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Measurement and comparison of settling velocities of cohesive sediments from the German estuaries Weser and Ems

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For An Improved Understanding Of Estuarine Sediment Transport – FAUST

The FAUST project addresses challenges in modelling sediment exchange at the water / soil interface by extracting natural soil samples from German estuaries, collecting quasi-in-situ data and performing lab experiments. In this poster a novel methodology for determining settling rates is discussed, measurement results from lab experiments are presented and parameterizations of settling models are realized.

Poster InterCOH 2019	Poster InterCOH 2021	Paper Frontiers 2022	Data Lutoclines & Density profiles

1. Motivation

- Deposition and accumulation of fine sediments even in the fairway is an increasing challenge for authorities of waterways
- Improved prediction of location and amounts of deposited sediments is required
- Estuary-specific parameterization of bottom exchange characteristics is required to improve numerical models

2. Concept

- Collect natural samples at sedimentation sites in the fairway
- Investigation of quasi-in-situ behavior (erosion, density, grain size distribution, settling behavior)
- Development of a methodology to determine settling velocities in the flocculation and hindered settling regimes
- Determine effective settling velocities for different SSC, salinities & temperatures to study their influence
- Use settling data generated in the lab to fit appropriate models

3. Site & Sampling

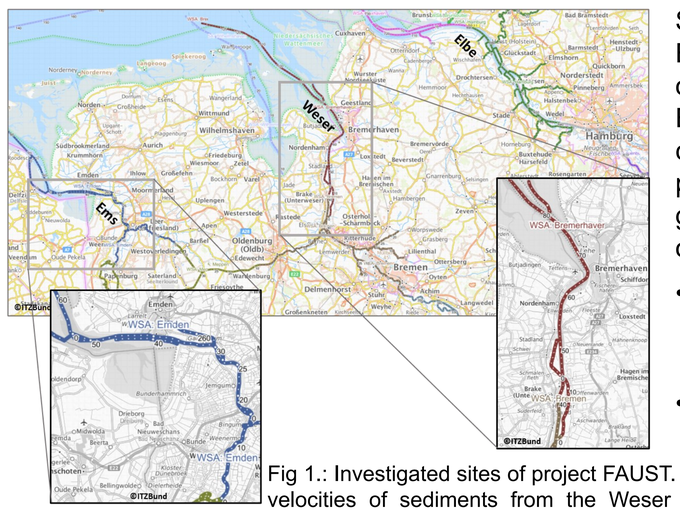


Fig 1.: Investigated sites of project FAUST. Focus of this poster are settling velocities of sediments from the Weser (at Nordenham) and Ems (at Weener), Maps from ©ITZBund2023

Sediment cores from the ETM within the fairway of the estuaries Weser, Elbe and Ems were collected. For this poster, data was generated from samples of two sites:

- **Weser (W), Nordenham (NH), Weser-km57**
- **Ems (E), Weener (W), Ems-km 8**

4. Experimental Setup

A settling column approach has been developed to determine settling velocities and to provide a deeper understanding of the settling behavior of cohesive sediments from German estuaries as a function of SSC. Suspensions of defined initial SSC are prepared and homogenized by stirring. Signal Processing's 4Mhz ultrasonic sensor is aligned and fixed in a downward vertical direction with contact to the suspension's surface, see figure 2. Initial measurements are taken immediately after stirring, see Figure 3. In this way, a sensitivity analysis is performed to define the time lag until settling and stirring induced turbulence are in equilibrium. At this point free settling is assumed and effective settling can be determined.

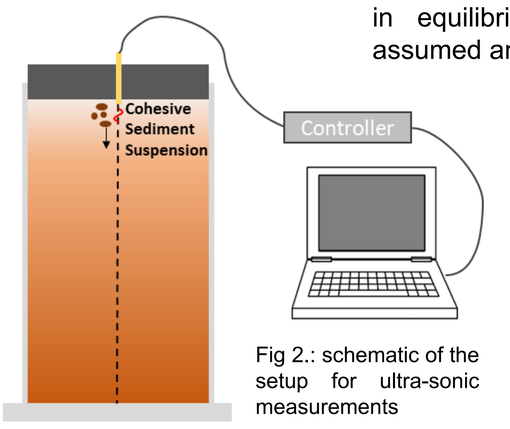


Fig 2.: schematic of the setup for ultra-sonic measurements

Assumptions:

- Initially turbulence prevents particles to settle freely and forcing flocculation processes.
- Effective settling velocity is determined when gravitational settling becomes dominant.

