Bundesanstalt für Wasserbau
Federal Waterways Engineering and Research Institute

Hydromorphological features of Estuaries

A very complex topic in short

www.baw.de

Harro Heyer

picture © Harro Heyer

Understanding Estuary Functioning in terms of Hydromorphology

- Hydromorphology – what is this?
- Key processes of German tidal estuaries
- Hydromorphological features (some examples)
- A simple method to make an assessment
- Summary and Perspectives

Definition

Hydromorphology

- deals with the structure, evolution, and dynamic morphology of hydrologic systems at nearly all spatial and temporal scales
- is driven by both natural and anthropogenic influences
- hydrologic systems are transformed by human activities that impact water use, land use, and climate (hydromorphologic response)
  - As a side effect uncertainty and nonstationarity is increased.
- can be regarded as a new field (a subfield of hydrology) and is closely related to numerous social sciences including geography, urban planning, and environmental economics

with regard to Richard M. Vogel, 2011

Definition

Tidal estuary in general

- is a most complex hydrologic system
- a coastal body of water with free connection to the open sea –
  sea water is measurably diluted with fresh water from river discharges
- physical processes play a major role:
  tidal range, advection and mixing, variation of friction to tidal flows
  due to water depths and bed roughness,
  salinity gradients in channel axis and transverse (varying density fields)
  stratification and gravitational circulation, net flow pattern,
  SPM (suspended particulate matter) concentrations, turbidity zone,
  mass transport of mainly suspended load,
  net-transport direction, tidal pumping phenomena, …

European estuaries

- Waterborne transport is very important.
  Sea going vessels are still growing in size, draught and width.
- EC Guidance on the implementation of the EU nature legislation in estuaries and coastal zones (citation):
  - *… it is important to understand how such complex ecosystems function, how they evolve "morphologically" and how they may be influenced by anthropological pressures and climate change.*
  - *The balance between the different components (physical, chemical, biological and hydro morphological) … is very complex and can be easily affected by human activities such as port related activities, agriculture or flood alleviation measures.*
- Estuaries are ecosystems comprised of a number of different habitats.
- Above physical and ecological properties they are also social systems.

Perspectives of the German tidal estuaries

What are the main topics and

key processes of the tidal estuaries

Weser, Elbe and Ems?

put together next slide.

Hydromorphology

hydrology geology
hydrography geomorphology
hydrodynamics

morphodynamics
erosion
material transport
deposition

transport of fines -
substrate

in equilibrium ?

Habitats

Tidal Estuary

asymmetries
residual tidal processes
long term development

regime shift

maintenance dredging

Core questions

What are hydromorphological features of the estuaries?

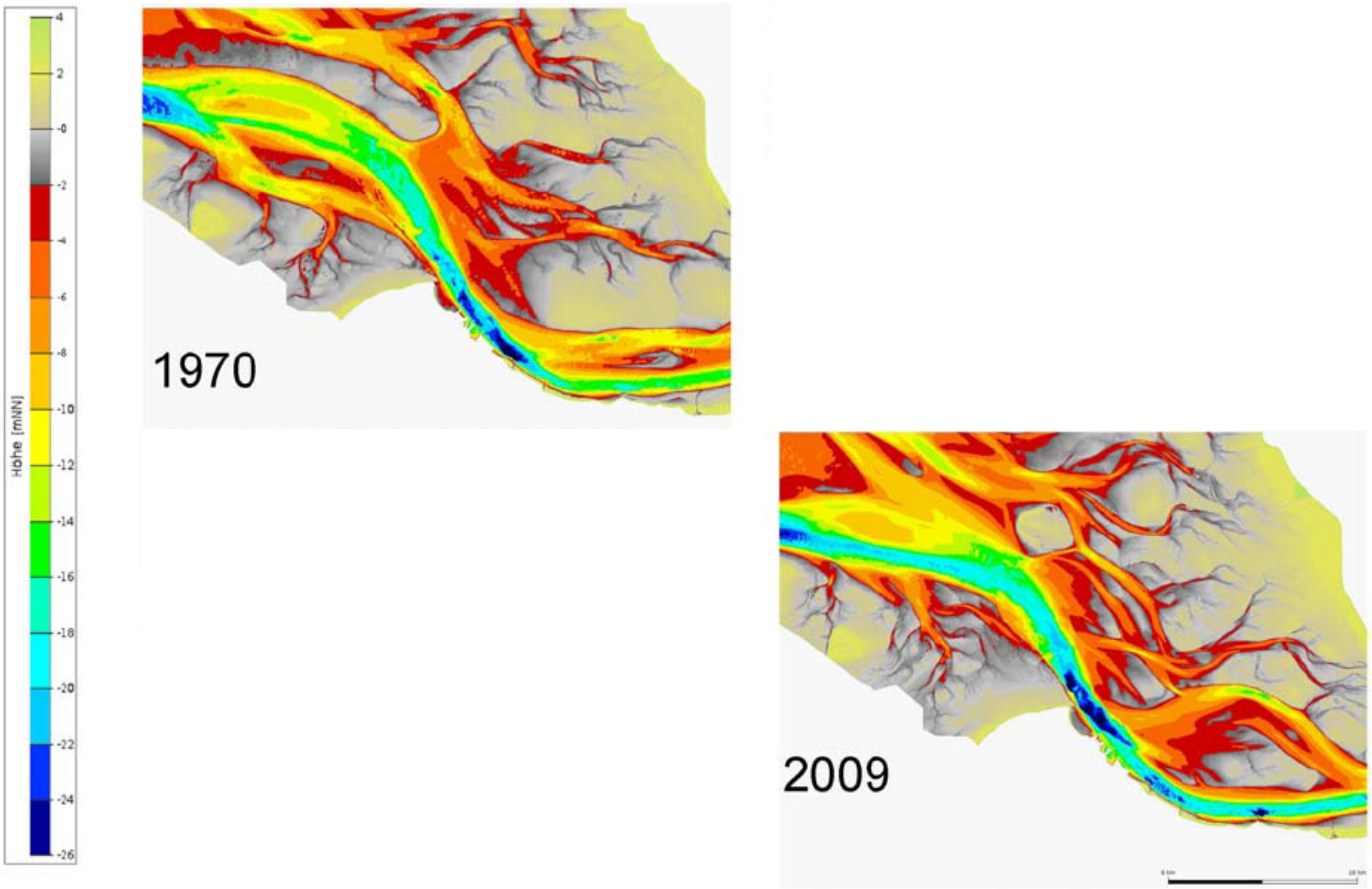
- structure
- evolution
- dynamic morphology

<u>Structure</u>: form elements of the system like
length, width, depth, hypsometry, variation of cross sections along axis, ….

<u>Evolution</u>: great information summarized in TIDE Project

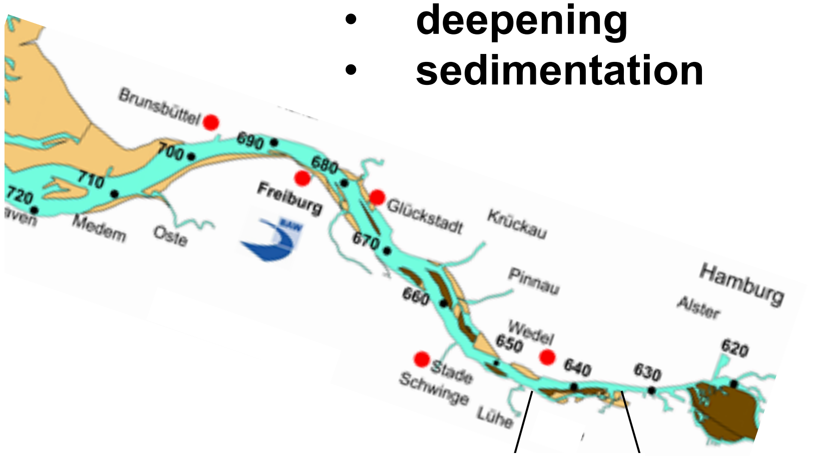
<u>Dynamic morphology</u>: e.g. channel migration, sedimentation on flats, ….

