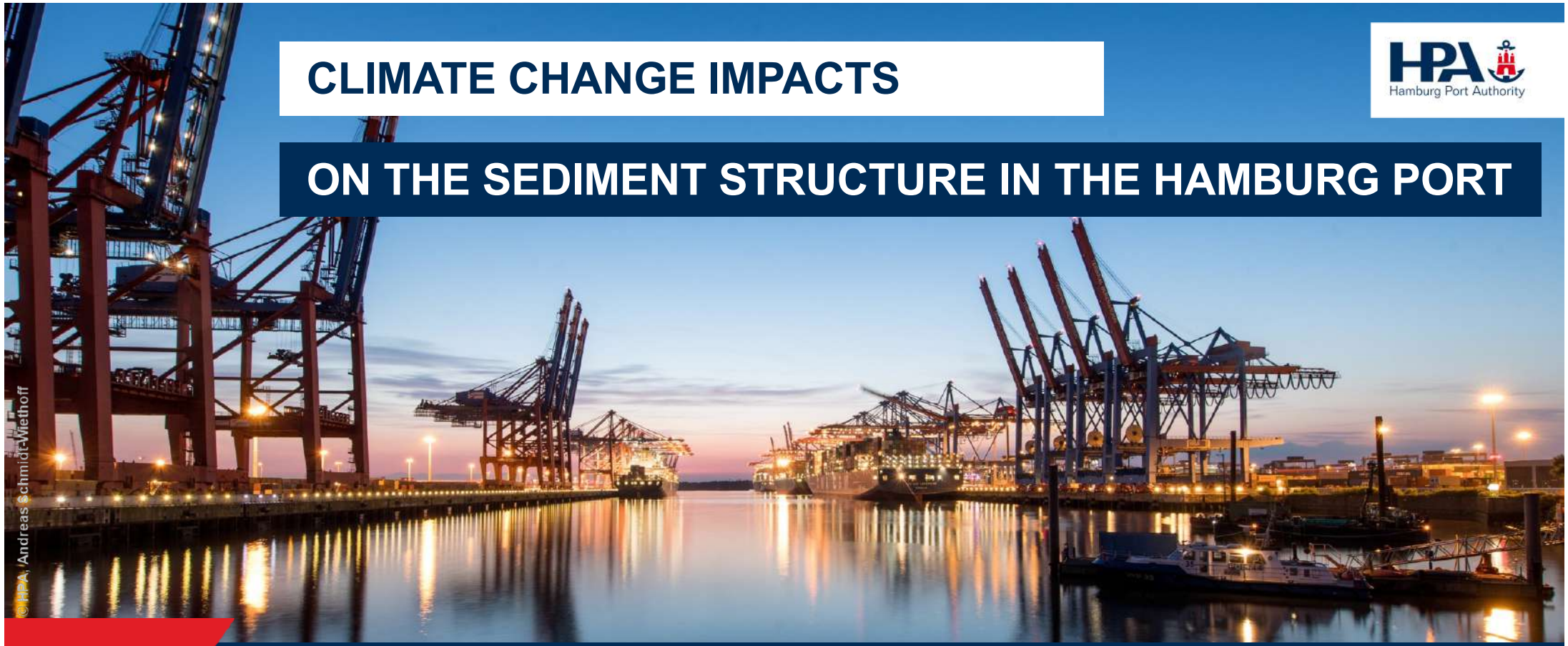


CLIMATE CHANGE IMPACTS

ON THE SEDIMENT STRUCTURE IN THE HAMBURG PORT

- Challenges and Opportunities: Use of Fluid Mud for Navigational Aspects -

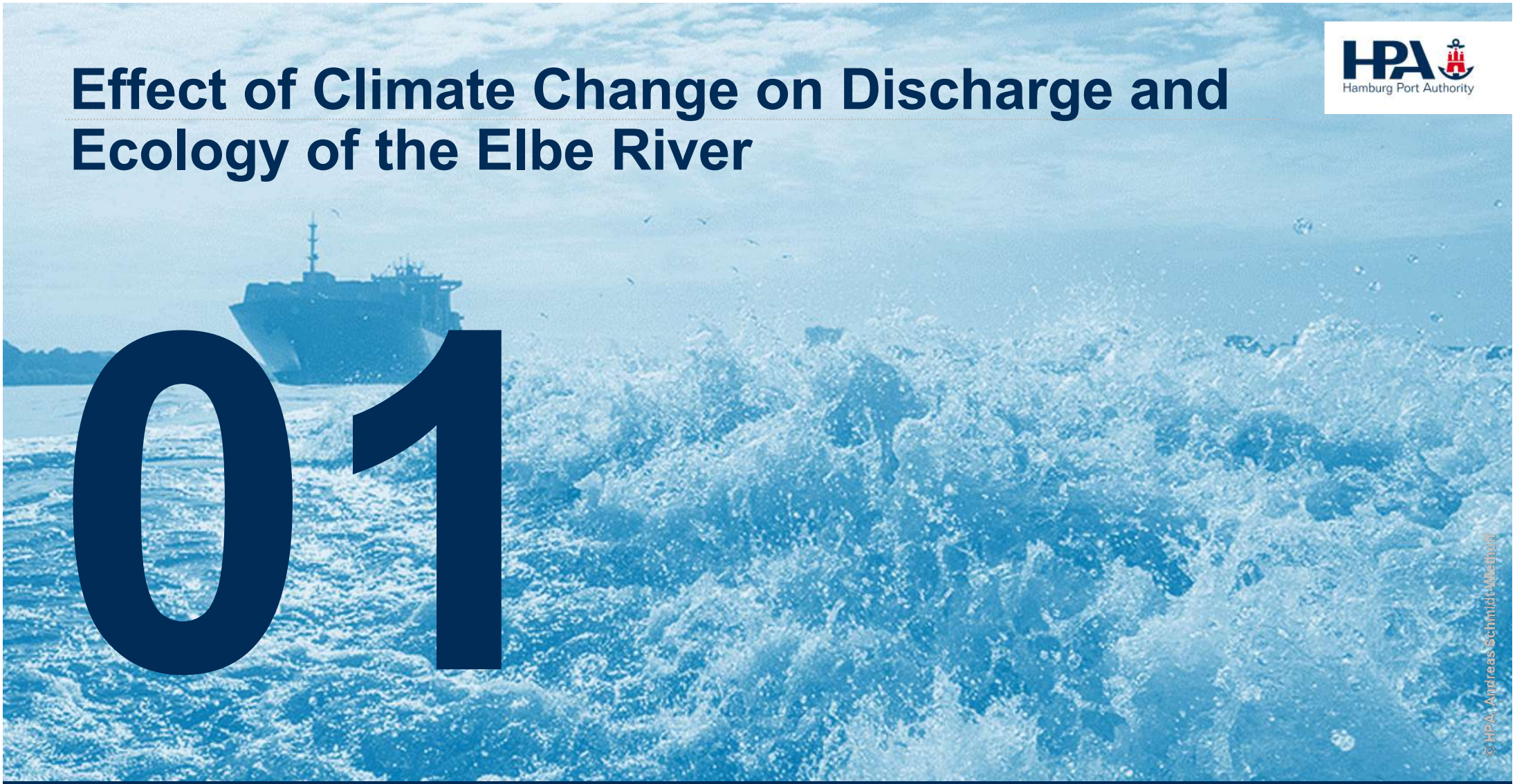
13th International SedNet Conference 6th – 8th September 2023 in Lisbon, Portugal

Nino Ohle[1], Ulrich Schmekel[1], Ivan Shevchuk[2], Carl-Uwe Böttner[3]

[1] Hamburg Port Authority (HPA) [2] Technical University of Hamburg (TUHH), Institute for Fluid Dynamics and Ship Theory, Hamburg

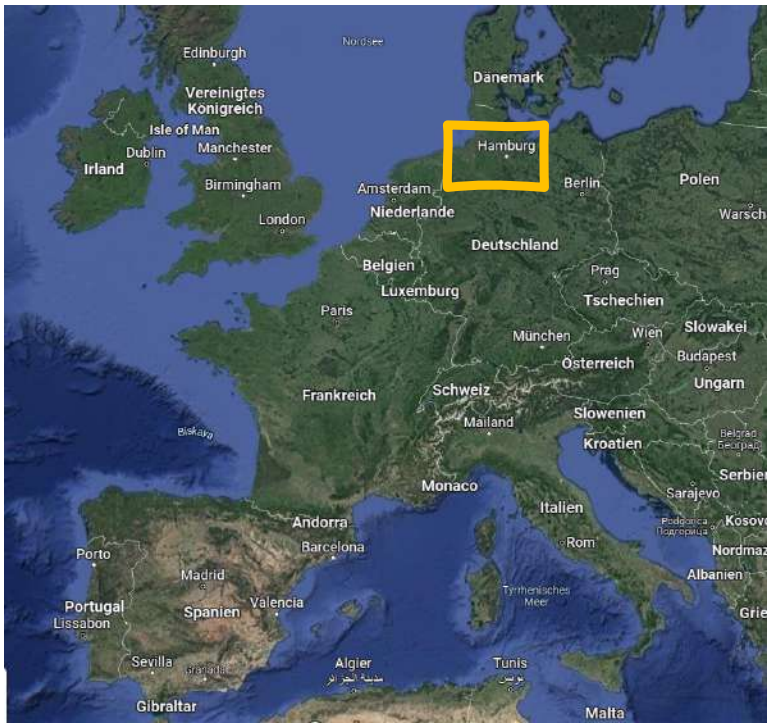
[3] Bundesanstalt für Wasserbau (BAW), Federal Waterways Engineering and Research Institute, Hamburg - all Germany

Effect of Climate Change on Discharge and Ecology of the Elbe River

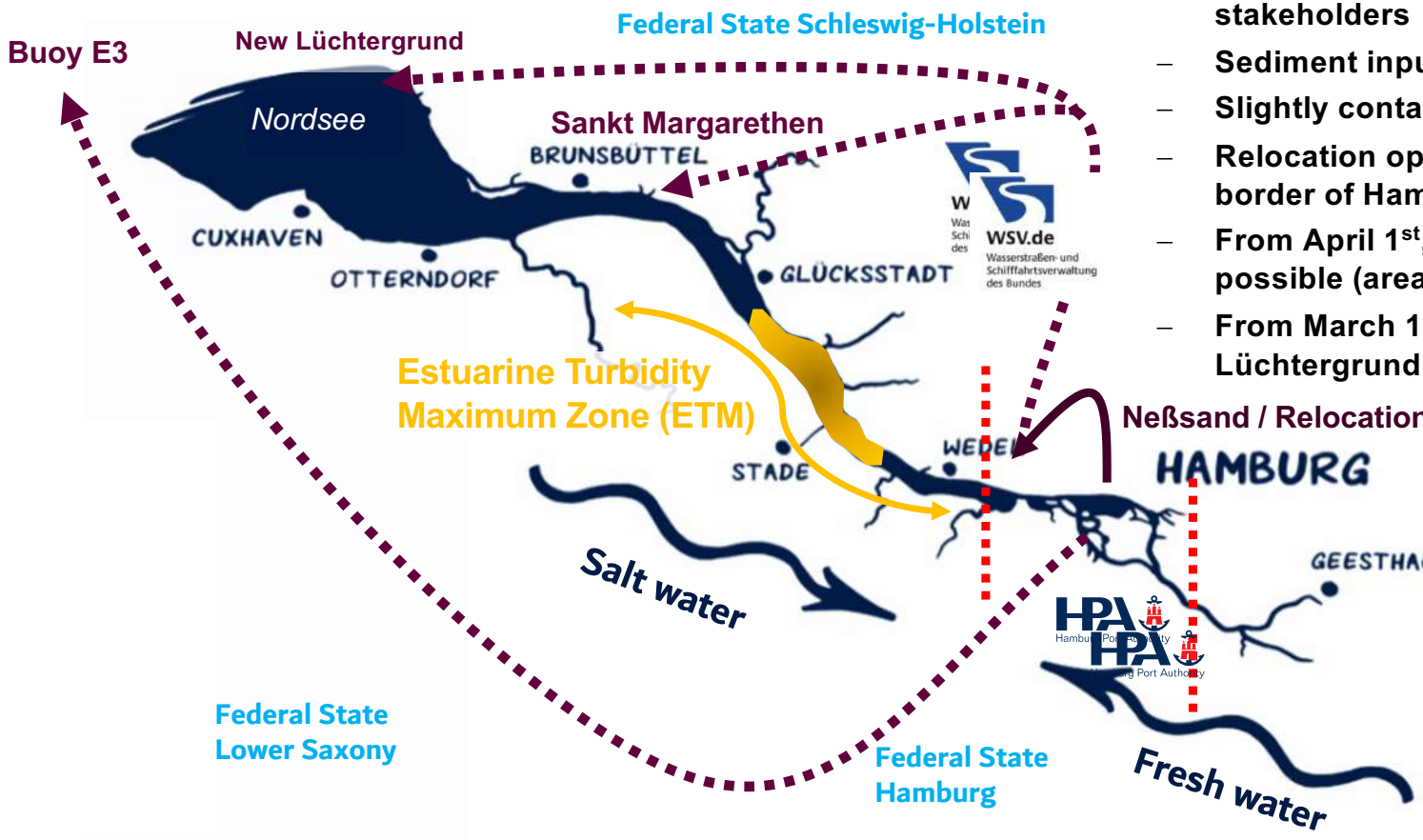


01

Introduction
Area of Investigation

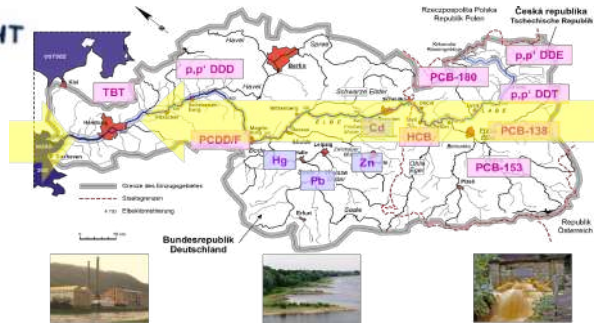


Boundary conditions of the HPA with regard to sediment management options



- Federal system / a lot of responsibilities and stakeholders
- Sediment input from upstream and downstream
- Slightly contaminated sediments from upstream
- Relocation options within Hamburg at Neßsand (state border of Hamburg) and in the North Sea at Buoy E3
- From April 1st, 2021 also relocation at St. Margarethen possible (area of the federal agency)
- From March 15th, 2022 also relocation at New Lüchtergrund possible (area of the federal agency)

