HARBASINS

HARBASINS Report:

Hydro- and Morphological Pressures and Impacts

Prepared by: Gerald Herrling and Hanz D. Niemeyer
Lower Saxony Water Management,
Coastal Defence and Nature Conservation Agency
- Coastal Research Station -

NLWKN

Interreg North Sea Region

HARBASINS is a project funded under the European Regional Development Fund INTERREG IIIB North Sea Region Program – A European Community Initiative concerning Trans National Co-operation on Spatial Development 2000-2006.

Document history

Revisions

Version	Status	Date	Name	Changes
1.0	1st draft	20.05.2008	Herrling	
2.0	2nd draft	31.05.2008	Niemeyer	revision
3.0	3rd draft	09.06.2008	Herrling	
4.0	Final draft	13.06.2008	Niemeyer	

Distribution

This document has been sent to:

Version	Date sent	Name	Position
4.0	13.06.2008	F. Zijp	Project leader
4.0	13.06.2008	HARBASINS webpage	

Authors:
Gerald Herrling
Hanz Dieter Niemeyer

Table of Content

Table of Figures

1 Introduction

In the course of the last centuries, many European estuaries and coastal waters experienced significant changes in their littoral environment not only due to natural processes but more and more due to human interference. Major anthropogenic pressures in estuaries and their habitats have been: land reclamation by establishing dykes on supratidal marshes and more recently also on tidal flats, harbour extensions, groynes, training walls, deepenings and streamlining of waterways by dredging, cutting-off of secondary channels, implementation of groynes and training walls. These anthropogenic impacts changed primarily both topography and hydrodynamics of estuaries resulting mostly in follow-up morphodynamical processes directed towards a new dynamical equilibrium. Any changes of hydrodynamics and topography effect the estuarine habitats and respectively the biology. Changes in intertidal and supratidal habitats and resulting species composition may alter food availability for birds and fishes and the variety and abundance of phytoplankton and macrozoobenthos.

This report summarizes the preceding and detailed HARBASINS reports of work package 4 “Hydro- and Morphological Pressures and Impacts” focused on the analysis of human impacts on estuarine hydrodynamics and morphology (Elsebach et al. 2007, 2007b; Herrling & Niemeyer 2007 a, b, c and 2008 a, b, c) specifically aimed at the development of objective criteria for the identification of heavily modified water bodies (HMWB) due to the EC-Water Framework Directive (EC-WFD).

The investigations have been carried out exemplarily for the tidal estuaries Ems-Dollard and Weser at the southern North Sea. Basis for identifying, classifying and evaluating significant human impacts on coastal waters and estuaries are both recent and historical topographical data being used for the evaluation of long-term spatial developments of habitat zonations. Furthermore mathematical hydro- morphodynamical models are used as well for highlighting hydrodynamical changes and the spatial effects of artificial structures. The investigations enabled to identify and analyze changes of topography in recent decades and centuries with respect to habitat zonation particularly with respect to human impacts. The evaluation of changes in the tidal regime does not only determine the alterations of the physical environment but is also indispensable for assessment studies on its ecological impacts and the ecological potential of heavily modified water bodies.

The Water Framework Directive of the European Communities distinguishes between natural, artificial and heavily modified water bodies. In coastal areas and particularly in estuaries a lack of straightforward procedures for the objective identification of HMWBs is evident. Therefore it is of high interest to define a natural reference status and thus the distribution of the former habitat zonation and the former hydrodynamic regime in order to evaluate the classification of the present state of the water body as natural or heavily modified. Aim of the investigation is to identify water bodies by comparable standardized methods like habitat mapping or applying mathematical models.

2 Basic estuarine hydro- and morphodynamics

Tidal estuaries are shaped by the interactions of the tidal wave and the soil in the estuary determining accretion and erosion. The tidal wave experiences reflection, damping and shoaling while propagating from the sea into the estuary. Resultantly the tidal range increases from the estuarine mouth upstream until damping is more effective than reflection and shoaling. The energy dissipation leads than to a reduction of the tidal range until none is left.

Nowadays a lot of estuaries have got artificial borders of their tidal regime by barrages where a remarkable tidal range is still existent. In coincidence with other human impacts the maximum of tidal energy has been shifted further upstream, in extreme even towards the tidal border.

Morphodynamics of tidal estuaries are steered by the dynamics of their multiple-channel systems. Their permanent meandering is the driving force of a continuous reshaping of estuarine morphology. The channels migrate and change also within a mid-term time-scale their ranks as primary and secondary channels accompanied by alterations of water depth.

Whereas in the past people were forced to adapt navigation to estuarine migration, since the 19^{th} century increasing vessels and also improving technical capabilities led to human impact on estuaries which affect both hydrodynamics and morphodynamics more and more: deepening, streamlining and guidance of main channels, reduction or even cutting-off of secondary channels.

3 Dependence of habitat formation on hydro- and morphodynamics

Habitats in tidal environments are generally distinguished in subtidal, intertidal and supratidal areas. Subtidal areas are all those below mean low water, supratidal those above mean high water and intertidal those in between. Subtidal areas are again subdivided into deep and shallow water zones, supratidal areas into siltation zones and marshes (Fig. 1).

In subtidal areas only animals and plants survive which could bear being permanently flooded or are able to swim there temporarily. Large water volumes perform and maintain deep channels due to the strong currents they force. Therefore only such animals and plants live there which can cope with strong currents. Whereas those, that are unable to bear high current velocities and need permanent flooding are found in the adjacent shallow water zones.

Close to the shore are the salt or river marshes with a transition zone to the tidal flats: the siltation zone where often the growth of future marshes starts in those parts with low hydrodynamics. Wildlife in all these three amphibious areas is dominantly determined by and adapted to local flood duration. Some of the animals live there permanently, the other with respect to their needs during flooding or in the period the areas have fallen dry.

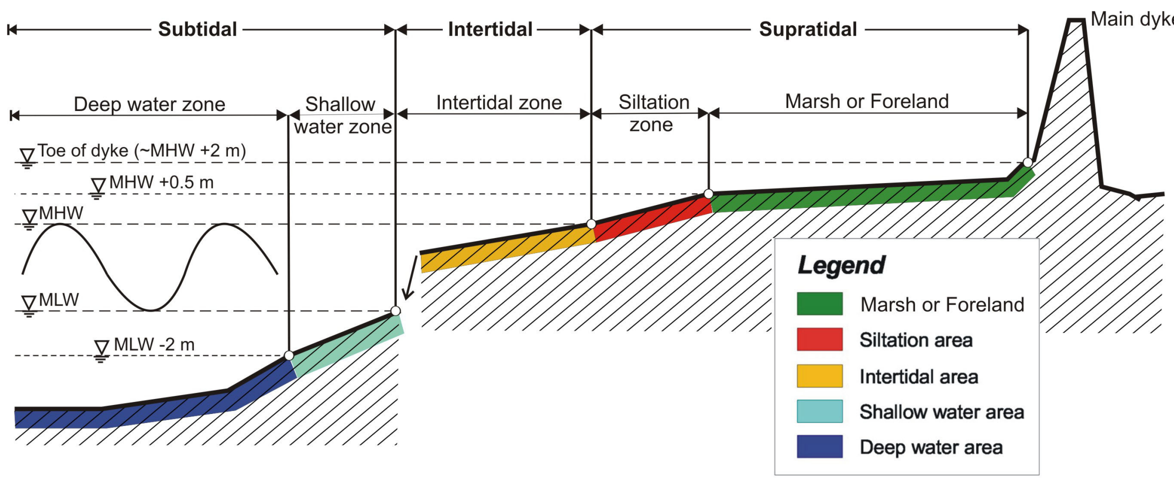


Fig. 1: Definition of five distinct habitat zonations

4 Natural impacts

4.1 Bay creation and following silting-up

A specific feature of the Ems-Dollard estuary is the Dollard Bay. As other bays at the Frisian Wadden Sea coast like the Zuiderzee, Lauwerszee, Ley Bay or Jade Bay the Dollard was created by the erosional forces of catastrophic medieval storm surges. The Dollard developed as a bay in the course of the 14th century and had its largest extension after dyke breaches, flooding and erosion of adjacent areas due to storm surges in the 15th and 16th century (Fig. 2). The afterwards existing spatial extensions of eroded storm surge bays were not in tune with the hydrodynamics occurring during the frequently dominating ordinary tides. Due to a lack of dynamics sedimentation occurred leading to a silting-up along the sheltered shorelines (NIEMEYER 1991). From the beginning of the 17th century siltation and accretion of extended supratidal marshes dominated the morphodynamical development of the Dollard Bay.