Example mouth of Elbe Estuary – dynamic morphology

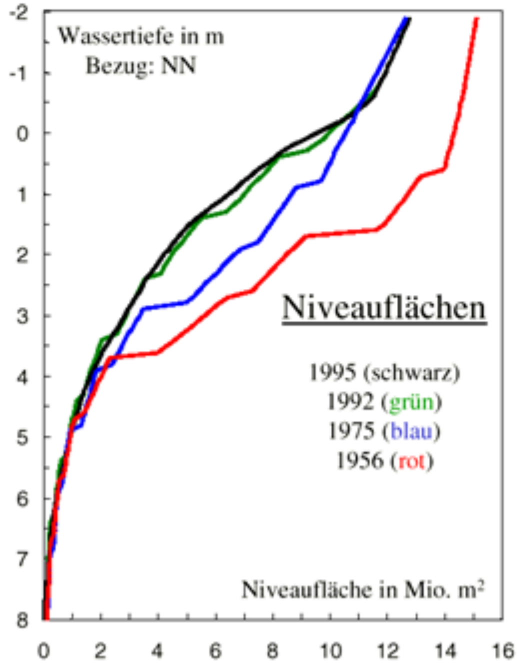


Example section of Elbe Estuary

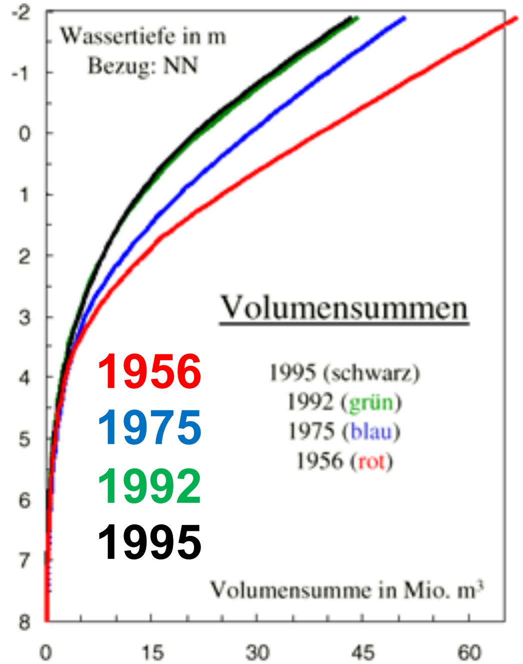
- hypsometry
- deepening
- sedimentation

