The Tidal Elbe
Natural Development
Sediment Management (Physical Basics)
Climate Change
1. German tidal areas (focus on Tidal Elbe)
2. How-to estimate development of the estuary?
3. Tools for optimization of estuary systems
4. Asymmetry – A physical process based view
5. Minimize effects of fairway deepening
6. Climate Change – Sediment dynamics in the future
7. Conclusion
The natural development of Tidal Elbe is interfered by man-made measures.

The shape (component geometry) is modified by hydraulic structures (fairways, groins, ..)

Shape alterations cause alterations of tidal processes (energy of tidal waves, tidal range, tidal currents, symmetry and asymmetry of tidal processes).

Alteration of tidal dynamics can lead to unwanted sediment transports.

Tools are needed to improve the predictability of the processes and sediment management strategies.
Goal is to improve the predictability of the processes.

Decompose nature into components.

The approximation of the continuum is growing with the resolving power of the tools – but tools always lack resolution.
Goal is to improve the predictability of the processes.

Resolution of physical processes is needed.
Resolution of physical processes:
- tidal constituents
- astronomic tidal constituents
- hydrodynamic tidal constituents

Measured tidal curve:

- $M_2$
- $S_2$
- $N_2$
- $K_2$
- $L_2$
- $M_4$
- $M_6$

1. day 2. day 3. day 4. day 5. day 6. day
Tidal Elbe

Distance Bake Z to Hamburg
~ 120 km

Morphodynamics

25 years
app. 200 m3 loss
Tidal Ems

- Distance: Borkum to Papenburg
  - Approximately 90 km
How-to estimate Development of the German Estuaries

What can be the leading (tidal) parameter for an assessment of ongoing development of tidal processes?
How-to estimate Development of the German Estuaries

What can be the leading (tidal) parameter for an assessment of ongoing development of tidal processes?

• chronology of low tide development in the upper estuary region

• gradients of the water level during incoming tidal wave
Tidal Elbe
sink of low tide
in Hamburg:
0.8 m in 50 years

~ 0.8 m

sink of 1.6 cm / a

50 years

step by step measures
Tidal Elbe

typical distribution of low tide
Δ (German Bight – Hamburg) ~ - 0.15 m
Tidal Elbe

typical tidal curves today

- Bake_Z
- Cuxhaven
- Brunbüttel
- Kollmar
- Hetlingen
- Seemannshöft
- Bunthaus
- Geesthacht

m [NN]

03:00 06:00 09:00 12:00 15:00 18:00 21:00 00:00
Tidal Elbe - speed of local water variation

As a rule we can say: an increasing climbing speed goes on with increasing flow velocities. The largest speeds occur during the first flood phase.

Vertical velocity of water level (m/h)

Water Level (m)

Asymmetry

1955
1,5 m/h

1998
0,8 m/h

0,8 m/h

0,5 m/h

Federal Waterways Engineering and Research Institute (BAW)  Karlsruhe  •  Hamburg  •  Ilmenau
sink of low tide
>1 m in 30 years
in Papenbug

sink of app. 3.3 cm / a
30 years
Tidal Ems: Water-Level Gauges (2005)

3.6 m/h
Tidal Ems

Typical distribution of low tide

$\Delta$ (German Bight – Papenburg) $\sim -0.7$ m

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Federal Waterways Engineering and Research Institute (BAW) Karlsruhe · Hamburg · Ilmenau
Estimating the development of the system, data of water level measurements are very important to get an idea of asymmetry.

To become more insights into the operating principles of asymmetric tidal processes we need additional tools.

This can only be achieved with the *best mathematical models*.

The term *best mathematical model* means:
- realize any possible improvement of the model code
- never give up to achieve better model validations.

We need organizations with money and staff for that task.
Detail of German Bight Model at BAW

- high resolution
- local grid refinements
- unstructured grid
- 3D
- transport of solved and particulate matter
- parallel computing
- embedded in a scientific community
- experienced users
- usage of different models
- Open Modelling Interface
Asymmetry - A Physical Process based View in Terms of Sediment Management

The shape of tidal curve indicates the amount of asymmetry.