Slightly Contaminated Sediment from the catchment area of the Elbe



Boundary conditions of sediment management in the Elbe estuary

„Boundary conditions" for sediment management options:

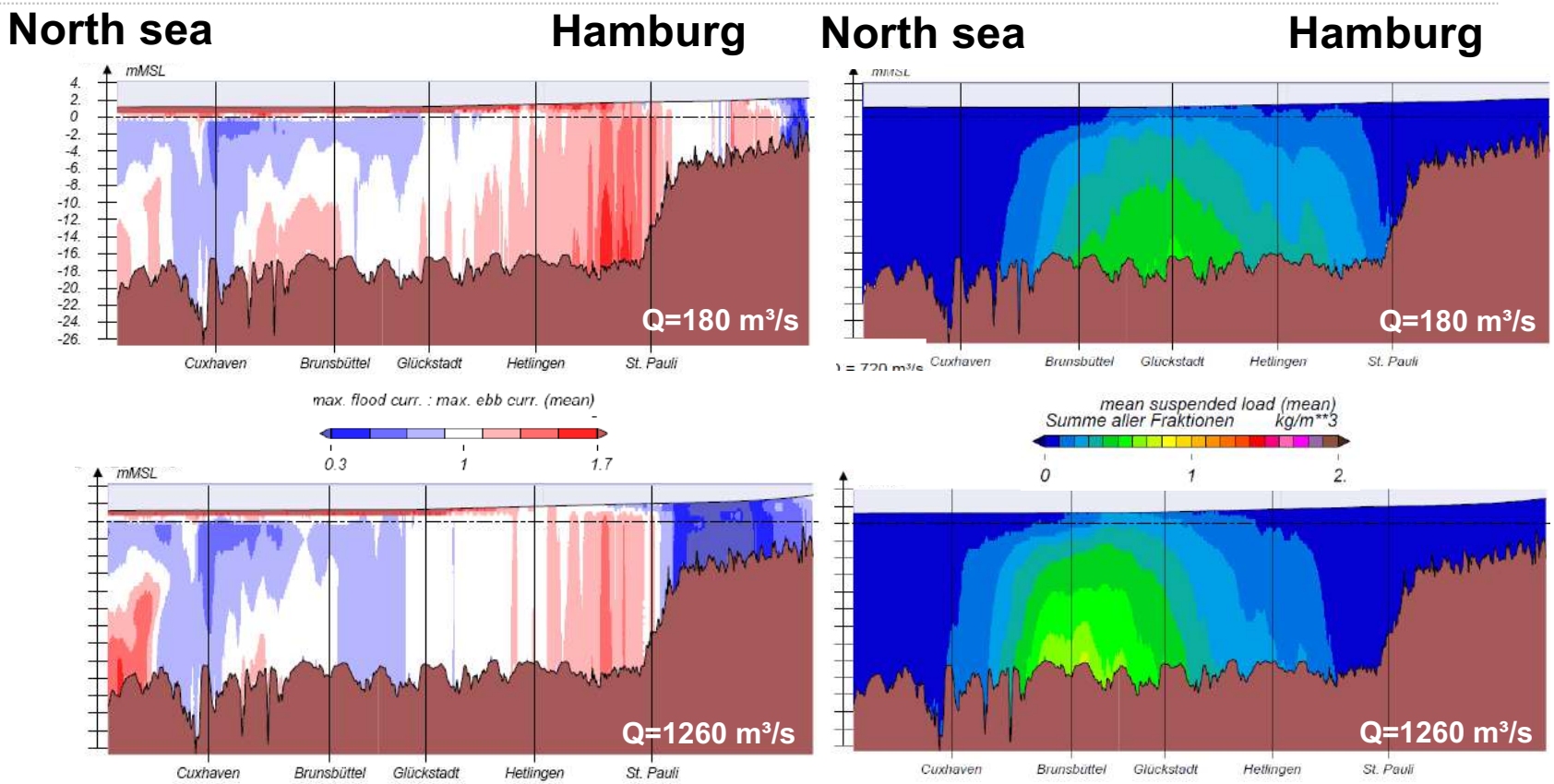
- **Slightly contaminated sediments from upstream**
- **Hydrology and morphology**
- **Water quality / oxygen balance**
- **Nature conservation / Natura 2000 areas**
- **Politics (fishery, tourism, environmental associations...)**

In average 16 - 17 Mio. m³/a dredged material with TSHD (costs: ~ 60 to 70 Mio. €/a) and

In average 1 - 2 Mio. m³/a relocated material with BLD or WID (costs: ~ 5 – 7 Mio. €/a)

- Use of TSHD units with volumes of usually 6,500 - 8,000 m³ (→ more than 2000 dredging cycles/year)
- ≥ 7 Mio. m³/a of dredged sediment is silt or fine sand Fine material is increasingly relocated depending on discharge conditions

Discharge of catchment area have influences on estuarine turbidity maximum (ETM) and suspended matter (SPM) concentrations → Flood/Ebb–domination (left) & SPM conc. (right)



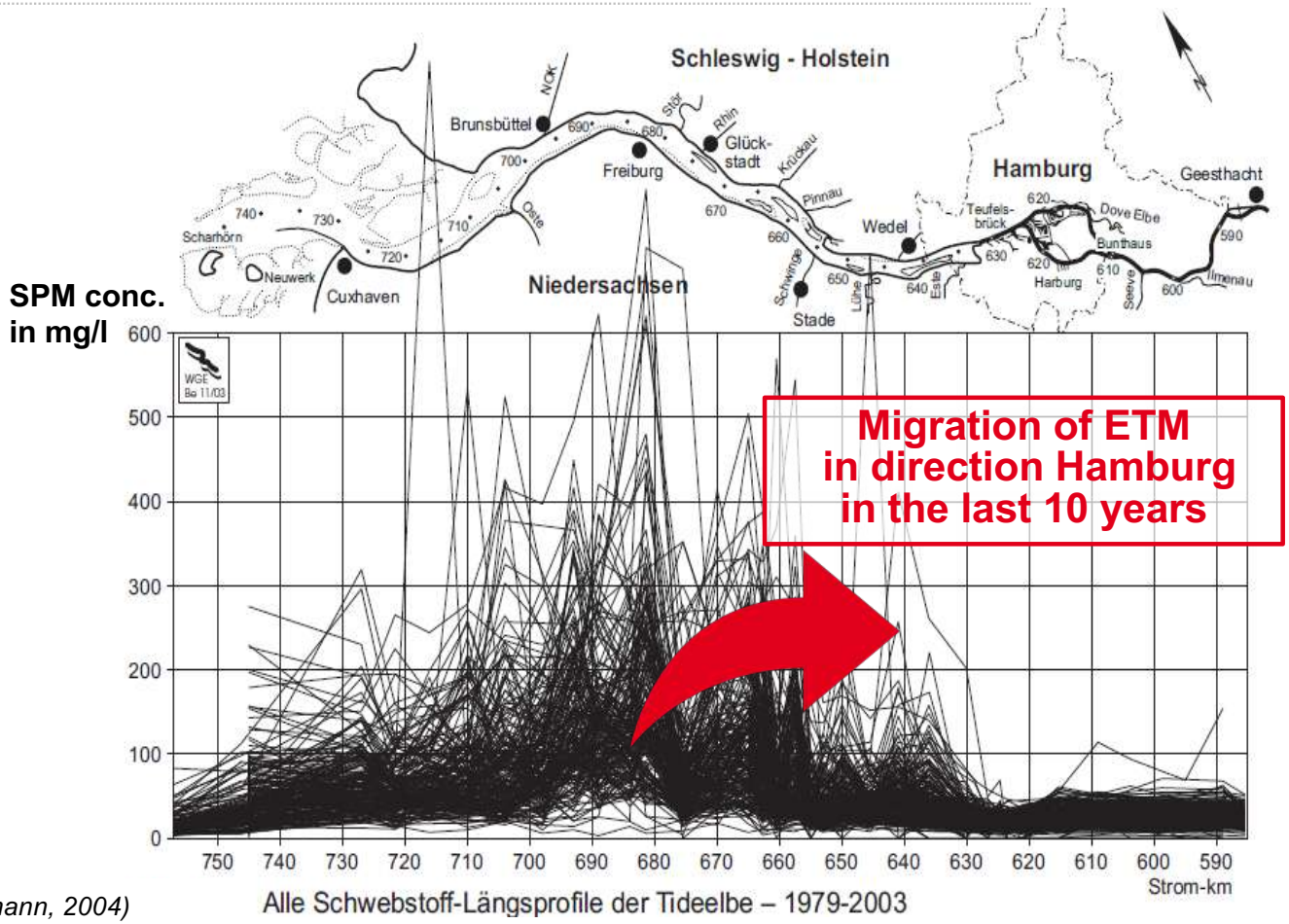
(Figure from BAW / Weilbeer et al. (2011),
Numerical simulation 11.06.-25.6.2006; longitudal section in centre of fairway)

Discharge of catchment area have influences on estuarine turbidity maximum (ETM) and suspended matter (SPM) concentrations → development over the years (1979 – 2003)

"The turbidity zone arises dues to accumulation of suspended matter, as over longer periods of time the net transport of silt towards the North Sea is smaller than the transport of upstream.

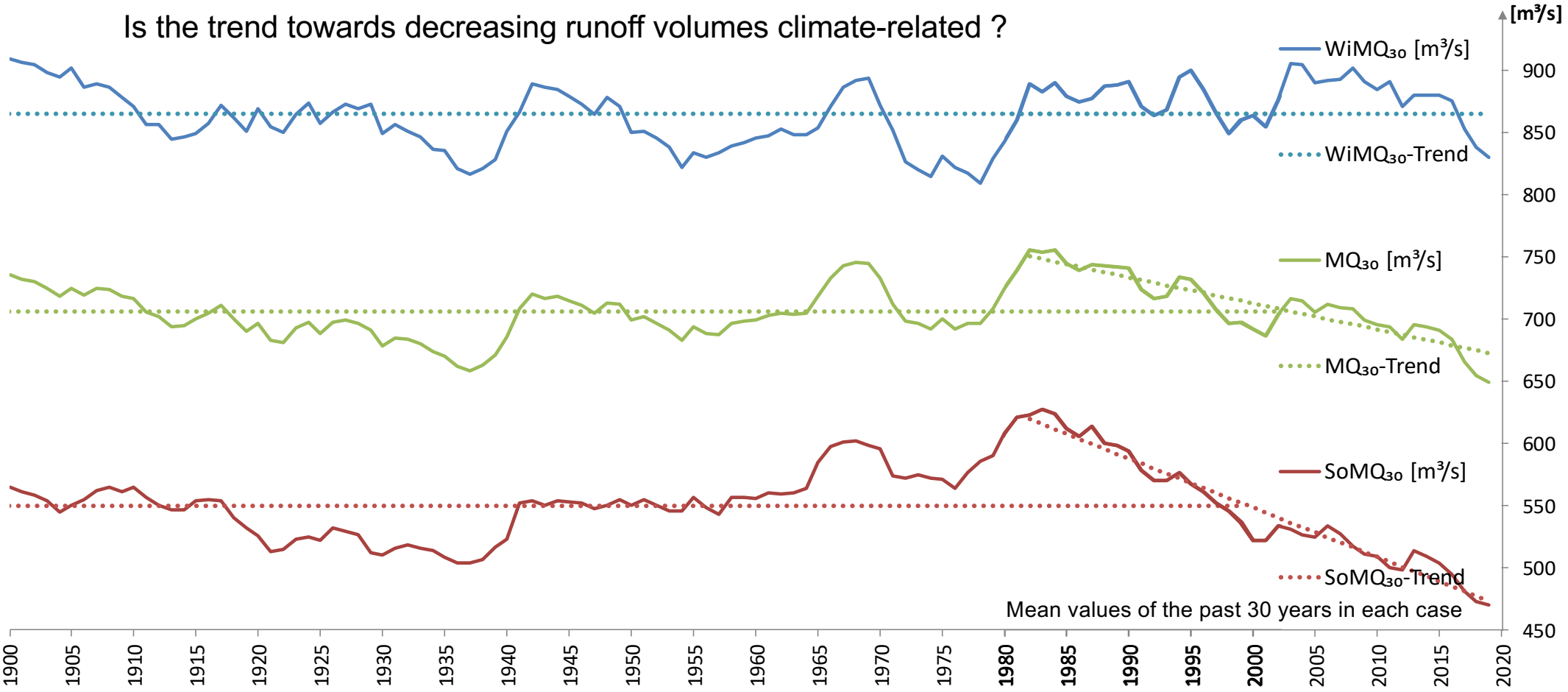
During periods of low discharge, the suspended sediment inventory increases upstream the ETM .

On the other hand**, a flood event, drifts a large part of the suspended matter into the North Sea**, where the tidal flats are fed."



