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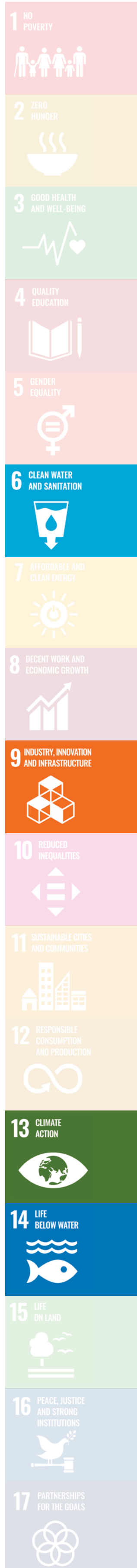


Allowing Natural Sedimentation in the Nieuwe Waterweg to Reduce Salinity Intrusion and the Effects of Sea Level Rise

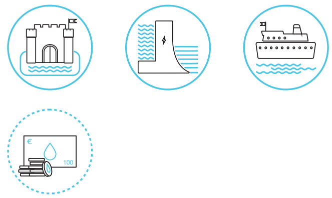
Maarten Kleinhans, Silke Baltussen, Eise Nota, Jana Cox, Han Meijer & Jasper Hugtenburg

Abstract
The Nieuwe Waterweg is the artificial mouth of the Rhine and Meuse Rivers in the Netherlands and an important shipping channel for the Port of Rotterdam. The channel, about a half-kilometer wide, is dredged to depths of more than 16 m to allow navigation. This substantial depth has adverse effects on flood safety, ecology and salinity intrusion in the lower river system. Mitigating these effects through engineering is costly and increasingly unviable with rising sea levels. A straightforward, nature-based alternative is to allow natural sedimentation, gradually making the channel shallower again while the port continues to expand seaward. We present 1:1000 scale physical experiments as a future vision for sedimentation in the ports and the Nieuwe Waterweg. The observed behavior aligns with that of similar estuaries and ports worldwide, demonstrating the broader applicability of this approach. Based on the current sediment budget, the sedimentation rate is estimated 0.5–1.0 m per decade. If transitional and structural changes in port logistics are coordinated with this sedimentation rate, the port economy can be expected to benefit.

KEYWORDS

Sea level rise
Dredging
Port
Salinity intrusion
Analogue scale modeling

WATER VALUES



CLIMATE

A B **C** D E

Cfb: Temperate oceanic climate

Policy Recommendations

- Conduct a large-scale pilot field study of sedimentation in the Nieuwe Maas, building on existing small-scale inventories and tests with local stakeholders and knowledge institutes.
- Redirect dredged sediment from seaward ports to the Nieuwe Maas and disused port areas, instead of the North Sea, to enable the development of tidal flats and new urban spaces.

< Fig. 1 Vessels moored in the New Waterway (Source: Jana Cox, 2022).

Introduction

The Netherlands is regarded as one of the best-protected lowlands against fluvial, pluvial and coastal flooding, demonstrating clear awareness of the accelerating climate crisis, as evidenced by a national program headed by an appointed "delta commissioner" (van Alphen et al. 2022). At present, the port and city of Rotterdam are protected against storm surges by a storm surge barrier, which closes at seawater levels above 3.05 m, while the upstream rivers have dikes designed to withstand extreme river floods. However, the barrier was constructed in the late 1990s as the final part of the Delta Works, built after the 1953 flood, to cope with a 1 m sea level rise that will likely be reached by 2070. Strategies to construct a new barrier and manage the mouth area are now being devised.

Long-term dynamic planning is urgently needed to address the compound challenge of increasing frequency and magnitude of river floods and precipitation, combined with the certainties of sea level rise of 1–2 m at the end of the century and soil subsidence of a few cm per year in the deepest polders, at 6 m below sea level. Such dynamic planning can involve many strategies ranging between the two extremes of continued reliance on hard engineering structures and accommodation by strategic coastal retreat. While public discourse in the Netherlands indicates support for technological solutions, replacing and strengthening hard infrastructure is unlikely to keep up with the external changes (e.g., Haasnoot et al. 2021). The necessary change from a strategy based on strengthening hard infrastructure toward a strategy based on the dynamics of the natural system is relevant for many ports in estuaries, like Antwerp (Meire et al. 2005), Hamburg (Van Eekelen et al. 2017), New Orleans (Lewis 2023), Nantes (Duval and Bahers 2023), and many others.

