TIDE
Tidal River Development

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The Interreg IVB North Sea Region Programme

Secondary Channels in European Estuaries

Occurrence and Importance of Secondary Channels in European Estuaries - Literature study in the framework of the Interreg IVB project TIDE

In charge of the project:
Lower Saxony Water Management, Coastal Defence and Nature Conservation Agency, Germany

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Disclaimer

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1 Aim and Scope

The aim of this study was to investigate the occurrence and importance of secondary channels within tidal rivers along the southern North Sea. It aimed at retrieving valuable information on existing secondary channels which are comparable to the situation of secondary channels in the Weser estuary. The study focusses on natural (or nature-oriented) and self-sustaining secondary channels and the crucial factors of success for their stability and durability.

Due to the continuous adaptation of the main navigation channel, existing secondary channels and old channels respectively are suffering from increased sedimentation. The German Federal Waterways Administration (WSA) commissioned a system study regarding the left side branch/anabranch of the Weser estuary (Schweiburg) (BAW 2012). The aim of the system study was a better understanding of the side branch/ anabranch system by investigating its reactions on extreme hydraulic changes. Based on the findings, the Lower Saxony Water Management, Coastal Protection and Nature Conservation Agency (NLWKN), Department Brake-Oldenburg, is currently conducting a pilot study on how to revitalise the Schweiburg considering the guidelines and specifications of European environmental directives such as NATURA 2000 (Habitats and Birds Directives).

Thus, this study will provide additional information and insights for the management of secondary channels by elaborating on the lessons learned from European estuaries.

The first chapter gives an overview on the aim and scope of this report. Furthermore, a very short description of several terms connected to the object of investigation of this study is provided (see box). The second chapter summarises the results of the first phase of this study, the Quick-Scan. A table is shown with rough information on secondary channels in European estuaries. Chapter 3 will concentrate on three selected estuaries, the Humber, the Elbe and the Weser. Within this chapter it is elaborated on the knowledge and experiences in the treatment and prospects of secondary channels of those estuaries. This chapter closes with a summary and short concluding remarks related to river management. The last chapter provides conclusions on the European dimension of secondary channels.

Within the framework of this study, two terms were found to describe an additional branch of the main channel of a river: *secondary or side channel* and *anabranch*. The term *anabranch* it mostly used in Australia and its definition is as follows: An *anabranch* leaves the main channel of a river and re-joins it further downstream (Oxford Dictionaries, oxforddictionaries.com/definition/anabranch – access April 2012). The investigation retrieves that the utilisation of the term *secondary or side channel* varies. On the one hand, the term *secondary or side channel* is used to describe a branching system of creeks in estuaries. On the other hand, it is used to characterise an additional channel beside the main channel of a river (e.g. Simons et al. 2001; Schoor 2007, 2010, 2011; Buijse 2010). This encompasses branches of a river which are not used as shipping lanes, thus, it indicates a by-pass of limited length ranging from hundreds of meters to a few kilometres, and a system consisting of two branches, i.e. one for the ebb and the other for the flood current (for the Thames e.g. Burningham & French 2011). Within this report the term ***anabranch*** will be used, because the background of this study fits best with the situation found in the Weser estuary where the existing branches are the remainder of an old branching system before engineering work took place (see e.g. Franzius 1888; Wetzel 1988; Lucker et al. 1995; Schirmer 1995).

2 Methodology

This chapter gives a short description of the methodological approach of this study. Fig. 1 illustrates the working steps and the resulting products.

In order to identify estuaries with branching systems, a satellite photo interpretation was conducted. Although a number of these pictures were not taken during low tide, anabranches and secondary channels could be identified. At the mainland coast the investigation area covers the northern part of the English Channel in France up to the river Seine. Going up north the investigation area ends at the Varde Å in Denmark. In the UK, the investigation starts at the river Tay near Dundee in Scotland and ends in the south with the river Swale.

Additionally, an internet enquiry has been executed in order to get a rough idea where secondary channels and anabranches could be found. The relevant information about the investigated estuaries have been summarised in Table 1.

In a next step, two estuaries containing anabranches similar to those of the river Weser have been identified and selected. To complete the picture of anabranches and secondary channels in the investigation area, a short description of the existing anabranches in the Weser is given.

Based on the available information and data, conclusions were drawn as lessons-learned for the Weser estuary according to anabranches and their consideration in river management.

Finally, at the end of the study it is tried to summarise the lessons-learned and fed them into general conclusions for the management of anabranches in a European dimension.

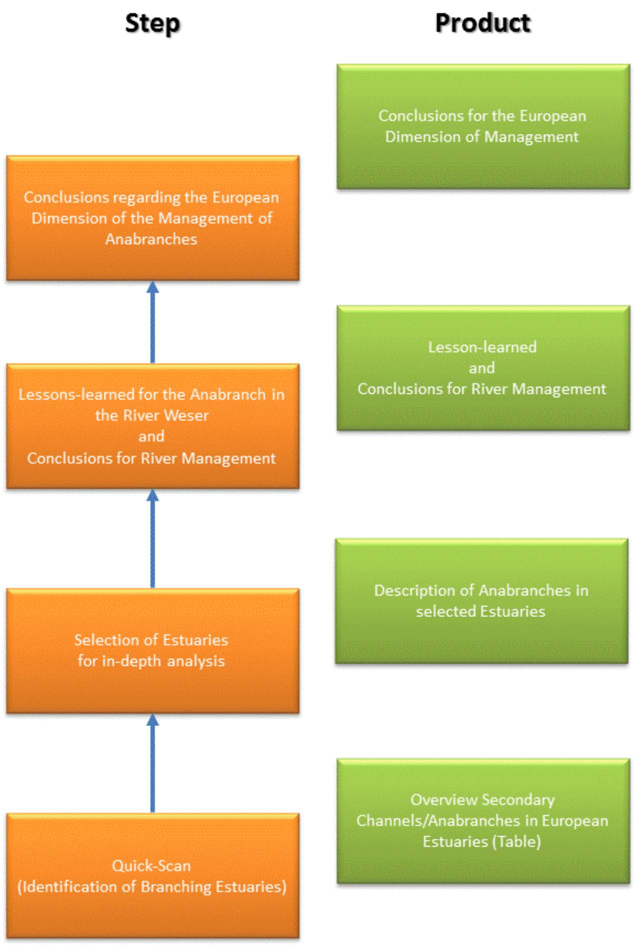

Fig. 1: Methodological steps and their products.

3 Results of the Quick-Scan

Table 1 shows the result of the Quick-Scan of estuaries along the southern North Sea and the northern part of the English Channel. The Quick-Scan retrieves that not many anabranches exist in European rivers of the North Sea. In some European estuaries, secondary channels exist. Depending on the utilisation by shipping, e.g. leisure or transport, the estuaries have undergone several engineering works over the last decades or even centuries (called “channelization”; see e.g. Gregory 1977; Brookes et al. 1983; Franzius 1888; Wetzel 1988; Gregory 2004, 2006; Simon & Rinaldi 2006; especially for the European *TIDE* estuaries described in Ducrotoy 2010). For better accessibility of harbours to the sea, navigation lanes (*fairways*) were and will be dredged and regulated. In many cases this led to a single channel system of the estuary whereas the other channels suffer from regulation and straightening of the fairway. For example, the navigation lane of the outer Weser estuary probably shifted from north to south with a frequency of 400 to 500 years (Homeier 1967). Nowadays, only one – recently fixed – branch of this originally shifting system is used as navigation lane by big vessels (container and bulk).

A comprehensive overview of the historical morphological development over the last 100 years of the *TIDE* estuaries has been investigated (Hamer et al. 2012).

This chapter gives a rough overview on the current status of the estuaries in the investigation area which do not have anabranches in their reaches. The description is based on the current visual impression of the investigation by freely available satellite photographs and antique maps, and backed up by the publication of Ducrotoy (2010). However, there is sparse information available on secondary channels or anabranches within the investigation area of this study. Most available information concentrates on different issues of rivers, e.g. hydrology, morphological development and ecological status, but not in relation to the specific objective of this study. Nevertheless, in chapter 4 a detailed description of the development of selected estuaries with anabranches will be given.