(Quelle: Bergemann, 2004)

Classification of the hydrological boundary conditions 2014 - 2020



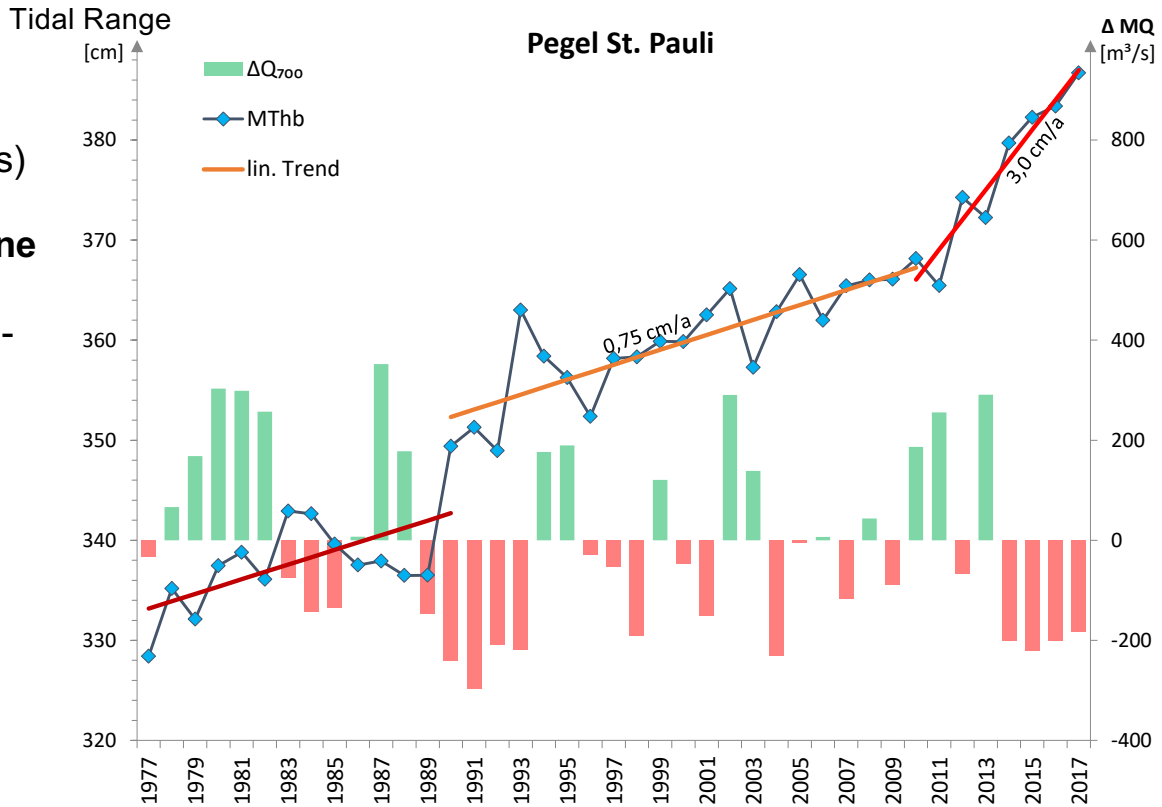
Consequences of the "drought" for the hydromorphology of the Tidal Elbe

Worrying observations:

- Spontaneous **increase in tidal range** in HH (+20 cm) (without temp. reference to anthropog. system changes)
- **Upstream shift of the turbid and brackish water zone**
- **Reduction** of the tidal Elbe habitat dominated by fresh-water due to prolonged residence time **of the limnic water body**

  ⇒ **Accumulation of organic substances** that increase the oxygen depletion potential

  ⇒ **Can lead to pronounced oxygen deficiency situations** and associated fish mortality



Consequences of the "drought" for the hydromorphology of the Tidal Elbe

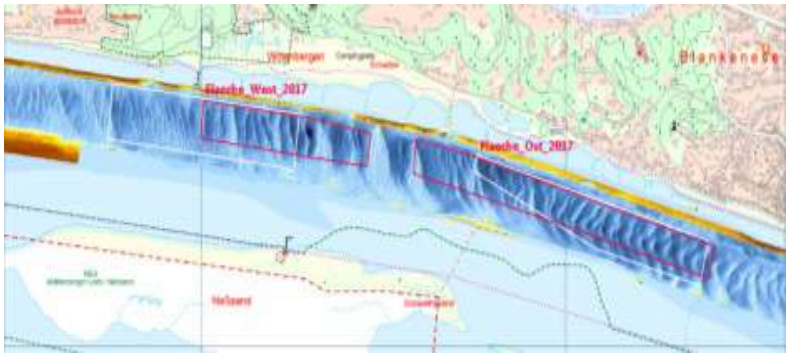
Worrying observations:

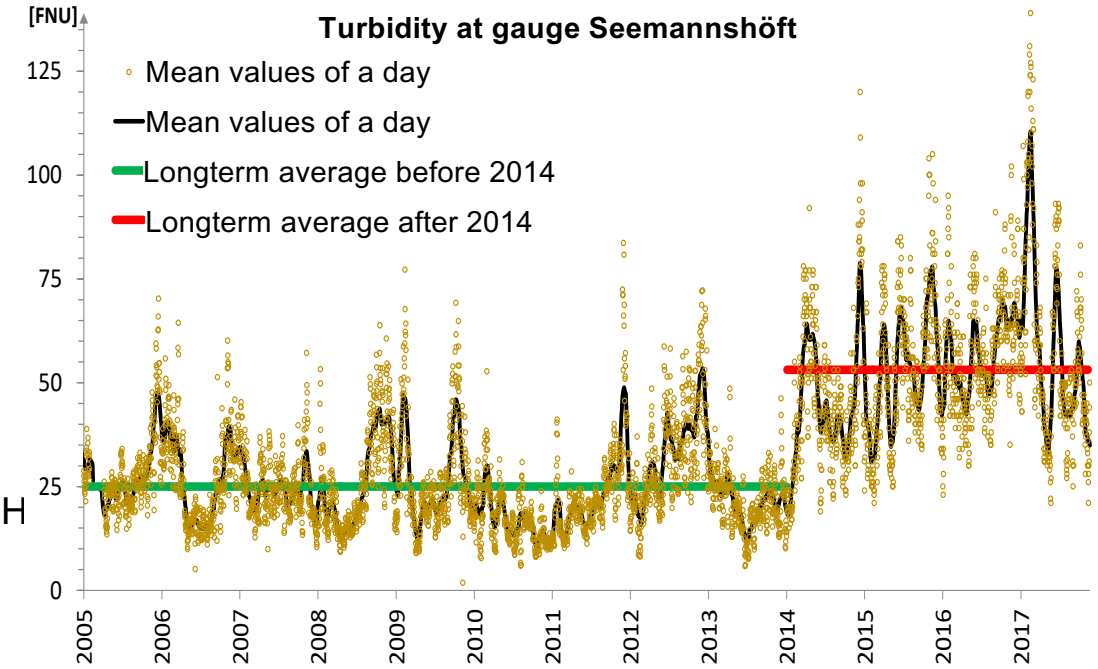
- Persistently **high SPM concentration** in the Lower Elbe (turbidity doubled **since the beginning of 2014**)
- **Partial loss / depletion of sandy riffle / dune** stretches due to filling of valleys with fine grain fractions

  ⇒ **Reduction of bottom roughness** =
  - Energy dissipation + Tidal Range

  ⇒ **Increase in 'tidal pumping'**

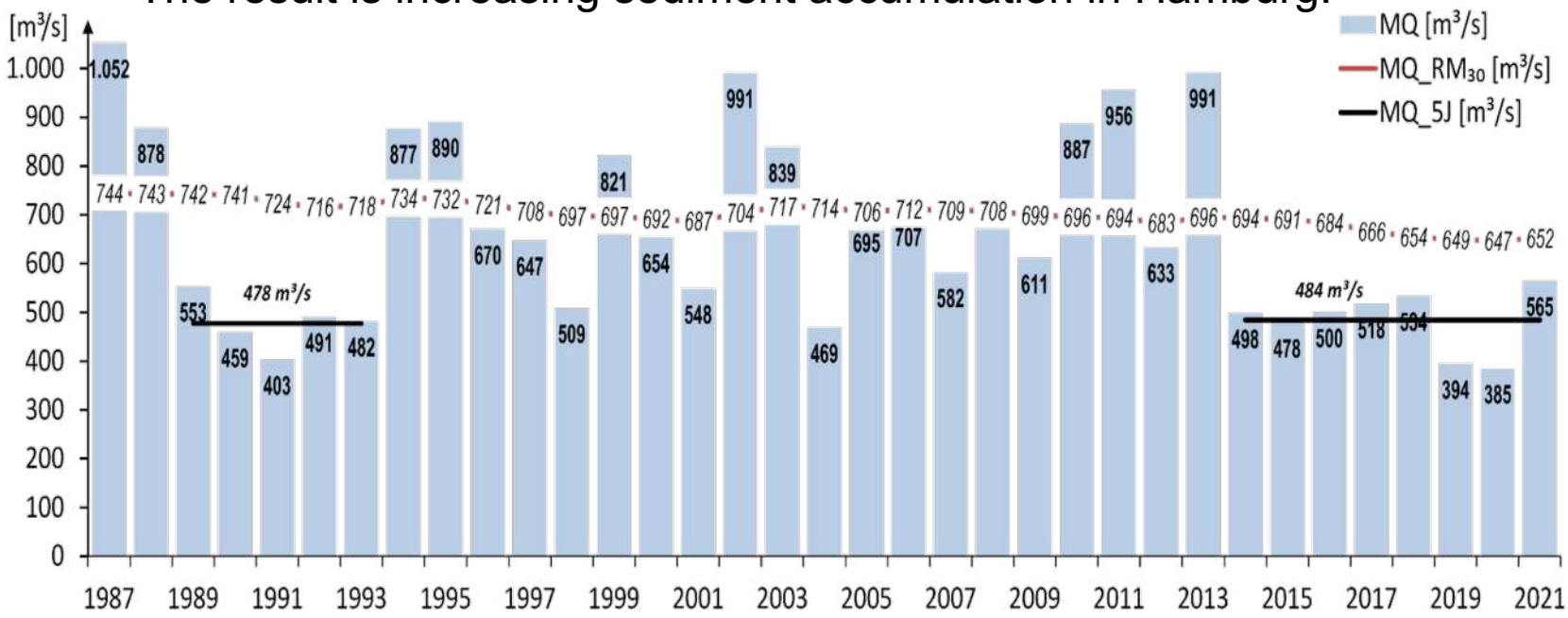
  ⇒ **Increase in maintenance dredging amounts** in HH





Climate Change influences the dredging quantities in Hamburg

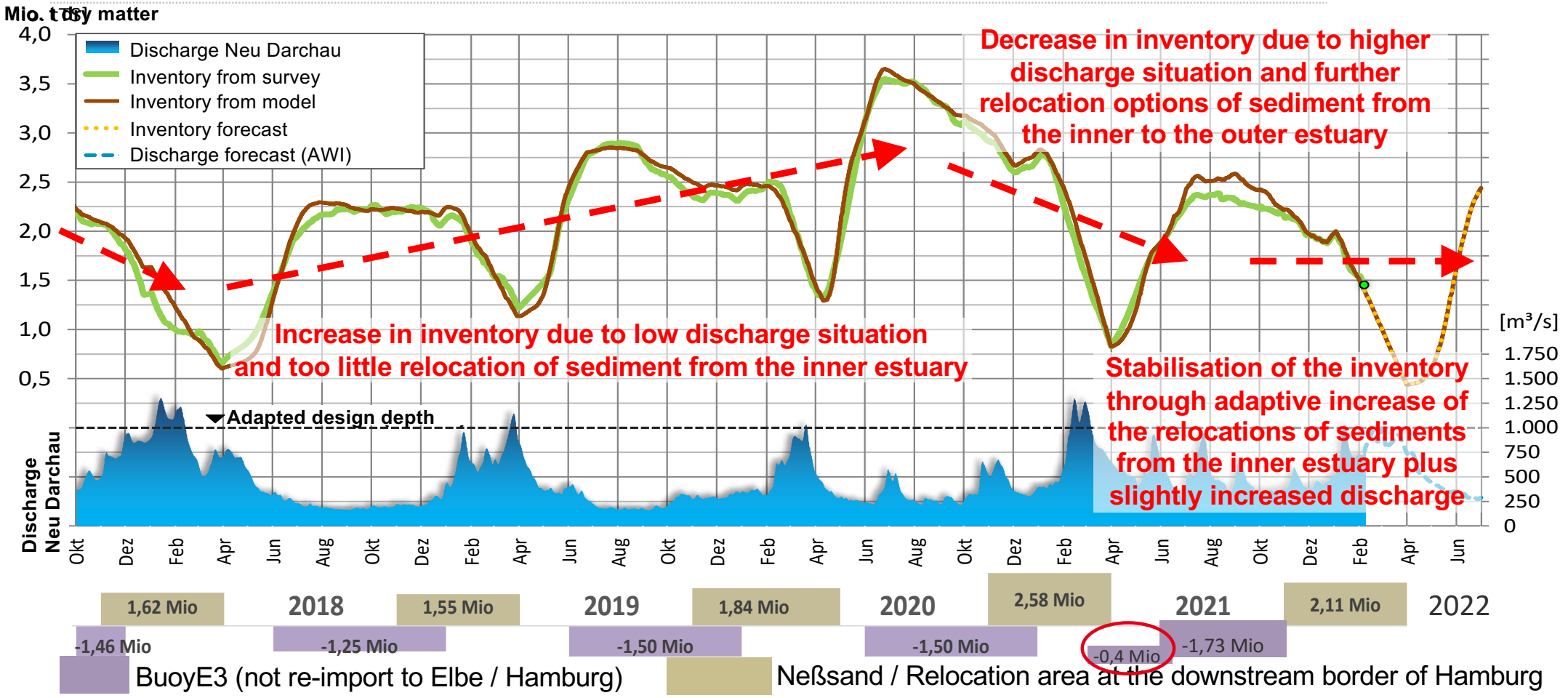
- Extremely low discharges (climate change) that have persisted for 10 years! This means that more sediment enters the port and not enough material can be relocated sustainably to buoy E3 for export.
- The result is increasing sediment accumulation in Hamburg!