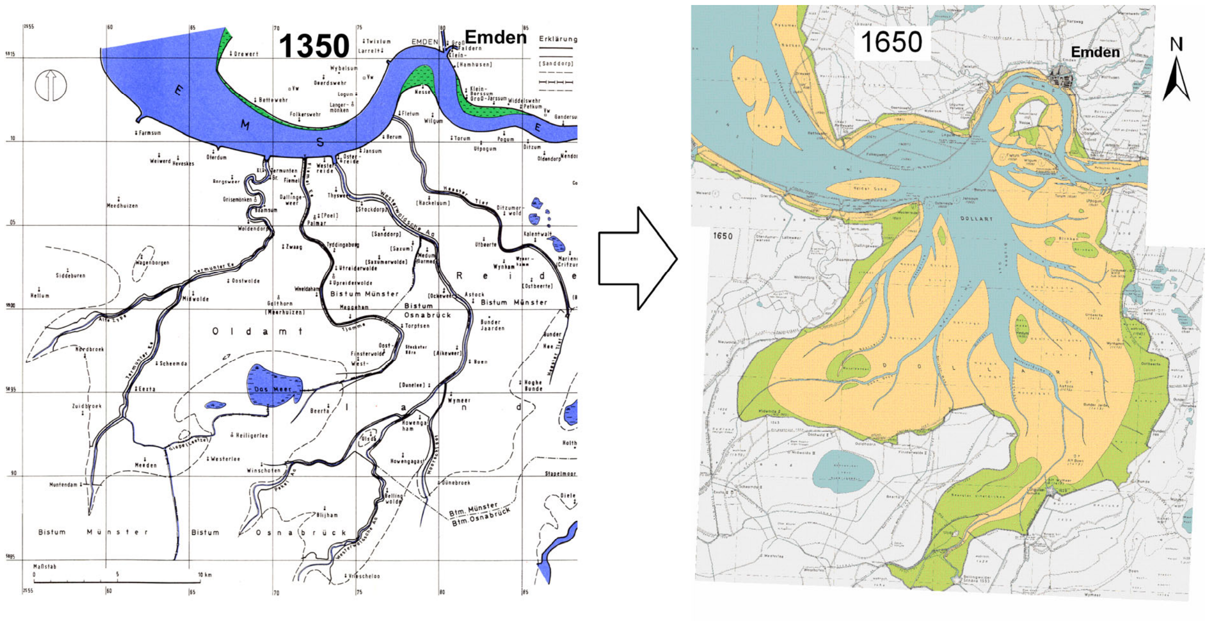


Fig. 2: Reconstructed maps of the transitional waters of the Ems-Dollard estuary of 1350 and 1650 showing the natural impact of the medieval storm surges on estuarine morphology (HOMEIER 1962, 1977)

4.2 Channel migration

Tidal estuaries consist generally of multiple channel systems with a hierarchy. But these systems are never constant in time: they are permanently migrating leading also to changing hierarchies. Such a development is well-documented for the outer Weser estuary since 1860 (HOMEIER 1962; NIEMEYER et al. 2007).

In 1650, the main channel of the estuary is the Butjadinger Arm in the western part of the estuary with a secondary channel in the eastern part. Close to the western shore is a small third channel as a tributary of the main channel. In 1750 the main channel is closer to the western shore and the small tributary has disappeared (Fig. 3a). Whereas in 1860 the situation has dramatically changed: Now the channel in the eastern part is dominating whereas the former main channel is only third-rate, since a secondary channel has developed in the eastern downstream part of the estuary (Fig. 3b). After 1860 a trend occurred, leading to a more westerly located main channel. The migration was then stopped by human interference: the main channel was fixed in the 1920s as the major waterway (Fig. 3c) for the large vessels connecting Europe and the United States across the North Atlantic.

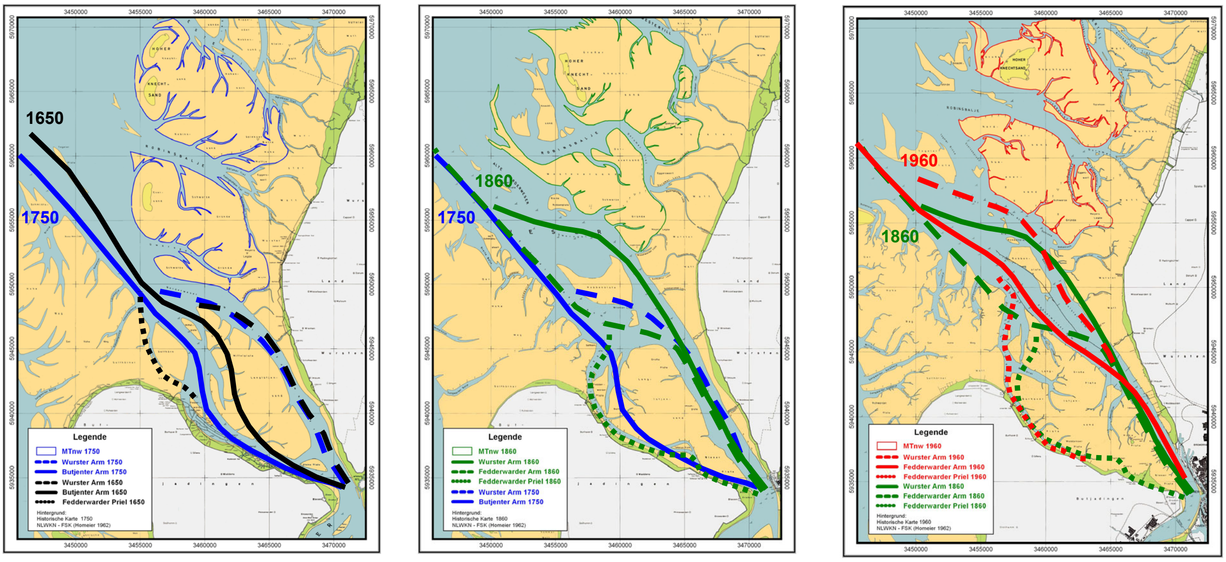


Fig. 3: The permanent channel migration in the multiple channel system at the outer Weser estuary reconstructed for a) 1650/1750, b) 1750/1860 and c) 1860/1960 leads to changing channel hierarchies (HOMEIER 1962; NIEMEYER et al. 2007)

5 Human Impacts

Human pressures on the habitats of estuaries and coastal areas will be classified here into land reclamation and waterway expansion. The latter happens due to deepening by dredging, streamlining of the main-channel, cutting-off of tributaries or secondary channels and is often terminally stabilized by the implementation of solid structures.

5.1 Land reclamation

Land reclamation in tidal environments happens in two distinct stages: first by supporting natural existing sedimentation in intertidal areas and second by the construction of dykes protecting the marshes against inundation during storm surges. Until the 20th century the technical means allowed only the construction on supratidal marshes but not in the intertidal zone as later possible.

The enclosure of marshes and mudflats by dykes was initially aimed at agricultural use but later also for urban and industrial development. Coastal people accelerated the siltation and the growth of supratidal marshes by building land reclamation groynes which the coastal communities claimed then by erecting dykes. Land claim involves the direct removal of ecosystem elements resulting in significant losses of particularly supratidal habitats and to a much lesser extent of intertidal habitats. The loss of these areas reduced the capacity of the estuarine landscape to provide place and food for benthic, bird and fish populations.

The natural silting-up and the growth of supratidal marshes continued also in the Dollard Bay supported by human interference by building land reclamation groynes and leading ultimately to further land reclamation (Fig. 4). Again this process was accompanied by further reduction of the tidal prism which was followed by a reduction of the channel cross-sections. In the Dollard Bay the reduction of the tidal volume was mainly a follow-up of natural processes. Human interference took mainly place on the supratidal marshes and by accelerating the naturally occurring sedimentation.

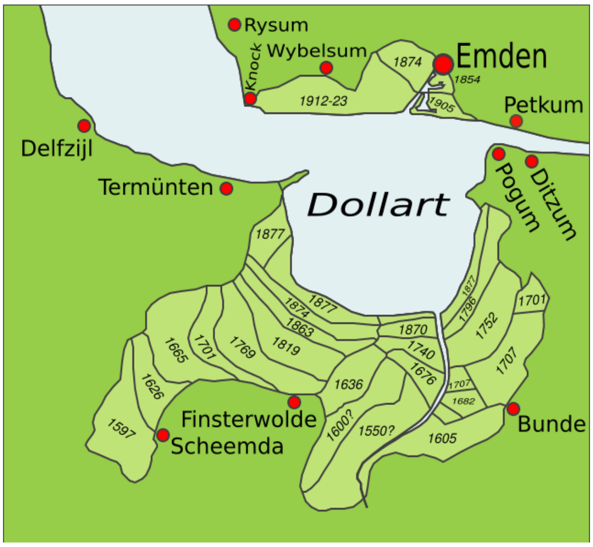


Fig. 4: Land reclamation by poldering the marshes around the Dollard Bay (adapted from HOMEIER 1969)

5.2 Waterway Deepening

The waterway expansion by deepening and widening is aimed at the creation of accessibility of harbours by vessels with larger dimensions and particularly deeper draughts.

Historically most harbors developed further upstream in the estuaries where better shelter against storms was naturally provided. This advantage has become less and lesser important in the 20th and 21st century when the vessels became larger and larger requiring larger water depths and widths in the waterways and being less sensitive against storms in open waters. In order to guarantee the access of such large vessels to important harbours in the estuaries capital and afterwards maintenance dredging is required. In this respect, the Lower Weser estuary is a representative example for many other European estuaries (Fig. 5).

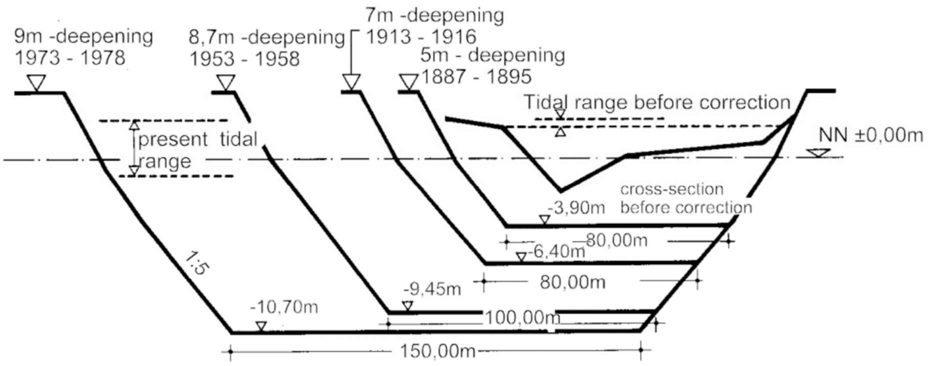


Fig. 5: Successive deepening and widening of the Lower Weser (source: WETZEL, 1987)

The deepening of estuarine waterways enforces essential changes of mean tidal water level peaks and range (Fig. 6). They start immediately after deepening but continue after execution of dredging for a certain period of time being necessary for the development of a new dynamical equilibrium between estuarine geometry and tides. The order of magnitude of changes of mean tidal water levels is particularly of importance for water management and ecological zonation but is also regarded as a primary indication for changes of tidal currents, salinity and storm surge levels. (NIEMEYER 1999)

Deepening of the waterways reduces damping of tides and storm surges: both tidal range and storm surge levels increase (NIEMEYER 1997). In order to provide a sufficient protection against flooding along upper parts of estuaries in some cases storm surge barriers have been built in estuaries since it was expected to be more cost-effective than the strengthening and afterward maintenance of long stretches of dykes.

