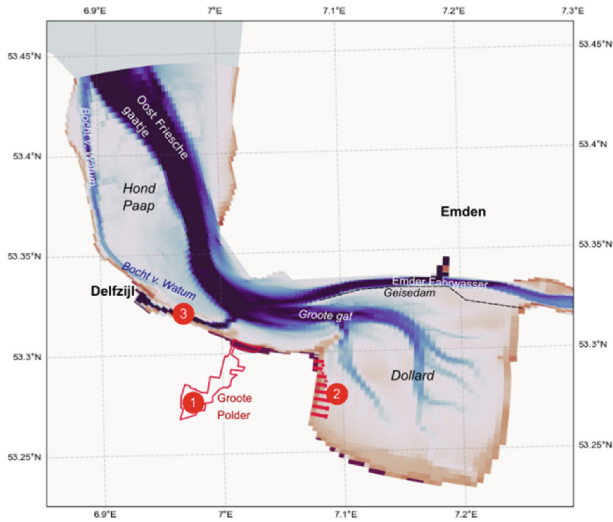


Fig. 1. Map of the Ems estuary and Dollard with the locations of the NbS strategies.

2.2 Scenarios

Three NbS are explored through numerical modelling (Fig. 1): 1) the creation 300 hectares of intertidal wetland (Grootte Polder); 2) promote sediment deposition and salt marsh expansion using 400x400 meter brushwood groyne field in the western Dollard (with groynes permeable to flow but blocking incoming waves); and 3) the extraction of sediment dredged from the harbour of Delfzijl, where instead of disposing the sediment outside the harbour entrance, it is removed from the model domain. The NbS measures are assessed for the short-term (2030), mid-term (2050) and long-term (2100) for three sea-level rise scenarios: no sea-level rise (ssp000), low sea-level rise (ssp245), and high sea-level rise (ssp585), corresponding to the latest IPCC shared social economic pathways (ssp's) at the location of Delfzijl up to 2100 [11].

The NbS are assessed based on three metrics:

Flood risk reduction. The model is forced with a hindcast of storm Herwart (Oct-2017) to derive the change in wave height along the estuary as a result of morphological changes and the implemented NbS measure.

Water quality. Water quality is assessed by turbidity as the average suspended sediment concentration along a transect from the Oost Friesche gaatje through the main navigation and tidal channel of Grootte gat into the Dollard.

Ecotopes. Ecotopes are categorized from the model results with the D-Eco Impact model [12] and the classification rules for the Wadden Sea as described in Baptist et al [13].

3 Results

3.1 Flood Risk Reduction

Only changes in storm wave height by 2100 are discussed to illustrate the findings (see Fig. 2). Without sea-level rise, wave heights are projected to decrease locally by up to 25 cm due to the expansion of salt marshes and the infilling of the Bocht van Watum. With sea-level rise, wave heights are expected to increase near Delfzijl and the southern Dollard marshes, but decrease near areas with substantial salt marsh development. The new channel connecting Groote polder with the Ems increases local wave exposure, while brushwood groynes in the western Dollard significantly reduce wave heights locally. The extraction of sediment leads to a negligible increase in wave height (<1 cm) across the estuary.

3.2 Water Quality

The model predicts a significant increase in turbidity in the Ems estuary over time, exacerbated by sea-level rise (see Fig. 3). By 2100, turbidity is expected to rise across all scenarios, with suspended sediment concentrations in the Dollard increasing by 25% without sea-level rise and nearly doubling under ssp585. While NbS measures have some impact, their overall capacity to regulate turbidity is limited. Sediment extraction from Delfzijl shows a decrease in suspended sediment between 10 and 20 km of the transect by 2030. The Groote Polder acts as an effective sediment sink initially, preventing increases in sediment concentrations up to 12.5 km of the transect, but is insufficient to offset the projected increase in sediment import under high sea-level rise conditions. Brushwood groynes in the western Dollard do not significantly affect suspended sediment concentrations.

3.3 Projection of Ecotopes

The model projects marsh ecotopes and tidal channels (infralittoral zone) to expand at the expense of the lower unvegetated intertidal (littoral) zone, even without sea-level rise. This trend becomes more pronounced with sea-level rise. The Groote Polder measure is expected to add most new marsh area, and similarly, the brushwood groynes are projected to cause a noticeable expansion of marshland within the western Dollard. Sediment extraction at Delfzijl partially counteracts the increasing mud content on the tidal flats, resulting in a larger area of sandy littoral ecotopes and a corresponding reduction in muddy ecotopes compared to a situation without this intervention.