If the discharge drops from 700m³/s to 200m³/s, then the amount of sediments in HH is five times higher !

At discharges of 200 m³/s, the sedimentation rates are around 10,000 t/d!

Increasing sediment inventory in the harbour: Dredging circles due to higher sediment import and limited export to buoy E3



Change of Mud Characteristics due to Climate Change

02

MUDNET

Link between HPA investigations and HPA-Project Nautical Depth and TU Delft research activities

https://www.tudelft.nl/mudnet

HPA Hamburg Port Authority

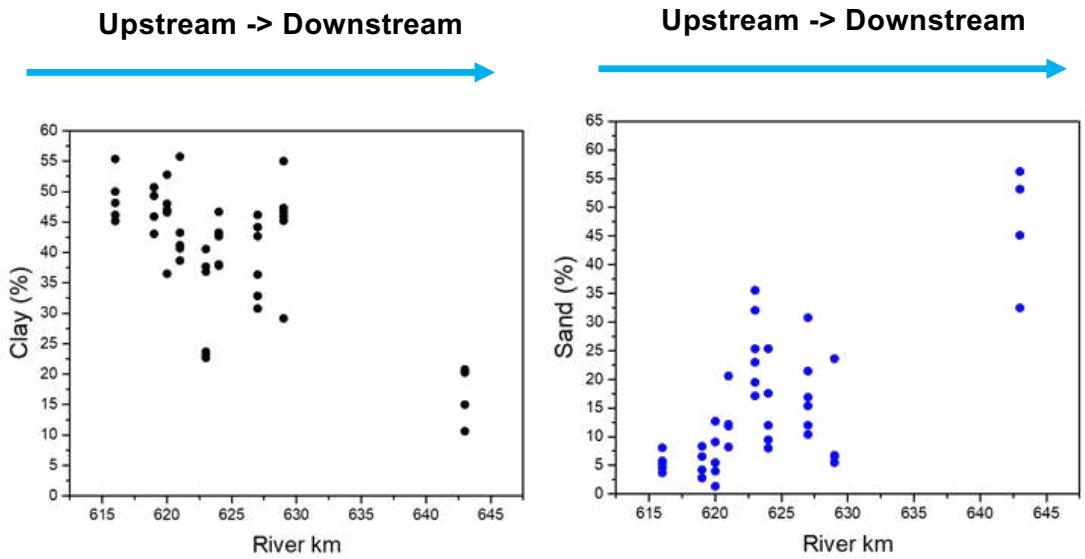
TU Delft

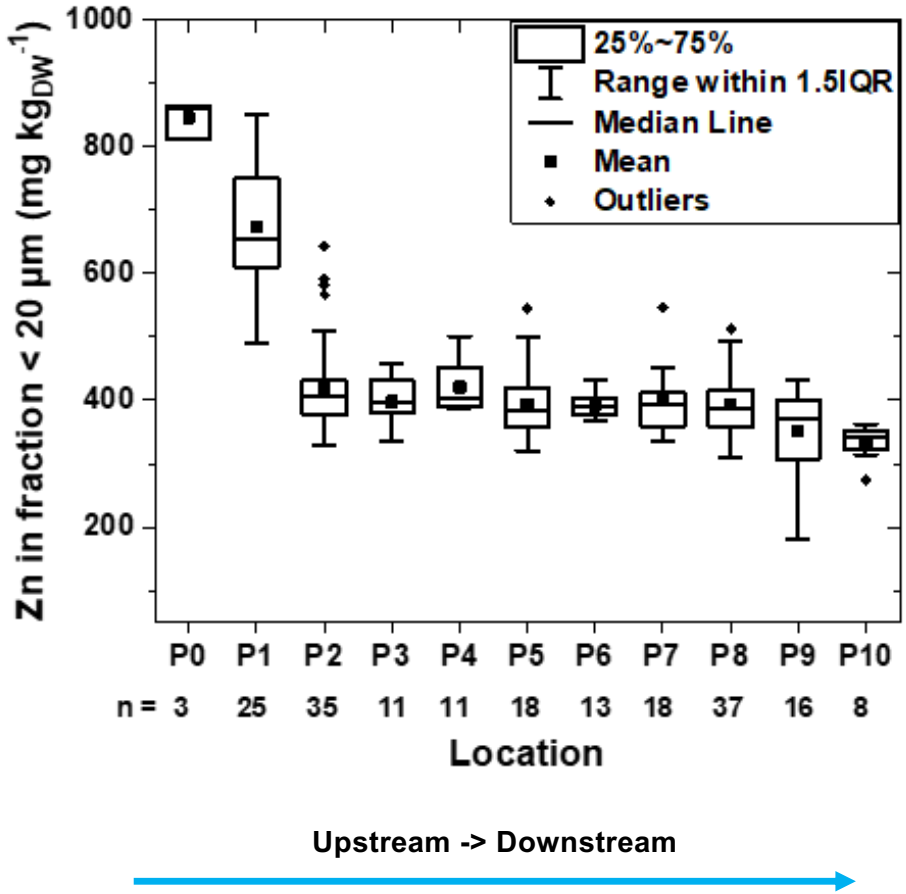
HPA Hamburg Port Authority

Co-financing / involvement

Distribution of grain size and upstream origin of sediments (zinc)

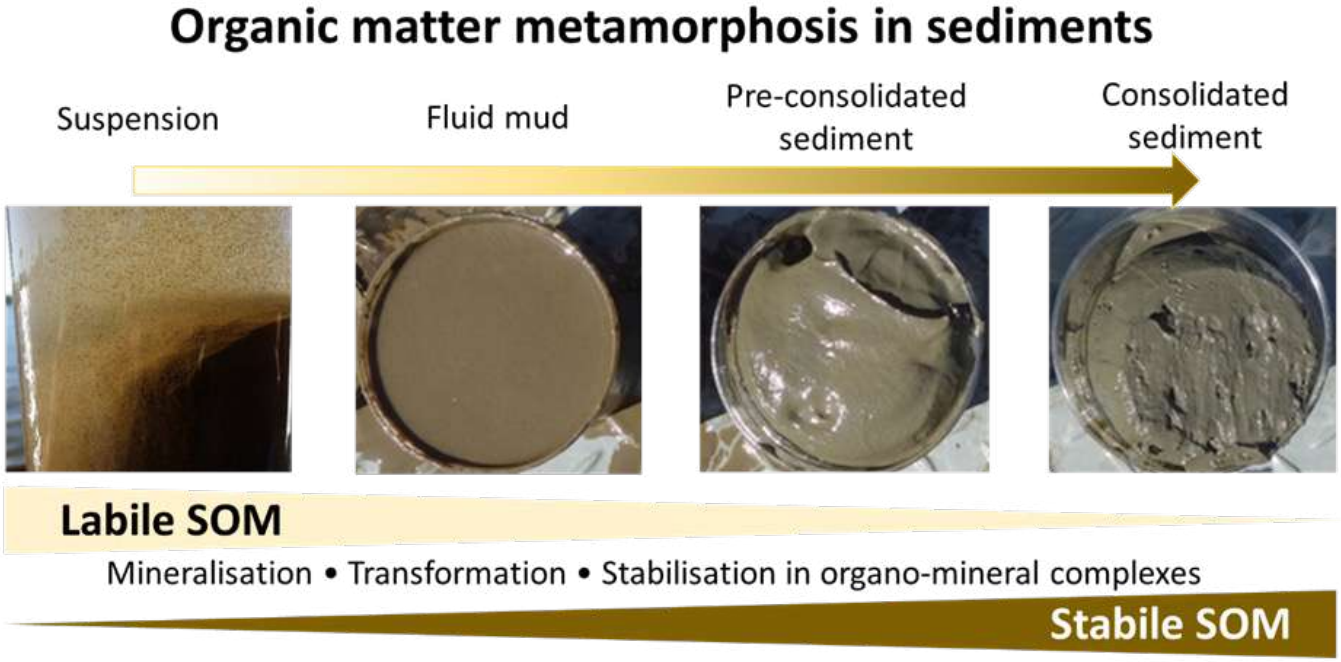
- Sediment origin (Zn in fraction < 20 µm)
  - most upstream locations (to RV): fluviatile sediments
  - other locations: downstream signature
- Grain size becomes finer downstream

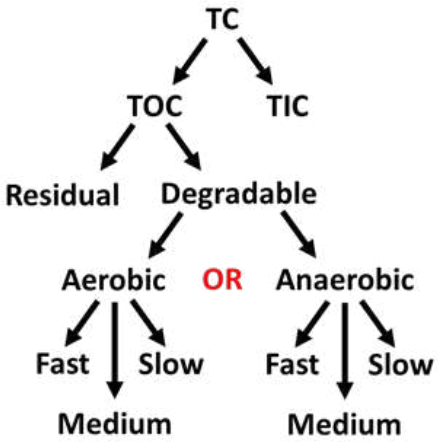


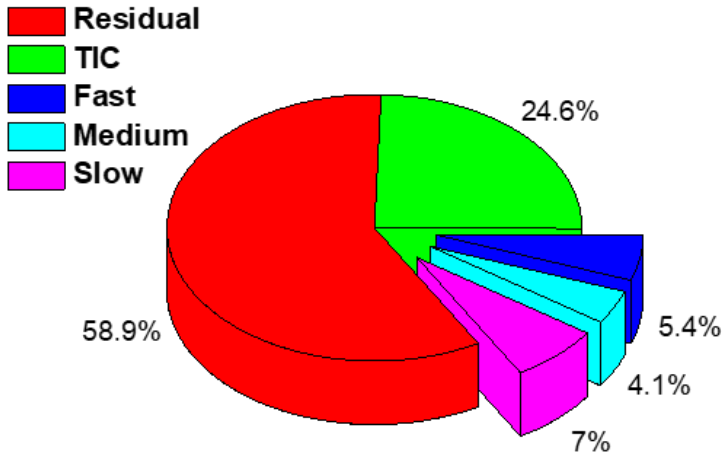


Organic matter metamorphosis important for the consolidation

- Aerobic or anaerobic decay depending on redox conditions
- Classification by organic matter pools with organic matter rates



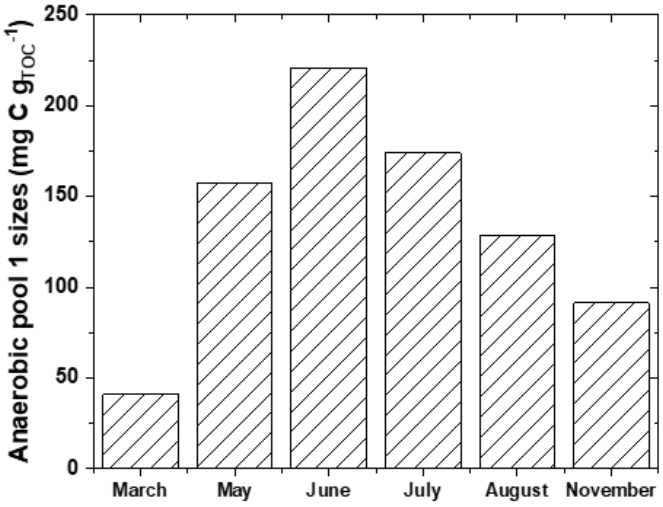


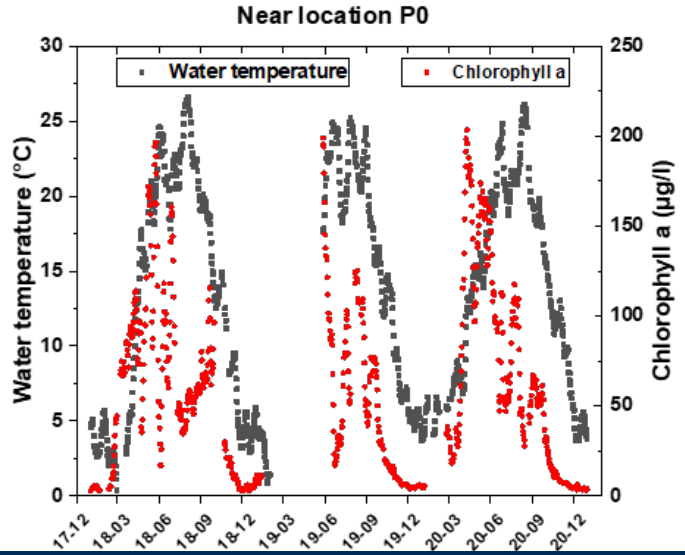


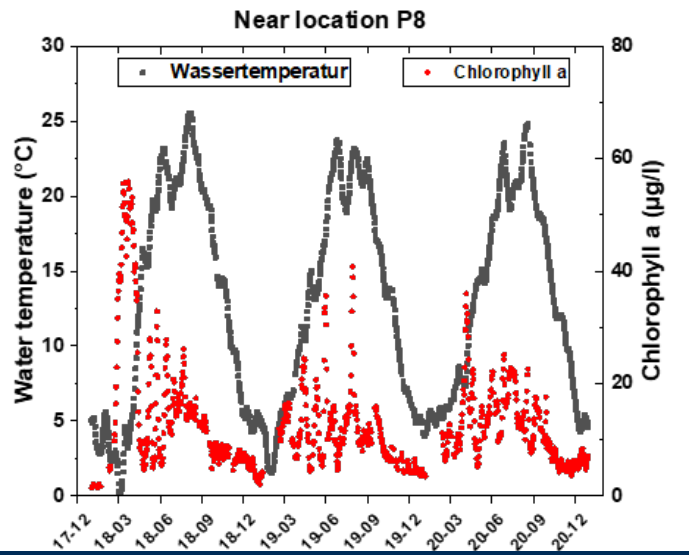
More boundary conditions due to dependencies on temperature and seasonal effects (algae bloom and Chlorophyll)

- Chlorophyll a as algal biomass indicator
- Clear temporal trends (summer winter)
- Temporal pattern explained by input of fresh, easily degradable OM from upstream in spring and early summer (phytoplankton)
- Light deficits in winter lead to lower net primary production (algal biomass)

Climate Change has an important impact!