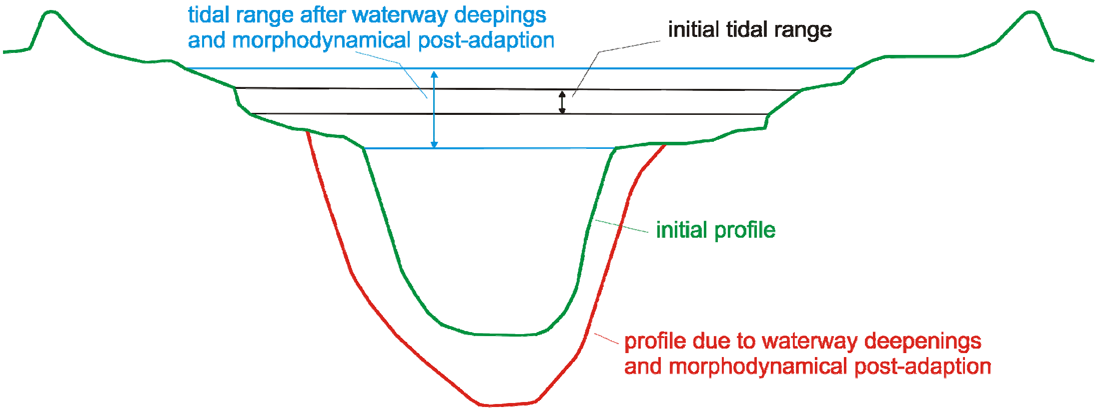


Fig. 6: Schematisation of waterway deepening, hydro- and morphodynamical adaption

5.3 Waterway streamlining and fixing

A mayor reason for streamlining estuarine channels is to enhance their navigability. The streamlining of meandering river arms and cutting-off of secondary tidal channels keeps the waterway stable preventing random changes of directions as shortening of the waterway's length. Groynes and training walls are built to fix the waterway by guiding flow directions. Another aim has been to limit the river extension to one fixed channel for supporting land reclamation of the adjacent areas close to the shore. A third purpose of estuarine streamlining and fixing is the reduction of maintenance dredging by increasing the current velocities in the waterway by both shortening the way for tidal motion and concentrating the tidal volume in the waterway itself.

Streamlining has predictable effects like the loss of shallow water zones and intertidal areas and therefore reducing rare habitats for many forms of wildlife. The loss of fish diversity and abundance is considered as an effect of habitat losses particularly by both elimination of shallow water areas and secondary channels, as the nursery of marine fishes and larger fluctuation of water levels and therefore increased current velocities.

The Weser estuary was straightened by FRANZIUS in 1888. The spatial balance between 1887 and 2000 confirms as a whole the phenomenon that estuarine dredging and deepening increases the intertidal area at the expense of subtidal areas and in particular at the expense of the shallow water areas (Fig. 7).

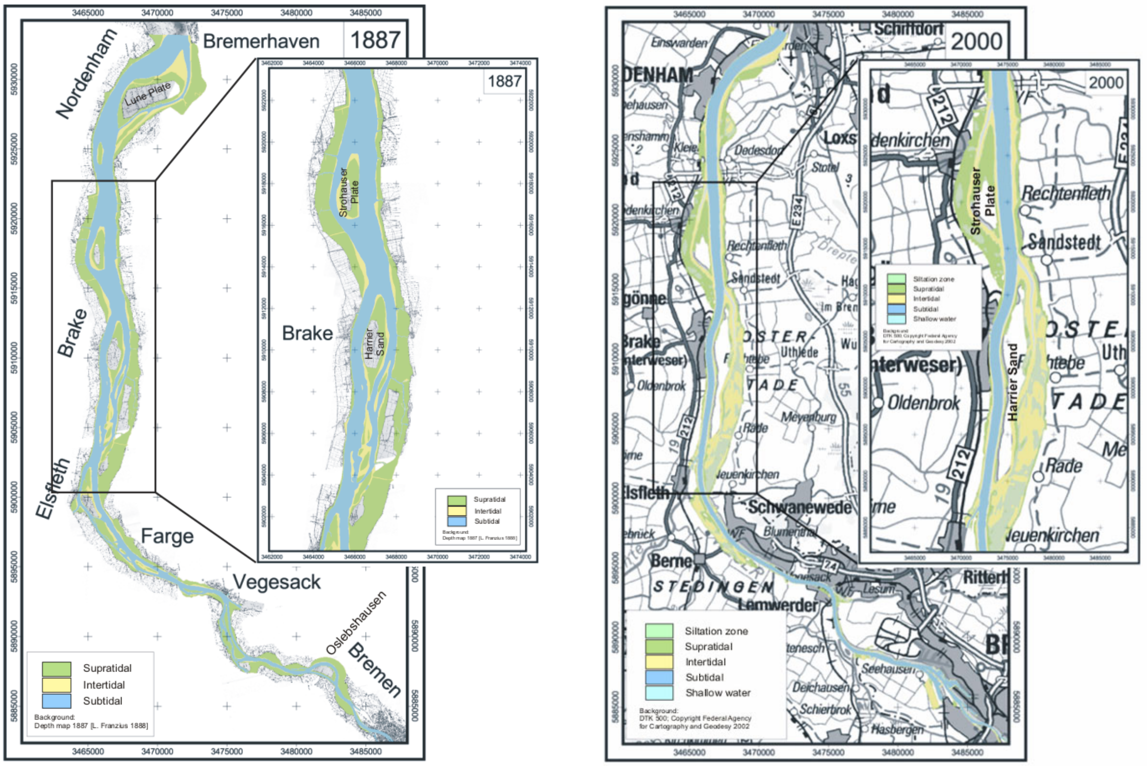


Fig. 7: Elimination of shallow water areas and secondary channels by streamlining the Lower Weser in 1888 by FRANZIUS. Displayed are the states prior to the streamlining and nowadays. (ELSEBACH et al. 2007)

Explanatory for significant changes due to streamlining a section of the Lower Ems between Leerort and Mark is taken into particular consideration. The strongly meandering Ems was straightened at Coldam at 1928 and further upstream at Pottdeich at 1925 and at Mark at 1911. The straightening reduced the length of the Lower Ems by about 15 percent (Fig. 8).

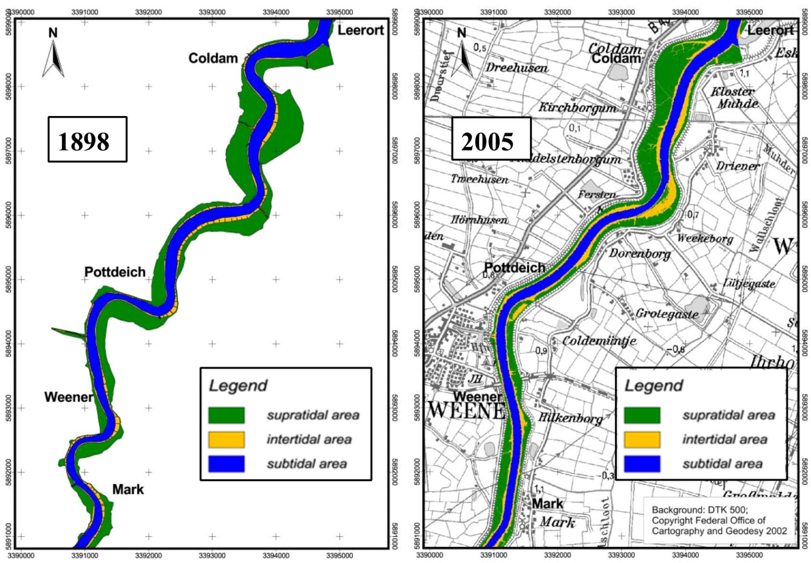


Fig. 8: Habitat loss along the Lower Ems between 1898 and 2005 due to straightening and shortening of the estuary highlighted for the section between Mark and Leerort

6 HMWB assessment due to EC-WFD

The Water Framework Directive of the European Communities (EC-WFD) distinguishes between natural, artificial and heavily modified water bodies (HMWB). For coastal areas and particularly for those with large intertidal components like estuaries or the Wadden Sea an urgent need for the development of straightforward procedures for the objective identification of HMWBs according to the EC-WFD has been identified.

Assessment criteria for the HMWB identification according to the EC-WFD and its CIS-guidance document are summarized. On that basis practical approaches for the identification of heavily modified water bodies in estuaries which have been established in the framework of the HARBASINS project are basically explained.

6.1 Criteria for HMWB identification due to the EC-WFD and the CIS-guidance

Due to the EC-WFD (article 4(3)), the achievement of the good ecological state can be dispensed for water bodies, which hydro- and morphological characteristic have been heavily modified and if a revision of that modifications will create significant disadvantages for the use of the water body like e. g. danger for the population or significant economical setbacks. But for these water bodies being designated as heavily modified, the ecological potential of the water body has to be defined and aspired.