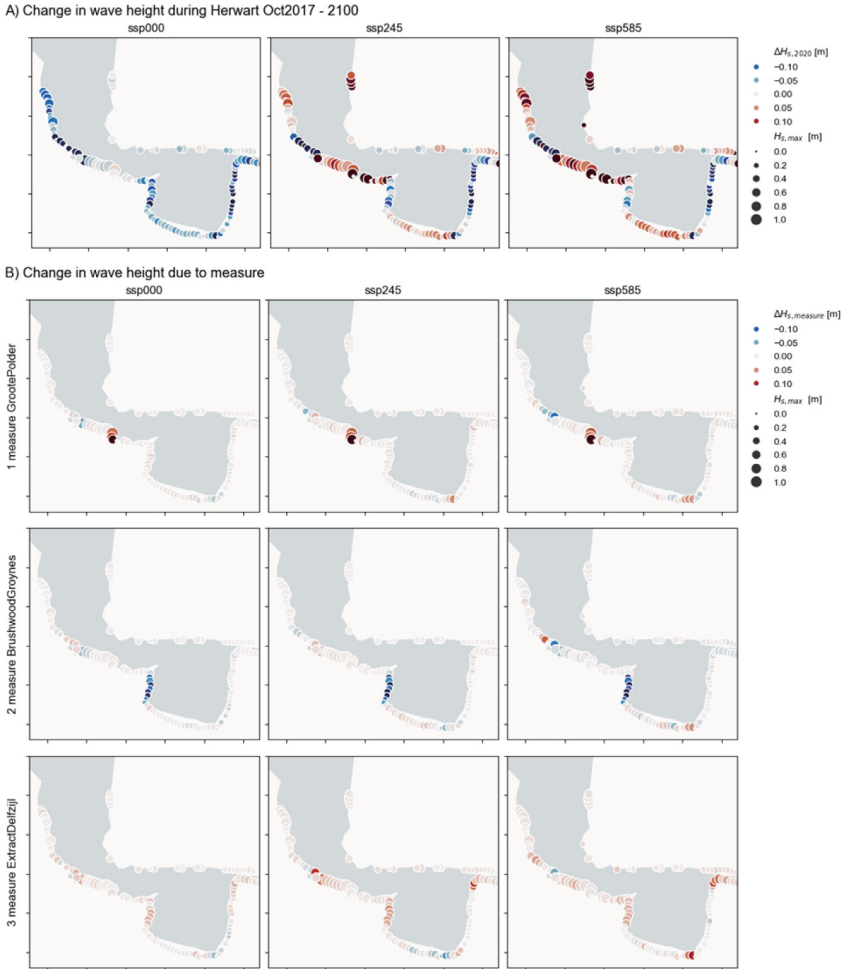


Fig. 2. A) Change in wave height in 2100 compared to 2020 during storm Hewart at various sea-level rise scenarios and B) Change in wave height due to implemented measures in each sea level rise scenario

4 Discussion

The model in this study predicts a significant increase in sediment import with sea-level rise, suggesting that the up-estuary transport capacity will strongly increase. This could lead to more sediment deposition in the estuary, enhancing marsh expansion but also increasing turbidity, which may further limit primary production. Nevertheless, it is also projected to result in greater sediment availability and marsh expansion, mitigating hazards like flooding and coastal erosion but worsening water quality. This is, however, highly conditional on the availability of sediment from the Wadden Sea. Sediment supply from the Wadden Sea is likely to decrease in case of rising sea levels because of higher deposition of sediments in updrift areas. Sediment extraction from Delfzijl was found

to be the most effective in reducing turbidity, with no benefits for wetland restoration or flood risk reduction. Brushwood groynes are effective locally in reducing wave heights and increasing marsh area, yet are not effective in reducing turbidity in the Ems estuary. The reconnection of 300 ha of polder for wetland restoration has benefits in reducing turbidity as well as increasing marshland, but locally increases flood risk where the polder is reconnected. A combination of measures is thus required to improve all metrics: water quality, flood risk reduction, and wetland restoration.

