Monitoring sediment transport patterns on an energetic ebb-tidal delta using dual-signature tracers

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Abstract

The morphodynamic response of the Dutch Wadden Islands to the effects of climate change (e.g. sea level rise) or human interventions (e.g. nourishments) is closely tied to the evolution of the ebb-tidal deltas between them. To understand the fate of these ebb-tidal deltas, we must quantify the behaviour and transport patterns of sediment as it moves across them. In September 2017, 2000 kg of dual signature (fluorescent and ferrimagnetic) sediment tracer was deployed on the seabed at Ameland ebb-tidal delta in the Netherlands. The tracer's physical characteristics (d50= 285 μ m, $\rho = 2628 \text{ kg/m3}$) closely matched those of the native sediment to ensure that it was eroded, transported and deposited in a similar manner. The tracer study was complemented by simultaneous measurements of hydrodynamics and suspended sediment at four locations across the ebb-tidal delta. Over the subsequent 41 days, the tracer's dispersal was monitored via the collection of seabed grab samples and determination of tracer content and particle size within each sample. In addition, high-field magnets mounted on mooring lines 1, 2, and 5 m above the seabed at strategic locations around the deployment site were used to sample tracer particles travelling in suspension. Tracer particles were recovered from over 60 of approximately 200 samples, despite the occurrence of two significant storm events (Hs > 4 m). Although hydrodynamic measurements suggest an eastward tidal residual flow, the spatial pattern of the recovered tracer indicates that transport is highly dispersive, likely due to the storms. Furthermore, the samples recovered from the suspended magnets show an upward fining trend in grain size through the water column. The active sediment tracing approach provides useful insight into sediment transport patterns and sorting processes in energetic coastal environments. The study also demonstrated the potential of dual signature sediment tracers to monitor sand nourishment effectiveness. In particular, the use of magnets proved highly effective at sampling tracer travelling in suspension, enabling both bed load and suspended load transport processes to be investigated. The data obtained through this study will serve as a basis for future numerical model calibration and validation.

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1. Motivation

Dutch Wadden Islands Flood safety and vital ecosystems in the northern Netherlands depend on the fate of the Wadden Islands. Their morphodynamic response to sea level rise and sand nourishments is closely tied to the evolution of the ebb-tidal deltas between them.

Sediment Pathways

To understand the fate of these ebb-tidal deltas, we must quantify the behaviour and transport patterns of sediment as it moves across them



2. Methodology

Tracer Preparation

Dual signature (fluorescent and ferrimagnetic) sediment tracer was developed by Partrac Ltd. for use in this study. The tracer's physical characteristics ($d_{50} = 285 \mu m$, $\rho_c = 2628 kg/m^3$) closely matched those of the native sediment to ensure that it was eroded, transported and deposited in a similar manner.

Deployment & Monitoring

In September 2017, 2000 kg of tracer was deployed at slack tide on the seabed at Ameland ebb-tidal delta in the Netherlands. Simultaneous measurements of hydrodynamics and suspended sediment were made near the tracer source. Over the next 41 days, the tracer's dispersal was monitored via the collection of seabed grab samples. In addition, high-field magnets mounted on mooring lines 1, 2, and 5 m above the seabed around the source were used to sample suspended tracer particles.

Laboratory Analysis

Tracer particles were magnetically separated from the background sediment and counted under UV lights. Samples containing visible tracer particles were then further analyzed using a Keyence VHX-5000 digital microscope. Particle size analysis of the separated tracer was performed using the microscope's built-in image processing software.









Figure 3. Tracer sediment particles with fluorescent and ferrimagnetic coating (x100 magnification).

3. Preliminary Results

Tracer Recovery

Tracer particles were recovered from over 60 of approximately 200 samples, despite the occurrence of conditions likely to mobilize 99% of the deployed particles. Although hydrodynamic measurements suggest an eastward tidal residual flow, the spatial pattern of the recovered tracer indicates that transport is highly dispersive, likely due to wave action.

Grain Size Distribution

Among samples collected in the first 4 days after deployment, there is a general trend of fining and improved sorting behaviour with increasing distance from the source. Samples recovered from the suspended magnets show an upward fining trend in grain size through the water column.



Figure 4. Spatial distribution of tracer recovered in the first 4 days after deployment with pie charts indicating the relative fraction of a particular sediment class. The green triangles marked "n>1 (*)" denote samples with visible tracer particles whose particle size distribution has not yet been measured.



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4. Conclusions & Next Steps

Conclusions

- Magnetic character of tracers makes them easier to recover in the field and process in the laboratory Tracer approach enables tracking of differential transport (per grain size) from a specific location Sediment transport on the ebb-tidal delta is highly dispersive

- Tracer becomes both finer and better-sorted further from the source and higher in the water column This can be explained by the **preferential suspension** of finer sediment classes (Figure 5)
- Behaviour of tracer suggests that **nourishment sand** will also be highly dispersive

Next Steps

- Compare grain size of tracer with other particles retrieved via grab sample and magnet . Comparison of suspended grain sizes from magnets with nearby LISST measurements Numerical particle tracking model calibration and validation



Figure 6. Conceptual diagram indicating dispersal of tracer on the seabed and in the water column. Finer grains are preferentially resuspended and transported further than coarser grains, which travel more often as bedload.

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Figure 5. Inverse Rouse number (ku_{*}/w_c) and transport mode for each sediment class. Calculated using the method of Soulsby (1997) from wave and near-bed velocity measurements taken near the tracer source.

Large quantities of tracer were recovered in a highly dynamic environment