In 2005 a provisional designation of heavily modified water bodies was carried out, the final decision will be taken until the end of 2008.

The classification of a water body as ‘heavily modified’ is defined after the EC-WFD due to the hydromorphology of the watercourse comprising its water balance, discharge and dynamic, connectivity to groundwater bodies, passability of the river, depths and widths variation, structure and substrate of the bed as well as the structure of the littoral and shore area. In article 2 (9) of the EC-WFD, a HMWB is defined as “a body of surface water which as a result of physical alterations by human activity is substantially changed in character”. Furthermore it is mentioned that the alterations have to be, profound, spatially extensive and drastic. In general the hydrology and the morphology have to be significantly altered to justify the designation as a HMWB (CIS 2003).

The following parameters are considered as criteria for the designation of a water body whether as ‘heavily modified’ or ‘natural’ regarding the aspects of the hydro-morphology due to the CIS-guidance document No. 4 (CIS 2003) and the Annex 5 of the EC-WFD:

1. Variation of the water depth, structure of the intertidal area,
2. prevailing current directions,
3. structure and substrate,
4. wave conditions.

For transitional and coastal waters these parameters are not directly applicable in order to achieve meaningful criteria. With respect to that purpose the following parameters and specifications are added:

1:
a) Evaluation of the spatial development of physical habitats by distinguishing in deep water, shallow water, inter- and supratidal areas with siltation zones in between.
b) Evaluation of changes of tidal water levels (peaks and range) being the consequences of human interferences like waterway deepening and straightening, harbour constructions and coastal defence schemes.

2:
Changes of current directions can be identified as direct consequences with respect to waterway regulations and solid constructions, e.g. training walls and groynes. However, the lack of current measurements or similar data generally makes a direct assessment mostly impossible. Significant changes of tidal currents can be identified indirectly by comparing of topographies where the migration of tidal channels and gullies is evaluated. The prevented dynamic of channel migrations being found in regulated estuaries can be regarded as a significant difference to the natural state.

Furthermore, in the framework of this project, the application of mathematical modeling allowed the development of comparative criteria to identify changes of tidal currents and the overall tidal regime.

3:
The change in substrate reflects indirectly the alterations of the acting tidal currents; thus it gives no additional information regarding the identification of HMWBs. Moreover, the lack of data makes a comparable assessment impossible.

4:
Similar as for the changes in substrate, the assessment of changes of the wave climate is mostly not possible due to the lack of historical data being essential for a comparison with the present wave conditions.

6.2 Methodology

Basis for any approach is the definition of a reference status as close as possible to the natural situation. The availability and evaluation of historical data is crucial for the achievement of this aim. The use of appropriate reconstructions of the reference status and the application of methods being generally applicable allows the development of objective criteria for the classification of the water body as a natural or heavily modified one.

Within the framework of HARBASINS, three approaches were used to develop comparable assessment criteria for the identification of HMWBs explanatory for the estuaries of the Weser and the Ems-Dollard with the prospect of being also applicable for other estuaries:

1) Habitat zonation, i. e. evaluation of the spatial development of distinct habitats
2) Parameter comparison, e. g. evaluation of long-term water level measurements
3) Mathematical modeling of hydro- and morphodynamics

After the general investigation of the water body and its environmental changes, the reference state has to be identified. The relevance of the human changes occurred, but also the availability of historical data like topographical charts, water level observations or flow measurements will determine the approach being followed. The methodology is summarized in a flowchart (Fig. 9).

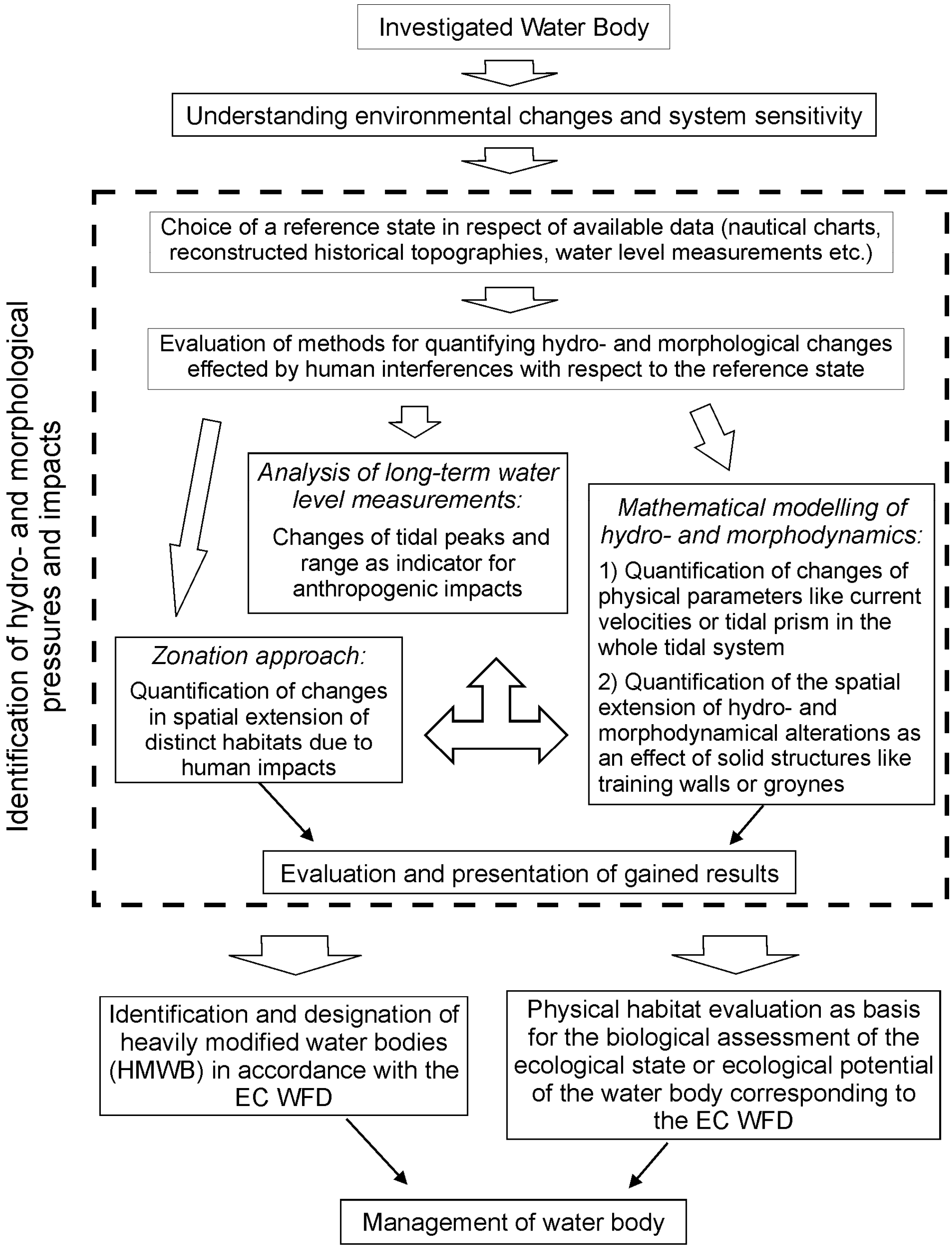


Fig. 9: Methodology and approach for identifying heavily modified water bodies (HMWBs)

The findings are then evaluated and presented being applicable as comparable assessment criteria for the identification of anthropogenic impacts and finally for the designation of the water body as heavily modified or natural. The results of these studies provide furthermore information on possibilities for restoration or recreation on one hand and on their limitations on the other.

7 Evaluation of human impacts on tidal estuaries

The here described approaches are proposed to identify and quantify human pressures on estuarine habitats and develop comparable assessment criteria for the identification of the water body as natural or heavily modified with respect to the Water Framework Directive of the European Communities (EC-WFD).

Habitat zonation reflects the changes in the dominating tidal peaks. The quantification of the long-term spatial losses and changes in distinct estuarine habitats allow an analysis of the impacts of estuary modification on wildlife with a limited amount of work capacity. The existence of sufficient topographical data for both reference and actual situation is an indispensable preposition.

Hydro- and morphodynamical mathematical modeling is applied in order to evaluate criteria, i.e. relevant physical parameters, for the identification and quantification of the effects of waterway deepening, streamlining and fixing. Since modeling requires much higher efforts than the evaluation of habitat zonation it is only regarded as a suitable tool for cases being in need of a research in depth. Again the requirements for topographical data are basically the same as for habitat zonation but the required resolution of data is significantly higher.

7.1 Habitat zonation

The estuary consists of a variety of habitats which all provide a suitable environment for specific plants and animals being optimally adapted to the local environmental conditions. The borders of the distinct habitats have here been chosen with respect to the local tidal water levels. They are mostly shore-parallel correspondingly to water level and topographical gradients with which mostly the grain size distribution correlates becoming finer with higher levels.

The zonation approach is due to the comparison of distinct estuarine habitat areas at historical and actual states. Some historical charts at least provide data enabling to differentiate the surface areas between Mean-Low-Water (MLW), Mean-High-Water (MHW) and the toe of the dyke. The topographical information being contained in the historical maps of the area has to be transferred into a digital data structure allowing an analysis by application of a geographic information system (GIS). The GIS allows the separation of the following habitat areas (Fig. 10):

- Supratidal areas: levels between MHW and toe of the dyke,
- Intertidal areas: levels between MLW and MHW,
- Subtidal areas: levels below MLW.