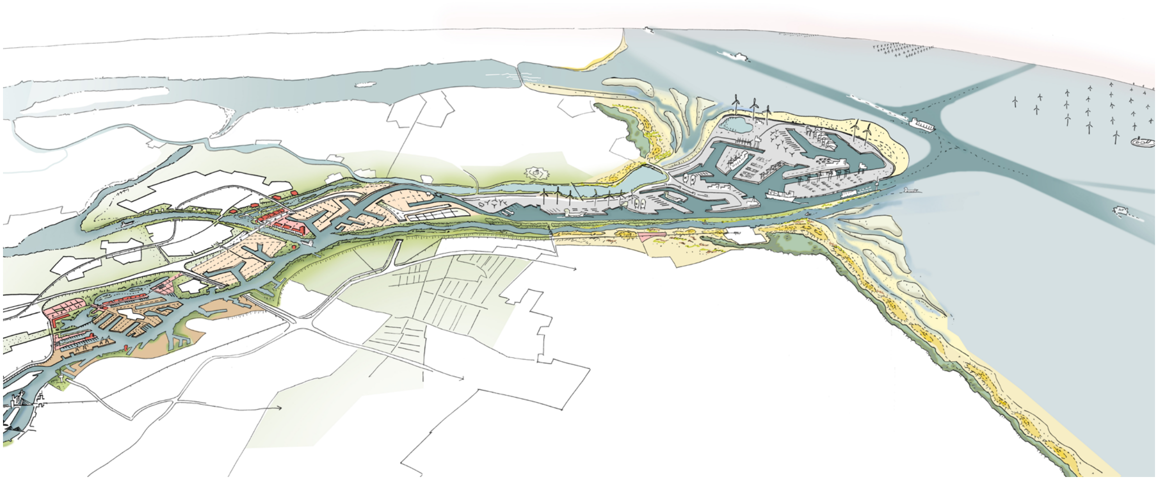
Rotterdam must confront these challenges and commit to a sustainable, adaptive pathway to climate adaptation. While over 60 per cent of the port's income depends on fossil energy – an important source of regional revenue – the port has set the ambitious goal of becoming the first fossil-free port.[1] Achieving this will require multiple transitions to be undertaken simultaneously lest the area remains in a lock-in situation.

Here we focus on a no-regret measure that can be part of any strategy: relying on natural sedimentation instead of continued dredging to reduce salinity intrusion and the height of upstream stormwater levels and to promote nature restoration. This paper has two parts. The first reviews a general plan for the area. The second part focuses on dedicated experiments in a unique laboratory facility, which provide tangible results and visualizations of what natural sedimentation in the Nieuwe Waterweg and harbors would look like.

A Multi-Purpose Plan for the River Mouth Region

In 2023, a competition was organized to deliver plans and ideas for the future of the mouth of the Rhine and Meuse.[2] The competition was won by an entry called Tweestromenland (Land of two rivers). The winning team included two design firms, two nature organizations and two universities.[3] The name *Tweestromenland* re-

1. Port of Rotterdam, "The Goal is Completely Fossil-Free Terminals," https://www.portofrotterdam.com/en/news-and-press-releases/the-goal-is-completely-fossil-free-terminals.



^ Fig. 2 Tweestromenland proposal for sediment management strategy (Source: Palmbout Urban Landscapes, 2023).

fers to the two main outlets through which the Rhine and Meuse discharge their water to the sea: the Nieuwe Waterweg/Nieuwe Maas and the Haringvliet.