	River	Anabranches/ Secondary channels	Barrier/Sluice	Description of status of anabranches or secondary channels (if existent)	Shipping lane (leisure or transport)
France	Seine	not visible	no	fore land visible in the mouth of the estuary; old channels visible in the area beside the river; no side branches	non-leisure
	Bethune	none	yes	n.a.	no
	Somme	none	yes	wide fore land; sand plates	no
	Authie	none	yes	wide fore land; sand plates	no
	Canche	none	no	n.a.	no
Belgium	Ijzer	none	yes	n.a.	no
	Scheldt, Westerschelde	secondary channel	no	secondary channels: ebb and flood channels	yes
The Nethelands	Oosterschelde	none	yes	n.a.	leisure
	Lek	Bakenhof	yes	anabranches/secondary channel can be found behind the sluices, locks and barriers, i.e. without tidal influence	both
	Maas	secondary channel	yes		both
	Rhein/Ijssel	Klompenwaard	yes		both
		Beneden Leeuwen	yes		both
		Opijnen	yes		both
		Gameren	yes		both
		Vreugderijkerwaard	yes		both
Germany	Ems	Hatzumer Sand	yes	Length of secondary channel very short	both
		Bingumer Sand	yes	Length of secondary channel very short	both
	Jade	none		n.a.	
	Weser	Fedderwarder Shipping Lane		main navigation lane for shipping in the Weser estuary	both
		Wurster Arm		secondary channel in the estuary of the Weser	leisure
		Schweiburg, Strohauser Plate		Anabranch	both
		Harrier Sand		Anabranch	both
	Elbe	Borsteler Binnenelbe mit Hahnöfer Sand		Embankment 1962	both
		Bützflether Sand		Embankment 1971	both
		Haseldorfer Binnenelbe		Embankment 1978	both
		Hanskalbsand und Neßsand		Connection by a jetty 1967/68, artificial	both
		Hahnöfer Elbe entsteht		1973/74	both
		Rhinplatte		Jetties installed in 1983/85, artificial	both
		Pagensand		Jetties installed in 1987/89, artificial	both
		Schwarztonnensand		artificial	both
		Lühesand		morphologically stable, artificial	both
	Eider	none	yes	n.a.	no
Denmark	Ribe A	none	yes	n.a.	no
	Sneum A	none	yes	n.a.	no
	Varde A	yes	no	very short secondary channel	no
UK	Tay	none	no	n.a.	no
	Tyne	none	yes	n.a.	no
	Wear	none	no	n.a.	no
	Tee	none	no	n.a.	no
	Humber	Faxfleet	no	Short anabranch at the confluence of rivers Trent and Ouse	both
		Read's Island	no	Short anabranch	both
	Wash	none		n.a.	no
	Deben	none		n.a.	leisure
	Orwell	none		n.a.	leisure
	Stour	none	yes	fore lands are exsiting	leisure
	Colne	?	no	sand plates and fore lands are existing	leisure
	Blackwater	none	no	n.a.	leisure
	Crouch	Althorne Creek	no	n.a.	leisure
	Roach	none	no	n.a.	leisure
	Thames	secondary channel	yes	sand plates	both
	Swale	yes	no	sand plates	leisure

Table 1: Overview of investigation on secondary channels and side branches in European estuaries in the southern North Sea and the northern part of the English Channel (yellow – secondary channels; green – anabranches (old branches of the river or artificial branches); n.a. = not available)

In France, most of the rivers connected to the English Channel are closed by sluices, locks or barriers. Thus, the tidal influence on these rivers is limited to the area in front of these constructions. In the mouth of some rivers, e.g. Somme and Authie, wide fore lands exist, neither channel fragmentation is visible nor has respective information been found. Fig. 2 shows two historical maps dated back to 1705 and 1759 of the Seine estuary in the Normandy (***Important remark***: The minor quality of these maps is due to copyright permissions. The pictures are only available as download and not as a high quality scan of the original map; for further information see: www.tooleys.co.uk and www.philaprintshop.com). The maps show several sand plates creating a multiple branching system in the mouth of the Seine estuary (Fig. 2 right hand side), but no anabranches. According to Ducrotoy (2010, p. 179-180), the estuary lost more than 90% of its intertidal area due to major engineering works for the accessibility and the port development in Le Harve (Port 2000). For compensation and restoration of the Seine estuary, different options are considered such as reconnection of old channels and re-establishment of tributary confluences. Ducrotoy (2010) describes the future establishment of an artificial channel and the restoration of a mud flat as a resting place for birds.

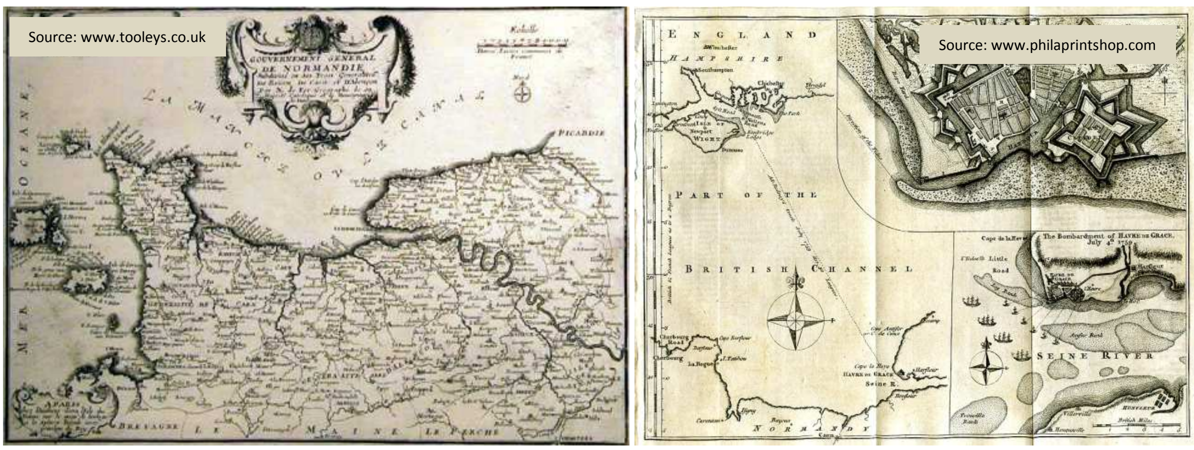

Fig. 2: Historical maps of the Seine estuary. Left: Nicolas de Fer, 1705. Right: Map from the *Gentleman's Magazine*, London, 1759. Sources: www.tooleys.co.uk and www.philaprintshop.com.

At the border of Belgium and The Netherlands, the river Scheldt (or Westerschelde) represents the major navigation lane for the ports of Antwerp (B) and Vlissingen (NL). The river Scheldt consists of a two channel system whereupon one channel is used by the flood current and the other one by the ebb current (see *TIDE* Factsheet for the Scheldt [www.tide-project.eu]). The concern for the river Scheldt due to the currently planned dredging was the negative consequence of increased siltation in the secondary channel. Therefore, a new solution for the sediment management has to be invented. One of the ideas is to nourish the existing sand plates in the river with the dredged sediment at specific places to achieve both the conservation of the existing two channel system and the increase of the flow velocity in the main navigation lane. Furthermore, the sand plates in the Scheldt are not as big as the islands in the river Weser. Consequently, the length of the channels around the sand plates is shorter than for the islands in the river Weser. Therefore, the situation at the river Scheldt is different to the situation of the anabranches in the river Weser.

Further up north in The Netherlands, the estuaries of the rivers Lek, Meuse and Rhine discharge into the North Sea. These estuaries were closed by barriers or locks due to the storm surge event in 1953. Only the port of Rotterdam is accessible, because the storm surge barrier will only be closed at a certain high water level. Within specific reaches of these freshwater rivers without tidal influence secondary channels exist which are already or will be restored in the near future. For these secondary channels investigations have been conducted in relation to navigation and ecological importance in line with the European environmental directives (see e.g. www.deltanatuur.nl; Bosschap 2011; Schoor 2007, 2010, 2011; Buijse 2010).

The Danish rivers which discharge into the North Sea are too small to be used by shipping and, in addition, are mainly closed by barriers and locks.

The situation on the east side of the UK is different. Many rivers discharge into the North Sea. They are more or less too small for transport vessels, but are intensively used by leisure shipping. Only a few such as the Humber and the Thames have navigation channels for transport vessels to the bigger ports. For example, a comprehensive investigation of the seabed behaviour over approx. 200 years has been described in Burningham & French (2011).

Summarising the results of the Quick-Scan, in the most European estuaries in the southern North Sea Region including the northern part of the English Channel anabranches or secondary channels are more or less absent. In historical times some bigger estuaries show a multiple channel system, e.g. the Seine. Later on in this study, a detailed description will be given for estuaries still having side channels and anabranches and for estuaries which have had anabranches and side branches in the past. During the last centuries the primary goal of river management was to improve the accessibility of harbours to the sea due to the economic drivers of trade and shipping. Many estuaries within the investigation area have been closed by sluices, locks or barriers. Thus, the tidal influence has been interrupted. On the other hand, the navigation lanes in estuaries without a technical construction were considerably regulated and straightened. The different stages of handling anabranches and secondary channels in European estuaries in the investigation area of this study can be identified as follows:

- Creating new channels besides existing navigation lanes, e.g. Seine, Humber
- Maintenance of multiple channel system (no anabranches), e.g. Scheldt, Elbe
- Revitalisation of old branches of a river (without tidal influence), e.g. Rhine, Meuse

A detailed description of the situation in the Humber and the Elbe will be given in the following chapter.

Finally, it can be stated that sparse information is available on anabranches and their management. Due to the absence of these items in many northern European estuaries, it is difficult to draw conclusions for the islands in the river Weser. The boundary conditions in the estuaries described above are different to those found in the river Weser. For example, the revitalisation of branches in the Rhine and Meuse is planned or has been realised in parts of these rivers without tidal influence. This is accompanied by e.g. a single flow direction and different boundary conditions for suspended matter. In the river Scheldt the surface area of the sand plates is smaller than the surface area of the islands in the Weser. Consequently, the length of the channels around these sand plates is shorter than for the islands in the river Weser.

4 Anabranches in European estuaries

4.1 Introduction and Methodology

The previous chapter gave an overview on the occurrence of secondary channels and anabranches in European estuaries. In some cases secondary channels exist in these estuaries, but are not comparable to the anabranches in the river Weser. This chapter will shortly describe the development of anabranches of the Humber and the Elbe estuary being more comparable to the anabranches of the Weser estuary. For further information on the morphological development of four European estuaries in the past 100 years it will be referred to (Hamer et al. 2012).