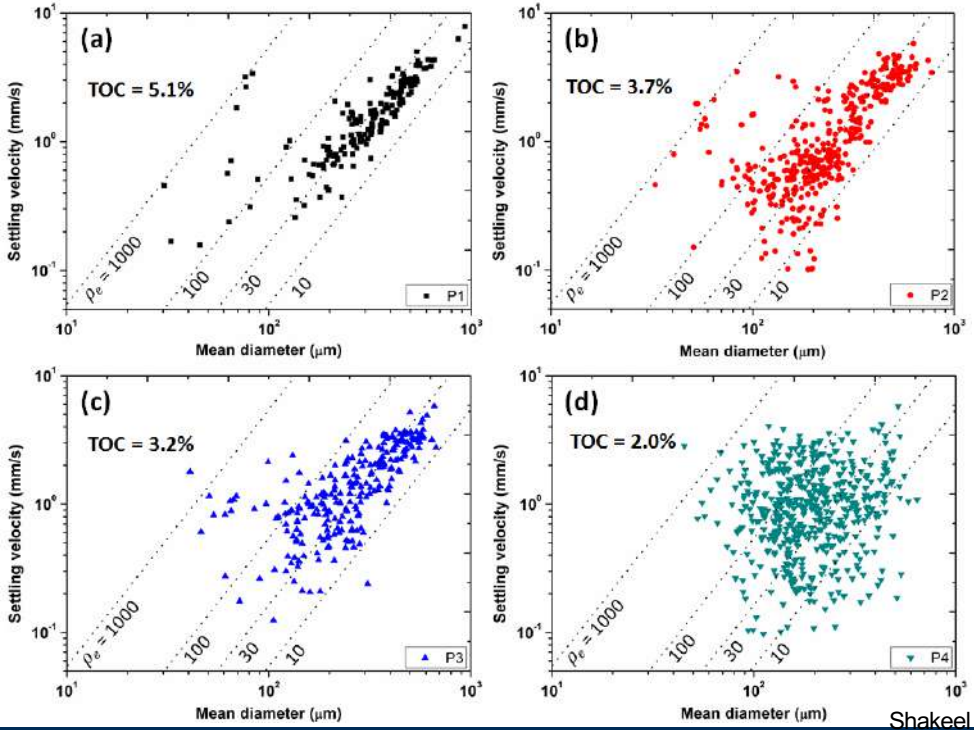




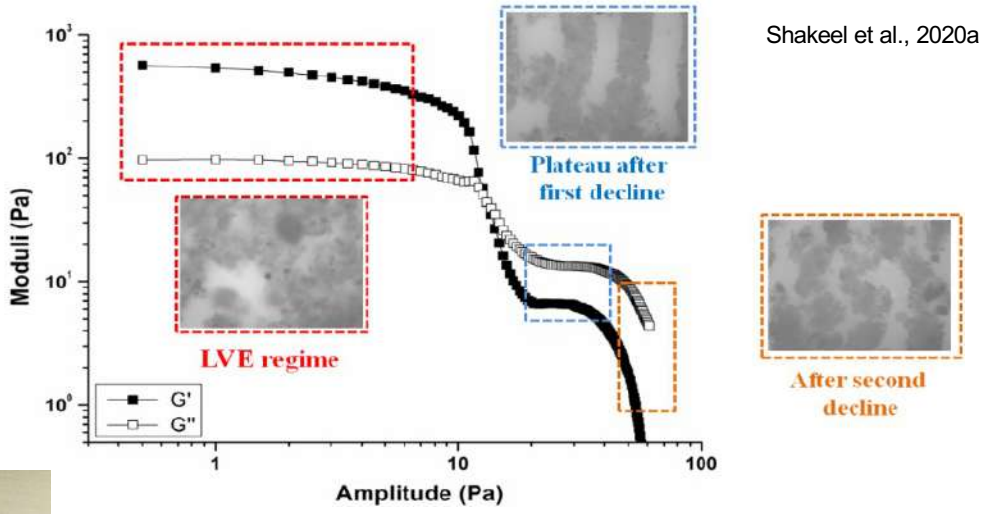


Does and how does the size, density and composition of particles (flocs) influence the rheology and consolidation?

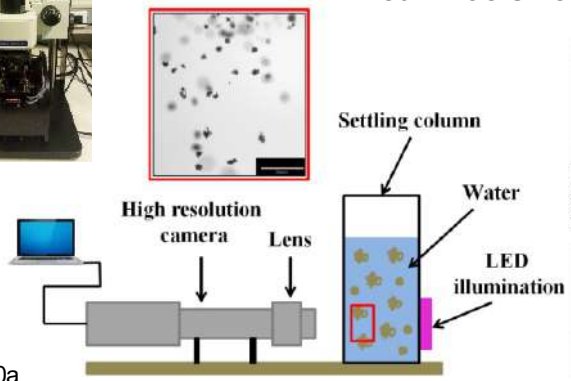
- TOC influences floc sizes
- TOC and grain size distribution influences settling velocity
- On-going research especialy important for numerical models



Shakeel et al., 2020a

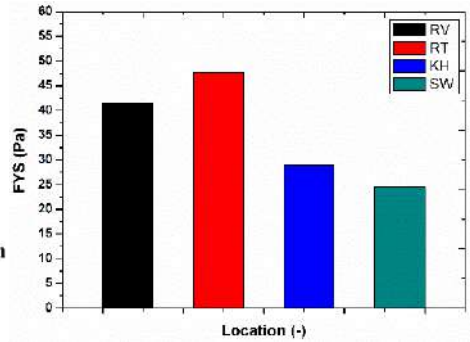


Shakeel et al., 2020a



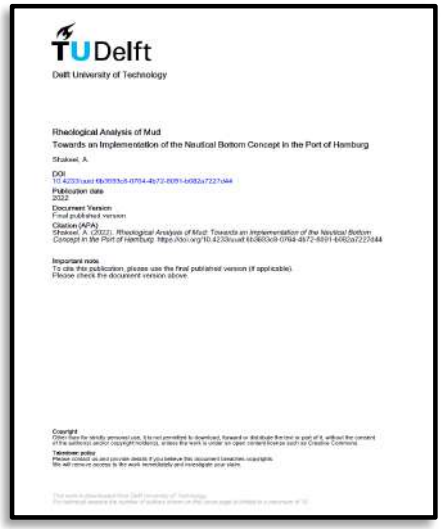
Mean floc size: RV > KH > RT > SW

Shakeel et al., 2021a



Results end up in publications, reports and 2 phD‘s

Rheological Analysis of Mud: Towards an Implementation of the Nautical Bottom Concept in the Port of Hamburg


TU Delft
Delft University of Technology

Rheological Analysis of Mud
Towards an Implementation of the Nautical Bottom Concept in the Port of Hamburg

Shakeel, A.

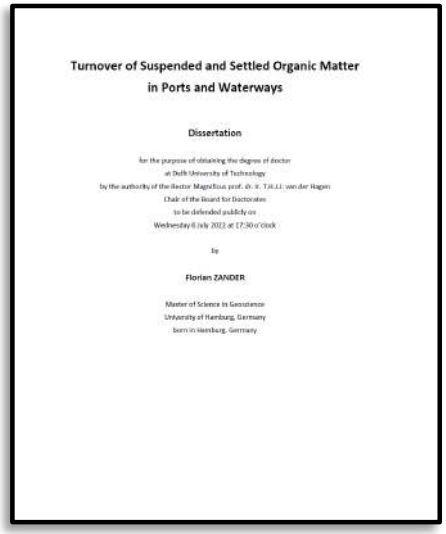
Author
Shakeel, Ahamad

Contributor
Pietrzak, J.D. (promotor)
Chassagne, C. (promotor)
Kirichek, Alex (copromotor)

Degree granting institution:
Delft University of Technology

Date: 2022-06-27
https://repository.tudelft.nl/islandora/object/uuid%3A6b3693c8-0764-4b72-8091-b082a7227d44?collection=research

Turnover of Suspended and Settled Organic Matter in Ports and Waterways


Turnover of Suspended and Settled Organic Matter in Ports and Waterways

Dissertation

Florian ZANDER

Author
Zander, Florian

Contributor:
Gebert, J. (promotor)
Heimovaara, T.J.

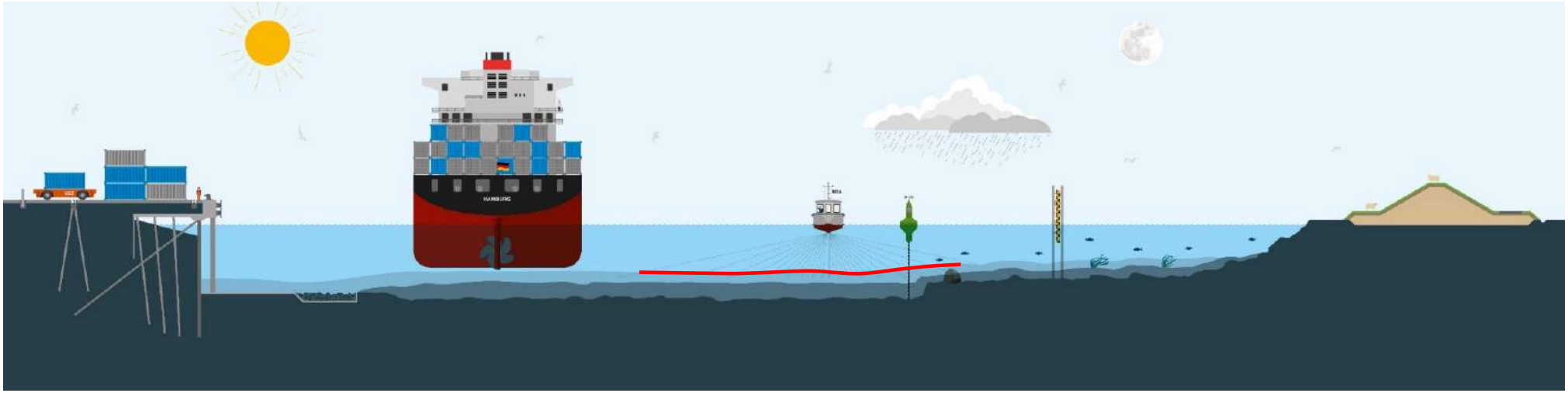
Degree granting institution:
Delft University of Technology

Date: 2022-07-06
https://repository.tudelft.nl/islandora/object/uuid%3Af4d57842-9603-41aa-950b-1009ab3c3fe3?collection=research

Influence on Nautical Aspects and adaptation of Nautical Depth

03

Goal: Use of the Nautical Depth Term according to PIANC* (1997)



“The nautical depth is the level where physical characteristics of the bottom reach a critical limit beyond which contact with a ship’s keel causes either damage or unacceptable effects on controllability and maneuverability.”