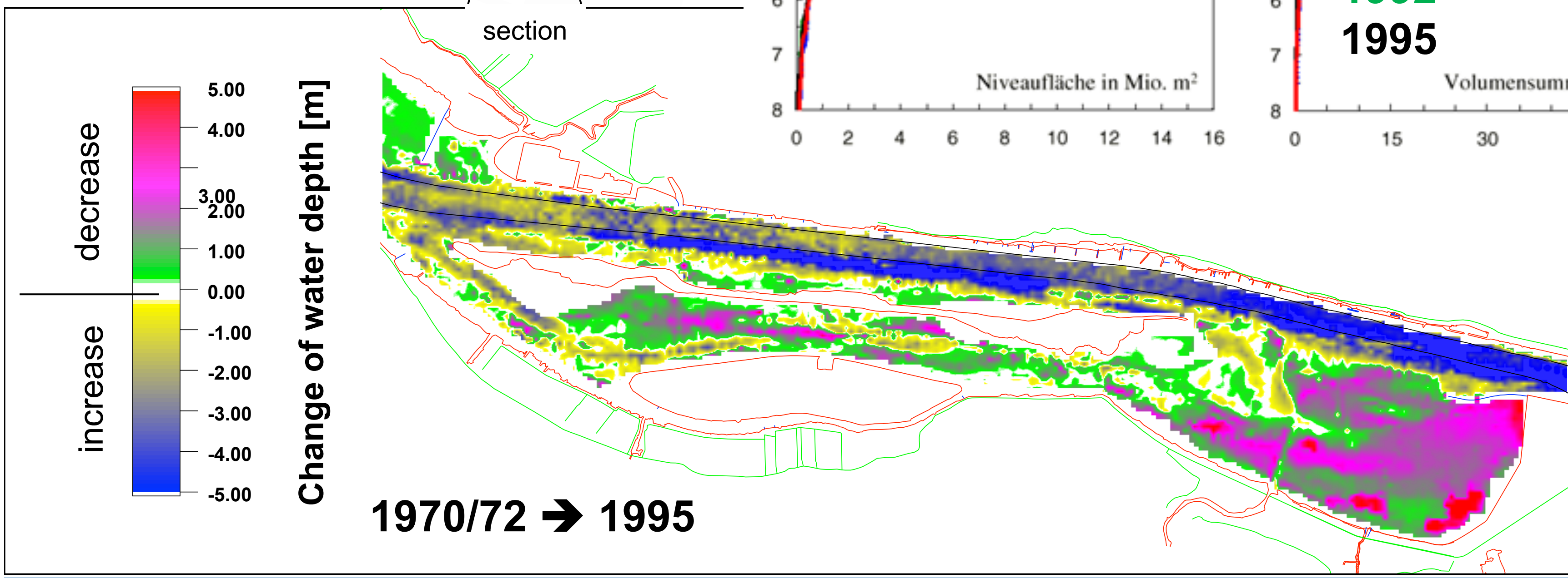


surface area



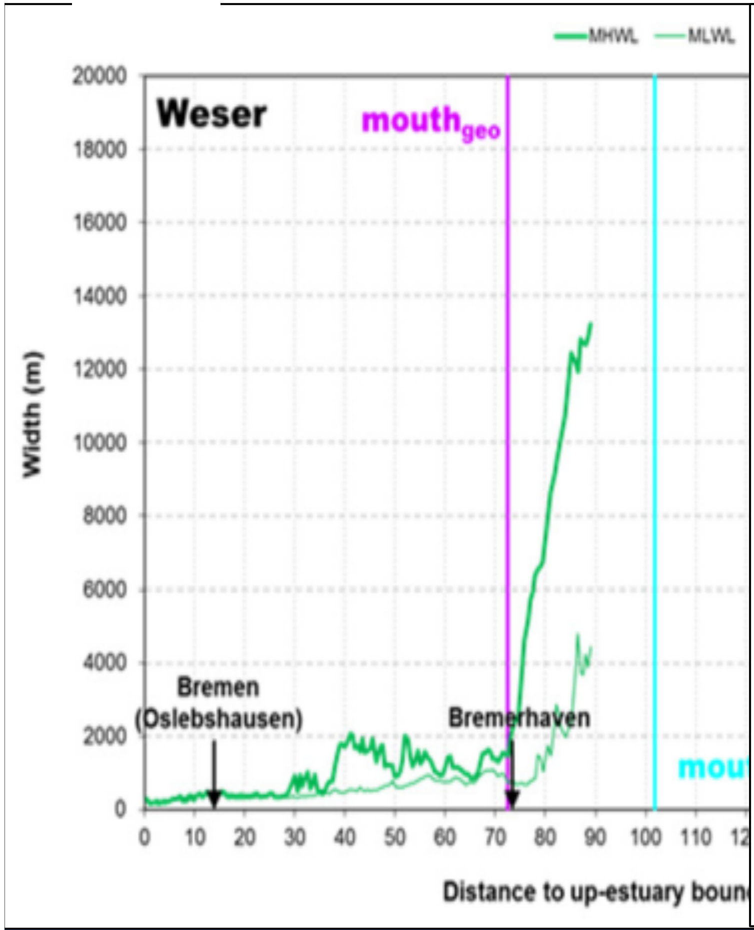
water volume

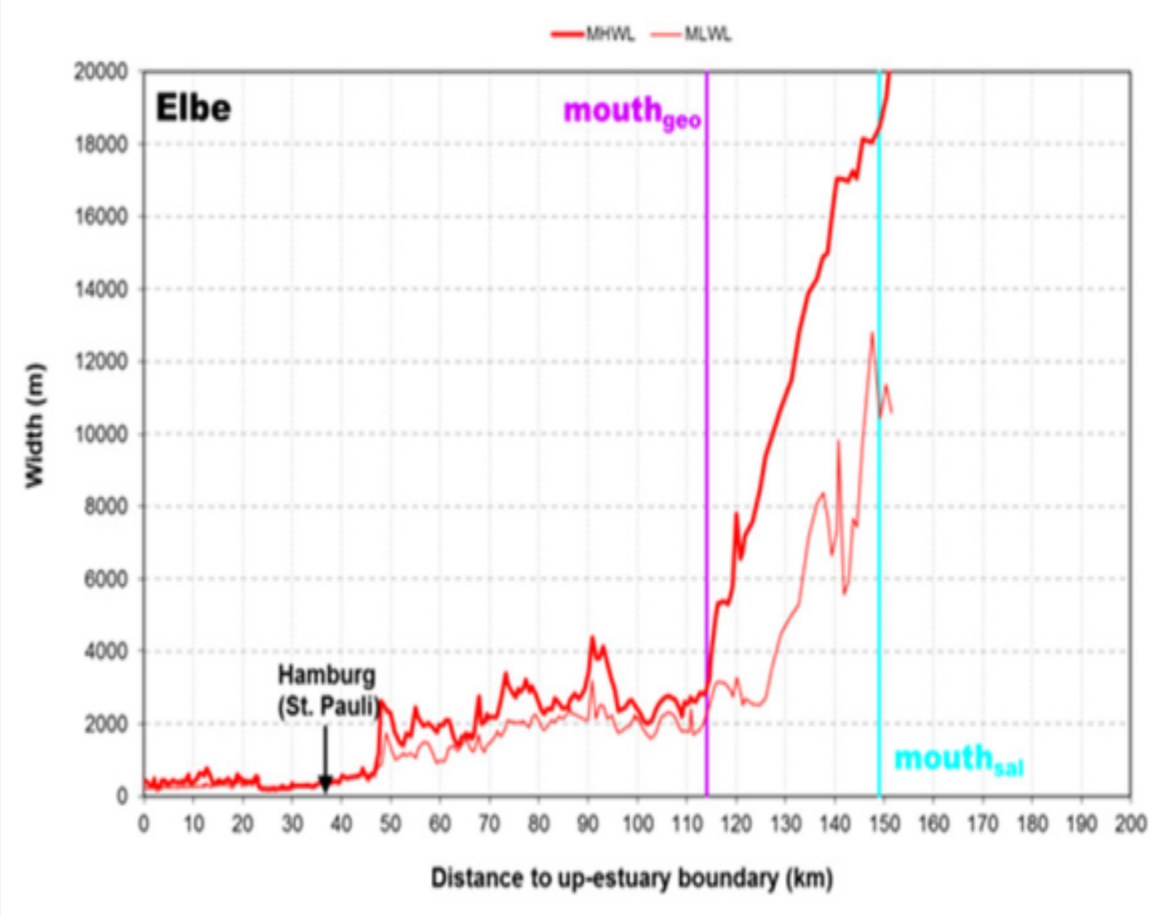




Width of water surface at MHWL and MLWL

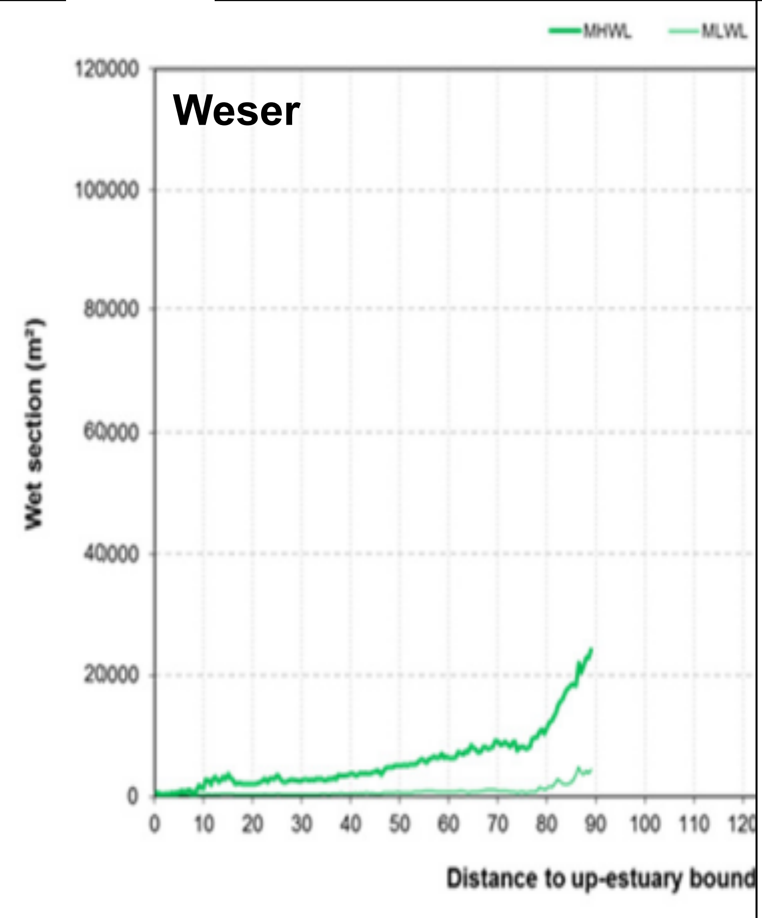
Vandenbruwaene, W.; Plancke, Y.; Verwaest,T.; Mostaert, F. (2013).

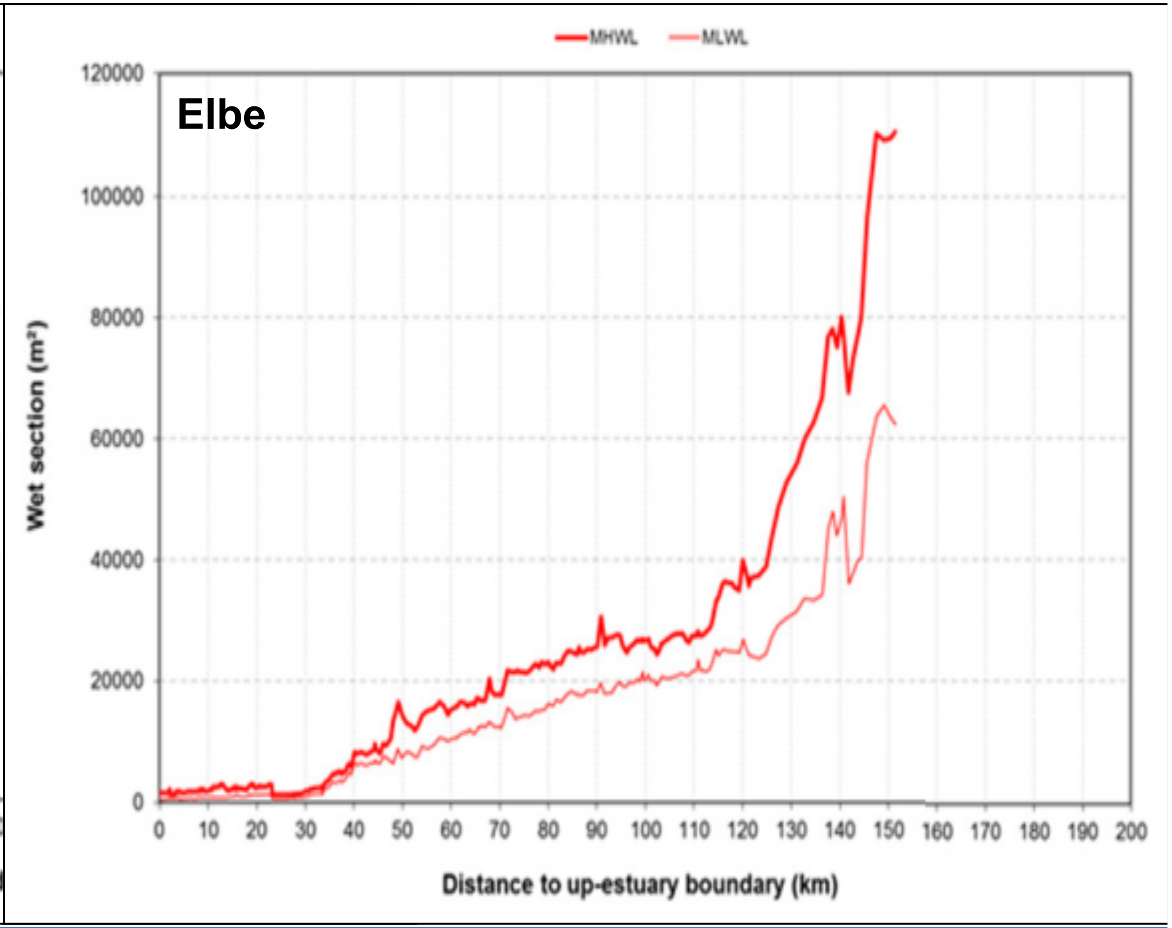




Wet cross section area at MHWL and MLWL

Vandenbruwaene, W.; Plancke, Y.; Verwaest,T.; Mostaert, F. (2013).





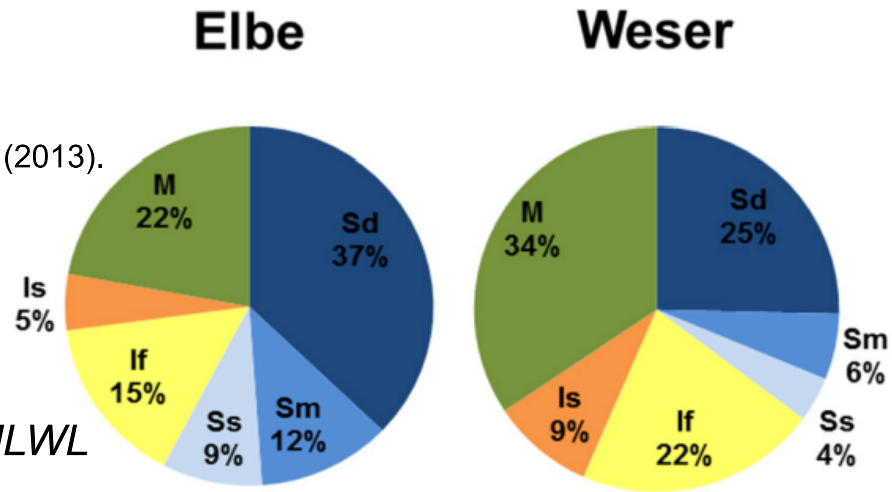
Core questions

How to define habitats of estuaries?

Approach of TIDE

Vandenbruwaene, W.; Plancke, Y.; Verwaest,T.; Mostaert, F. (2013).

Relative presentation of habitat areas (percentages)



Sd - Subtidal deep > 5 m below MLWL
Sm - Subtidal moderately deep 5 – 2 m below MLWL
Ss - Subtidal shallow 2 m below MLWL – MLWL
If - Intertidal flat MLWL – MHWL; slope < 2.5%
Is - Intertidal steep MLWL – MHWL; slope > 2.5%
M - Marsh > MHWL

The importance of substrate and dynamic morphology for habitats:
the sediment composition defines

- bedforms, hydraulic drag and
- living conditions for plants and animals

Core questions

What are morphological features of estuarine dynamic equilibrium ?