The detailed description in this chapter is based on literature found by internet search. Most of the references found and cited were available online at different research institutes, organisations or administrative bodies working at those estuaries. There are special websites available providing information on the natural environment and the current plans of river management in these rivers, e.g. in Germany the Federal Waterways Administration. At the end of each paragraph of this chapter, a list of references and websites for further information is provided.

4.2 Weser

4.2.1 Outline of historical development

The historical development of the Weser estuary is more or less comparable to the development of the Elbe estuary. Bremen is located approx. 70 km inland and has had a tradition of trade in the middle ages. Similar to the Elbe and the development of Hamburg the prospering harbour city Bremen has had an increasing demand for goods transported by vessels. Consequently, the river had to be adapted to the growing size of vessels. Therefore, Franzius (1888) started thinking about engineering and river works at the Weser estuary (Fig. 3). The three guiding principles were as follows:

- The channel of the estuary should become funnel shaped to increase the flow velocity and the eroding forces in the main channel.
- Closure and filling up of side channels and anabranches to focus the current on the main channel.
- Concentration of the tidal wave on the main channel by constructing jetties.

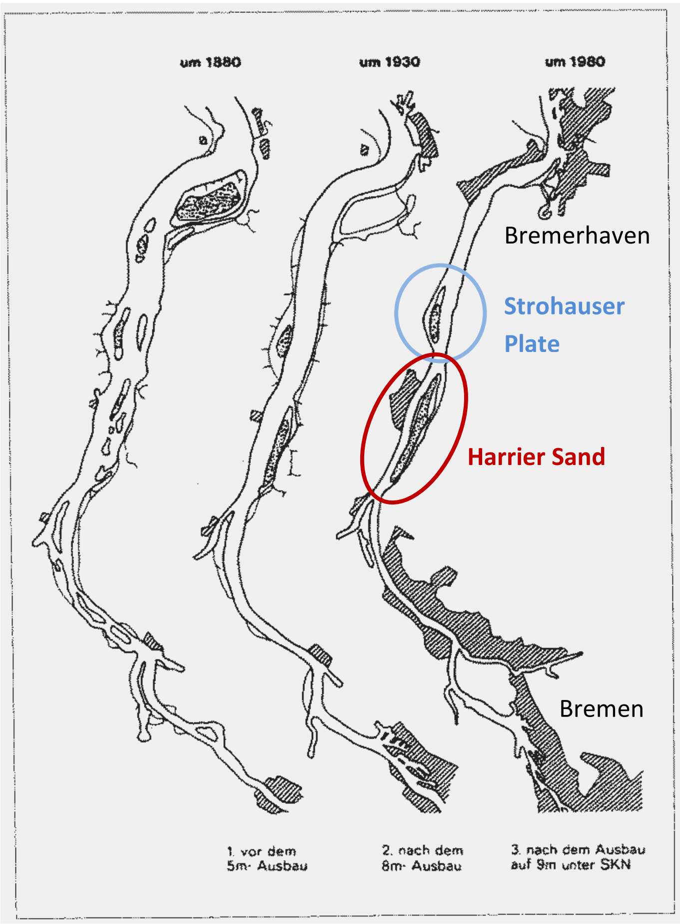

Fig. 3: Development of the Weser estuary between 1880 and 1980. Indicated are the two islands Strohauser Plate and Harrier Sand. Source: Lucker et al. (1995).

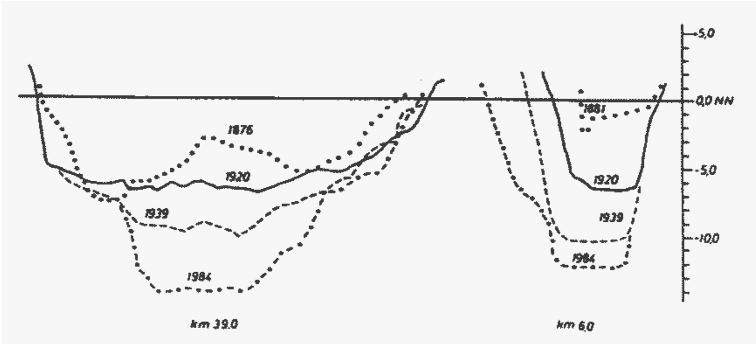

Fig. 4: Cross-section development of the Weser at selected stretches. Source: Lucker et al. (1995).

Fig. 4 shows the development of the cross-section of the Weser. The desired changes of Franzius according to the three guiding principles were achieved and have been improved by the following adaptations of the fairway. As a consequence of these river works the meandering of the Weser has been interrupted and several branches of the estuary were closed. After the impression of the storm surge in 1962 all tributaries of the Weser were closed off by barriers. Only two islands, Strohauser Plate and Harrier Sand, are still a remaining part of the former shape of the Weser. The channel between the island Strohauser Plate and the mainland is called “Schweiburg”.

The steps of the river works for the Weser fairway are shown in Table 2. The current process of fairway adaptation is in the state of the licensing procedure. A two-part adaptation of the fairway will be executed. The channel from the harbour of Bremerhaven up to the harbour of Brake shall be accessible for vessels with a draught of 12.80 m and the stretch between Brake and the harbour of Bremen shall be accessible for vessels with a draught of max. 11.10 m (WSA 2006).

Year	Draught (m)
1887 - 1895	5.00
1913 - 1916	7.00
1925 - 1928	8.00
1953 - 1959	8.70
1973 - 1977	11.00
Current	12.80 (Bremerhaven to Brake) 11.10 (Brake to Bremen)

Table 2: Steps of fairway adaptation in the river Weser since 1887. Source: Lucker et al. 1995, www.wsa-bremerhaven.wsv.de.

4.2.2 Anabranches and islands in the river Weser

Fig. 5 shows the location and shape of the two basis islands in the Weser estuary before the river works started in 1887. The island of Strohauser Plate and Harrier Sand were small islands in a multiple channel system such as the Lune Plate which is shown at the top of the figure near the city of Bremerhaven.

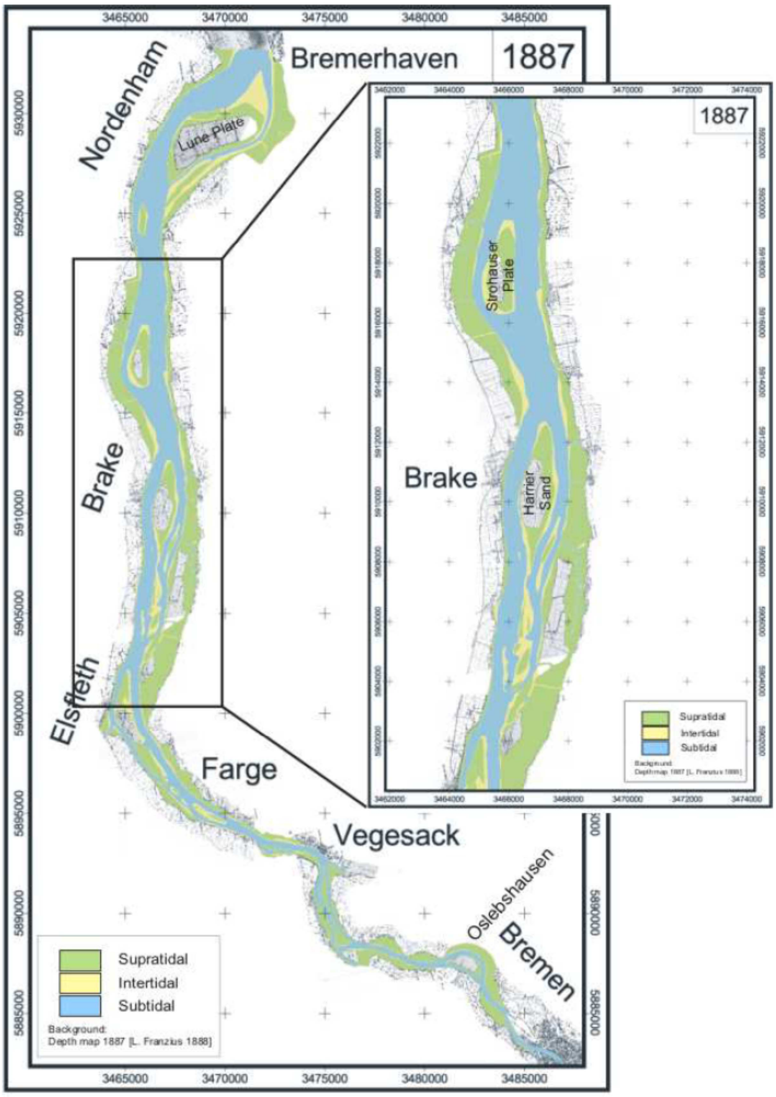

Fig. 5: Historical development of the anabranches in the Weser estuary. Source: Elsebach et al. (2007).

Fig. 6 indicates that the islands grew in size during the different fairway adaptations executed between 1887 and 2000. Within these periods the islands were armoured and fixed by jetties and groynes. Straightening and regulation of the main channel can be seen. The study of Elsebach et al. (2007) indicates a loss of subtidal areas between 1887 and 2000 of 20 km². Most changes have taken place before 1972, whereas afterwards the loss of subtidal was slight. The intertidal area grew from 12 km² in 1887 up to 22 km² in 2000. The supra tidal area decreased by approx. 15 km² (Elsebach et al. 2007, pp.13-14).