*PIANC: Permanent International Association of Navigation Congresses

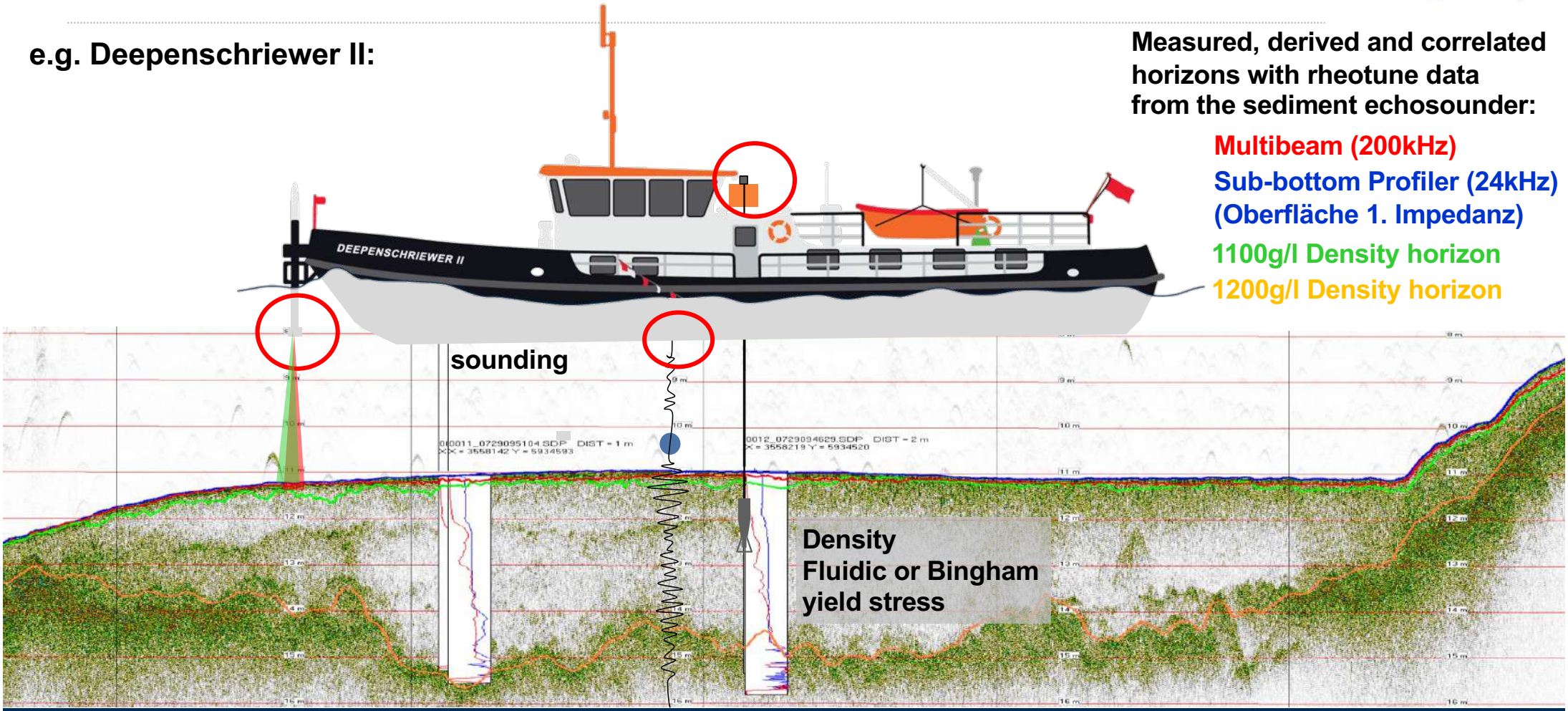
Recording the parameters of a suspension layer in 2D

Hamburg Port Authority

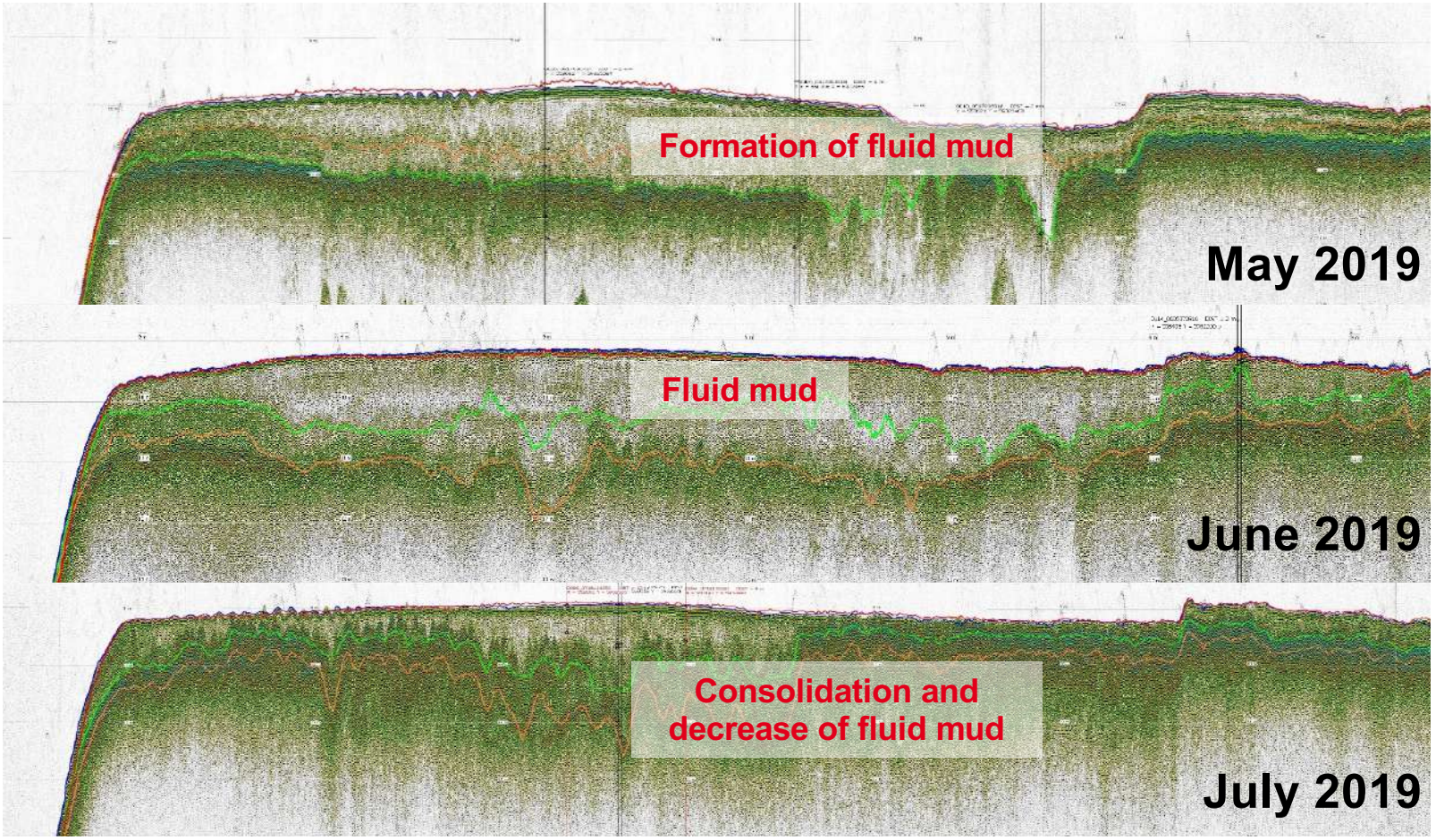
e.g. Deepenschriewer II:

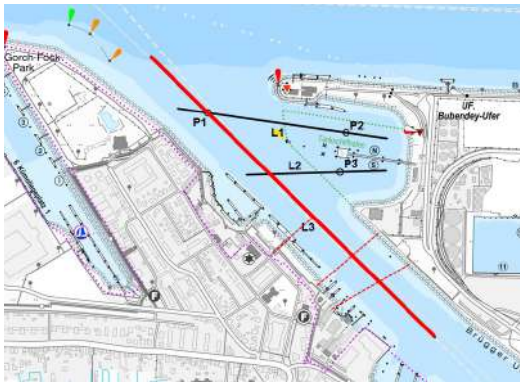
Measured, derived and correlated horizons with rheotune data from the sediment echosounder:

- Multibeam (200kHz)
- Sub-bottom Profiler (24kHz) (Oberfläche 1. Impedanz)
- 1100g/l Density horizon
- 1200g/l Density horizon

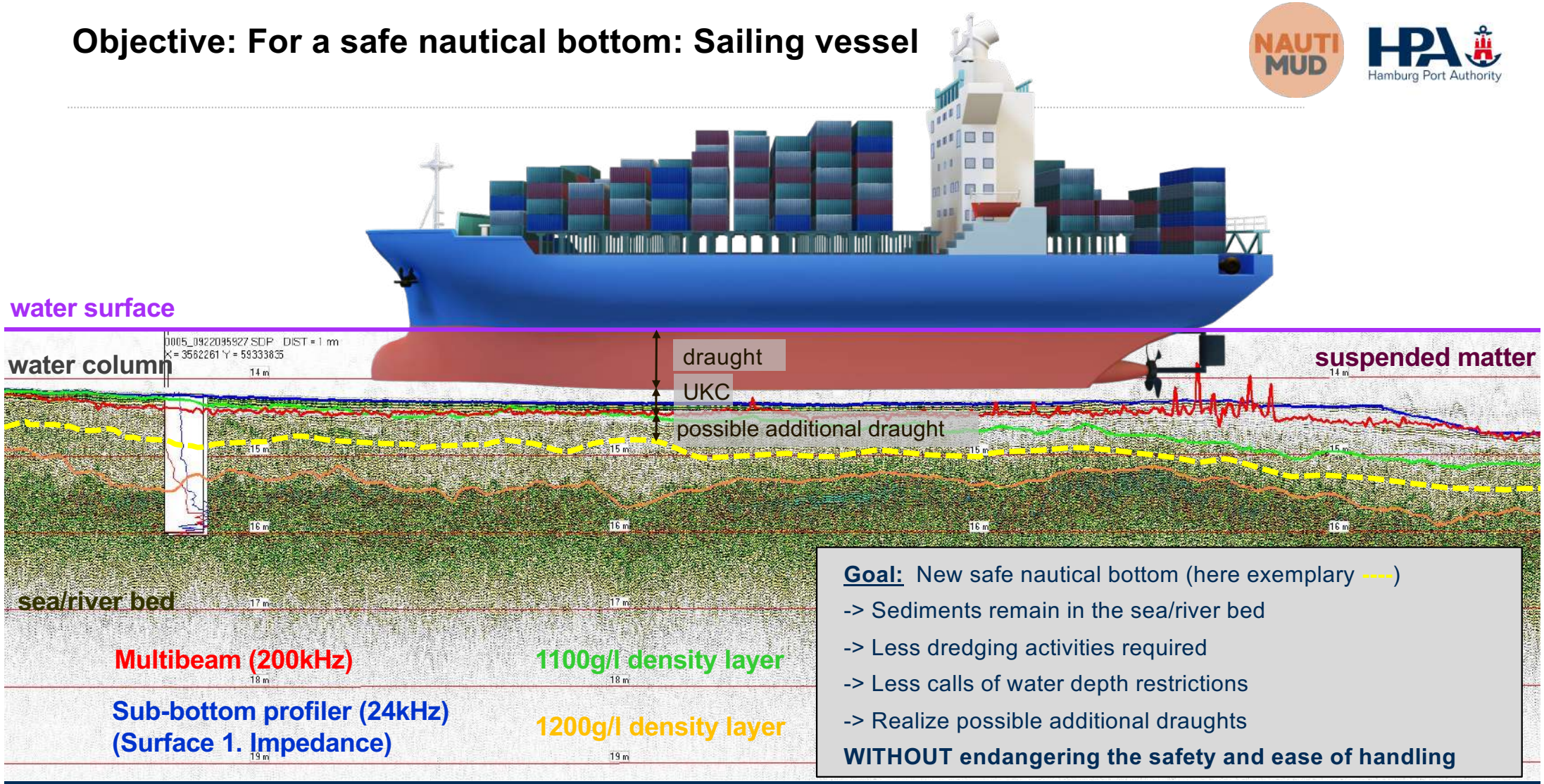


Recording the parameters of a suspension layer in 2D over the time





Objective: For a safe nautical bottom: Sailing vessel



Goal: New safe nautical bottom (here exemplary ----)

-> Sediments remain in the sea/river bed

-> Less dredging activities required

-> Less calls of water depth restrictions

-> Realize possible additional draughts

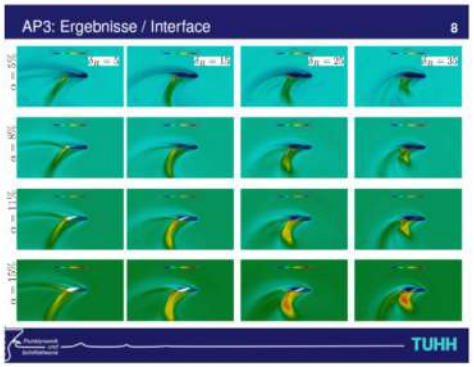
WITHOUT endangering the safety and ease of handling

Navigational Aspects (manoeuvrability of sailing vessel) & CFD-Simul. as basic update of ship handling simulators with fluid mud conditions

Investigations by the TUHH, Institute for Fluid Dynamics and Ship Theory on the force effect of fluid mud on ship hulls

- Extension of CFD models (Star CFD and OpenFoam) and consideration of the fluid mud parameters (implementation of the Shakeel / Chassagne model)
- Validation with "simplified" CUX-Sampler model within flumes and in-situ

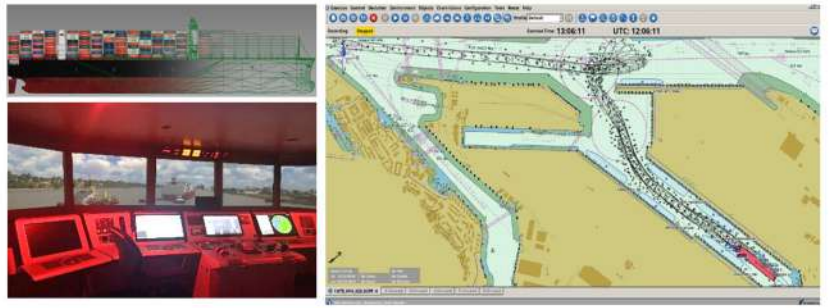
Validation and sensitive analysis of the CFD numerical model Here: Elevation of mud regarding different rudder angles and types



Determination of maneuver coefficients and behavior and verification in hydraulic-model test basin of BAW

Investigations by Federal Waterways Engineering and Research Institute (BAW) and Marine Training Center (MTC)