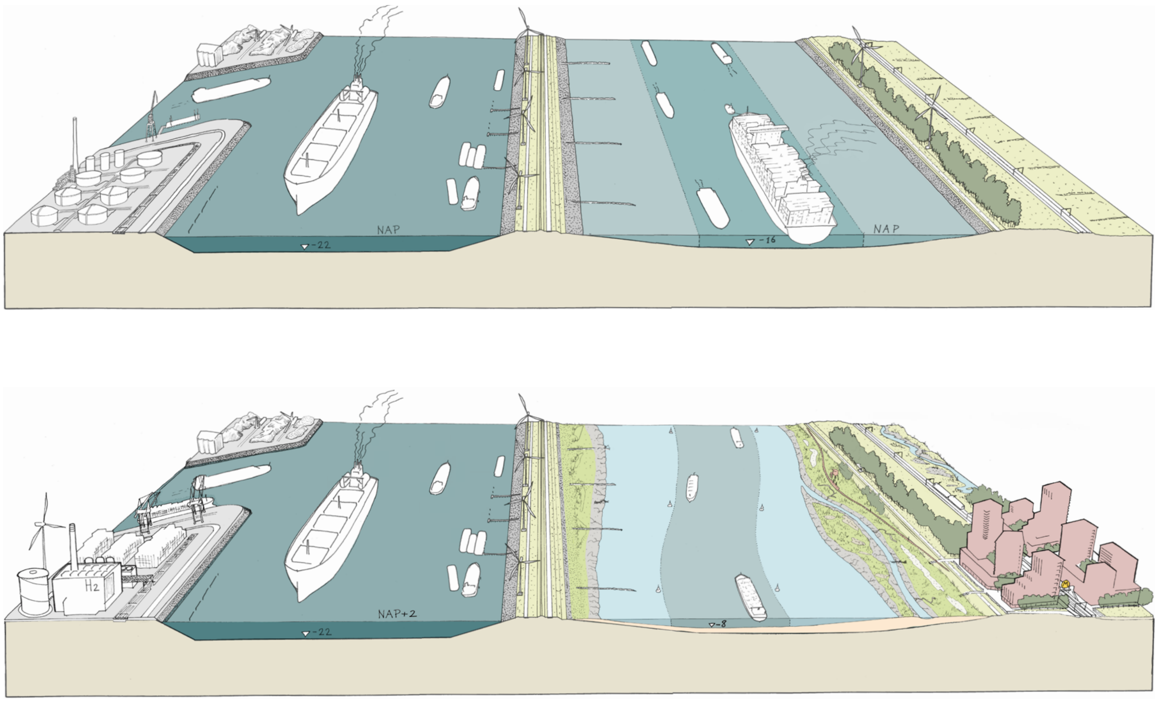
The role of the Haringvliet as the main discharge channel increased in the fifteenth century (De Haas et al. 2019). As a result, the Nieuwe Maas silted up, which created problems for the accessibility of the Port of Rotterdam (Cox et al. 2022b). In 1872, to enhance accessibility of the port for the increasing ship traffic and draft due to increasing ship size, a new navigation channel was dug between Rotterdam and the sea: the Nieuwe Waterweg. This was made possible by the introduction of steam-powered dredging technology, which marked the beginning of large-scale canal and channel excavation globally, driven by a fast-growing shipping economy.

In the twentieth century, the Nieuwe Waterweg was deepened repeatedly, from an original depth of 6 m to the current 16.2 m, to allow passage of increasingly larger ships. While the Port of Rotterdam experienced an explosive growth, 90 per cent of the intertidal flats in the estuary of the Nieuwe Maas-Nieuwe Waterweg disappeared, resulting in (1) a dramatic loss of biodiversity (Paalvast 2014), (2) an increase in high water levels upstream (Paalvast 2014; Cox 2021) and (3) greater salinity intrusion (Iglesias 2022).[4] Several engineered waterworks in the delta (especially the Haringvliet dam, part of

2. The competition was initiated by the Eo Wijers foundation, which organizes design competitions related to important issues on a regional scale every two to three years. The design competition on the Rhine-Meuse mouth was supported and coorganized by the City of Rotterdam, the Province of South-Holland, the National Delta Program and the Water Authority Hollandse Delta. See the Eo Wijersstichting web page at https://eowijers.nl/.

3. Members of the Tweestromenland team are H+N+S Landscape Architects, Palmbout Urban Landscapes, the World Wildlife Fund, ARK Rewilding the Netherlands, Technical University Delft and Erasmus University Rotterdam. Authors Meyer and Hugtenburg contributed to Tweestromenland and are proponents of executing the plan.

