

## 2.5 Water as a means of transport

HARRO HEYER & JÜRGEN STAMM

**SUMMARY:** *The German Federal waterways network consists of about 7,350 km of inland waterways and about 23,000 km<sup>2</sup> of sea waterways. It is part of the trans-European network (TEN) of transportation routes on water. Waterways are an efficient, safe, and environmentally-friendly means of transport for national and international navigation. Sea ports are connected to international trade by sea-side access routes to the North Sea and Baltic Sea coasts. The continuing increase in traffic volume in sea and hinterland due to the globalised economy as well as rising inland traffic mainly related to EU enlargement in Eastern Europe require an efficient network of European inland waterways. Thus a major objective is to cope with the rising volume of total transport as far as possible by means of environment-friendly vessels and to optimise intermodality with railways and roads. For instance, the current transport cost for a bottle of wine by ship from Chile to Hamburg is about the same as by rail or lorry from Franconia to Hamburg. The safety and ease necessary for transport on water are enabled by permanent observation of the state and economical maintenance of all objects in and along the waterways. In 2003, inland vessels provided a goods vehicle distance travelled of about 64.2 billion tkm (tonne-kilometre) in Germany! i.e. 17.8% of the total goods vehicle distance travelled (rail: 19.9%, lorry: 62.3%).*

Hydraulic engineering measures improve the efficiency of waterways mainly by increasing flow depth. They are planned and executed according to the state-of-the-art in waterways engineering. In Germany, waterways engineering – focussing on the fairway – nowadays mainly concentrate on maintaining and regulating flow and transport processes, including consideration of the ship-induced load on bottom and bank. Development measures are mainly caused by rising vessel size and focus on improving nautical conditions in bottlenecks. Already when planning these measures, environmental protection and land improvement concerns should be considered and environmental protection purposes fostered. The effects of measures taken along waterways need to be increasingly estimated for medium to long-term periods considering several disciplines and on an extended geographical basis. Bodies of water that serve as transportation routes can, together with their fairways and bordering banks and foreland areas, already be considered as structures within a natural environment to a greater or lesser extent – subject to different physical, chemical and biological conditions, depending on the location. So today the waterway needs to be understood as a complex and comprehensive system with effects following very different mechanisms. Thus water, serving as a means of transport, has a marked interdisciplinary character.

### Water as a means of transport in coastal areas

Most of the access routes to sea ports are characterised by brackish water, i.e. a mixture of freshwater from the land-side outflow and salt water from the sea. Freshwater has a very low salt content (less than 0.1%) whereas the salt content e.g. in the North Sea can be up to 3.5%. In the Baltic Sea, the salt content decreases from Kattegat (connection to the North Sea) via Beltsee to Darsser Schwelle and from there to Fin-

nischer Meerbusen with a salt content of about 0.3%. With increasing salt content, the water density rises too; as a consequence, water with a higher salt content may be found at the bottom of a specific measurement point if complete vertical mixing of the meeting fresh and salt water masses does not occur. Strong mixing of the water column is caused by turbulent flow or strong swell.

For centuries, sea port access has developed on the one hand at the mouths of large rivers discharging high quantities of freshwater into the sea and which are, as a consequence, sometimes already quite deep; on the other hand at natural bays with only low freshwater inflow but sufficient natural depth to allow large vessels to approach the coast or even to enter the land as far as possible. Rivers with a brackish water zone are called estuaries. They are called tidal estuaries when the river mouths and the adjacent river reaches rise and fall with the sea tide. In the brackish water zone, freshwater organisms are confronted with a salt content increasing downstream. If they do not have the ability to swim upstream or to tolerate the salt content they will die off. Suspended and settling sediments of the river water transported downstream by the flow and suspended and settling sediments of the salt or brackish water transported upstream by the flood tide give rise to a turbidity zone. In this zone an increased silt sedimentation is observed which settles in backwaters, tributaries, port access routes and ports with a soft mushy consistency. Due to complex physical processes silt sedimentation can also build up in fairways with stronger currents.