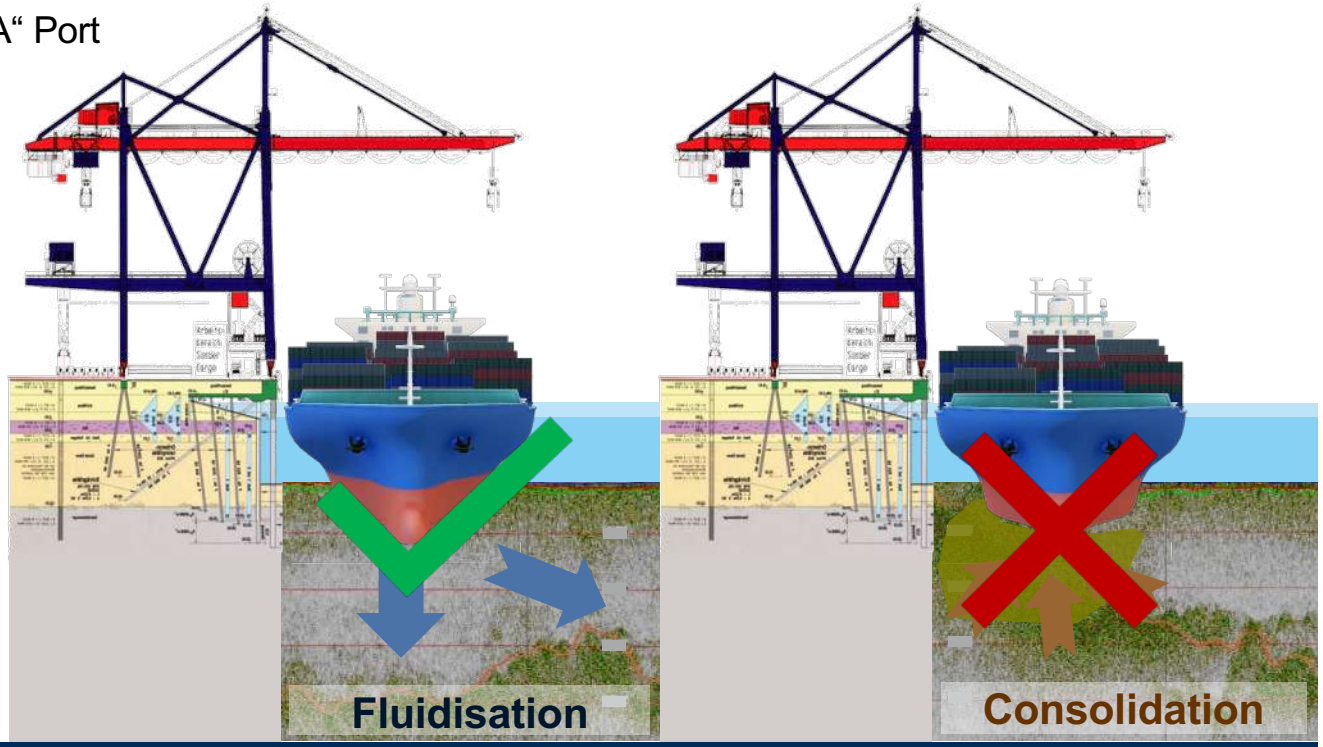
- Execution of maneuver runs as hydraulic-model test within the wave basin of BAW
- Extension and adaption of the ship handling simulator at Marine Training Centre - MTC



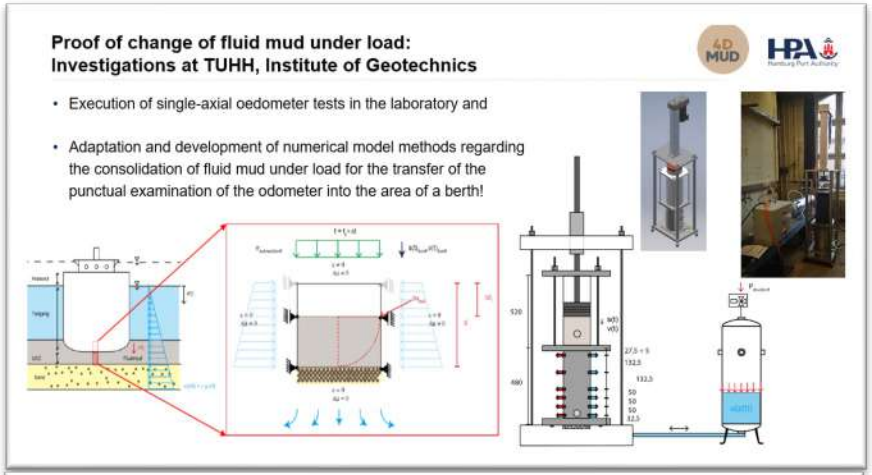
Objective: For a safe nautical bottom: Moored Vessels

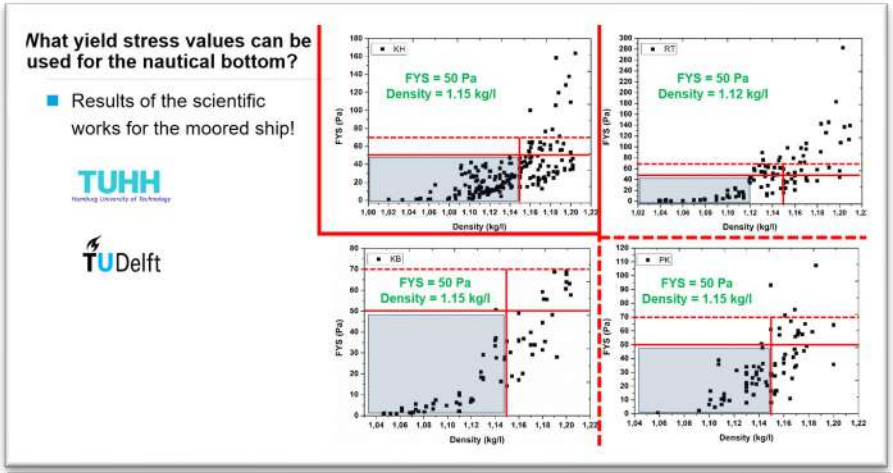
- Determination of limit values for "safe" penetration of ships in fluid mud layers during low water situations
- Results of initial interviews with stakeholders (BG Transport, Shipowners, Insurance):
  - Insurance status must be observed:
  - Hamburg should not become a “NAABSA“ Port (Not Always Afloat, But Safe Aground)
  - Hamburg has the status of a "Safe Port"

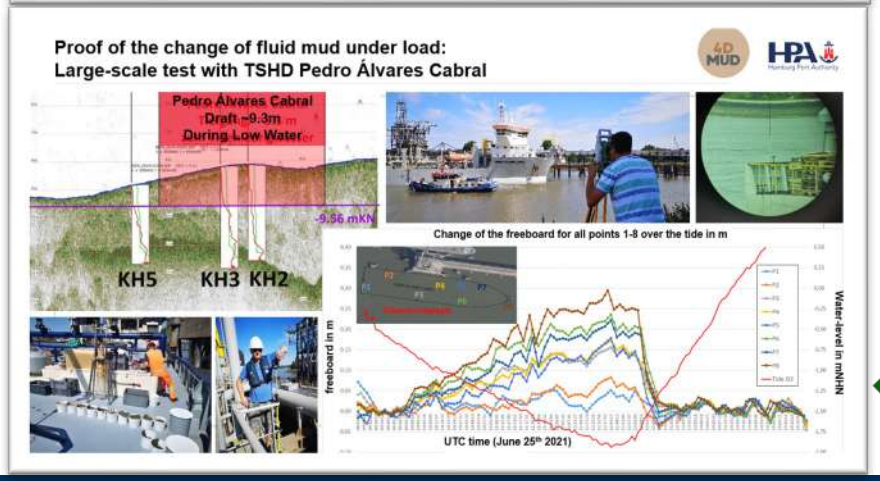
- For berths areas, this means: Ships have to swim all the times -> **The Archimedes Principle have to be observed!**
- The water cooling of ship machines have to be done via upper sea boxes!
- No other regulations known, which stand against the sinking of the ships in ground suspensions!

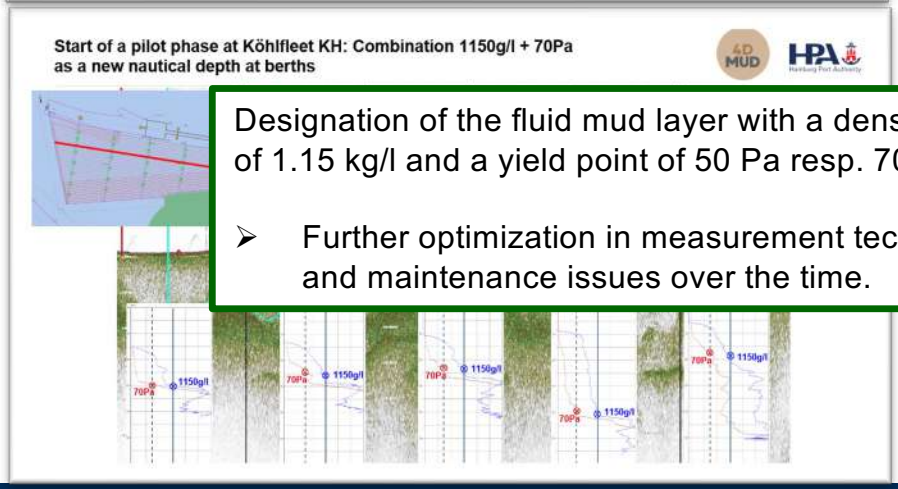


Investigations of safe nautical bottom of moored vessels in Hamburg









Work in the moment and Summary

04

Investigation of fluid mud for hydraulic model test

- February 2023
  - Investigation of the change and conditions over the time!
  - Sampling of mud on January 30th 2023

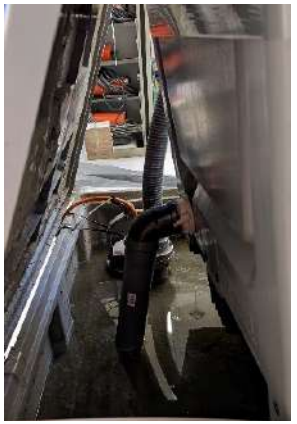
  - Box A: Fluid Mud without water undisturbed
    Box B: Fluid Mud with water overlay undisturbed
  - Box C: Fluid Mud without water disturbed after 7 days and mix-up
  - Box C#: Fluid Mud without water disturbed after 7 days and mix-up data start after mix-up