Today the anabranches of the Weser are suffering from high rates of infilling material. The river works, mainly straightening and deepening of the Weser led to a higher current velocity in the main channel and, therefore, the flood current enters the anabranch from both sides. This situation is similar to the Hahnöfer Nebenelbe in the Elbe. The drainage channel of the water board Stadland connected to the anabranch is depending on a specific depth for dewatering. Since 1973 a certain depth of the branch has to be maintained (BfG 2008b): in the northern part -3.27 m below sea level and in the southern part -0.5 m below sea level.

As reaction to the planned adaptation works in the fairway the tendency of siltation in the Schweiburg will stay the same level or will increase slightly (WSA 2006). Thus, similar to the situation in the Hahnöfer Nebenelbe a system study has been conducted to investigate the different options on how to maintain the current situation or even improve the situation with regard to the existing habitats in the anabranch (BAW 2006b).

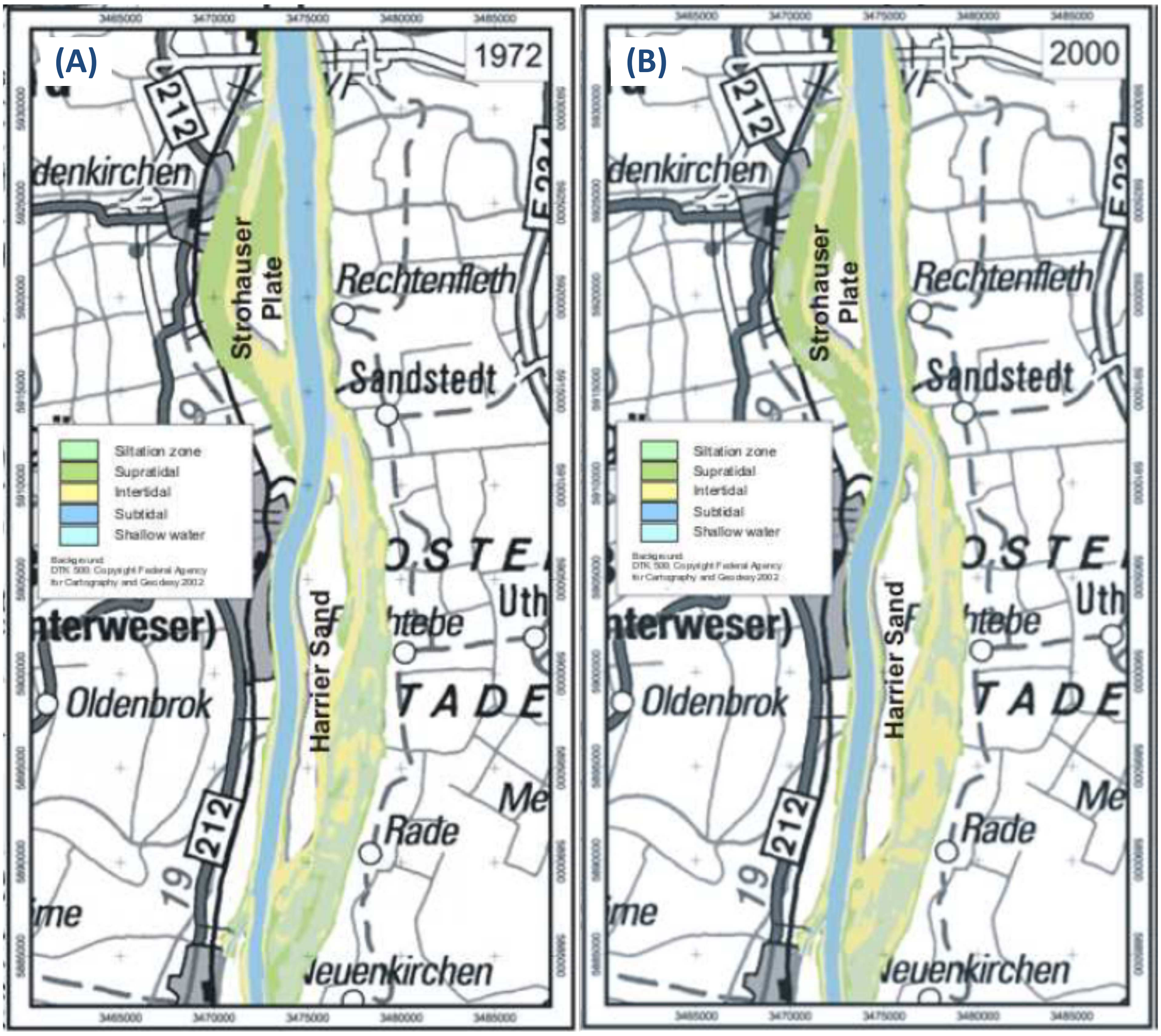

Fig. 6: Development of the anabranches of the river Weser shown in 1972 (A) and 2000 (B). Source: Elsebach et al. (2007).

4.2.3 Conservation status

In this section the conservation status of the Weser estuary will be described. In Fig. 7 the designated areas for the Habitats and Birds Directive in the Weser estuary are shown (NLWKN 2008/10). For the specific description of the ecological status and special regulations in view of nature conservation on regional and national level, it will be referred to BfG (2008b) and the websites of the NLWKN (Lower Saxony Water Management, Coastal Protection and Nature Conservation Agency, www.nlwkn.niedersachsen.de) and the River Basin Management District Weser (www.fgg-weser.de). For the anabranch of the Strohauser Plate a study is in preparation on the ecological potential of the anabranch with regard to the European environmental directives especially focusing on the Habitats and Birds Directive.

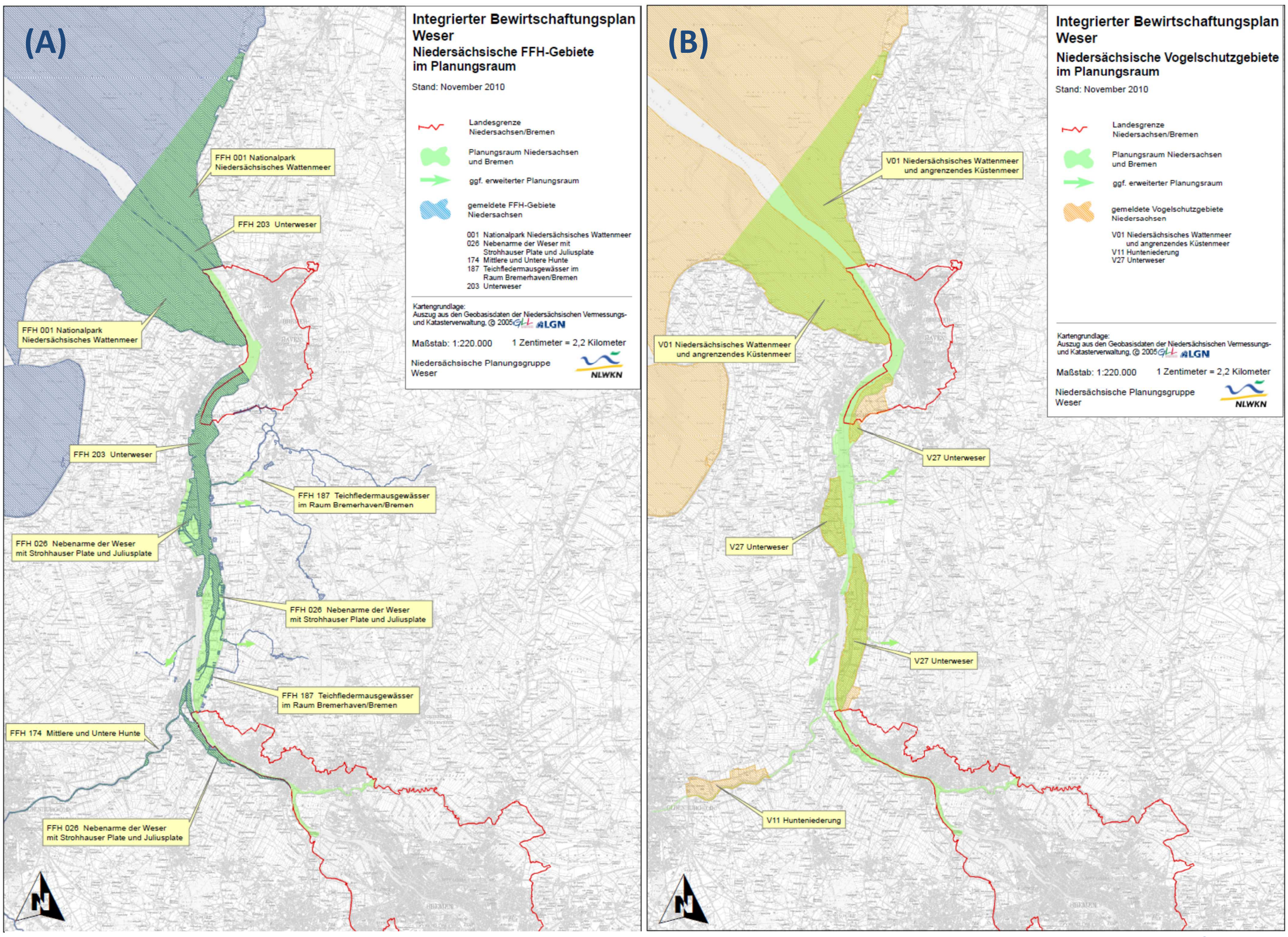

Fig. 7: Maps of the designation areas at the Weser estuary: (A) Habitats Directive and (B) Birds Directive. Source: NLWKN (2008/10).