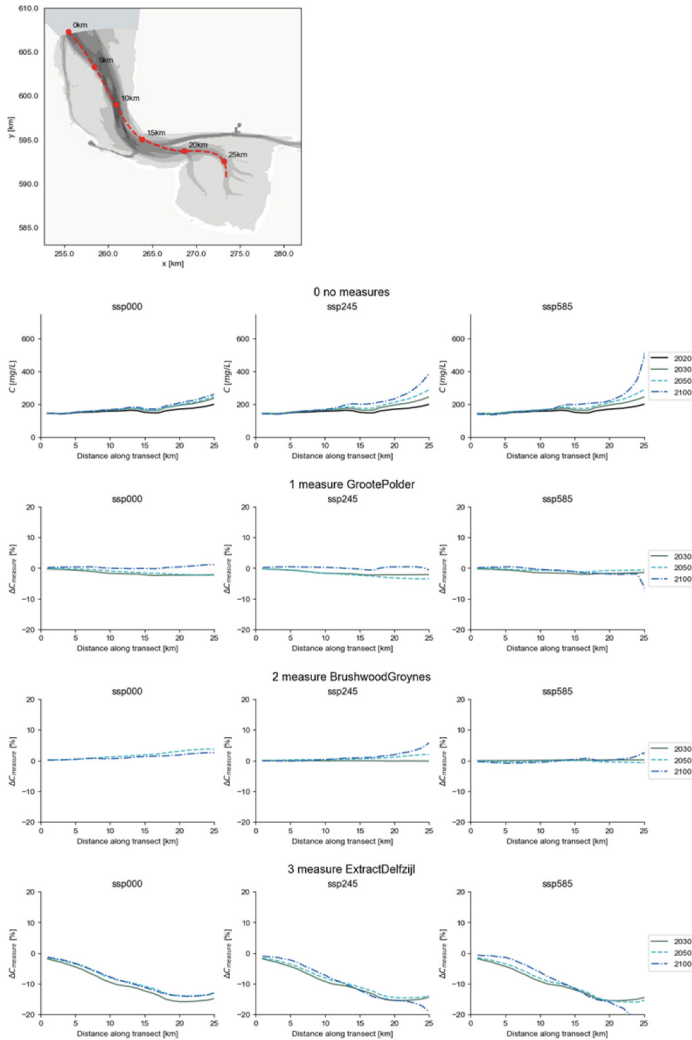


Fig. 3 Projected change in average suspended sediment concentration without NbS (0 no measures), and the effect of the different NbS as a % change in concentration.

Acknowledgements. This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 101037097 (REST-COAST project). We gratefully acknowledge Johan Reys, Bert Jagers, Qilong Bi, and the other members of the yellow development team of Deltares for their support in setting up the morphodynamic Delft3D-FM model.

References

1. van Maren DS, Oost AP, Wang ZB, Vos PC (2016) The effect of land reclamations and sediment extraction on the suspended sediment concentration in the Ems Estuary. *Mar Geol* 376:147–157. <https://doi.org/10.1016/j.margeo.2016.03.007>
2. Brinkman AG, Jacobs P (2023) Gross pelagic primary production in the Ems-Dollard estuary. *J Sea Res* 192:102362. <https://doi.org/10.1016/j.seares.2023.102362>
3. Zijl F, Groenenboom J, Laan S, Zijlker T (2022) DCSM-FM 100m: a sixth-generation model for the NW European Shelf: 2022 release. Deltares, Delft, The Netherlands
4. Schrijvershof RA, van Maren DS, Torfs PJJF, Hoitink AJF (2023) A synthetic spring-neap tidal cycle for long-term morphodynamic models. *J Geophys Res: Earth Surf* 128(3):e2022JF006799. <https://doi.org/10.1029/2022JF006799>
5. Walstra DJR, Hoekstra R, Tonnon PK, Ruessink BG (2013) Input reduction for long-term morphodynamic simulations in wave-dominated coastal settings. *Coast Eng* 77:57–70. <https://doi.org/10.1016/j.coastaleng.2013.02.001>
6. Baptist MJ et al (2007) On inducing equations for vegetation resistance. *J Hydraulic Res* 45(4):435–450. <https://doi.org/10.1080/00221686.2007.9521778>
7. Mendez FJ, Losada IJ (2004) An empirical model to estimate the propagation of random breaking and nonbreaking waves over vegetation fields. *Coast Eng* 51(2):103–118. <https://doi.org/10.1016/j.coastaleng.2003.11.003>
8. Bouma H, De Jong D, Twisk F, Wolfstein K (2005) A Dutch ecotope system for coastal waters (ZES. 1). To map the potential occurrence of ecological communities in Dutch coastal and transitional waters. Report RIKZ/2005.024
9. Brinkman AG, Riegman R, Jacobs P, Kuhn S, Meijboom A (2015) EMS-Dollard primary production research: full data report
10. van Maren DS et al (2023) Synoptic observations of sediment transport and exchange mechanisms in the turbid Ems Estuary: the EDoM campaign. *Earth Syst Sci Data* 15(1):53–73. <https://doi.org/10.5194/essd-15-53-2023>
11. Garner GG, et al (2021) IPCC AR6 sea level projections (2021). <https://zenodo.org/records/6382554>, <https://doi.org/10.5281/zenodo.6382554>
12. Weeber M, et al (2024) D-Eco Impact. <https://zenodo.org/records/10941913>, <https://doi.org/10.5281/zenodo.10941913>
13. Baptist M et al (2024) D4.1 Scorecard methodology (tool) for coastal system restoration effects on ESS and BDV. *ARPHA Preprints* 5:1–87. <https://doi.org/10.3897/arphapreprints.e128550>

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.