Investigation of fluid mud for hydraulic model test

- April 2023
  - Box D:
    Fluid Mud with
    water overlay

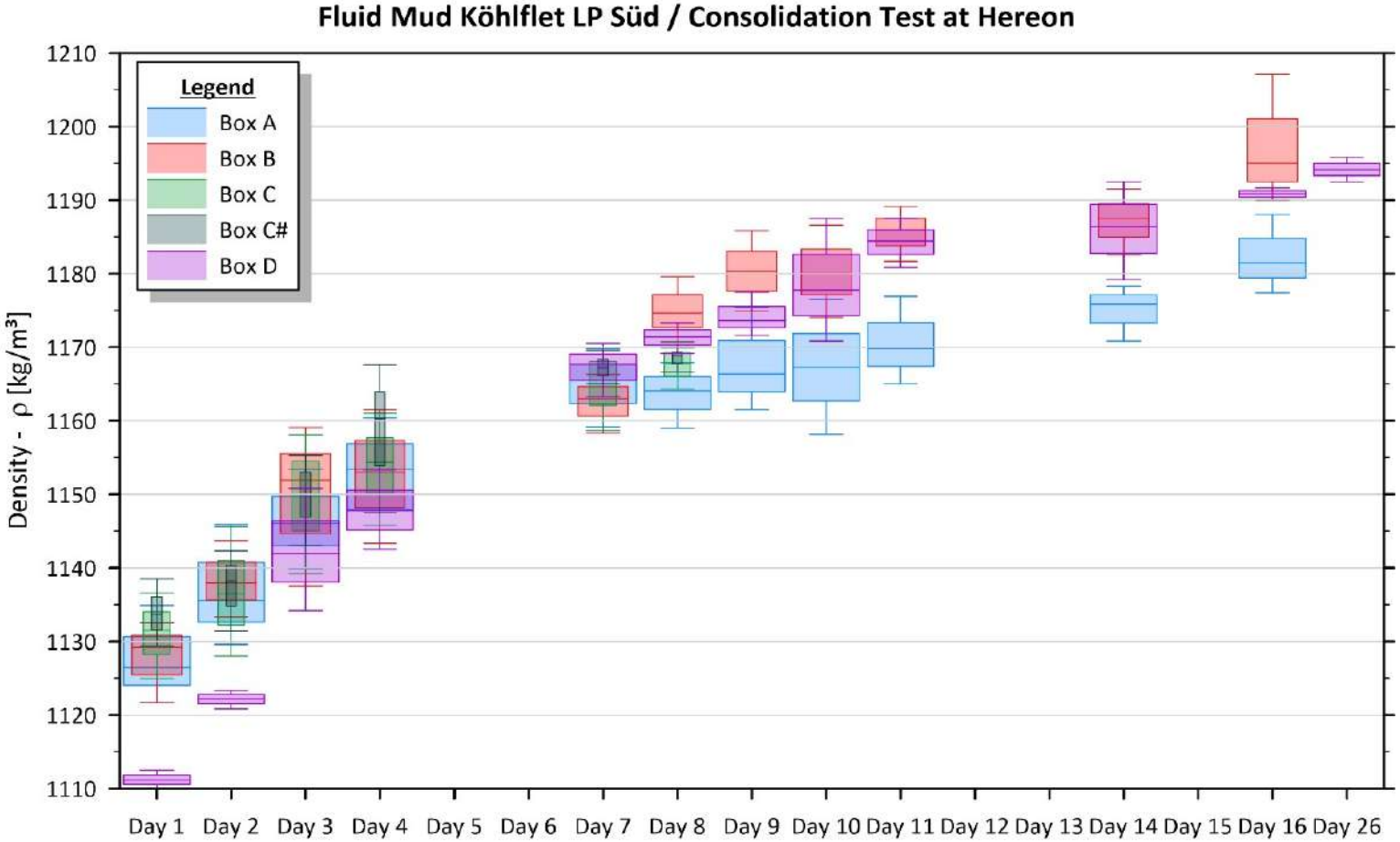
    and

    with sediment
    conditioning

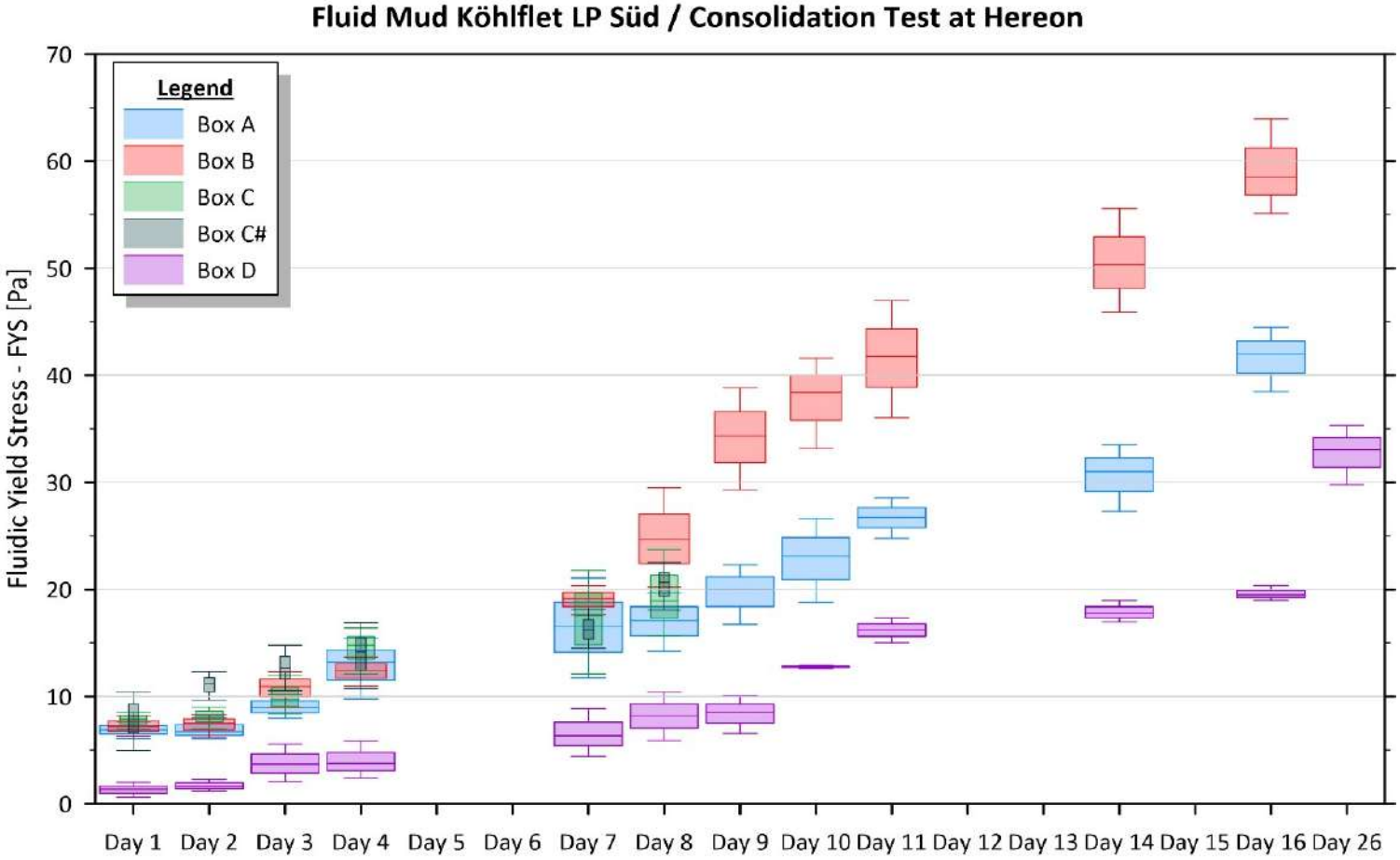




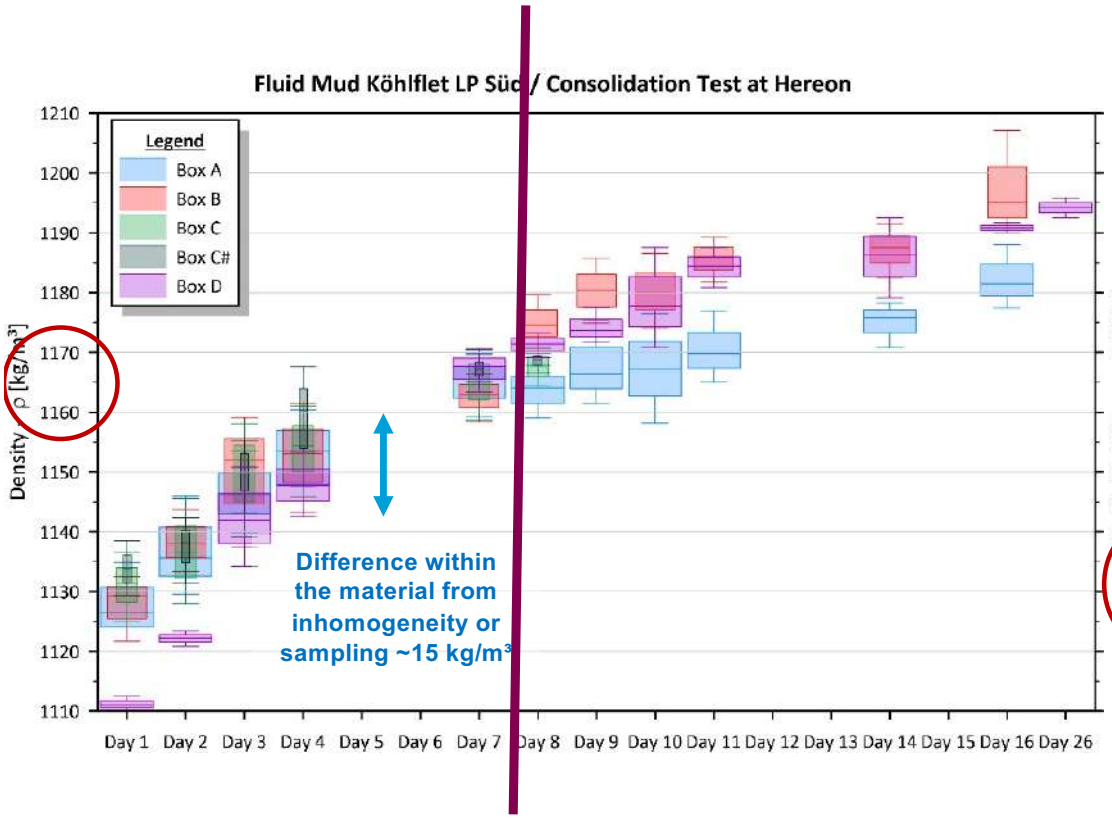
Work in the moment: Density results of all boxes

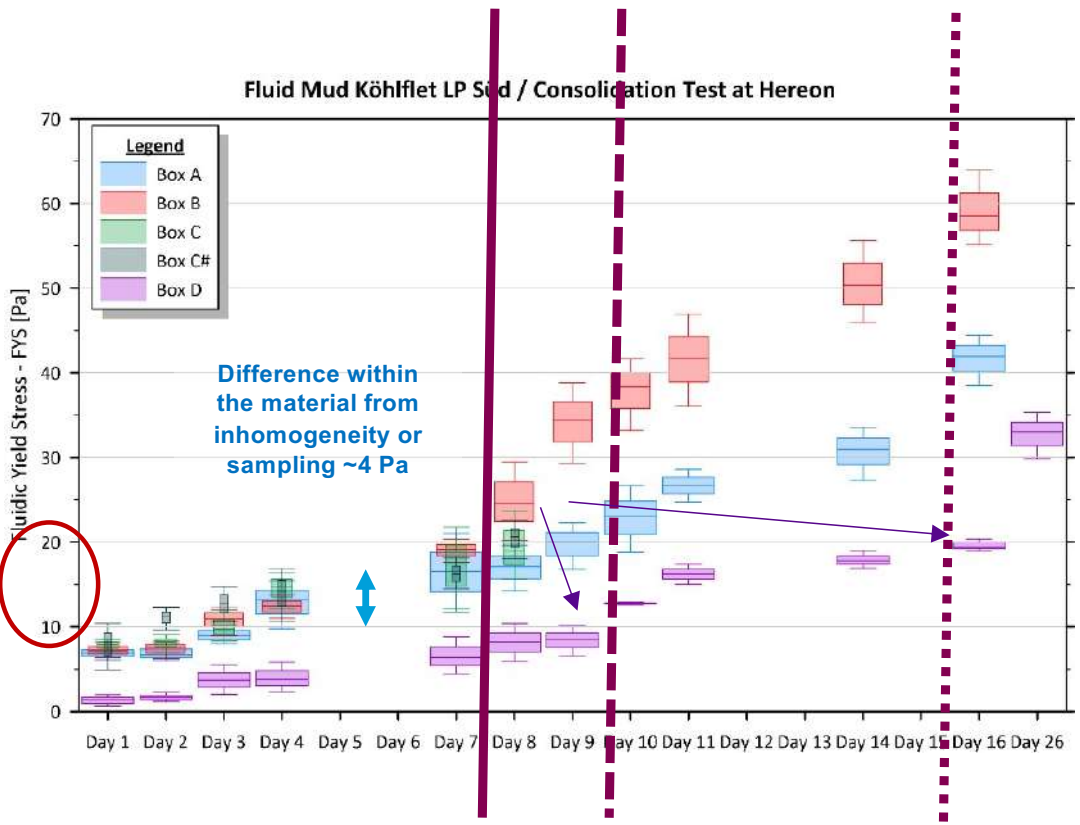


Work in the moment: Yield stress results of all boxes

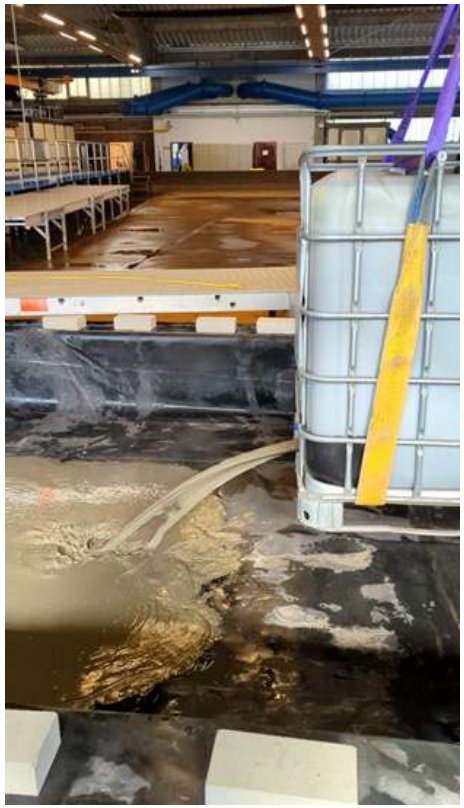


Yield point & density in comparision and as use in the hydraulic model

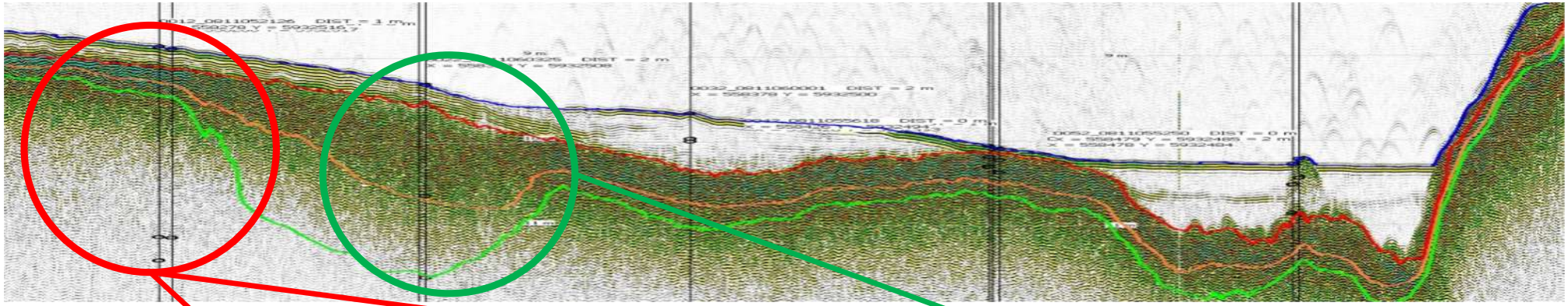




Work in the moment: Tests of propeller efficiency with model vessels



Limited use of hydro-acoustics due to gas in sediments and therefore further investigations of the “best” maintenance method (WID, BLD, RC)



Further investigations on gas formation and transfer to other berths in the harbour with silty/soft bottom structure

Gas inclusions in the subsoil

No gas and similar material

Summary

- Seasonal changes in the last 10 years have a close link to climate change over the last 30 years especially in summer discharge periods and tidal range changes
- ETM zone of Elbe estuary migrated upstream closer to Hamburg and SPM concentrations and dredging amounts increased as dissolved oxygen concentrations in summer decreased
- Organic matter and clay concentrations in suspended and non suspended sediment plays an important rule in the changed sediment characteristics
- Investigations for a safe nautical bottom of a sailing vessel through fluid mud are ongoing:
  - Comparison of hydraulic model tests and CFD-simulation are planed end 2023
  - Simulations with ship handling simulators and fluid mud conditions are planed end 2024
- Investigations for a safe nautical bottom of moored vessels are successful and a new nautical bottom approach is introduced in selected berths areas:
  - Further investigations on gas formation and optimization of maintenance strategies
  - Transfer of approach to other berths in the harbour with silty/soft bottom structure

Thank you for your attention!

MUDNET

HPA Hamburg Port Authority