4.2.4 Sources

Websites

www.wsa-bremerhaven.wsv.de
www.weseranpassung.de
www.nlwkn.de
www.fgg-weser.de

Reports

BAW [Federal Waterways Engineering and Research Institute] (2006b): Fahrrinnenanpassung der Unterweser – Fahrrinnenanpassung der Außenweser an die Entwicklungen im Schiffsverkehr sowie Tiefenanpassung der hafenbezogenen Wendestelle. Summationswirkungen der Anpassungen von Unter- und Außenweser. Gutachten zur ausbaubedingten Änderung von Transportprozessen und Morphodynamik. BAW 5.02.10048.00 – 2.

BfG [Federal Institute of Hydrology] (2008b): Unterweser. Unterhaltungsplan für den Abschnitt von km 44,0 bis km 52,0 – Berücksichtigung ökologischer Belange bei der Unterhaltung. Study prepared for the Federal Waterways Administration. BfG – 1588.

Elsebach, J., Kaiser, R., Niemeyer, H.-D. (2007): Spatial Balance of Habitats in the Weser Estuary. HARBASINS Report.

Franzius, L. (1888): Die Korrektion der Unterweser: auf Veranlassung der Bremischen Deputation für die Unterweserkorrektion. Guthe, Bremen.

Lucker, T., Busch, D., Knötzel, J., Schirmer, M. (1995): Unterweserausbau, Entwicklung des Schiffsverkehrs und Auswirkungen auf das Flusssystem. In Gerken, B., Schirmer, M. (eds.): Die Weser. Limnologie aktuell Vol. 6: 301 – 312.

NLWKN [Lower Saxonian Agency for Water Management, Coastal Protection and Nature Conservation] (2008/10): Integrierter Bewirtschaftungsplan Weser. Konzept der niedersächsischen Planungsgruppe.

WSA [Federal Waterways Administration] (2006): Teil B Unterweser (UW) Erläuterungsbericht zum Plan für die Anpassung der Bundeswasserstraße Unterweser von Weserkilometer 8 bis Weserkilometer 65.

4.3 Humber

4.3.1 Outline of historical development

The history of the Humber Estuary since the last ice age is comprehensively described in e.g. IECS (1994) and IECS & Shell UK (1987). Fig. 8 shows the status of the Humber in the 18th century. In the mouth of the estuary several channels can be seen whereas only some of them were navigable. The process of infilling mud and sand is dominating within the Humber Estuary. The sediment filling the estuary originates from the North Sea and from the erosion of the Holderness coast in the north of the estuary. Minor sources of the sediment are the rivers draining into the Humber (IECS 1994). Due to continuous siltation processes, land reclamation works had narrowed the Humber estuary. Today the entire Humber is constraint by sea defences. For example, the reclamation of Sunk Island (see red box in Fig. 8; starting in the 18th century and lasting until the 20th century) in the northern bank of the estuary led to higher current velocity in the southern part, and the sea defences are threatened by erosion.

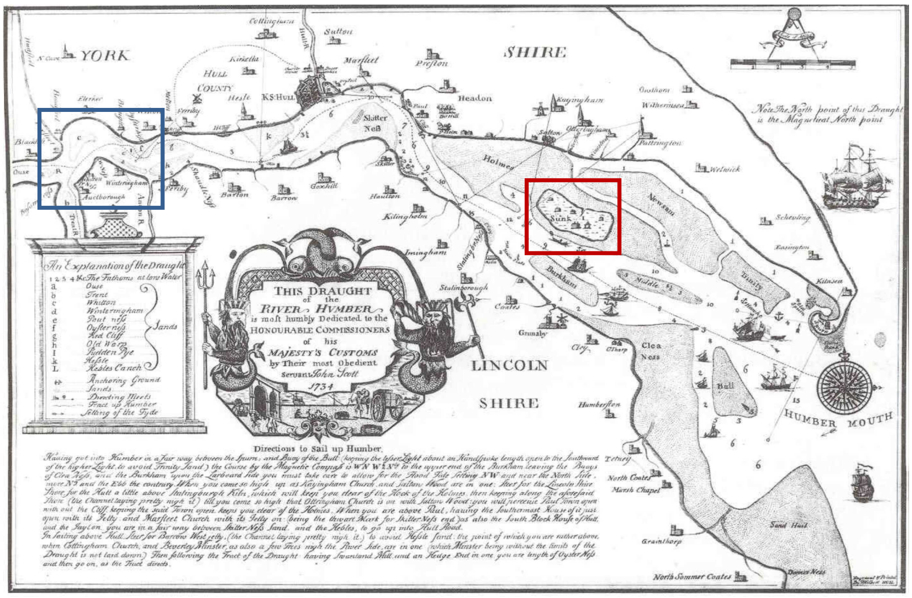

Fig. 8: Navigation map of the Humber from John Scott (1734), Sunk Island (red box) and the inner part of the estuary (blue box, see next figure). Source: IECS & Shell UK (1987).

At the inner part of the estuary (see blue box in Fig. 8 and detailed as satellite picture in Fig. 9), a net deposition of sediment is experienced. The flood current is able to move sediment to the inner part of the estuary, but the ebb current is not capable to remove it. Despite the fact of accretion, also erosion takes place due to the continuous shifting of channels. The shifting of the main channel between south and north is important for Read's Island which is a former mid-channel mud bank and was reclaimed in the 19th century (IECS 1994). Depending on the position of the main channel on specific stretches of the river erosion

Fig. 9: Map of the confluence of the rivers Ouse and Trent with Whitton Sand (green box) and Read's Island (violet box). Source: Google Maps (April 2012).

takes place or not. Read's island is a remainder of multiple channel system formerly existing in the inner part of the Humber estuary (Fig. 9). No further information on the morphological stability could be found for this study. This branch of the channel system is not as long as the anabranches in the Weser.

4.3.2 Conservation Status

This multiple branch system of the Humber Estuary has not been specifically investigated with regard to ecological values or special habitats, but it is part of international or national conservation designations (EA 2000, Aubry & Elliott 2005). These designations are ranging from "site-specific designations such as Sites of Special Scientific Interest (SSSI, under the Wildlife and Country Act 1981) to ecosystem-based designations such as Special Protection Area (SPA, under the EU Bird Directive) or Ramsar site, and the whole estuary is a European Marine Site" (Aubry & Elliott 2005; p. 29-30; Fig. 10).

The whole estuary shows a good status in case of productivity of benthic communities, it supports large populations of epibenthic crustaceans and approx. 83 species of fish have been found (Aubry & Elliott 2005). The Humber Estuary also serves as wildfowl habitat. Approx. 150,000 birds visit the area mainly in winter time (EA 2000).

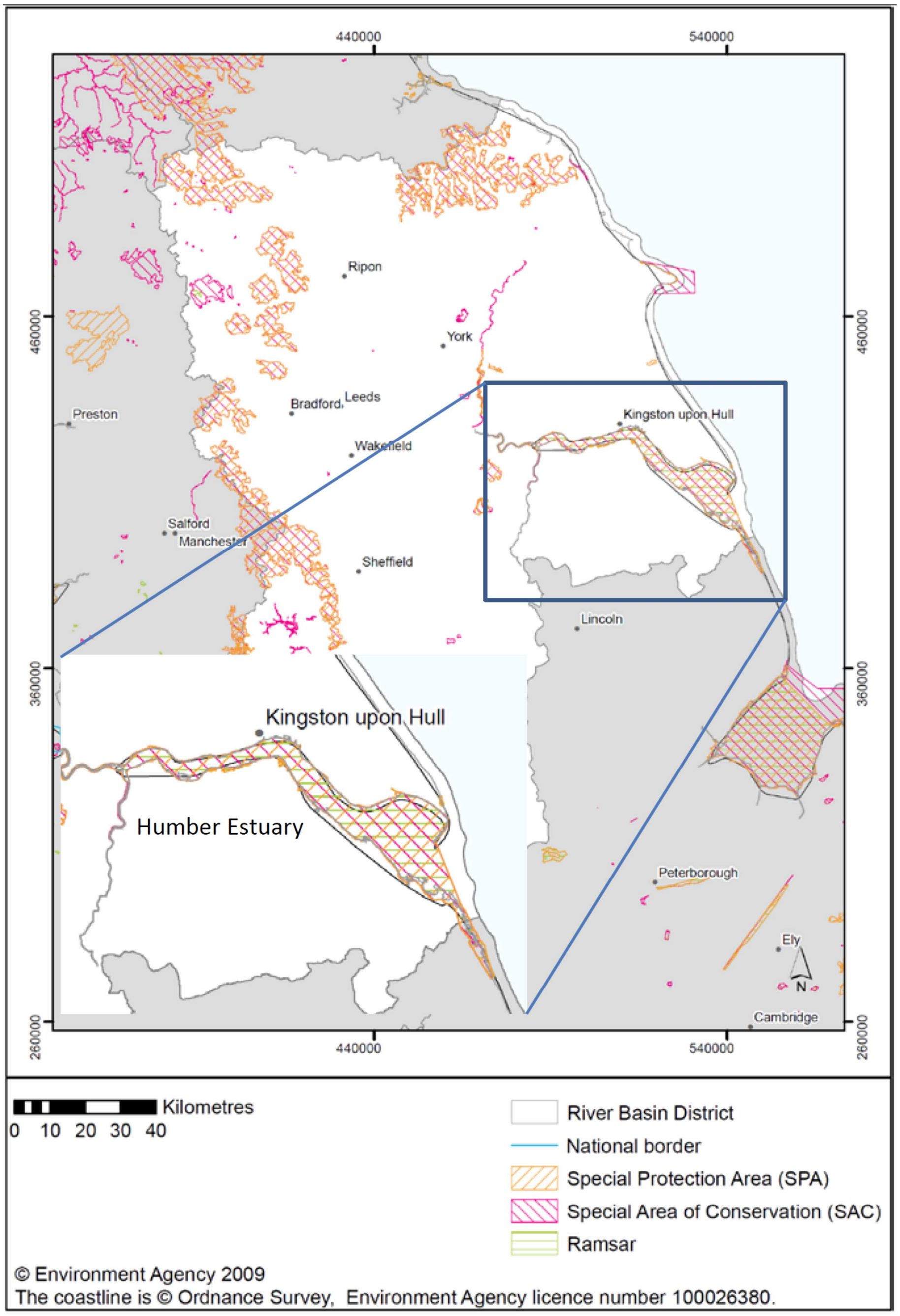

Fig. 10: Map of European sites within the Humber. Source: EA (2009).