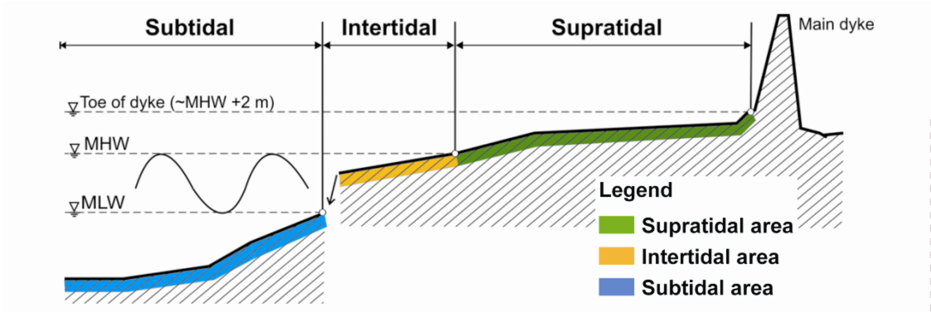


Fig. 10: Definition of three distinct habitat zonations

Depending on the availability and quality of the topographical data a refined differentiation of habitats is possible by subdividing the subtidal zone in a shallow and a deep water area (Chapter 3, Fig. 1):

- Deep water: levels below MLW -2 m,
- Shallow water: levels between MLW -2 m and MLW;

and the supratidal zone in a siltation area and marsh or foreland:

- Siltation area: levels between MHW and MHW +0.5 m,
- Marsh or foreland: levels between MHW +0.5 m and toe of the dyke

Explanatory habitat balance is here applied for a transitional water body of the Ems-Dollard estuary. In the course of the last centuries, the Dollard bay experienced significant reductions of the littoral environment due to silting-up and afterward land reclamation altering the spatial extension of littoral habitats like supratidal marshes and tidal flats. The comparison of topographic reconstructions of the states of 1650, 1750, 1860, 1960 (Homeier 1962) and 2005 were used as a basis for the evaluation and quantification of habitat changes and furthermore for highlighting the changes of the estuarine environment. Historical topographic data restricted the classification of the littoral into three habitat zonations: subtidal, intertidal and supratidal (Fig. 11).

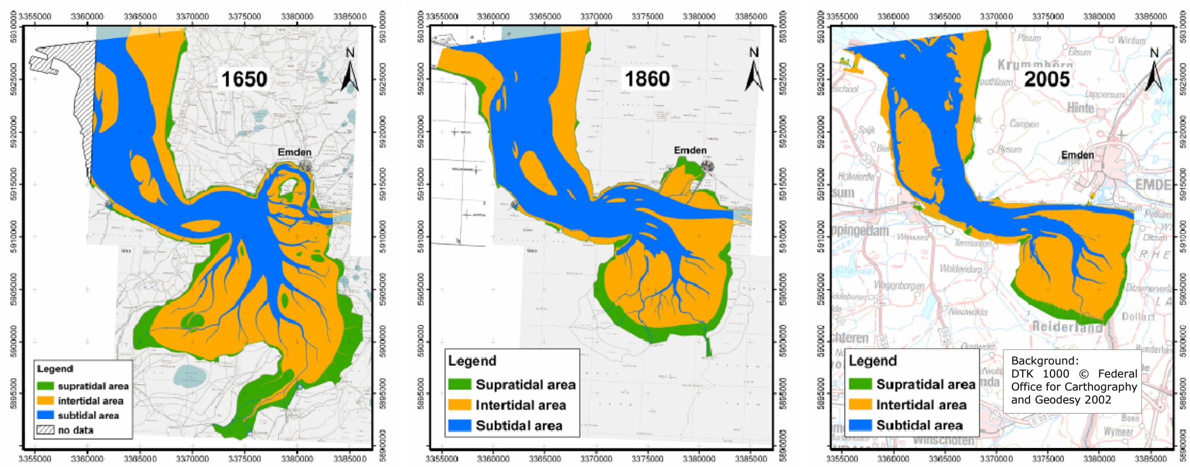


Fig. 11: Spatial development of distinct habitats in the transitional waters of the Ems-Dollard estuary (states of 1650, 1860 and 2005)

Considering the transitional waters of the Ems-Dollard estuary from their seaward limit close to Eemshaven in the outer estuary up to Pogum where the Lower Ems discharges into the Dollard Bay, the total littoral surface area has decreased from 435 km² to 268 km² in the period from 1650 until today. Both, sub- and intertidal habitats diminished by 32%, while supratidal marshes lost 75% of their extension in 1650. The main reduction of the tidal channels took place between 1860 and 2005 whereas the tidal flats lost most of their area between 1650 and 1860. Supratidal habitats such as salt marshes and forelands retreated almost gradually from 1650 up to 1960; the reduction between then and 2005 was quite small (Fig. 12).

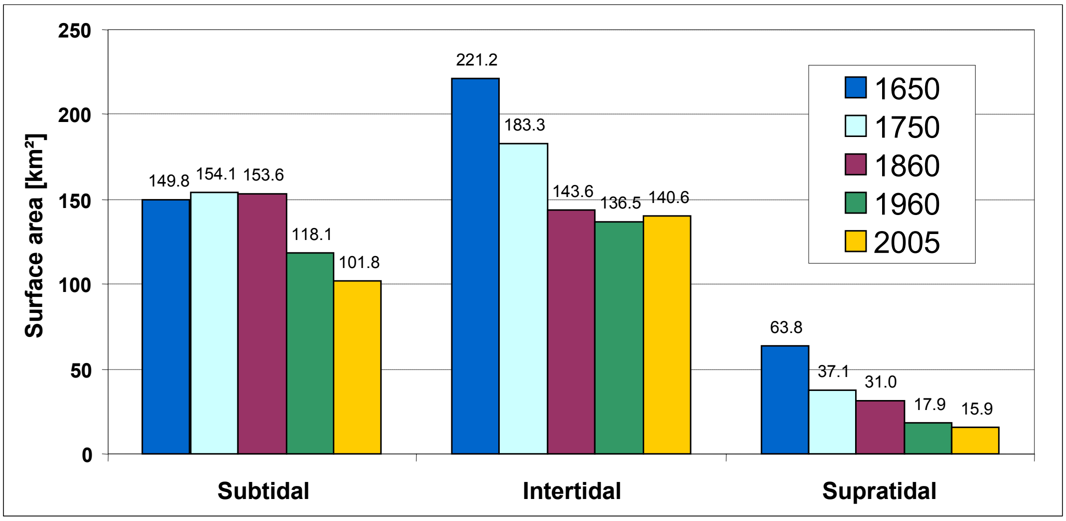


Fig. 12: Quantification of habitat loss in the transitional waters of the Ems-Dollard estuary for the states of 1650, 1750, 1860, 1960 and 2005 determined for sub-, inter- and supratidal areas

7.2 Parameter comparison

Waterway deepening leads to a reduction of the hydraulic resistance and results in an increase of tidal range, the effect increases upstream. E. g. in the Lower Ems, the upper part of the Ems-Dollard estuary, the tidal range at Herbrum at the artificially fixed tidal border has almost tripled since the beginning of water level recordings in the 1930’s (Fig. 13). Fixed tidal gauges give continuous observations of tidal water levels at many European estuarine locations. Analysis and evaluation of long- and mid-term observations is a primary indication for the dimensions of human interference in the tidal regime.

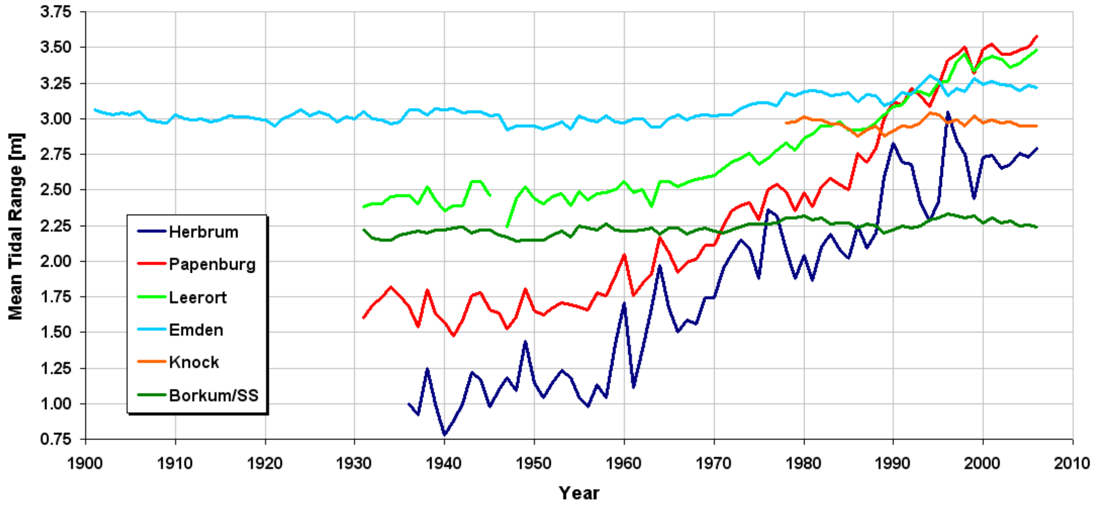


Fig. 13: Yearly mean tidal ranges at gauges along the Ems-Dollard estuary

Therefore the quantitative determination of changes of mean tidal peaks and tidal range due to waterway deepening is given high priority in order to qualify its impacts. This is not only necessary for planning purposes but also for the environmental assessment studies and for the later preservation of evidence procedures. Preservation of evidence gets increasingly difficult if subsequent deepenings have been carried out and their impacts are still continuing at the beginning of the successive one (NIEMEYER 1999).

7.3 Mathematical modeling

To identify water bodies that had experienced significant changes in their tidal regime due to human interferences, it seems reasonable to evaluate and quantify the changes of tidal currents. But continuous current measurements of historical states hardly exist or are temporally and spatially limited in most cases. Alternatively mathematical hydrodynamic modelling could compensate this lack of data if for a chosen reference status sufficient bathymetrical data are available.