4. The salinity intrusion problem has long been recognized, e.g., in the draft Deltawet (1955): Kamerstuk II, 1955-1956, 4167, nr. 1-3, https://repository.overheid.nl/frbr/sgd/19551956/0000278501/1/pdf/SGD_19551956_0002279.pdf.



^ Fig. 3 Top: current situation with unnaturally deepened beds of both the Calandkanaal (left) and Nieuwe Waterweg (right). Bottom: future situation according to Tweestromenland: the Calandkanaal can be maintained as a deep shipping channel while the Nieuwe Waterweg will become shallower; regeneration of intertidal areas and combination with new urban development (Source: Palmbout Urban Landscapes, 2023).

the Delta Works, completed in 1971) contributed to directing the main discharge through the Nieuwe Waterweg. Continuous dredging activities remain necessary to maintain the depth of the bed, especially in port areas. The volume dredged from the Nieuwe Waterweg and adjacent harbor basins and returned to the North Sea has increased with deepening to over ten million m^3.

The basic idea of the Tweestromenland proposal is to discontinue maintenance dredging and allow the natural tendency of the Rhine and Meuse to discharge their water mainly via the Haringvliet (fig. 2). The hypothesis is that this “nature-based solution” will, over time, result in the gradual shallowing of the Nieuwe Waterweg, moving it toward its natural undredged equilibrium depth, also allowing it to restore tidal flats, leading to substantial recovery of biodiversity and new urban landscapes in former harbor basins (fig. 3).

The Tweestromenland proposal assumes a parallel transition of the channel-port area of Rotterdam. Currently, more than 60 per cent of the port area is used for the transshipment, storage and processing of fossil fuels. Especially the Botlek area, completely dedicated to fossil fuel-related activities and situated 20 km upstream, will need to be transformed in the coming decades (Van der Lugt et al. 2025). The other large parts of the Rotterdam port area, Maasvlakte and Europoort, will not be influenced by this proposal, because they are accessible by independent channels.

In this paper we show how the natural process of the transport and depositing of sediments can result in (a) the transformation of the Nieuwe Waterweg from an artificial shipping canal into a river mouth with tidal flats, and (b) the accretion of new land and a change of function in the harbor basins of the Botlek area.

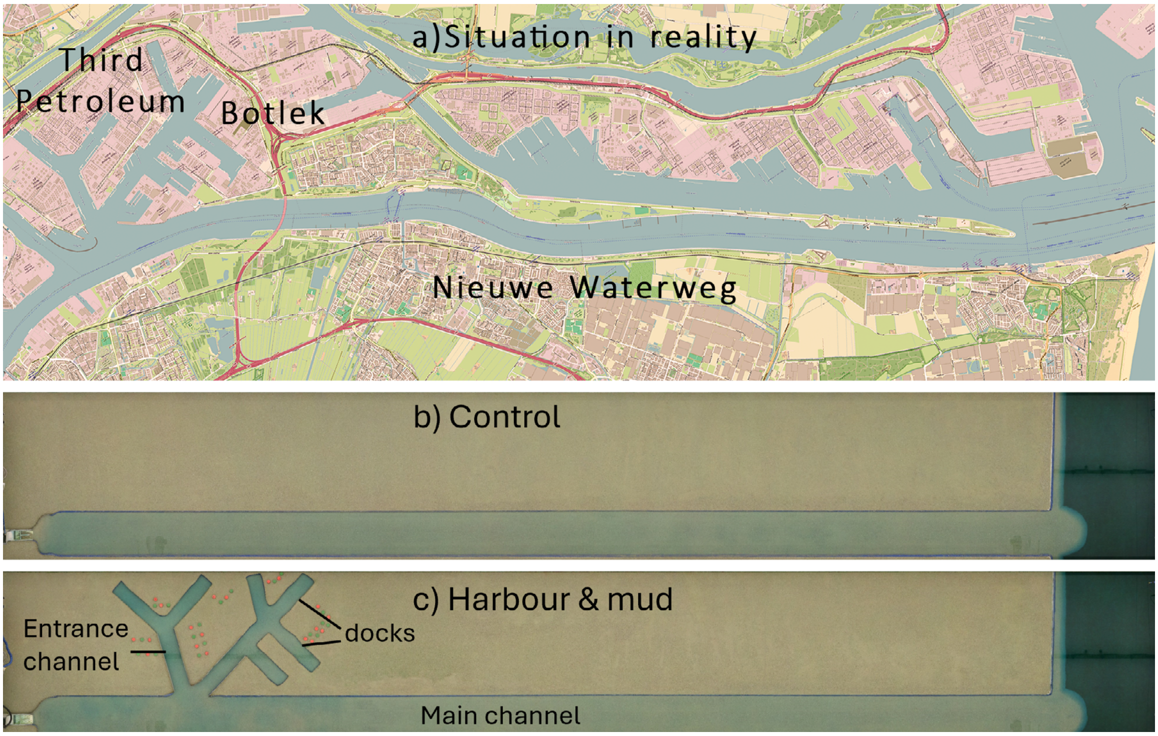
Experiments Demonstrating Sedimentation Patterns