4.3.3 Sources

Websites

www.humberems.co.uk
www.estuary-guide.net
www.hull.ac.uk/iecs/publications.html
www.humber-bib.hull.ac.uk
www.environment-agency.gov.uk
www.estproc.net

Reports

ABPmer (2008): Humber Holocene Chronology (13 p.). Summary prepared for the Environment Agency "Humber Estuary Geomorphology Study – Stage 2", Final report 2000. Found on www.estuary-guide.net – access April 2012.

Aubry, A., Elliott, M. (2005): The use of Environmental Integrative Indicators to assess anthropogenic disturbance in the estuaries and coasts. Application to the Humber Estuary, UK. Dissertation at the Institute of Estuarine and Coastal Studies (IECS) – University of Hull. Reference No.: YBB094-F-2005.

EA [Environment Agency] (2000): Planning for the Rising Tides. The Humber Estuary Shoreline Management Plan.

EA [Environment Agency] (2009): Habitats Regulations Assessment of the River Basin Management Plan for the Humber River Basin District.

EstProc (2003): The transport of fine sediment in the Humber estuary. Report 4 of Estuary Processes Research Project (EstProc) – www.estproc.net (access April 2012).

IECS & Shell UK (1987): The Humber Estuary. Environmental Background. ISBN 0-90538-11-4.

IECS [Institute of Estuarine and Coastal Studies] (1994): Humber Estuary and Coast. Technical Report prepared by IECS at the University of Hull commissioned by the Humberside County Council.

More information can be found on the websites mentioned above. Especially, the Humber Estuary European Marine Site as part of the Humber Management Scheme provides a lot of information on the Humber Estuary. Detailed information on further websites and responsible authorities etc. can be found in the "Humber Management Scheme Foundation Document" (www.humberems.co.uk/resources/reports.php).

4.4 Elbe

4.4.1 Outline of historical development

The harbour of Hamburg has a long tradition of shipping and trade of more than thousand years.

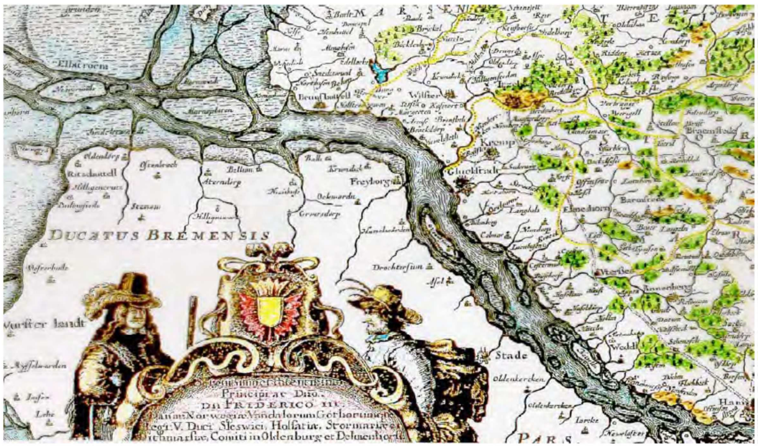

Fig. 11: Map of the Elbe from the North Sea (left) to the Hamburg. Source: GKSS 2007; the map is dated back to 1695.

Fig. 11 shows the shape of the Elbe in the 17th century. Despite the cartographic inaccuracy, this map shows the existence of several secondary channels and anabranches in the Elbe. At this period, the time for travelling from the open North Sea to the harbour of Hamburg could last up to four weeks (Boehlich 2006). Since the 1st century the river Elbe has undergone several works for regulating the main channel (Eichweber 2005). Tributaries, secondary channels and anabranches were cut-off from the main channel. The main channel has been dredged due to the necessary adaptation to an increased draught of sailing boats (e.g. clipper) and vessels. Considerable engineering works have taken place since 1896 (Table 3) in comparison to the centuries before. The historical hydrological and morphological development of the river Elbe is well documented (e.g. Schlüter 1988, Frässdorf 1999), and many documents can be found on the special website of the Hamburg Port Authority and the Federal Waterways Administration (www.tideelbe.de or www.wsa-hamburg.wsv.de).

Year	Depth (m)
1896/1897	6.00 (beneath MHW)
1897 - 1910	8.00 (beneath MLW)
1936 - 1950	10.00 (beneath MLW)
1957 - 1962	11.00 (beneath MLW)
1964 - 1969	12.00 (beneath MLW)
1974 - 1978	13.5 (beneath MLW)
1991 - 2000	14.50

Table 3: The steps of fairway works in the river Elbe starting in 1896 until to 2000 [MHW: mean high water level; MLW: mean low water level]. Source: www.wsa-hamburg.wsv.de – access April 2012.

Until 1920, the development of the fairway showed that increased dredging will not be sufficient to keep an appropriate draught. Consequently, further work had to be conducted such as the construction of jetties and the creation of artificial sand plates. During the following river works in the Elbe these artificial sand plates and islands have been enlarged and fixed (Schlüter 1988, Eichweber 2005, GKSS 2007). These works were realised due to the increasing effort of keeping the appropriate draught for the vessels in the fairway of the Elbe. Hence, the artificial islands and sand plates are regulation constructions for the main channel of the Elbe.

4.4.2 Anabranches and islands in the Elbe

In the river Elbe five islands exist which are mainly artificially constructed during the different river works starting 120 years ago (Fig. 12). The islands Rhinplate, Schwarztonnensand, Pagensand, Lühesand and Hanskalbsand-Neßsand are formerly mud or sand plates heightened by dredged material (Eichweber 2005). Hence, the former tidal creeks became anabranches of the Elbe. The development and the current status will be shortly described in this section.

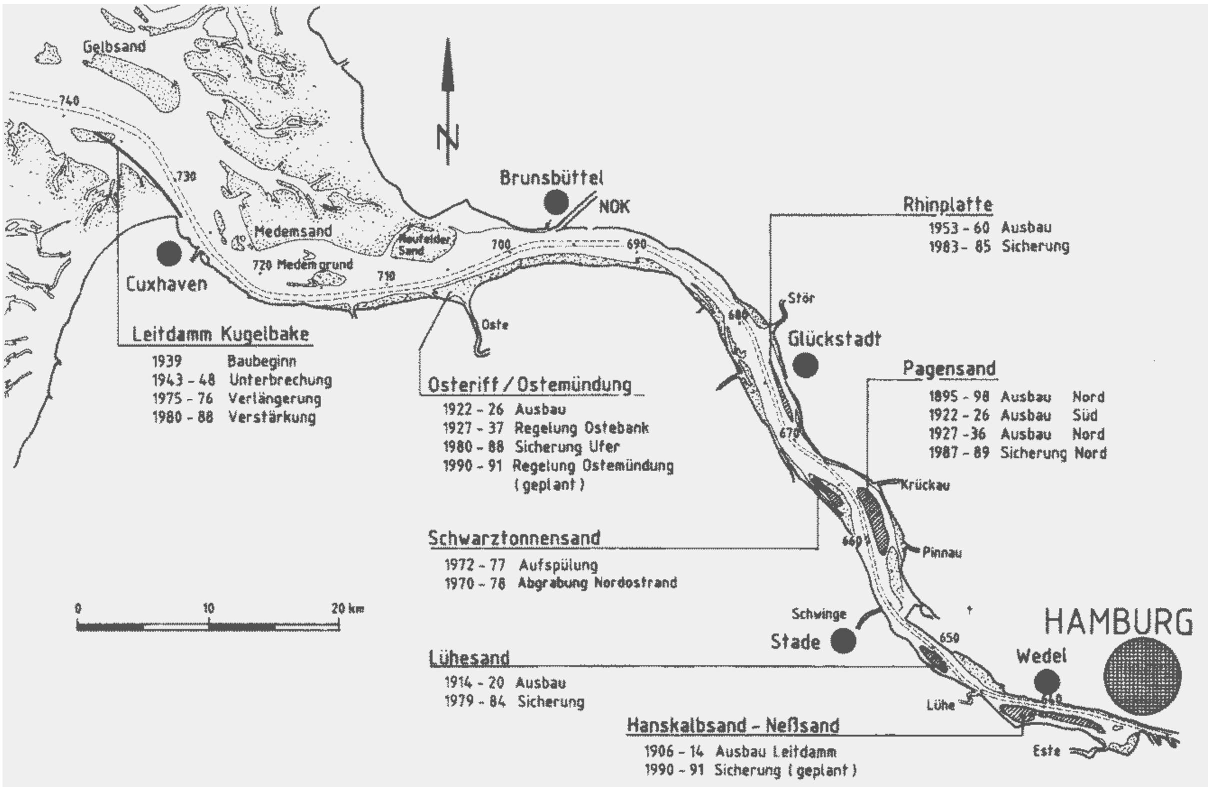

Fig. 12: Map of the river Elbe from Hamburg (right) to the North Sea (left). The map is showing the existing islands of the Elbe. Source: Schlüter (1988).