Explanatory the hydrodynamic regimes in the Ems-Dollard estuary respectively prior and after the main human impacts, i.e. streamlining and deepening of the Lower Ems, are modelled by applying bathymetric configurations of the years of 1937 and 2005 allowing to determine hydrodynamical parameters like current velocities and directions or tidal volumes for the whole investigation area. The results enable a quantitative assessment of changes to the hydrodynamic regime due to human impacts.

In the Lower Ems, the comparison of hydro-dynamical parameters is assessed at one specific location (Fig. 14) and at a longitudinal section from the tidal barrier at Herbrum to the Dollard Bay (Fig. 15). Mean tidal volumes, velocities and fluxes have increased from 1937 until nowadays significantly and can be used as objective assessment criteria for the human interferences in the system.

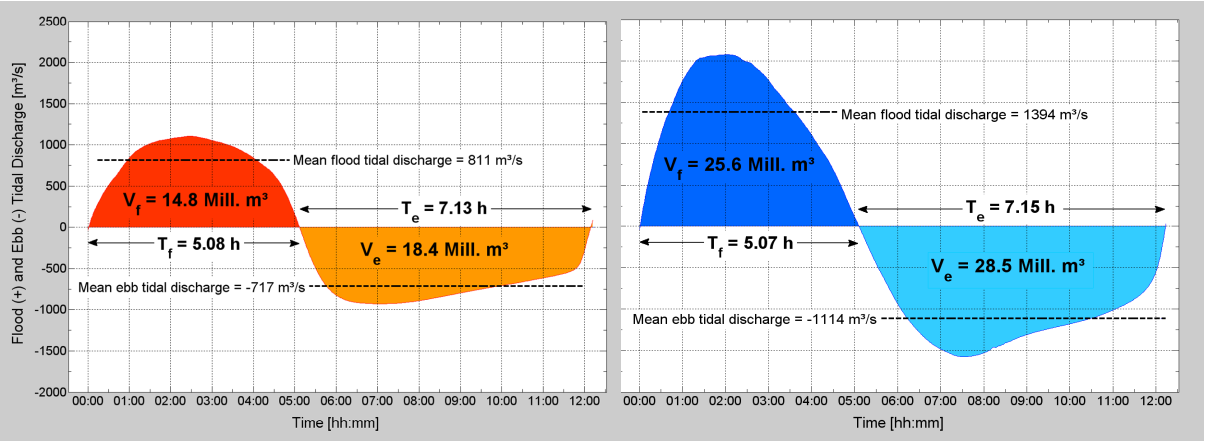


Fig. 14: Mean tidal volume in the cross-section at kilometer 35 downstream of the tidal barrier in the Lower Ems for the model state of 1937 (left) and 2005 (right)

The freshwater discharge which determines the difference between mean ebb and flood tidal volume has been assumed as identical for both model states. The model results highlight a significant increase of the mean tidal volume since 1937 until today. The mean ebb volume has increased by approximately 55% whereas the flood volume increases by nearly 73% (Fig. 14). This effect is mostly the result of a number of subsequent deepenings during the recent decades leading to larger water depths and wider cross-sections in the estuary.

Since there has been no remarkable change in ebb and flood duration the effect of tidal pumping became stronger: for relatively shorter periods sediment is transported upstream by strong flood currents before partly settling at slack tide. The lower ebb currents are unable to stir up all these sediments and shift them back downstream. In the areas without continuous maintenance dredging siltation dominates.

Parallel to the trend of upstream increasing changes in tidal range the relative increase of the mean flood tidal volume with respect to the state prior to the waterway deepening is also the larger the further upstream: It ranges from 170 percent at Papenburg to 600 percent at Herbrum (Fig. 16) whereas it decreases from Leerort with 70% downstream to Pogum at 40%. In 1937, the hydraulic resistance of the channel cross-section was higher than today provoking a stronger energy dissipation of the tidal wave than today.

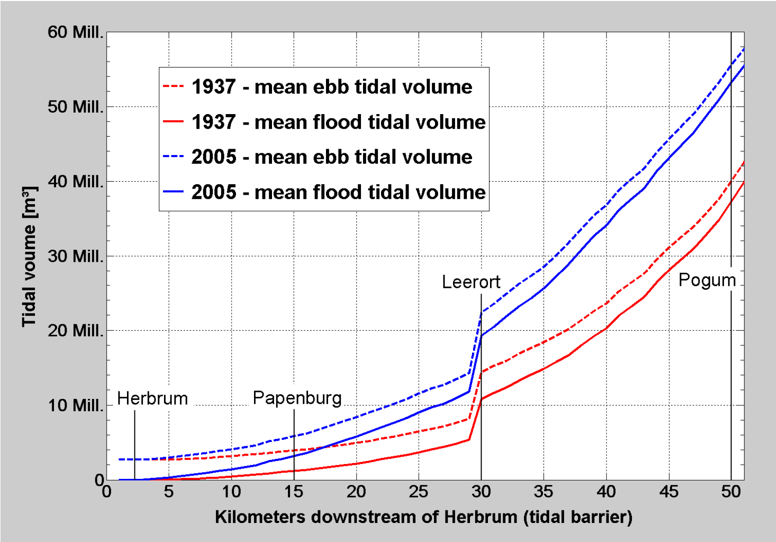


Fig. 15: Comparison of mean tidal volume or tidal prism in the Lower Ems between the model state of 1937 and 2005 for the longitudinal section downstream of the tidal barrier at Herbrum, respectively for flood and ebb tide

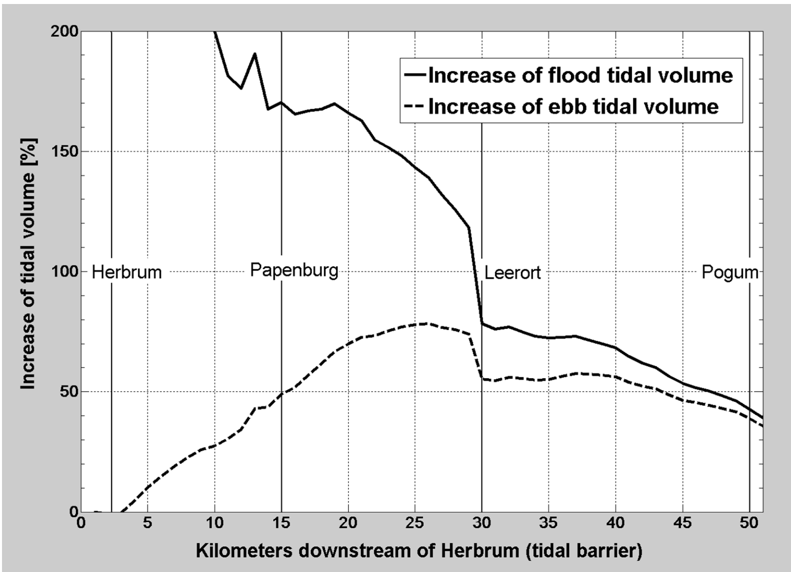


Fig. 16: Relative increase [%] of the mean flood and ebb tidal volume in the Lower Ems for the period between 1937 and 2005 with respect to the values of 1937

Another example for the application of mathematical hydrodynamical modeling has been carried out to highlight the enormous effects due to the main human impact on the Lower Weser estuary: the correction by FRANZIUS in 1888 during which the estuarine waterway was streamlined and deepened for the purpose of navigation (NIEMEYER et al. 1996).

The application of high-resolutional mathematical models allows the identification of areas that have been subject to changes of tidal and flow conditions. Model simulations applying topographic schematizations and boundary conditions based on the situation of 1887, representative for the state prior to the correction, were compared to the situation of 2000. In particular the effect of morphological alterations in shallow water areas and tributaries has been analyzed (Fig. 17). Those areas which were permanently subtidal, but with reduced current velocities provided an important nursery and habitat for many fish species. Nowadays, the current velocities in the streamlined channel are too high for most of the prevailing fish species whereas the shallow water zone in the secondary channel has mostly been replaced by intertidal areas. As long as the requirements for navigational purposes and the corresponding maintenance dredging will remain, restoration measures with the aim of recreation of a shallow water zone in the area of the secondary channel will only have intermediate, but no sustainable effect.