Given the sediment budget and a known potential sedimentation rate of 0.5–1 m per decade (Cox et al. 2021), an important question remains: what will sedimentation in the Nieuwe Waterweg look like? Laboratory experiments provide valuable visualizations of self-forming waterscapes, but reproducing tidal systems at scale is particularly challenging. Here we present experiments created in the Metronome at Utrecht University, a unique tilting tidal flume measuring 20 by 3 m. By periodically tilting the flume on its short axis with a 40-second cycle and an amplitude of less than 0.1 m, the facility generates tidal currents strong enough to transport sediment.

The Metronome has previously been used to model estuaries with sand, mud and vegetation, all with freely erodible banks, allowing estuaries to develop a natural, seaward-widening trend while being exposed to constant and rising sea levels as well as being subjected to dredging. Experiments with sand and crushed nutshell (a proxy for mud due to their similar behavior), showed that mud tends to deposit upstream and on higher intertidal elevations. The deposited mud takes up space which reduces the tidal prism (i.e., the volume of water that flows into and out of the system in a tidal cycle), which, in turn, reduces the tidal currents along the estuary (Braat et al. 2019).

Additional experiments compared estuaries with and without dredging, applying the same deepening and maintenance protocols used in the Western Scheldt, both with and without sea level rise (Cox et al. 2022a). The results showed that dredged estuaries experience greater bank and bed erosion, as well as increased upstream tidal penetration with rising sea levels. These effects occur because the surplus water and additional momentum are concentrated in the artificially deepened channels.

Here we present novel experiments conducted with fixed banks, representing the Nieuwe Waterweg (fig. 4) (Baltussen 2025). As in previous experiments, the riverbed was composed of coarse sand, the sea level was kept constant with waves generated from the seaward boundary and a small river inflow was supplied at the upstream boundary. Tidal components were M2 and M4 as in the North Sea, causing larger velocities in the flood phase than in the ebb phase (flood dominance), which leads to a tendency to import sediment making the system initially flood dominant. The banks were fixed at an angle of 45º and covered with coarse sandpaper. The Nieuwe Waterweg barely widens in a seaward direction because nineteenth-century engineers aimed to create a self-deepening canal, so we kept the experimental channel straight with a width of 70 cm, an initial uniform water depth of 1 cm representing the pre-deepened situation, and a bed thickness of 5 cm (fig. 4). Three experiments are presented here: (1) a control experiment with a straight channel and sand only, (2) an experiment with two harbors added, namely the Botlek and the Third Petroleum harbor to assess sand sedimentation and the tidal prism added by the harbors, and (3) an experiment with the same layout but a mud supply at the upstream boundary. The morphological development without dredging, as proposed in the