Rhinplatte and Lühesand

The situation at the Rhinplatte is similar to the situation at Pagensand (see below, Fig. 13). The former sand plate was enlarged and constructed as training wall for the main channel during the river works until the 1960ies for the 10 m draught (GKSS 2007). The island is also armored by jetties to reduce inappropriate currents between the main and the side channel (Schlüter 1988).

The same situation can be stated for the island Lühesand which was fixed and armored at the beginning of the 20th century and enlarged 30 years ago (Schlüter 1988).

Within the currently planned adaptation of the fairway no measures are provided at the Glückstädter and the Lühesander anabranch. These anabranches are morphological stable due to the relatively short length in relation to the main channel (Eichweber 2005).

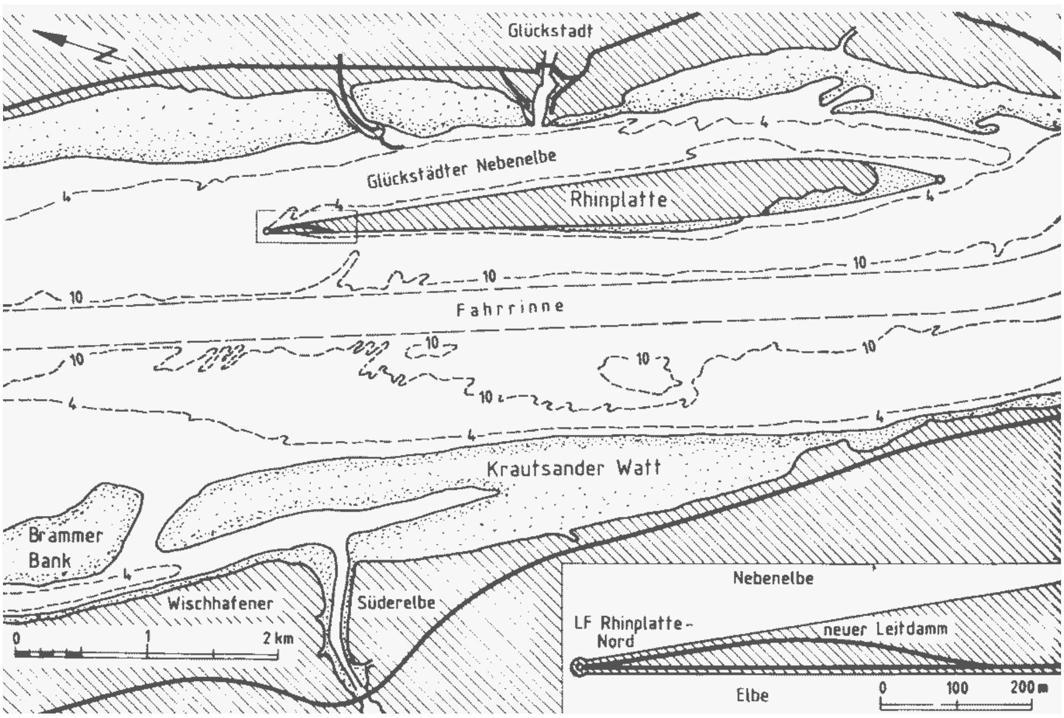

Fig. 13: Location and shape of the Elbe island Rhinplate. Source: Schlüter (1988).

Schwarztonnensand

The island of Schwarztonnensand was formerly an area consisting of mud and sand plates. During the river works at the beginning of the 1970ies these plates were filled up with dredging material from the main channel. Due to erosion of the island Pagensand on the opposite side the slope of Schwarztonnensand located at the main channel was dredged to smooth the bend of the river (Schlüter 1988). As a consequence of dredging the main channel and the regulation by the jetties, a continuous deposition of sediment and siltation was observed in this part of the anabranch (Frässdorf 1999, Fig. 14 (1) – status quo). The shallow water zone decreased about 22% since 1960 and the intertidal areas increased up to 75% (WSA 2010).

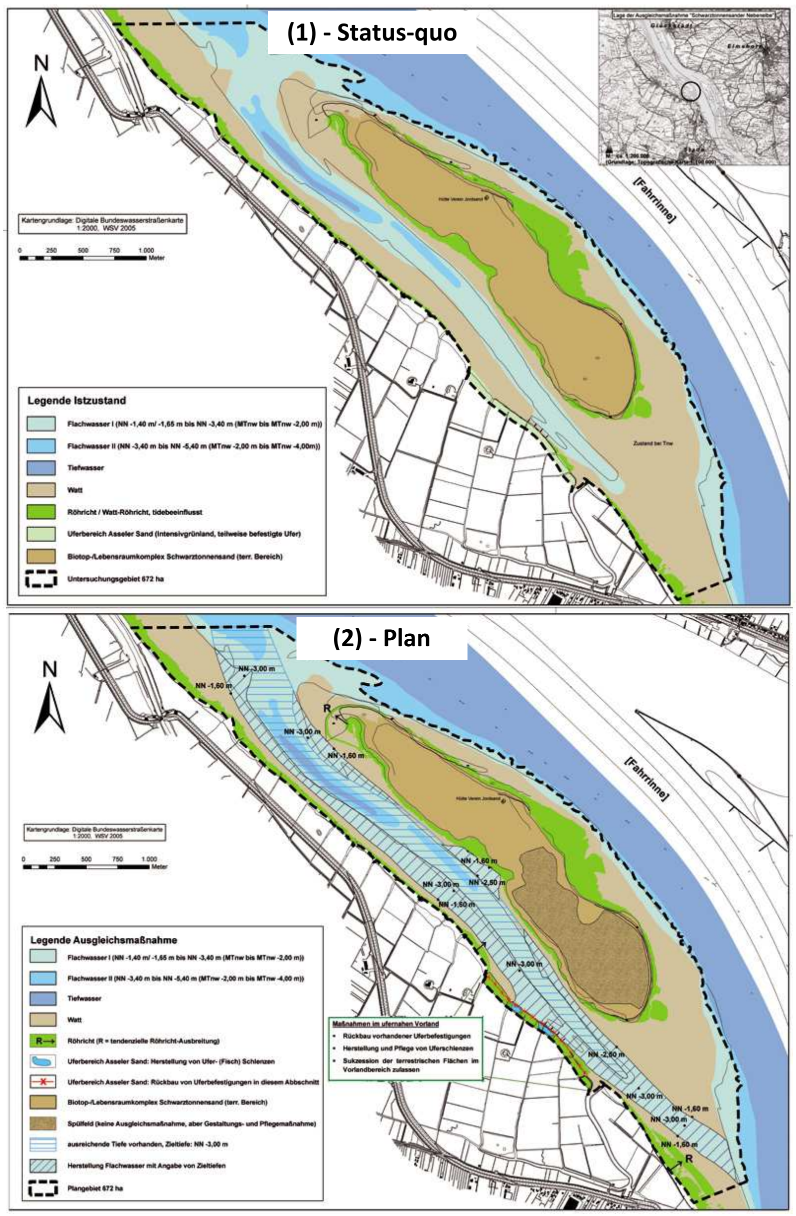

Fig. 14: Maps of the island Schwarztonnensand (north-west of Stade) showing in (1) the status-quo and in (2) the plan of creating shallow water zones. Source: www.zukunft-elbe.de – access April 2012.

Within the framework of the currently planned adaptation of the main channel the anabranch of the island Schwarztonnensand is envisaged to be restored. The former branch is intended to be opened again to create shallow water zones and to achieve a continuous stream discharge flow through (WSA 2010). Therefore it is necessary to dredge the amount of approx. 2 Mio. m³ of material to obtain a channel of a mean depth of 3m below sea level (=NN – Normal Null; Fig. 14 (2) – Plan). The durability of the planned measure within the anabranch of Schwarztonnensand is not predictable, the expertise of the German Federal Waterways Engineering and Research Institute (German: BAW – Bundesanstalt für Wasserbau) indicates a significant increase of suspended matter (BAW 2006a, p. 68).

Pagensand

The island Pagensand was formerly a sand plate which emerged in the 19th century. The sand plate was heightened by dredged material from out the main channel and armored against erosion over time (WSA 2008). The function of the island Pagensand with its jetties and groynes was to regulate the current within the main channel of the river. At the northern part of the island the jetties have been improved and enlarged to reduce inappropriate currents and to increase the ability of self-sustaining forces of the main channel (Schlüter 1988, see Fig. 15). The input of sediment into the anabranch of the island Pagensand could increase by approx. 5% (BAW 2006a), this may lead to increased siltation and shallower zones. The study of the GKSS (2007) indicates no significant changes in siltation and current velocity due to the river works between 1991 and 2000. For the currently planned adaptation of the fairway it is provided to dredge this branch to reduce the sedimentation rate in the area of Steinloch (HPA & WSA 2008).