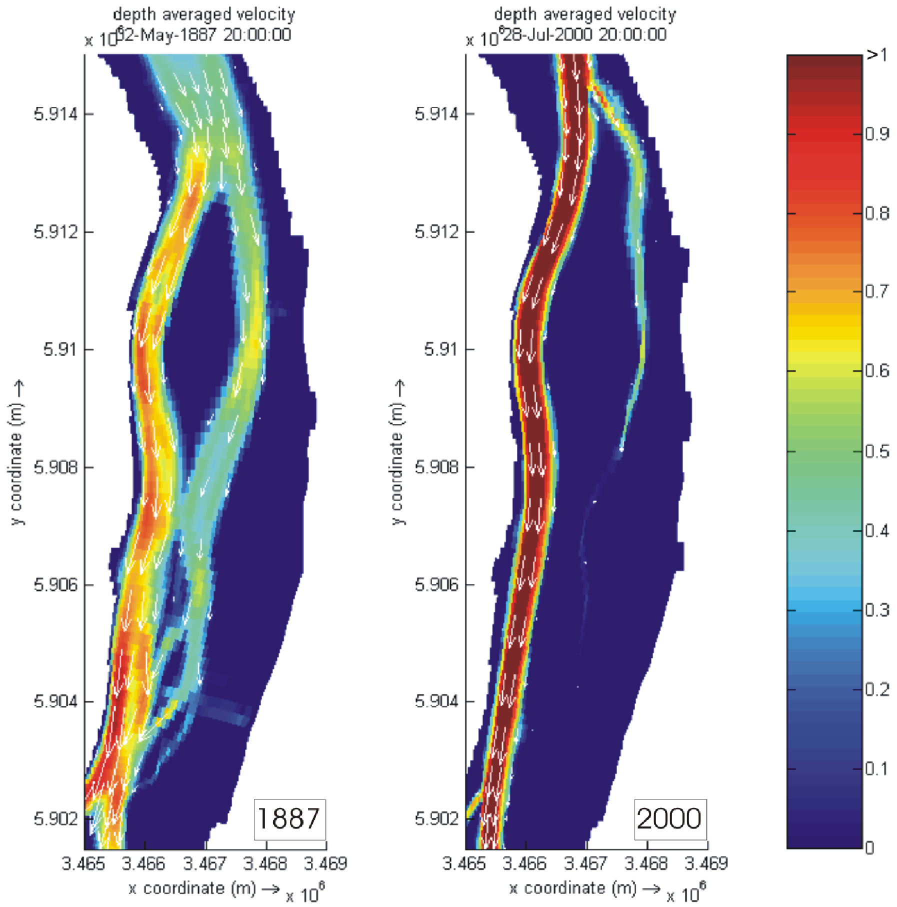


Fig. 17: Changes to current velocities [m/s] in the Lower Weser between Brake and Elsfleth as a result of the waterway correction of FRANZIUS in 1888; comparison of maximal flood current velocities for the model state of 1887 and 2000 (ELSEBACH et al. 2007b)

Solid structures as groynes and training walls are often built to fix the bed of a waterway or tidal channel against the natural but random migration. Currently, the assessment criteria of such constructions concentrates on the area of impact, but this approach may be insufficient when alterations to current regimes may affect salinity and sediment transport in areas outside of the direct impact zone. Mathematical models of hydro- and Morphodynamics are very suitable tools for highlighting those wide range effects.

The most remarkable solid structure in the Ems-Dollard estuary is the Geise training wall separating the Emden Waterway from the Dollard Bay (Fig. 18). It has a total length of about 12 kilometres and was constructed for navigational purposes and to increase the tidal currents in the Emden Waterway with the aim to prevent sedimentation and respectively maintenance dredging.

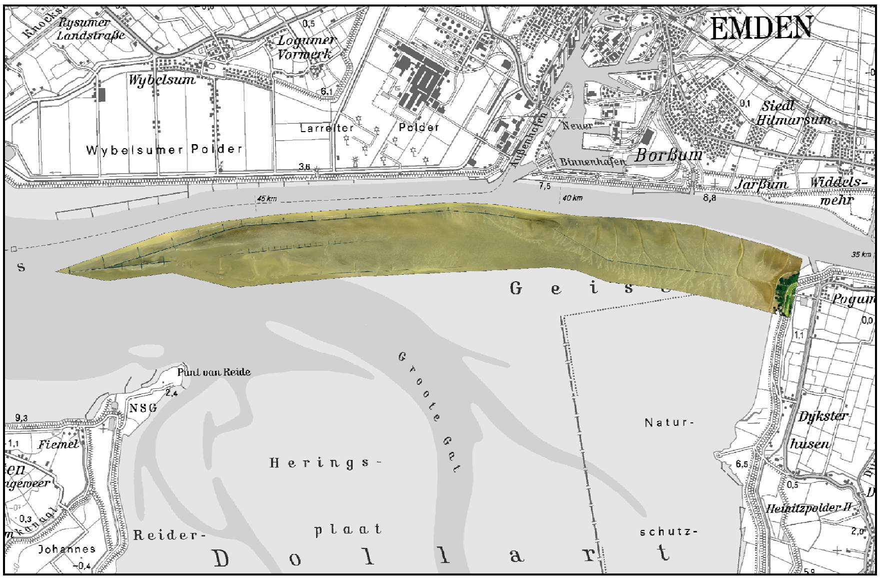


Fig. 18: Arial photograph of the Geise sand and training wall embedded in the map of the Dollard Bay

A straightforward procedure for quantifying the effects of that structure on the surrounding water body is the virtual removal of the Geise training wall in the model and the comparison of the resulting effect on current velocities and morphology to a model scenario with the structure (Fig. 19). The model runs with a continuously updating bathymetry, such as tidal currents affect the movable bottom by sediment transport processes and vice-versa. Bathymetrical changes being the effect of morphological adaptations to the removal of the structure can be identified and highlighted (Fig. 20). Mayor aim of this comparative modelling is the delimitation of the spatial scale and dimensions of morphological alterations occurring due to the removal of the structure quantifying the impact of the solid structure on the water body for the objective identification of a potential HMWB.

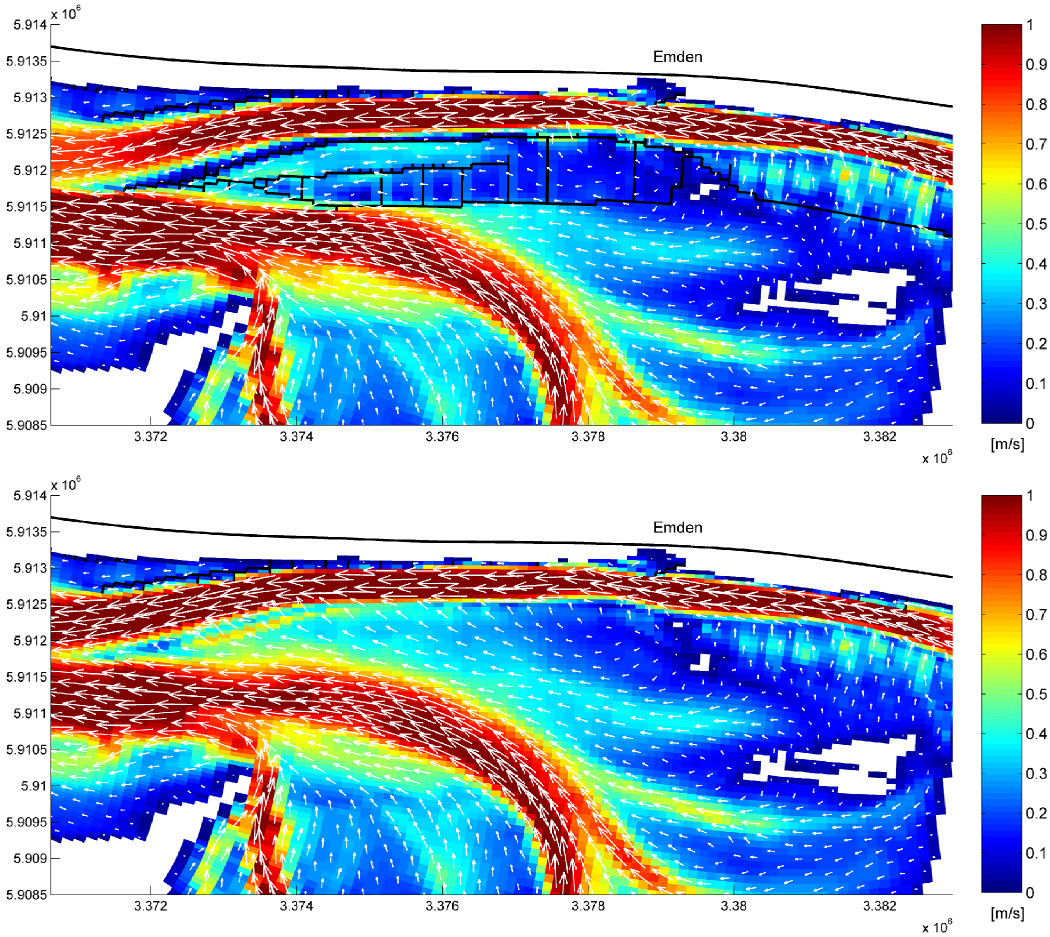


Fig. 19: Comparison of ebb current velocities [m/s] for the model state a) with and b) without the Geise training wall on July 8th 2005 at 2:30 a.m., approximately 2.5 hours after high tide. Intertidal areas or land are displayed in white colour.

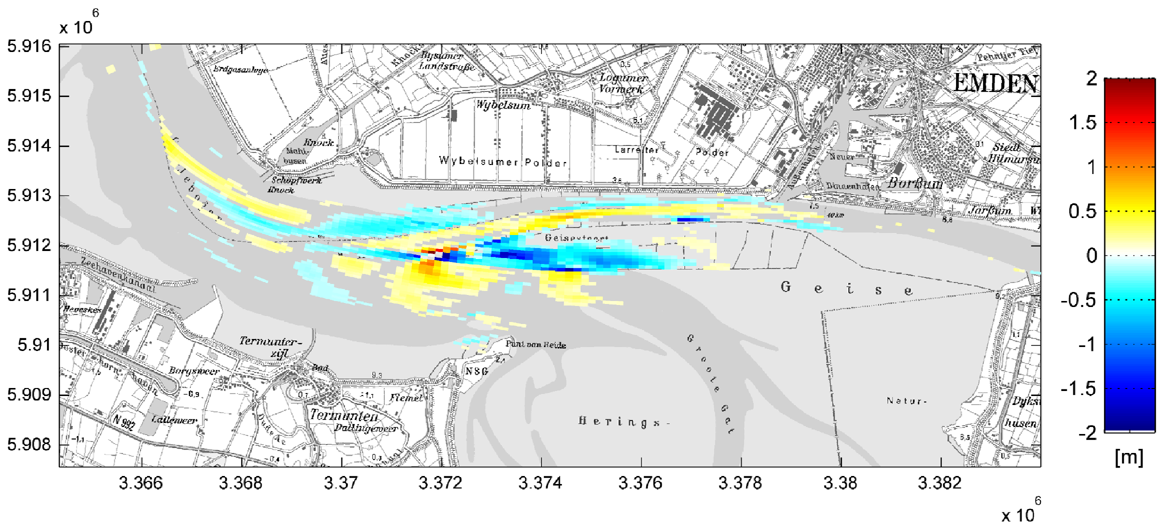


Fig. 20: Differences between the bathymetry of the model state without and with the Geise training wall evaluated after morphodynamical adaptation of 20 months. Highlighted are areas of net sedimentation (+) and net erosion (-) as an effect of the removal of the structure.

