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

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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 delta 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 through them.

Figure 1. Location of project site at Ameland Inlet, the Netherlands.

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 ($d_{50}=285\ \mu m$, $\rho_s=2628\ \text{kg/m}^3$) 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 dispersion was monitored using 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 light. 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.

3. Preliminary Results
Tracer Recovery
Tracer particles were recovered from over 60 of approximately 200 samples, despite the occurrence of conditions likely to mobilise 99% of the deployed particles. Although hydrodynamic measurements suggest an easterly 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 finer 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 2. Tracer sediment particles with fluorescent and ferrimagnetic coating (x100 magnification).

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

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.

Figure 5. Inverse Rouse number ($\kappa u*/w_s$) and transport mode for each sediment class. Calculated using the method of Smithley (1983).

Figure 6. Conceptual diagram indicating dispersal of tracer on the seabed and in the water column. Finer grains are easier to recover in the field and process in the laboratory. Large quantities of tracer were recovered in the field and further from the source and higher in the water column. Tracer becomes both finer and better-sorted further from the source and in the water column. Behaviour of tracer suggests that nourishment sand will also be highly dispersive.

4. Conclusions & Next Steps
Conclusions
- Large quantities of tracer were recovered in a highly dynamic environment.
- 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.
- 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 magnetic comparison of suspended grain sizes from magnets with nearby LISST measurements.
- Numerical particle tracking model calibration and validation.

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