5. Methodology

Time evolution patterns of of settling velocities for 9 settling columns with different initial concentrations C_0 are shown in figure 3. The y-axis contains positive settling in downward direction. As the blue colors fade, settling dominates over turbulence.
Turbulence is introduced by the stirring process. At t = 0 stirring stops and after some time the turbulence decreases and the effective settling velocity is derived. A sensitivity analysis has shown that the time lag is about 240s after stirring, see the black boxes in figure 3. Then, over a period of 45s velocities are recorded and averaged to an effective settling velocity. A high density layer is forming at the bottom where no measurements can be taken. This layer is colored in white.

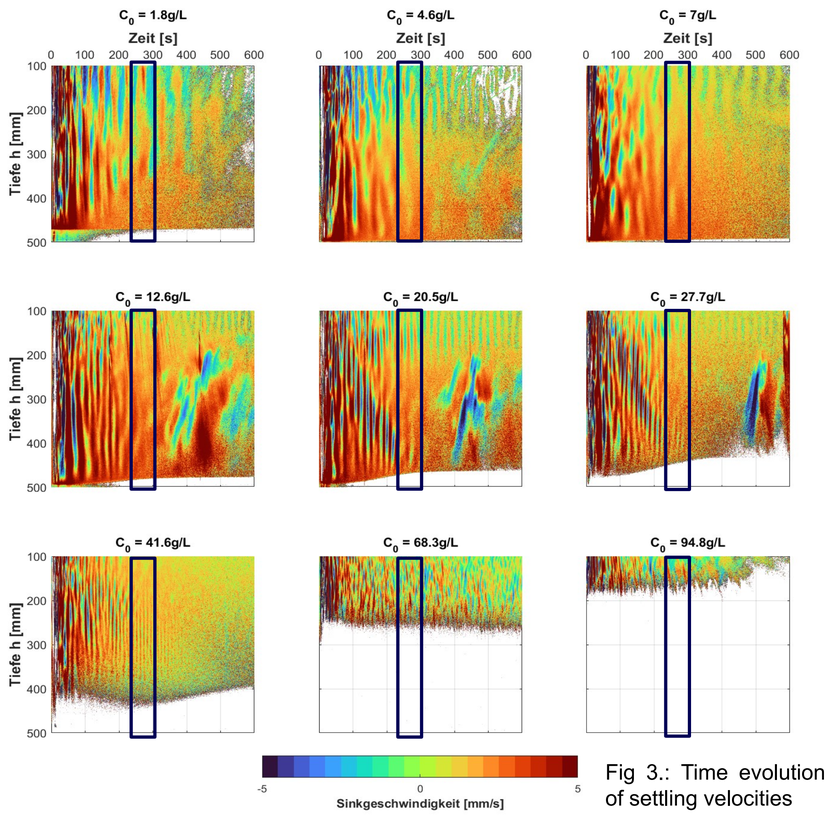


Fig 3.: Time evolution of settling velocities

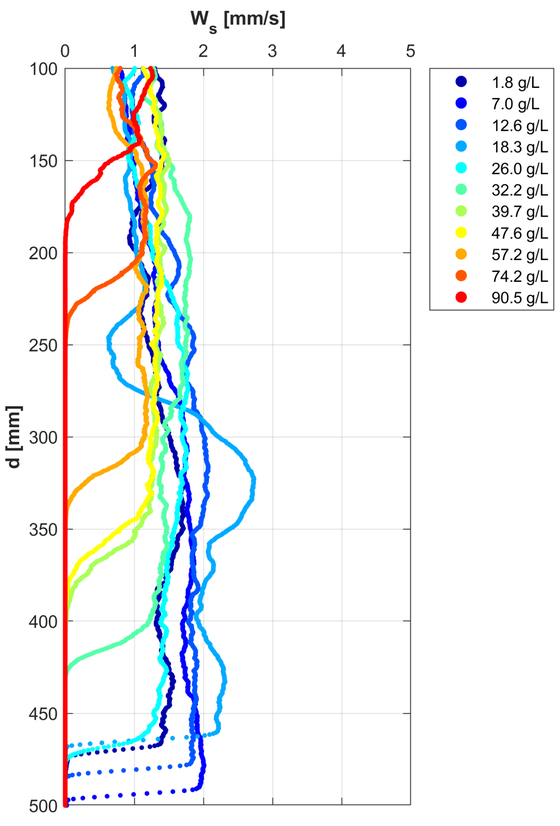


Fig 4.: Eff. Velocity profiles for different initial concentrations

Figure 4 shows resulting velocity profiles for 9 different C_0 with an evaluation period of 240s ≤ t ≤ 285s. With increasing C_0, the bottom layer thickness increases from a few mm at C_0 = 1.8 g/L to about 300mm at C_0 = 90 g/L. From the top of the column the vertical velocity profiles exhibit an almost constant gradient. Approaching the vicinity of the interface, the velocities decrease to almost zero mm/s within a range of about 50 mm. This indicates the thickness of the transition between flocculation settling and hindered settling.