8 Conclusions

In the framework of work package 4 “Hydro- and morphological Pressures and Impacts” of the HARBASINS project, the estuaries of the Ems-Dollard and the Weser have been investigated exemplarily to develop and establish methods and approaches for the identification of heavily modified water bodies (HMWB) providing objective and comparable criteria for this purpose.

The Ems-Dollard estuary has experienced a dramatic change of its shape by both natural processes and human interference. Medieval storm surges caused enormous coastal retreat and particularly the development of the Dollard Bay. Follow-up sedimentation led to salt marsh growth which was reclaimed by coastal inhabitants in the course of the last centuries. The subsequent deepening and streamlining of the Ems and particularly of the Lower Ems upstream of the Dollard Bay created long-term morphodynamical processes being still of importance.

The Weser estuary experienced strong human impacts due to waterway deepening and channel fixation. In the Lower Weser most of the secondary channels have disappeared and the remaining ones are no longer uninterrupted shallow water zones which mostly could never re-established as long as the major channels are maintained as waterway. In the Outer Weser estuary channel migration is nearly totally hampered by fixations.

The evaluation of long- or mid-term water level measurements at estuarine locations highlights the anthropogenic interferences in the tidal regime caused by the extensions of estuarine waterways. The zonation method quantifies both mid- and long-term spatial changes of estuarine habitats and highlights the areas of human interference by comparison of historical and actual topographies. Furthermore, hydro- and morphodynamical modeling is applied in order to evaluate criteria for the identification and quantification of human interferences in the estuarine tidal regime caused by waterway deepening or local flow regulations.

Application of all three approaches enables – if sufficient historical data are available – the establishment of comparable and objective assessment criteria for the evaluation of estuarine or coastal waters in respect of the designation of their water bodies as natural or heavily modified.

Literature

CIS (2003): WFD CIS Guidance Document No.4, Identification and Designation of Heavily Modified and Artificial Water Bodies, CIS Working Group 2.2 – HMWB (2003)

Elsebach, J.; Kaiser, R.; Niemeyer, H.D. (2007): Spatial Balance of Habitats in the Weser Estuary, report of the European project HARBASINS, www.harbasins.org

Elsebach, J.; Kaiser, R.; Niemeyer, H.D. (2007b): Identifikation von erheblich veränderten Gewässerbereichen in der Tideweser, Untersuchungsbericht 05/2007, NLWKN-Forschungsstelle Küste, Norderney (unpublished)

Franzius, L. (1888): Die Unterweserkorrektur, Schrifttum und Anlagen aus Abschnitt IV und V (Tafel I bis IV) und Abschnitt II und III (Tafel VI)

Gerritsen, F. (1952): Historisch hydrografisch onderzoek Eems. Report. Hoorn, Rijkswaterstaat. pp. 28

Herrling, G.; Niemeyer, H. D. (2007a): Long-term Spatial Development of Habitats in the Ems-Dollard Estuary, report of the European project HARBASINS, www.harbasins.org

Herrling, G.; Niemeyer, H. D. (2007b): Set-up of a hydrodynamic model for the Ems-Dollard estuary, report of the European project HARBASINS, www.harbasins.org

Herrling, G.; Niemeyer, H. D. (2007c): Reconstruction of the historical tidal regime of the Ems-Dollard estuary prior to significant human changes by applying mathematical modeling, report of the European project HARBASINS, www.harbasins.org

Herrling, G.; Niemeyer, H. D. (2008a): Comparison of the hydrodynamic regime of 1937 and 2005 in the Ems-Dollard estuary by applying mathematical modeling, report of the European project HARBASINS, www.harbasins.org

Herrling, G.; Niemeyer, H. D. (2008b): Set-up of a morphodynamic model for the Ems-Dollard estuary, report of the European project HARBASINS, www.harbasins.org

Herrling, G.; Niemeyer, H. D. (2008c): Identification of the spatial effect of solid structures on the hydro- and morphodynamics in the Ems-Dollard estuary by applying mathematical modeling, report of the European project HARBASINS, www.harbasins.org

Homeier, H. (1962): Historisches Kartenwerk 1:50 000 der niedersächsischen Küste, Jahresbericht der Forschungsstelle Küste, Band XIII

Homeier, H. (1969): Der Gestaltwandel der ostfriesischen Küste im Laufe der Jahrhunderte. in: J.Ohling (Hsg.): Ostfriesland im Schutze des Deiches. Bd. II. Eigenverl. Deichacht Krummhörn, Pewsum

Homeier, H. (1977): Einbruch und weitere Entwicklung des Dollart bis um 1600, Jahrbuch 1976, Forschungsstelle Küste, Bd. 28, Norderney, 1977

Niemeyer, H.D. (1991): Case study Ley Bay: an alternative to traditional enclosure. Proc. 3rd Conf. Coast. & Port. Eng. i. Devel. Countr. Mombasa/ Kenya

Niemeyer, H.D. (1997): Überprüfung der Bestickhöhen von Deichstrecken an der Unterems, Arbeiten aus der Forschungsstelle Küste Nr. 13

Niemeyer, H.D. (1999): Effects of estuarine waterway deepening on mean tidal peaks and range. Proc. 26th Int. Conf. Coast. Engg. Copenhagen/Denmark. Am. Soc. Civ. Engrs., New York

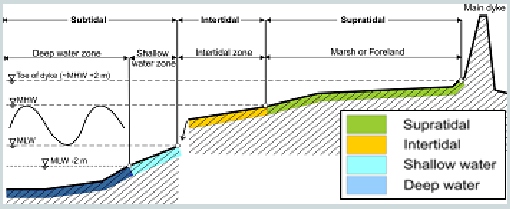
Wetzel, V. (1987): Der Ausbau des Weserfahrwassers von 1921 bis heute, Jahrbuch der Hafenbautechnischen Gesellschaft Hamburg, Band 42

Annex 1:

Identification and quantification of changes of littoral habitat areas as an effect of human interferences

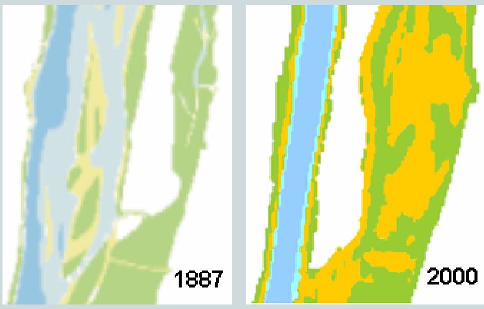
In the course of the last century most estuaries experienced significant changes in their littoral environment due to human impacts like e.g. land reclamation, waterway deepening and streamlining.

Historical and present states of the estuarine topography allow an evaluation with respect to the spatial extension of the distinct estuarine habitats differentiated in deep water, adjacent shallow water areas, intertidal flats and supratidal marshes.



Definition for distinct estuarine habitat zones

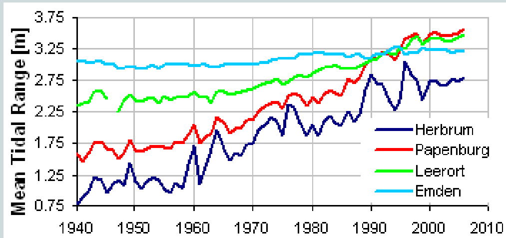
The comparison of the spatial extension has been used for the quantification of habitat changes and furthermore for highlighting the pressure due to human impacts on the estuarine environment.



Morphological alterations and changes of distinct habitats (Lower Weser)

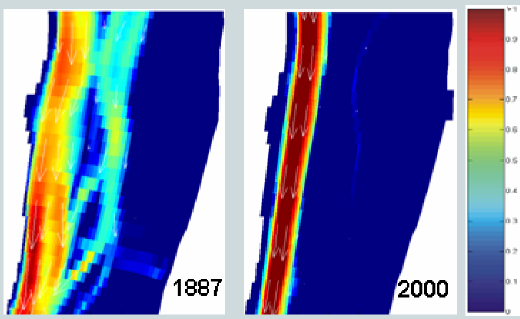
Quantifying the changes of hydro-dynamical parameters as an effect of human interferences

Changes of hydrodynamical parameters, e.g. of tidal range or of current velocities, are closely related to morphological alterations and vice-versa. An objective benchmark for the identification of significant changes in the tidal regime due to human interferences, is a comparison of representative hydro-dynamical parameters of today with those for the historical reference state.



Increase of tidal range in the Lower Ems as an effect of waterway deepening during the last decades

The application of mathematical hydro-dynamical models for current and historical bathymetries allow the quantification of the changes in water level and flow conditions in accordance to the changes in system geometry.



Current velocities in the Lower Weser before the first waterway deepening and nowadays

Biological assessment based on changes of habitat areas and of hydrodynamical parameters

The integrated investigation of hydro- and morphodynamical changes is the basis for the evaluation of the ecological state and eventually the ecological potential of the water body.

An estuary consists of a variety of habitats which all provide a suitable environment for specific plants and animals being optimally adapted to the local physical environment. Quantifications of the hydro- and morphodynamical alterations, e.g. the spatial loss of shallow water areas or the increase of current velocities, can be used as comparable assessment criteria for the biological assessment of the habitats, e.g. changes of the diversity and the assemblage of species.