- Balance in the distribution and surface area of all habitats.
  ➔ e.g. more intertidal areas are needed for a deeper channel
- Balance between up- and downstream net sediment transport masses.
- Balance between the forcing of the flood and ebb dominated processes.

How to assess the balance or imbalance of such processes?

- 1st asses first order forcing during ebb and flood phases
  ➔ simple comparison: tidal dynamics of Weser, Elbe, Ems (next slides)
- 2nd look at the grain size distribution of the sediments
- 3rd asses the net SPM transport over cross sections during normal cond.

1st asses first order forcing during ebb and flood phases

momentum equation	
$u_t + A = - F + D$	*A - advection* *D - dissipation* *F - forcing (pressure gradients)*

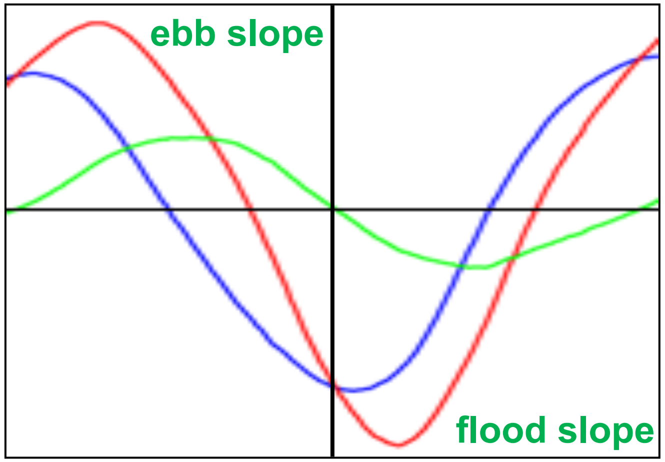
First order forcing of Weser, Elbe and Ems is the tidally induced variable water level gradient within the tidal cycle (slope of the tidal wave).

We compute water level slope in cm per km for outer and inner part of each estuary on the basis of measured tidal curves during calm wind conditions.

Curves

gauge downstream
gauge upstream

water level difference divided by distance of the gauges in km

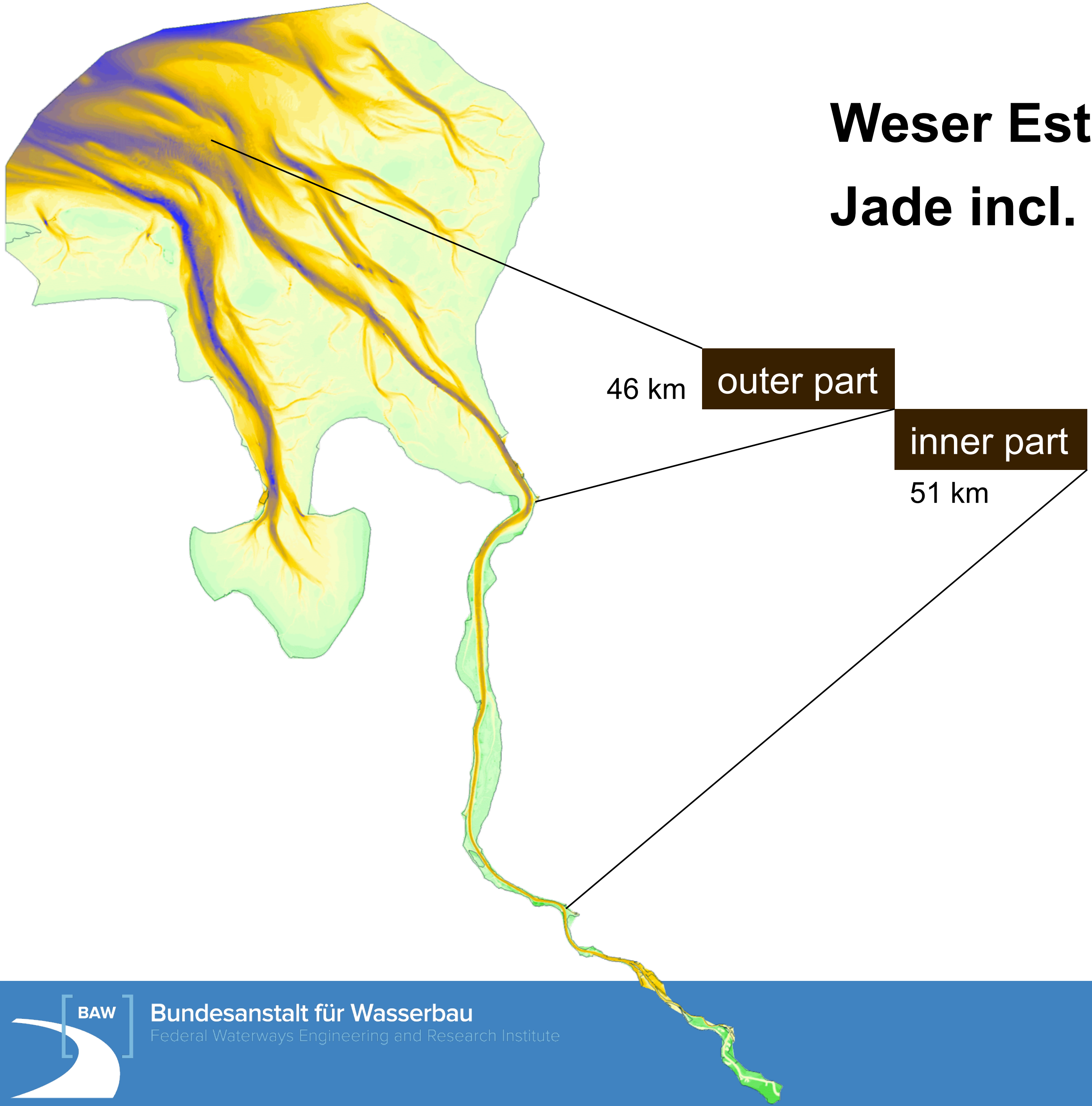


sketch to understand the Following graphs

ebb slope > flood slope

We compare max. values

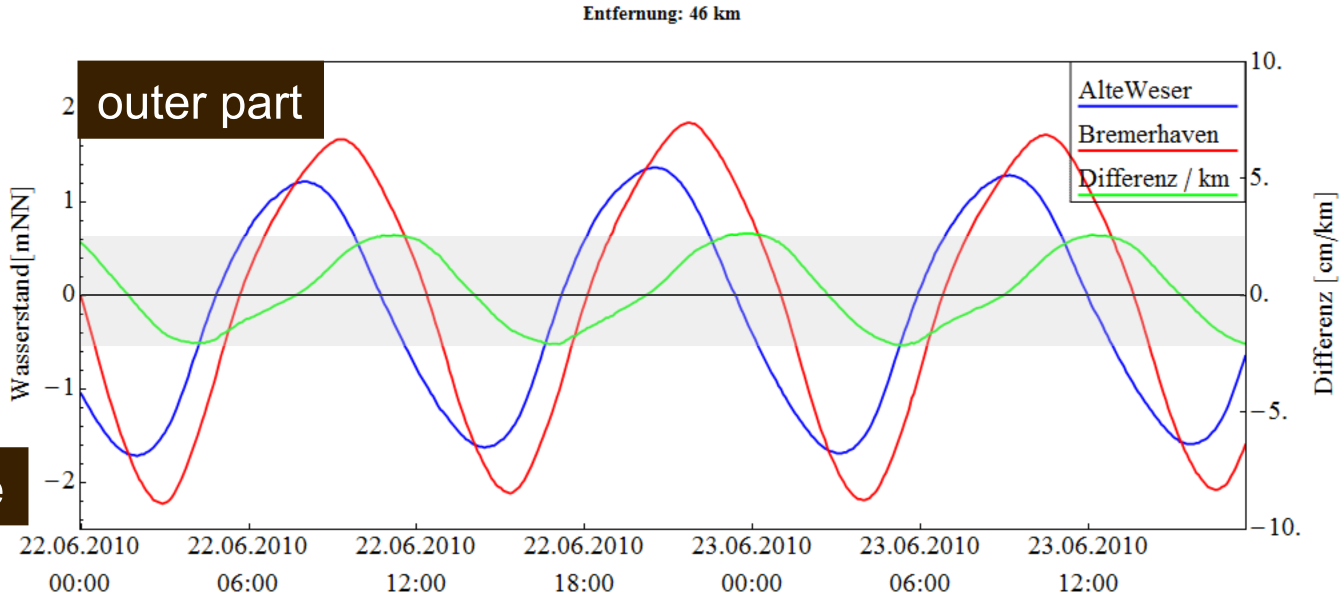
Weser Estuary
Jade incl.