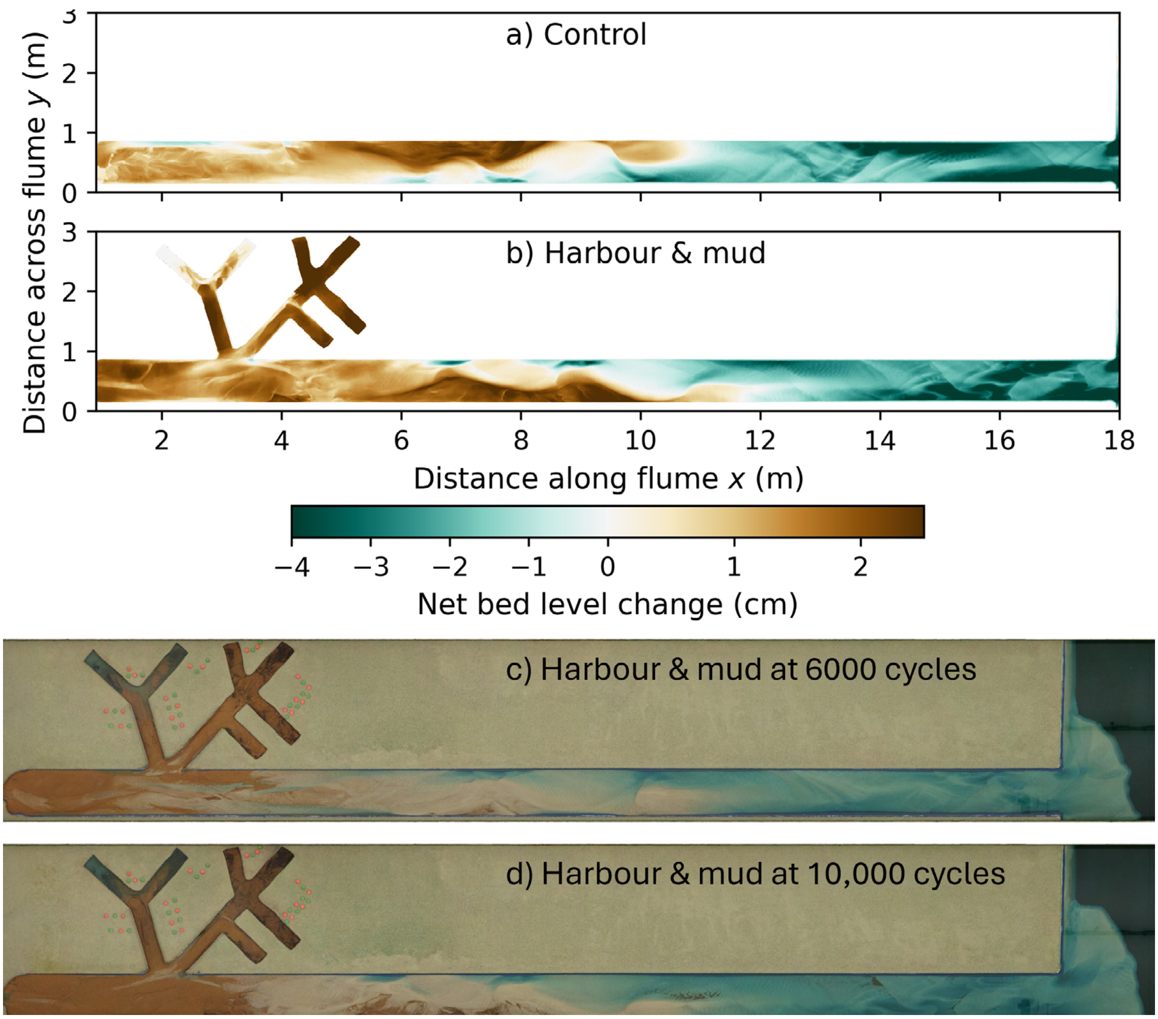
^ Fig. 4 a) Situation of the Nieuwe Waterweg and setup of the straight channel with harbors in the Metronome (sea is on the right side in the images; Metronome is 20 by 3 m) (Source: © OpenStreetMap contributors, 2024. Open Database License, ODbL v1.0); b) Control; c) Harbor and mud setup schematic representations (Source: Authors, 2025).

Tweestromenland plan, was documented in over 10,000 tidal cycles by frequently repeated overhead photography and less frequent dry-bed laser scanning.[5]

The experiments showed net sedimentation in the upstream reach of the channel and erosion in the seaward half (fig. 4). In the experiment, the erosion occurred because the channel was not over-deepened initially as in the Nieuwe Waterweg. The experiment with the harbors without mud showed more downstream erosion and upstream sedimentation than the control experiment because the harbors increased the tidal prism. The experiment with mud, on the other hand, showed more sedimentation upstream and less erosion downstream, but otherwise showed similar patterns and trends. In both experiments with the harbors, net sedimentation took place in the harbors, especially with mud (fig. 5). This demonstrates that the harbors function as efficient sediment traps.