6. Results

The Methodology was applied to derive effective settling velocities for sediments from the German estuaries Weser and Ems, see figure 5. Weser sediments exhibit higher velocities in both regimes.

- Next, models by Raudkivi (1998) and Winterwerp (2007) are utilized for regime-specific parameterization
- Additionally, Mehta's model (1996) is used for cross-regime simulation of settling velocities
- Using max. velocities $W_{smax,M}$ from Mehta's model (1996) the transition concentration between flocculation and hindered settling is determined to about 8 g/L (W) & 7 g/L (E)
- The transition is also sought by dividing a measurement series in two parts and fit Raudkivi and Winterwerp's model (dotted verticals) correspondingly. The transition point is moved dynamically using a sliding window. By this, several realizations of the model fits are realized (light gray and blue lines in fig. 6)

Figure 6 shows exemple results and model fits for Ems sediments with a salinity of 7 ppt and a temperature of ~20°C. The Raudkivi (light grey), Winterwerp (light red) and Mehta (black line) models are fitted to the data (black points). Thus, several critical parameters are derived from the measured data and the model fits:

- Max. settl. Vel., $W_{sm,mes}$ (measured) ≈1,35-1,7 mm/s & $W_{smax,mod}$ (Mehta) ≈ 1,2-1,5 mm/s
- Mehta: (Max.) deposition flux, $F_{s(m)}$ ≈ 20-45 kg/m²s
- Winterwerp: Gelling point, C_{gel} ≈ 100-250 g/L & individual velocity W_{s0} ≈ 1,0-2,75 mm/s
- Combination of models: Transitional conc. (floc vs. hindered settl.), C_{trans} ≈ 7-8 g/L

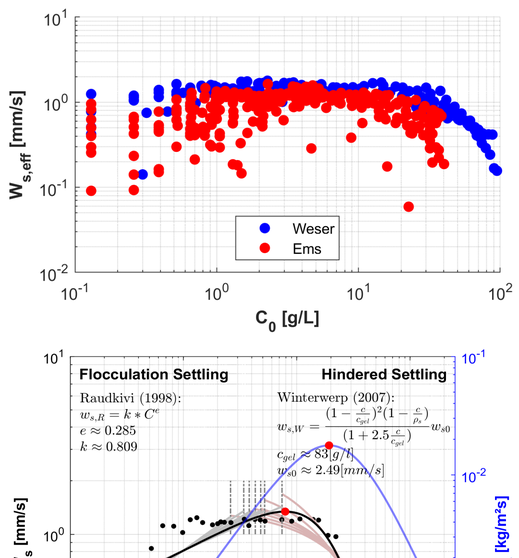


Fig 5.: Effective settling velocities for Weser and Ems estuaries

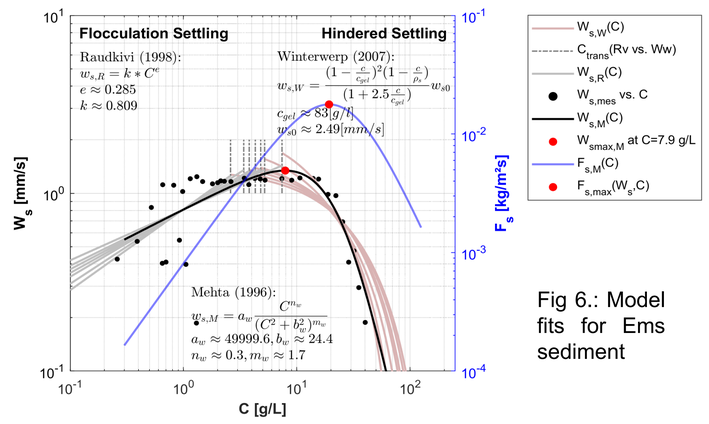


Fig 6.: Model fits for Ems sediment

Take Home Messages

FAUST investigates the exchange at the sediment-water interface:

1. Natural mud was collected from the fairway of the Ems and the Weser estuary
2. A methodology using ultrasonic sensors was developed to analyse settling velocities and their temporal and spacial distribution
3. Eff. settling velocities are derived as a function of SSC, avg. max. vel. are $W_{sm,Weser}$ ≈ 1,7 mm/s, $W_{sm,Ems}$ ≈ 1,35 mm/s
4. Parameterization of appropriate expressions for W_s is applied
5. Sediment specific values for regime transition, gel point and the settling velocity of an individual floc have been derived

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