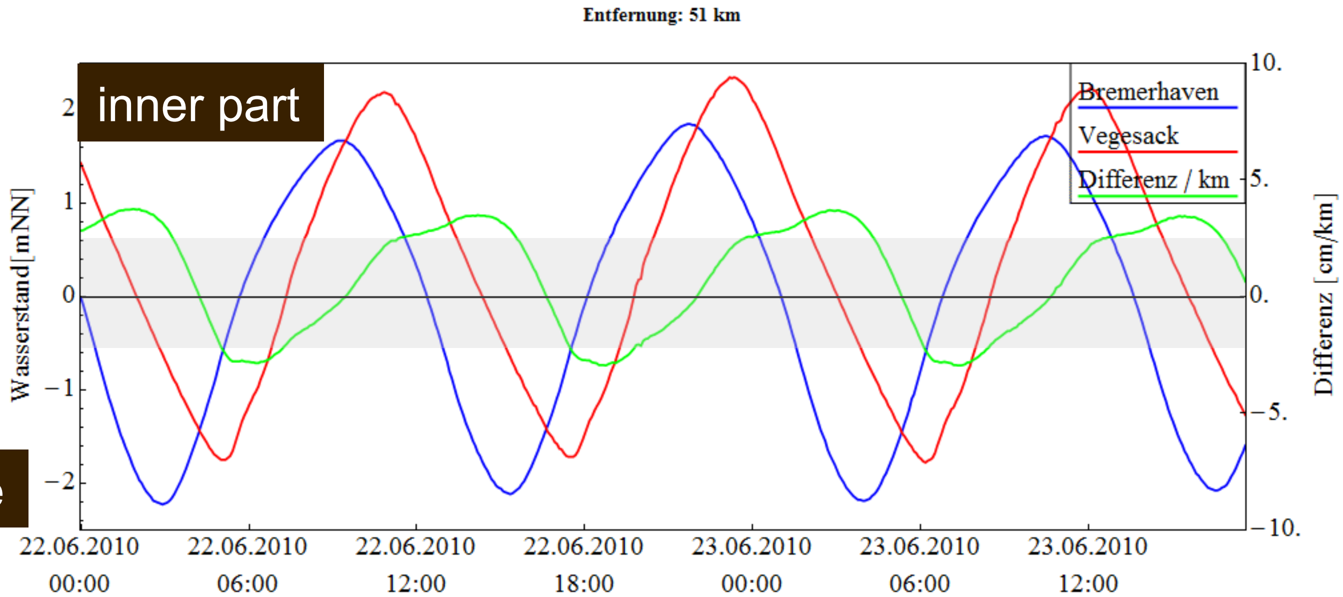


Weser

The gray band in this graph is unaltered shown for comparison in next graphs.