### Use of coastal waters

A sea port can be located more than 100 km upstream of a river mouth. The further a large seagoing vessel can go upstream to reach its destination port within the river, the more economical the transport can be realised. Therefore various facilities have developed historically especially at

the estuaries. Increasing development of residential and industrial areas with the need and treatment of process and service water, the increase in modern tourism, local recreation and private boat traffic, the expanding international sea traffic with associated coastal and internal navigation, the extension of logistics centres for storing and handling goods, and the expansion of ports for seagoing vessels with a very large draught acting as junctions of an expanding traffic infrastructure are only some examples of the demands of these facilities. The utilisation pressure continuously rising especially in the estuary zones is confronted with the increased social need to safeguard and improve the special life spaces at the coast and in the estuary given by nature. In this context it has been crucial for centuries to minimise the risk for man caused by episodic storm tides.

Coastal areas are characterised by long-term change (development of marshes, secular rise of sea level, climate change) as well as by highly dynamic system states; therefore the further development of these areas requires more extended knowledge in order to set up sustainable concepts for realising construction measures compatible with nature.

**Development of sea port access routes**

Containers have been used in sea traffic since the early 1960s when seagoing vessels with a draught of 10 m could transport about 1,000 TEU (»Twenty Feet Equivalent Unit« standard container). The world’s largest »jumbo« container vessels that have been ordered recently and are planned for use at the end of 2005 will have a draught of 15 m and a cargo capacity of 9,200 TEU. Already in the early 1990s container vessels had reached dimensions preventing them from passing the Panama Canal. This »Post-Panmax-Class« with a maximum length of 318 m, maximum width of 42 m and maximum draught of 13.5 m can transport up to 6,750 TEU. Besides the development of container vessels, oil tanker size had increased already by the 1970s on oceans all over the world (in individual cases up to a

maximum draught of 25 m and a maximum width of 68.8 m).

For larger vessels, the cross-sections of sea port access routes have been adapted in several steps. For oil tankers, the fairway of the outer and inner River Jade had already been deepened to a reference bottom depth of 18.5 m below sea chart zero in the 1970s. Fairways to the container ports at Bremerhaven and Hamburg had been adapted to a reference bottom depth of 11 m below sea chart zero by the 1960s and, by the turn of millennium, further to a reference bottom depth of 14 m below sea chart zero in the outer River Weser and to a reference bottom depth of 14.4 m below sea chart zero in the lower and outer River Elbe. The system behaviour in and on the water is modified by deepening and widening the fairway. Fig. 2.5-1 shows, as an example, the change of mean high and low tide observed along the lower and outer River Elbe over a period of 100 years. Water levels given for 1900 are taken from TOLKMITT (1907).

It can be recognised that the tidal range has increased especially because of the lowering of low tide upstream of Glückstadt. As a consequence, more water flows into and out of the River Elbe today with the tide. Thereby flow velocities as well as flood and ebb stream paths of water particles can increase in the deep fairway, and the tidal path of the brackish water zone increases too; a consequence is that, due to the rising salt content, freshwater species are limited in their downstream spread earlier today than some decades ago. It is also important to consider tidal wave lines describing the current water level course along the river. Because of the reduced low water level at Hamburg and the increased high water level in Cuxhaven, the gradient of tidal wave lines increases during flood phases and decreases during ebb phases. This affects the sediment transport ratio within the body of water and at the bottom during flood and ebb current phases. This example gives a first idea of the complex interactions governing the activity in estuary systems.

**Water as a means of transport in inland areas**

Up to the early 19<sup>th</sup> century, mainly local modifications were undertaken within the beds of large rivers in order to protect property or to improve navigation conditions and they did not have large-scale effects. Urban construction measures defining banks, e.g. bridges or fortifications, mainly had local effects too. Notable changes to the river course were only caused by natural or man-made cut-offs (most of the time in order to prevent flood risks due to ice jams in meandering river sections). Most of the anthropogenic changes in river landscapes before the 19<sup>th</sup> century were flood protection measures serving land improvement purposes.

A new era dawned for international river navigation in

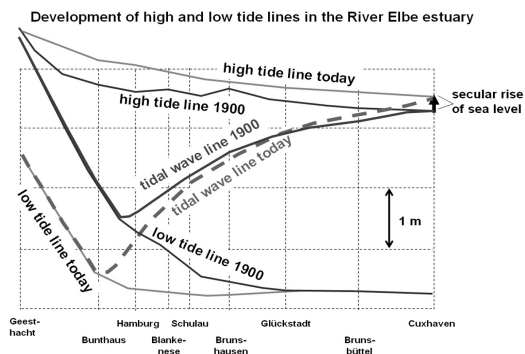


Fig. 2.5-1: Changes of characteristic tidal water levels in the River Elbe estuary.