Figure 4. A and B, laser scans with initial bed level subtracted, showing siltation in the upstream half in the control and in the experiment with harbors; C and D, overhead images of the experiment with harbors and mud showing continuous sedimentation in the upstream half of the system.

5. The overhead images, laser scans and movies are available here: https://doi.org/10.24416/UU01-T9W1M2. The methods of photogrammetry and projection mathematics are given here: https://doi.org/10.24416/UU01-SGM22N.



^ Fig. 5 A and B, laser scans with initial bed level subtracted, showing siltation in the upstream half in the control and in the experiment with harbors; C and D, overhead images of the experiment with harbors and mud showing continuous sedimentation in the upstream half of the system (Source: Authors, 2025).[6]

In the Nieuwe Waterweg, landward sedimentation is expected to commence when dredging ceases. The tidal amplitude in the upstream part of the system was reduced in the experiments. In reality, the depth reduction would reduce the landward salinity intrusion. As the natural pre-urbanization depth of the upstream river was about 5 m (width-averaged) (Cox et al. 2022b), ships for inland navigation, adapted to long periods of reduced discharge, will remain unhindered while seagoing vessels would navigate through the Caland canal to the seaward ports, the Europoort and the Tweede Maasvlakte. The harbors trapped a lot of mud and formed new supratidal land, which could be used for nature development, recreation

6. Movies and data are available on https://doi.org/10.24416/UU01-T9W1M2.

and housing. At present, such new land must be created by sediment disposal as in a pilot planned in the expired Rijnhaven.[7] The sediment budget for the lower Rhine and Meuse Rivers indicates that without dredging, the sedimentation rate would be 0.1–0.15 m per year (Cox et al. 2021). Although this estimate spans a wide range, it implies that shallowing from 16 to 5 m would take roughly a century. This timescale coincides with projections of significant sea-level rise of 1–2 m (van Alphen et al. 2022) as well as with the energy transition and port transitions required to address the causes and effects of the climate crisis (Notteboom et al. 2022; Van der Lugt et al. 2025).

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Useful Links

https://www.proeftuinsediment.nl/

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Maarten Kleinhans is a professor of the bio-geomorphology of rivers and tidal systems at Utrecht University. He invented the Metronome flume (www.uu.nl/metronome) to create experimental models of estuaries at a 1:1000 scale and leads research programs combining experimental and numerical modelling.

Contact: m.g.kleinhans@uu.nl

Silke Baltussen graduated with an MSc in Earth Science from Utrecht University, with a focus on the geomorphology of rivers and coastal systems. Her master's thesis was on the Metronome experiments representing part of the Nieuwe Waterweg, followed by an internship on mud dynamics in a Wadden Sea port.

Contact: silke.baltussen@arcadis.com

Eise Nota is a PhD candidate at Utrecht University working on experiments in the Metronome to simulate estuaries and study their bar and channel network dynamics. Eise also specializes in applying photogrammetry to optimize data processing from multiple instruments.

Contact: e.w.nota@uu.nl

Jana Cox is an assistant professor at Utrecht University specializing in sustainable delta systems and coastal communities. She works in conjunction with the Delta Climate Center in Vlissingen (the Netherlands). Jana did her PhD research on multiscale sediment dynamics of the lower Rhine-Meuse system and studied effects of dredging and sea level rise in the Metronome.

Contact: j.r.cox@uu.nl

Han Meijer is Emeritus Professor of Urbanism at Delft University of Technology. His research focused on urban and port development in deltas and estuaries. He participated in the Tweestromenland consortium to address the potentially locked-in situation using a complex adaptive systems approach.

Contact: v.j.meyer@tudelft.nl

Jasper Hugtenburg is a senior landscape architect with H+N+S Landscape Architects and team leader of the Tweestromenland team. Currently (2024–2025) he is enjoying a sabbatical year as adjunct professor at the School of Architecture and Landscape Architecture of the University of British Columbia.

Contact: j.hugtenburg@hnsland.nl