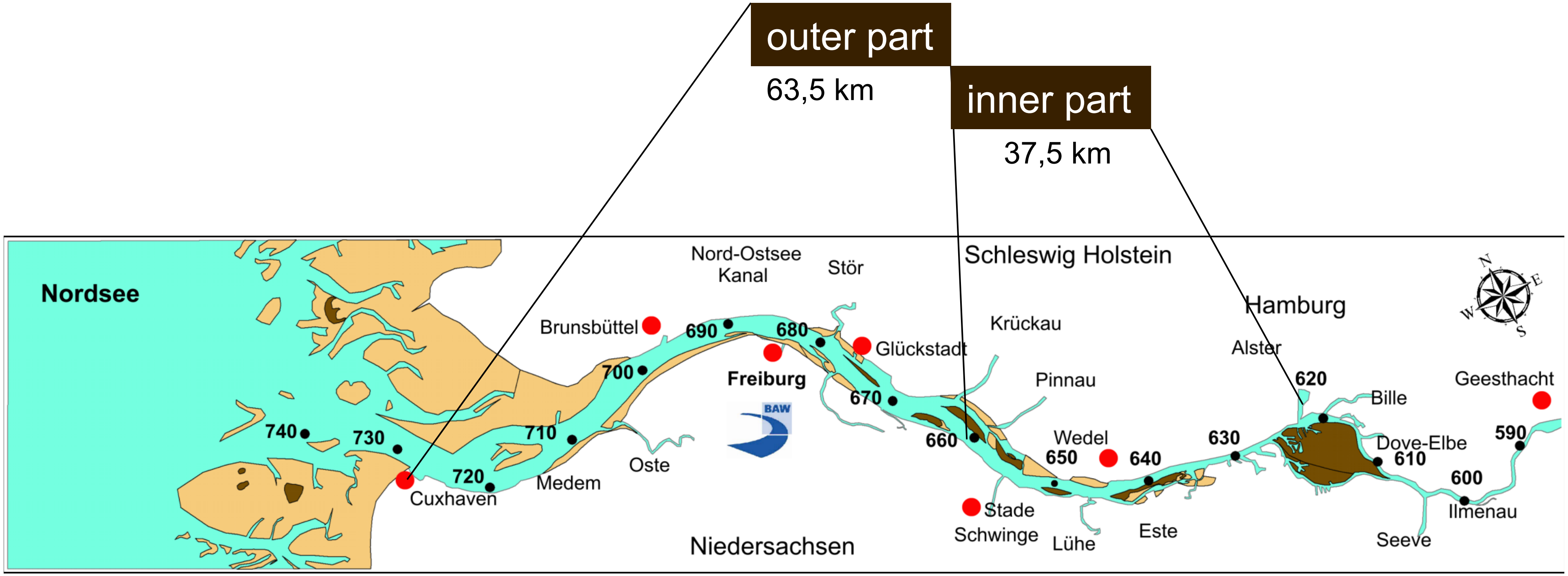
ebb slope > flood slope



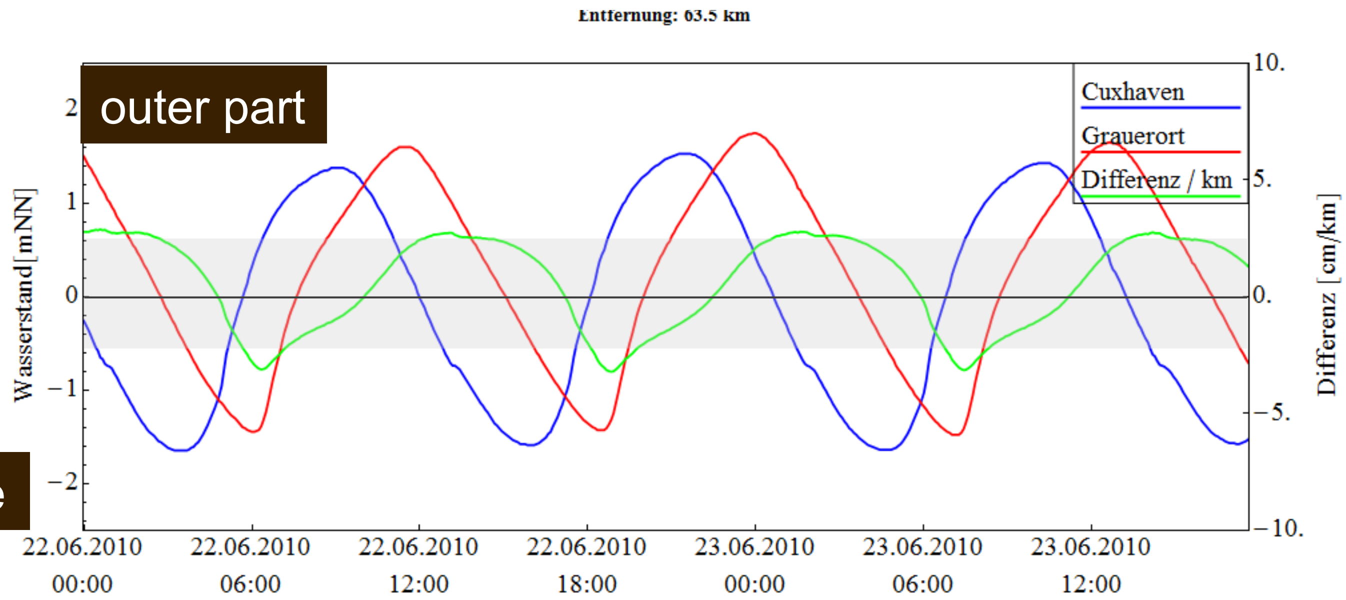


ebb slope > flood slope

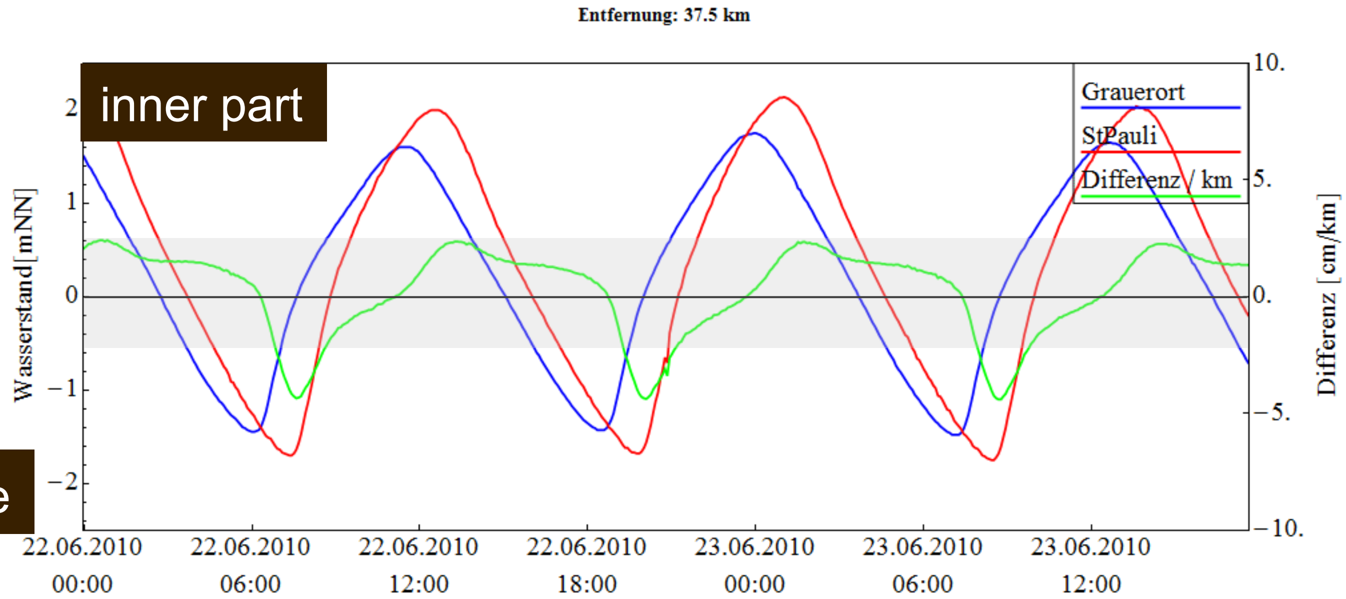
Elbe Estuary



Elbe



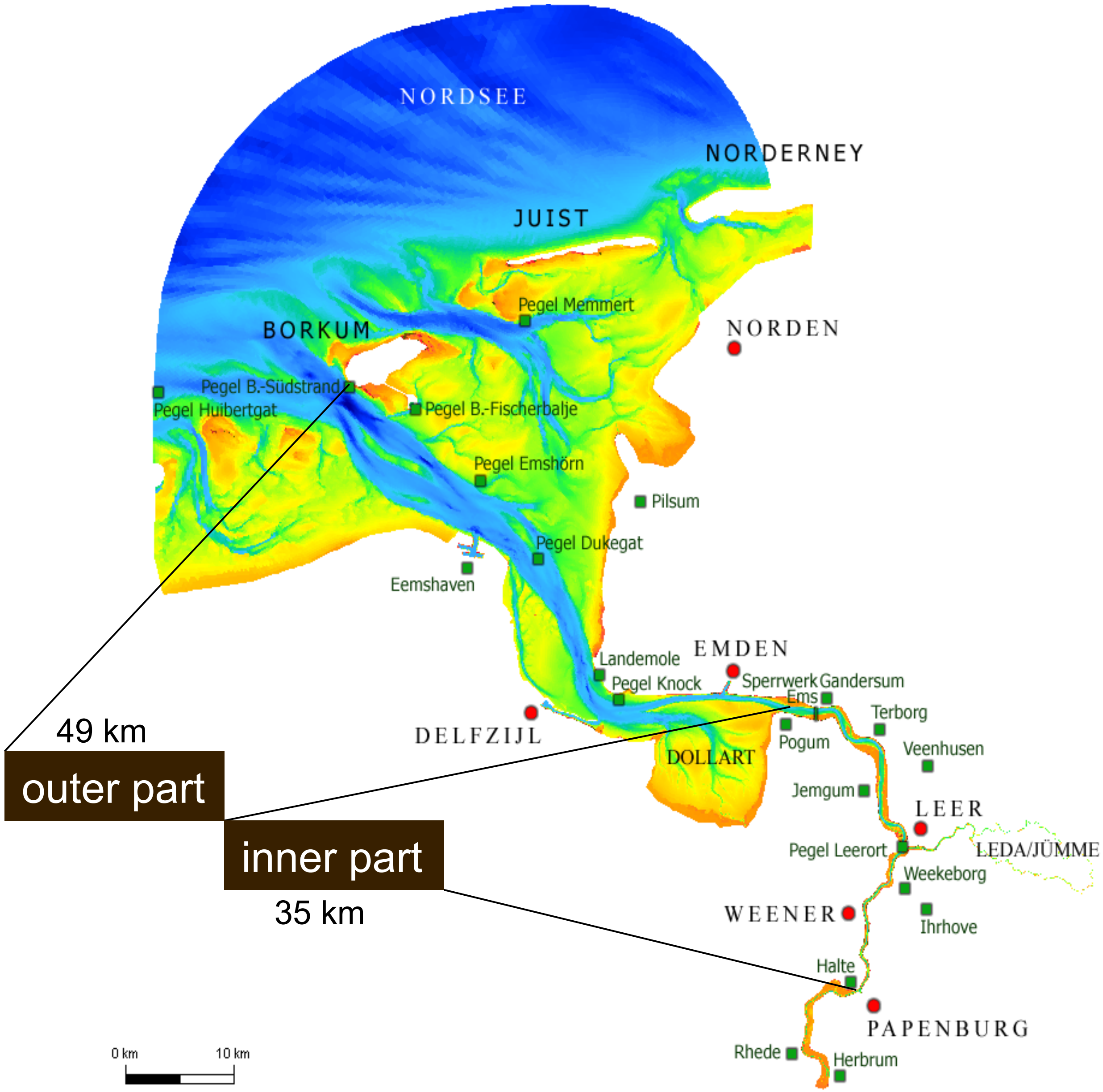
ebb slope ≤ flood slope



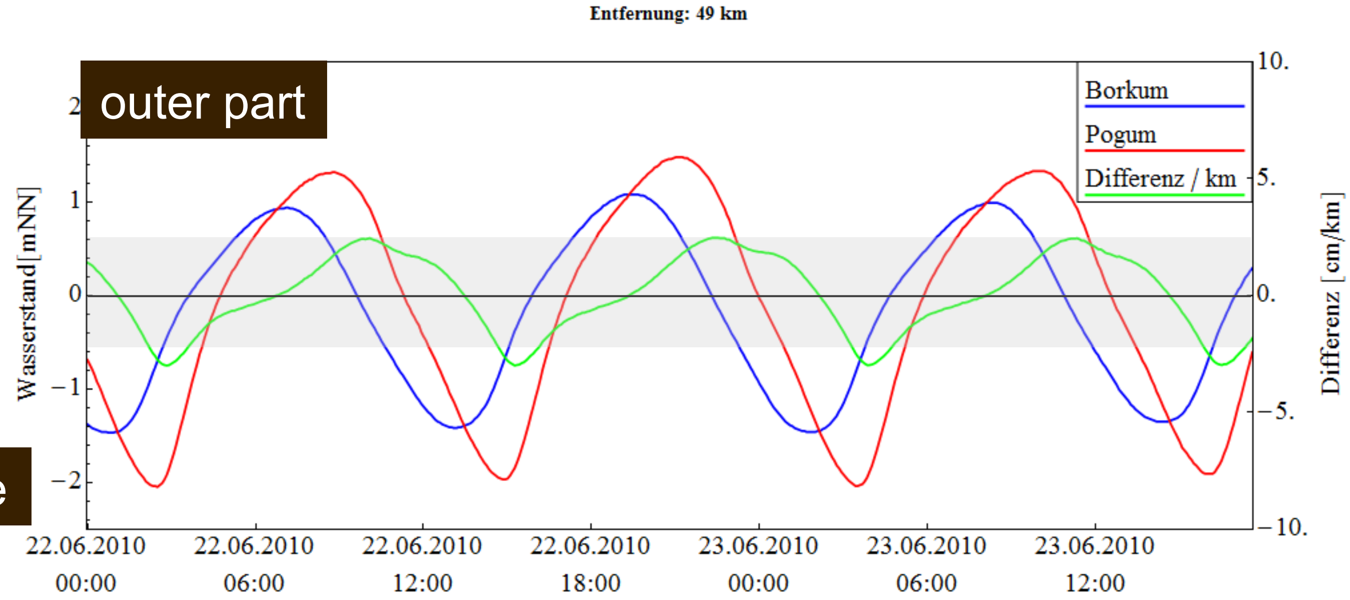
!