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1815 with the reorganisation of Europe decided by the Congress of Vienna and the declaration of freedom for navigation (free of charge on TEN). This was the beginning of river development for the purpose of improving navigation conditions; however the development works could only be planned and realised following a uniform approach for multiple riparian states after 1850, once river engineering administrations had been created (ECKHOLDT 1998). But even the »Correction of the Upper Rhine« started in 1817 by J.G. Tulla (1770–1828) and completed only in the second half of the 19<sup>th</sup> century – with its main objective of deepening the Rhine by means of severe channel shortening – still aimed at the flood protection of settlements and at enabling agricultural use of the Rhine flats.

When judging past actions nowadays, we need to bear in mind that they had been socio-politically motivated too. By aiming at flood protection and making the river and its surroundings useable by man, these measures helped to secure people's existence.

## **Waterways engineering in inland areas**

Today, river correction initiated by waterways engineering mainly aims at improving navigation conditions at low to mean water level. This can be achieved by appropriate river correcting elements like groynes or longitudinal dikes in connection with management of bed load transport by the river (sediment supply in erosion reaches and bed load displacement which means local dredging in less deep reaches with subsequent discharge of dredged material into the current), where the river's free-flowing character is still maintained. The main river correction objectives consist not only in increasing the useable depth of water at low to mean water levels but also in producing a stable fairway and in equalising discontinuing bed slope gradients while – if necessary dynamic – bottom stability should be kept or obtained.

Regarding hydro- and morpho-dynamics, a river is a complex system. So these objectives can only be met if the river correction parameters are chosen in line with the natural processes characterising the respective river section, i.e. if their implementation is carried out in line with the characteristics of the respective river section. Particular care has to be taken when correcting rivers with a shifting bed; here a successful correction can only be lasting if the long-term and large-scale effects of the planned correction measures are already taken into account in the design.

So river training consists in modifying correction parameters (e.g. flow width during low water) as planned while considering and using natural morphodynamic development processes. It is connected with construction measures (erection, adaptation, and maintenance of river

regulating structures, e.g. groynes, longitudinal dikes, bottom sills) able to reach defined regulation objectives. In this context, regulating structures by themselves are a necessary but insufficient precondition; i.e. besides the structures themselves, the morphodynamic processes which are related to their effect and have been taken into account when designing the structure are an indispensable element of the overall measure. So the objective of a specific measure is typically not met by the structure on its own but requires the river's reaction. Therefore river training requires that the river is understood as a »dynamic system« where the structures provoke or modify natural processes that should be brought into a (sometimes new) dynamic equilibrium. Depending on the time frame and on the variance of the natural processes, the planned new dynamic equilibrium is not achieved immediately after execution of the structural measures.

In cases where it is not possible to obtain the necessary water depths to a sufficient extent by mere river regulating measures because of the hydrological and hydraulic conditions, the desired navigation conditions can be produced by constructing one or several impoundments.

If one compares a river regulated by river engineering measures with a non-regulated river, the following is noted regarding the discharge behaviour of flood waves: with a non-regulated river, damage caused by bank failure, jammed ice and floating material, formation of silting-up zones or even islands and generation of river branches even up to channel displacements is far more devastating for the riparian residents than in the case of regulated rivers. This is largely confirmed by historical documents.

## **Conclusions**

For more than 150 years man has been harnessing internal and coastal waters by increased waterways engineering activities. In accordance with navigation, land improvement, and ecological objectives, bed load management issues with the objective of creating a large-scale and long-term dynamic bottom stability of inland rivers are among the crucial river engineering activities nowadays (e.g. at the lower Rhine or middle River Elbe). Studies of an optimised design of flood channels and relocating dykes (e.g. at the middle River Elbe) regarding their effects especially on flood routing and bottom stability, studies about groyne forms optimised for ecological purposes as well as an assessment of development and maintenance measures at the River Elbe regarding their flood and storm tide neutrality and their environmental impacts have been undertaken; they show that river engineering measures will only be socially accepted nowadays if different disciplines collaborate while respecting the differing interests ♦