But a lot of other features in tidal processes are driving the long term sediment transport in distinct directions.

⇒ Analysis of more tidal parameters on the basis of model results.

A sediment manager should have knowledge about basic correlations of factors driving the system.
computed mean duration of flood current
Tidal Elbe: computed ratio of max. flood current to max ebb current

longitudinal section through the deep fairway

max. flood current : max. ebb current

0.1  0.9  1.7  2.9
Tidal Elbe: computed ratio of max. flood current to max ebb current

Mechanisms responsible for upstream transport

1. Asymmetry of tidal curve in upper part of the estuary
2. Near river bed density driven transport
3. Flood currents acting after high tide until slack water (mainly in the outer part of the Tidal Elbe)
A next fairway deepening of Tidal Elbe is on the agenda.

Measures against further decline of low water levels in Hamburg are necessary.

For deepening a total volume of 34 Mio. m$^3$ should be excavated.

About 60% of this volume could be used for two hydraulic structures (submerged bar / sand bar) for which maintenance procedures are required.
Fairway deepening - use of dredged material

submerged bar

sandbar
Fairway deepening - change of tidal range

Zeitraum:
11.05.2002-16:40 bis 25.05.2002-23:30

red for increase
blue for decrease of tidal range
Fairway deepening - change of low tide

Zeitraum: 11.05.2002 16:40 - 25.05.2002 23:30

German Bight

Hamburg

1 d mittleres Tnw AZ_09-PIZ_LElbeTRAS
2 d maximales Tnw AZ_09-PIZ_LElbeTRAS
3 d minimales Tnw AZ_09-PIZ_LElbeTRAS
Climate Change
Sediment Dynamics in the Future?

What can be the outcome of sea level rise in the North Sea with respect to sediment transport processes?

If we assume a certain amount of sea level rise e.g. 0.6 m or even 1.0 m we can predict the outcome with a detailed model, including North Sea, German Bight and Estuaries.
Scenario
MSL + 1 m
⇒ high water level
= 1,0 m + Δ MThw

Development of mean high tide after sea level rise
Federal Waterways Engineering and Research Institute (BAW)

Tidal Elbe

tidal wave lines
today
spring condition

26.05.2002 - 06:30 to 18:30

Water level [m NN]

Elbe - Kilometer

- 3.00
- 2.00
- 1.00
  0.00
+ 1.00
+ 2.00
+ 3.00

750 730 710 690 670 650 630 610 590

Geesthacht
St. Pauli
Glückstadt
Cuxhaven

+9 hrs.
+10 hrs.
+11 hrs.
+12 hrs.

+6 hrs.
+7 hrs.
+8 hrs.

+0 hrs.
+1 hrs.
+2 hrs.
+3 hrs.
+4 hrs.
Tidal Elbe

26.05.2002 - 11:30

Water level [m NN]

Elbe - Kilometer

Cuxhaven
Glückstadt
St. Pauli
Geesthacht

increasing slope with sea level rise

tidal wave line today
Change of Net-Sediment Transport

Szenario
MSL + 0,6 m

tons per meter

decrease
increase
Finding: Sea level rise leads to increased sediment transports within Elbe Estuary.

More net-sediment transport is mainly directed into the Tidal Elbe.

The sediment sources are nourished by local erosions.

As a consequence, the tidal range in Hamburg will increase further more due to
• climate change and
• further sediment losses in the outer Elbe river.
Sediment Management is directly combined with the history and future of characteristic tidal parameters.

Leading parameters for the German estuaries are low tide values and water level gradients of incoming tides.

Models are today usable tools for analysis, diagnosis and forecast of estuary systems especially for sediment movements but further improvements are necessary.

With respect to climate change sediment managers should look into the future.