ebb slope < flood slope

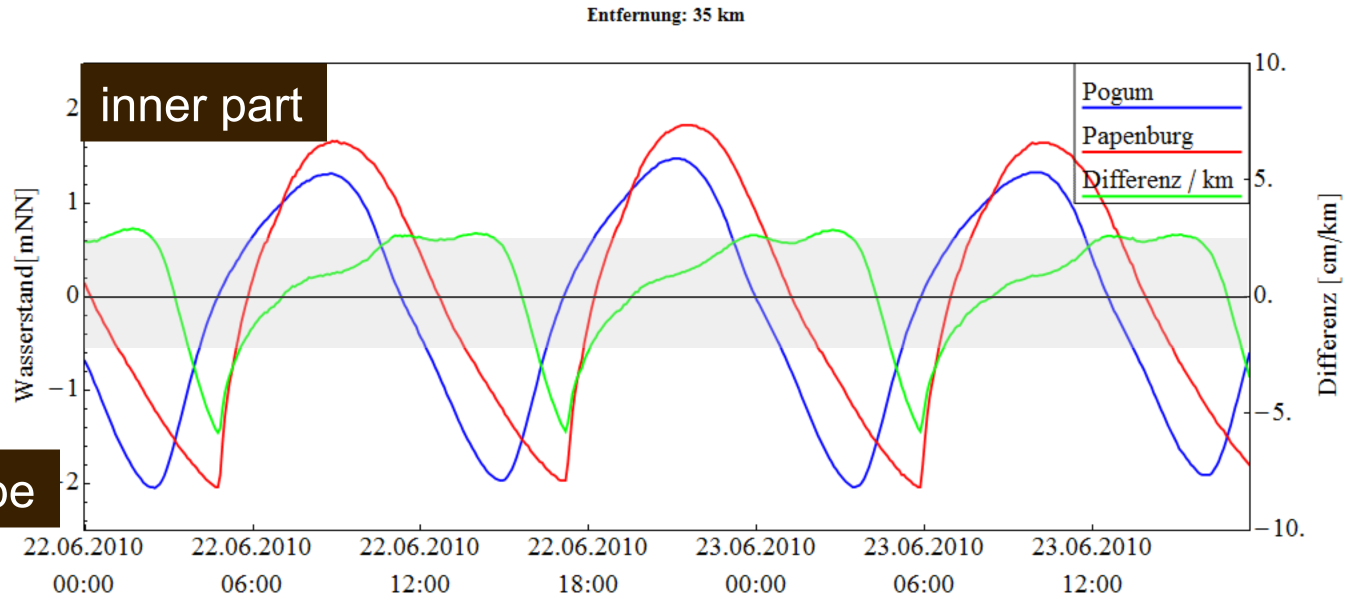
Ems Estuary


NORDSEE
NORDERNEY
JUIST
BORKUM
NORDEN
Pegel Memmert
Pegel B.-Südstrand
Pegel Huibertgat
Pegel B.-Fischerbalje
Pegel Emshörn
Pilsum
Pegel Dukegat
Eemshaven
EMDEN
Landemole
Pegel Knock
Sperrwerk Gandersum
Ems
DELFZIJL
DOLLART
Pogum
Terborg
Veenhusen
Jemgum
LEER
LEDA/JÜMME
Pegel Leerort
Weekeborg
WEENER
Ihrhove
Halte
PAPENBURG
Rhede
Herbrum
49 km
outer part
inner part
35 km
0 km
10 km

Ems



ebb slope < flood slope



! !

ebb slope << flood slope

Summary of findings

Comparison of max. water level gradients (slope of water level)

- ebb slopes of outer and inner parts of the Elbe and Ems are roughly the same compared to ebb slopes of outer Weser Estuary.
- **Weser is mainly ebb dominant** because of larger ebb slope in inner part
- **Elbe is (often) flood dominant** – larger flood slope in inner part
- **Ems is extremely flood dominant** – much larger flood slope in inner part

This result is congruent to residual transport pattern in the estuaries, the reason for maintenance dredging of fine material in upper parts.

Of course residual transport is in second order dependent on river discharges and gravitational circulation (see next slide).

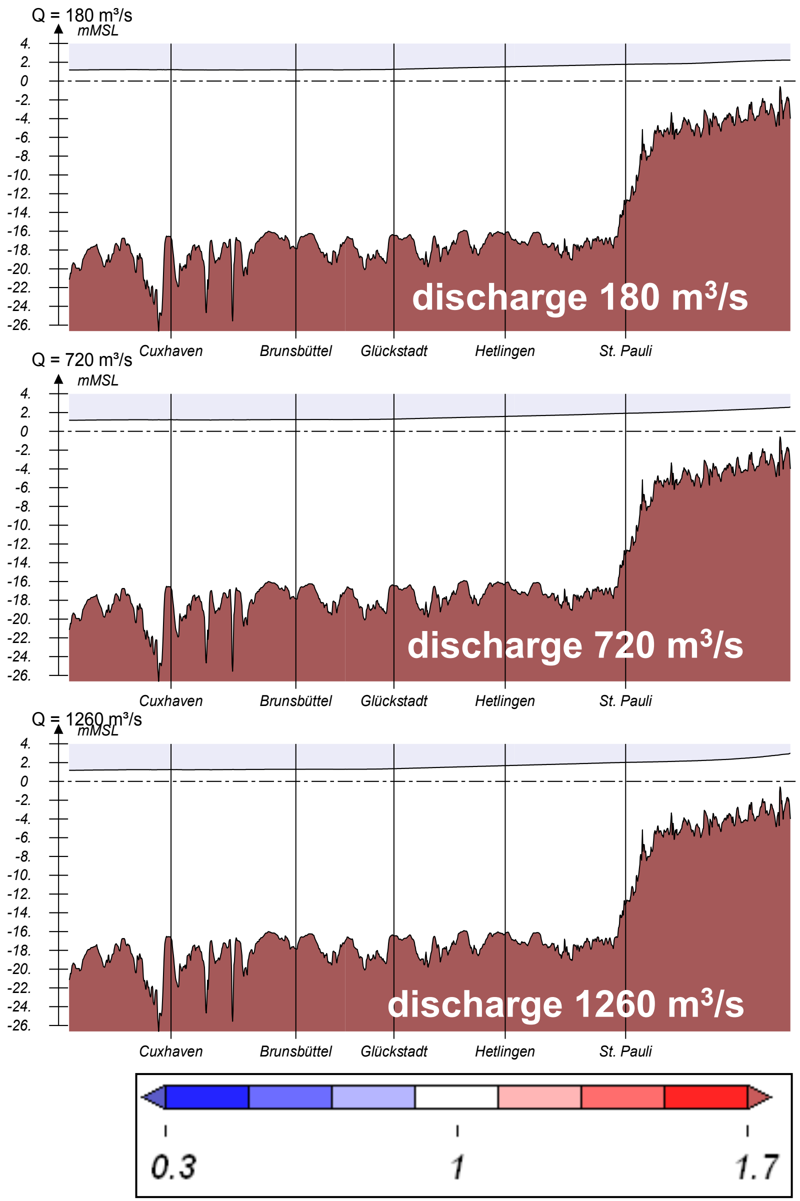
Modulation of residual SPM transport by river discharge

Example Elbe Estuary

longitudinal profile (3D model result)
ratio of flood to ebb transport [-]

upstream transport

downstream transport



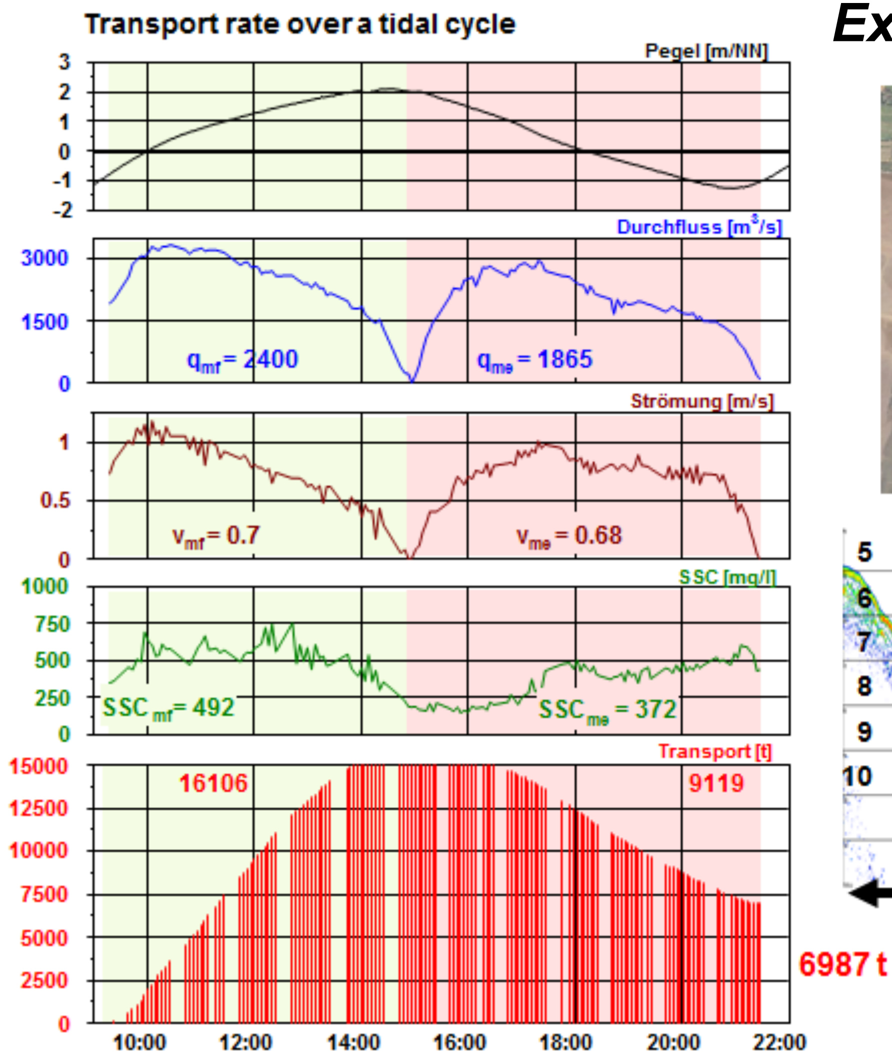
2nd look at the grain size distribution of the sediments

1. With enough fine material in the estuary a flood dominant system can pump it into shallows and flats (import of material). Hydromorphologic response: Reduced tidal volume in shallows and flats can enhance the flood dominance.
2. In a very flood dominant system with huge fine material the turbidity zone can spread over the whole section of inner estuary part. Hydromorphologic response: formation of fluid mud layers.
3. Bed roughness is reduced by fluid mud layer leading to increased flood dominance.

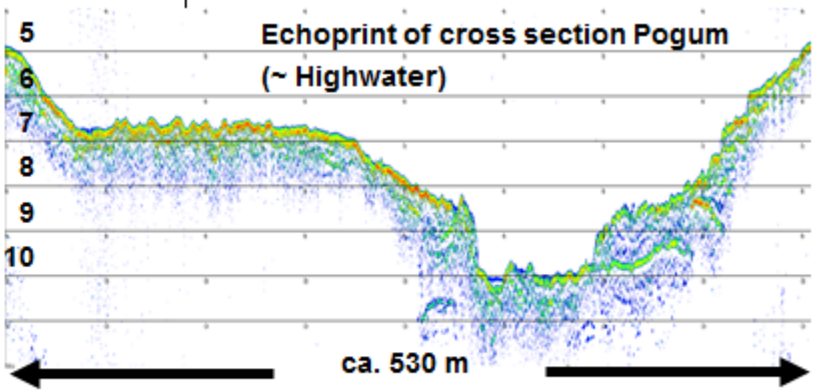
These are creeping self-reinforcing processes.

Consequences for habitat degradation are possible.

3rd asses the net SPM transport over cross sections



Example: Field study Ems Estuary



6987 to net upstream

Summary

We know that estuarine hydromorphology is very complex.

We have to assess the impact of many parameters and of various time dependent processes, e.g.:

- geometry of the system (for characteristic water levels)
- tidal forcing – nonlinear effects - tidal asymmetry
- discharge – flushing effects
- salt intrusion - density effects - gravitational circulation
- SPM transport – residuals – loss of intertidal volume
- sediment properties – substrate – habitats

We understand hydromorphology as a very important scientific field, esp. regarding estuaries.

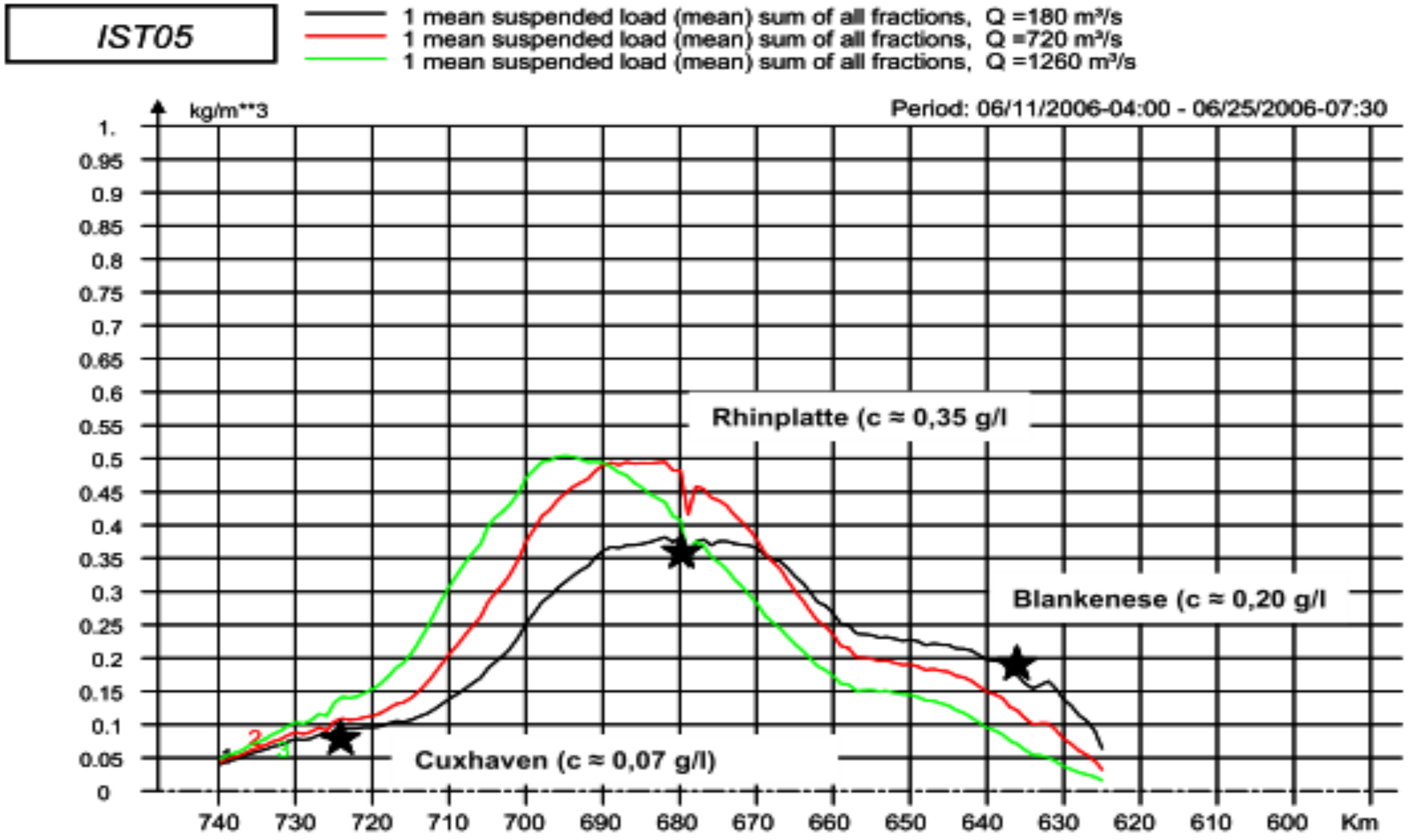
We need a profound scientific basis for healthy estuaries in future.


Thank you for listening
Elbe beach km 640 - loss of sand
picture Harro Heyer

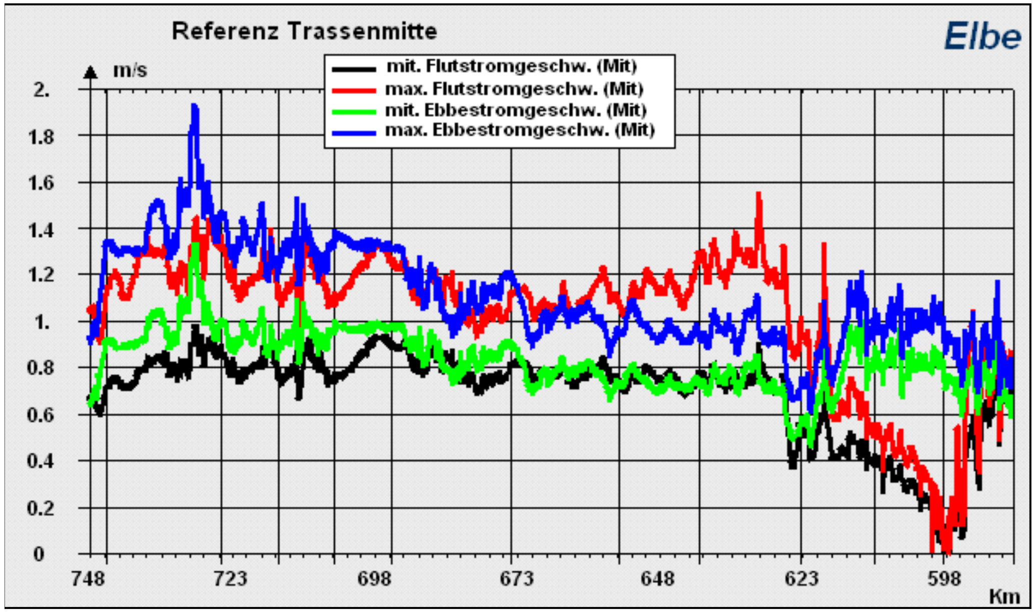
Hydromorphology   Editorial by Richard M. Vogel
JOURNAL OF WATER RESOURCES PLANNING AND MANAGEMENT
ASCE / MARCH/APRIL 2011

GUIDELINES ON THE IMPLEMENTATION OF THE BIRDS AND HABITATS DIRECTIVES IN ESTUARIES AND COASTAL ZONES with particular attention to port development and dredging
European Commission, January 2011

Vandenbruwaene, W.; Plancke, Y.; Verwaest,T.; Mostaert, F. (2013).
Interestuarine comparison: Hydro-geomorphology: Hydro- and geomorphodynamics of the TIDE estuaries Scheldt, Elbe, Weser and Humber.
Version 4. WL Rapporten, 770_62b. Flanders Hydraulics Research: Antwerp, Belgium.



Mean computed SPM concentration for Q = 180/720/1260 m³/s.
Comparable values from measurements are indicated.



Mean an max Tidal currents

Each estuary has it´s own characteristic