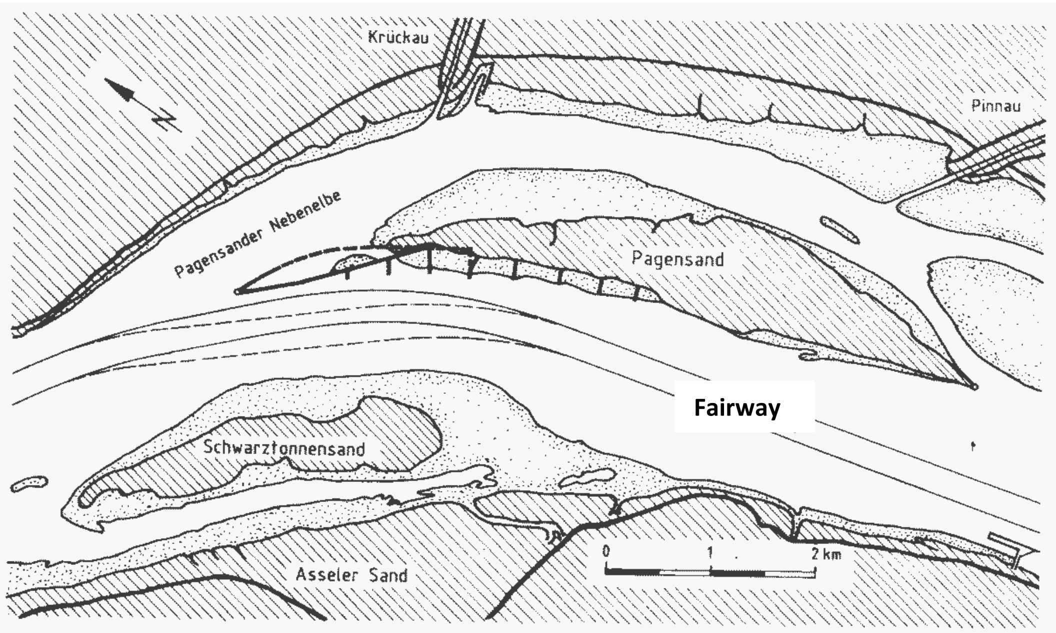

Fig. 15: Location and shape of the island Pagensand. Source: Schlüter (1988).

Hanskalbsand-Neßsand

The former sand plates Hanskalbsand and Schweinesand were heightened by dredged material and were fixed for regulation reasons at the beginning of the 20th century. In order to improve and to fix the fairway of the Elbe near Hamburg in 1920th a jetty between the islands Hanskalbsand and Neßsand were built (Schlüter 1988). The anabranch splitting up from the main channel is called Hahnöfer Nebenelbe, and is the longest of the five anabranches in the Elbe (Fig. 16).

The Hahnöfer Nebenelbe is part of a system consisting of the tributary Este (a small river draining an area in the south of Hamburg), the main channel of the Elbe and the "Mühlenberger Loch". Today, the "Mühlenberger Loch" is a small bay at the end of the Hahnöfer Nebenelbe of which dimension was reduced in 2003 due to the extension of an industrial area. Formerly, this bay was fresh water tidal flat at the confluence of the northern and southern branch of the Elbe.

Fig. 16: Map of the islands Hanskalbsand-Neßsand with the anabranch of the Hahnöfer Elbe. Source: Google Maps (2012).

The study of the BAW (1996) indicates that since 1950 minor siltation rates have been recorded for the Hahnöfer Nebenelbe, but other river works such as the closure of two side channels and the connection between the islands of Hanskalbsand and Schweinesand have had more influence on the development of this branch. Based on data sets available for the water flow through the Hahnöfer Nebenelbe the BfG (2008a) stated that no assured statements could be made for the development of this branch. The investigation of BAW in 1996 indicated that the flood current is first entering the upstream part of this branch and collides with the flood current also entering from downstream the Elbe. At the concourse of both currents the flow velocity is reduced which may facilitate adequate circumstances for sedimentation.

In the framework of the fairway adaptation in 1999 a new channel should be dredged as compensation. Due to the reclamation of approx. 875ha from the Mühlenberger Loch for industrial extension significant changes in hydrological boundary conditions were measured (BAW 2010). Therefore, also the new channel of the Hahnöfer Nebenelbe showed in 2003 significant sedimentation rates. The system study of the BAW (2010) is based on a two-step approach including seven different scenarios to achieve an optimal stream discharge within the Hahnöfer Nebenelbe. In the second step a detailed investigation of selected approaches has been conducted. The general conclusion of this study is that “taking all uncertainties and several assumptions into account the time period of siltation might be 2 or 3 years” (BAW 2010, p. 80). Another main conclusion of this study is that the Hahnöfer Nebenelbe and the adjacent Mühlenberger Loch will be filled up by sediment over the long-term. Only maintenance work could preserve the desired status of an open anabranch. Therefore, two recommendations have been given for long-term and short-term approaches. The short-term approach is based on the scenario *dredging the Este fairway* which is crossing the Hahnöfer Nebenelbe. The long-term approach depends in the basic decision whether the Hahnöfer Nebenelbe should kept open or not. Based on the outcome of this decision process different management measures are possible, but for all options human action is necessary (BAW 2010).

4.4.3 Conservation Status

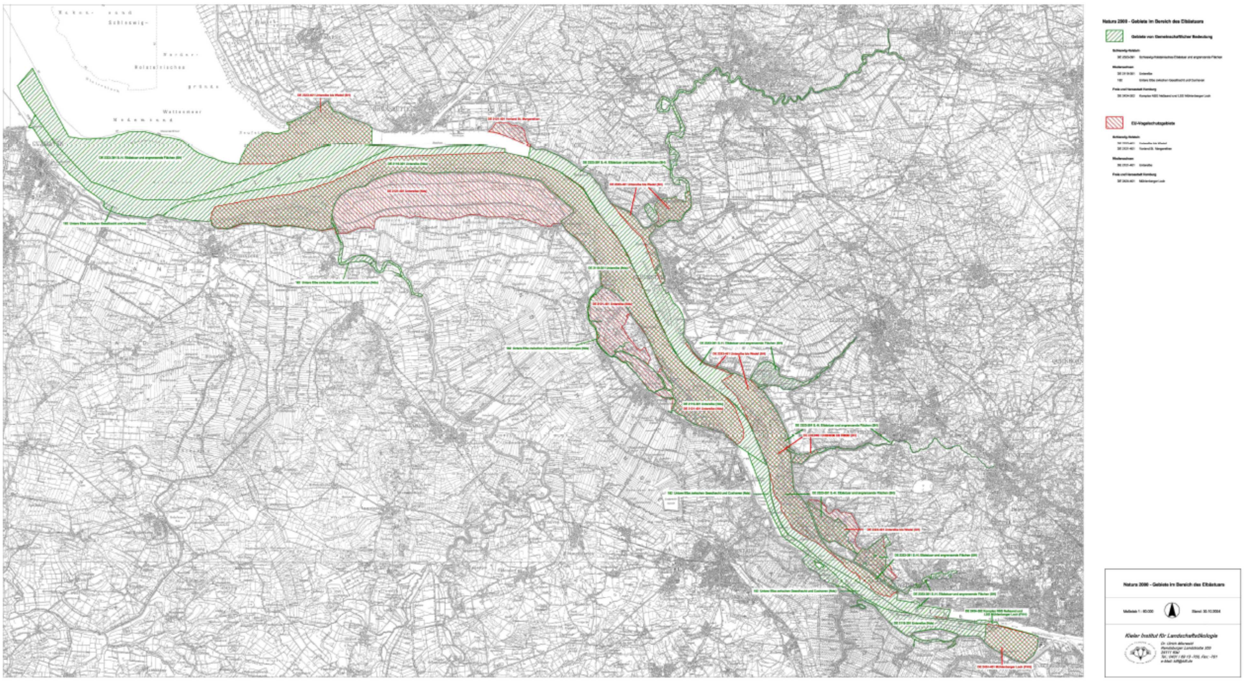

Fig. 17: Map of the conservation status of the river Elbe. Source: Institute for Landscape Ecology, Kiel 2004.

In Fig. 17 the conservation status of the Elbe with tidal influence is shown. For a comprehensive description of the ecological status and the designation areas at the Elbe it will be referred to the websites *www.NATURA2000-unterelbe.de* and *www.fgg-elbe.de*. On the website concerning NATURA 2000 the integrated management plan for the Elbe estuary is displayed with several documents and studies. Available information on the status and the implementation of the Water Framework Directive and the Flood Risk Management Directive can be found on the website of the River Basin District Elbe (www.fgg-elbe.de).

In line with the planning process of the fairway adaptation to today's requirement of shipping the responsible authorities initiated a comprehensive study on the ecological potential of the Elbe estuary. This study was conducted by the Federal Institute of Hydrology and was split into three parts (BfG 2002, 2003, 2004). The ecological deficits and the options to improve the identified deficits were described in the first part of the study (BfG 2002). In the second step the options to improve the ecological deficits were substantiated and detailed measures were developed (BfG 2003). The last part of the study comprises the ecological evaluation of detailed engineering measurements (BfG 2004).

For example, in Fig. 18 four measures are indicated in order to improve the ecological status at the island Schwarztonnensand. One of these measures is the re-connection of the anabranch to the main land in order to facilitate the creation of specific habitats such as shallow water zones or intertidal areas.

The improvement of the ecological status for the other anabranches which have been introduced in this report concentrates on the surface of the islands itself. Options are proposed in line with the dismantling of hard structure at the shore, or it is suggested to regrade and recontour slopes (BfG 2003).

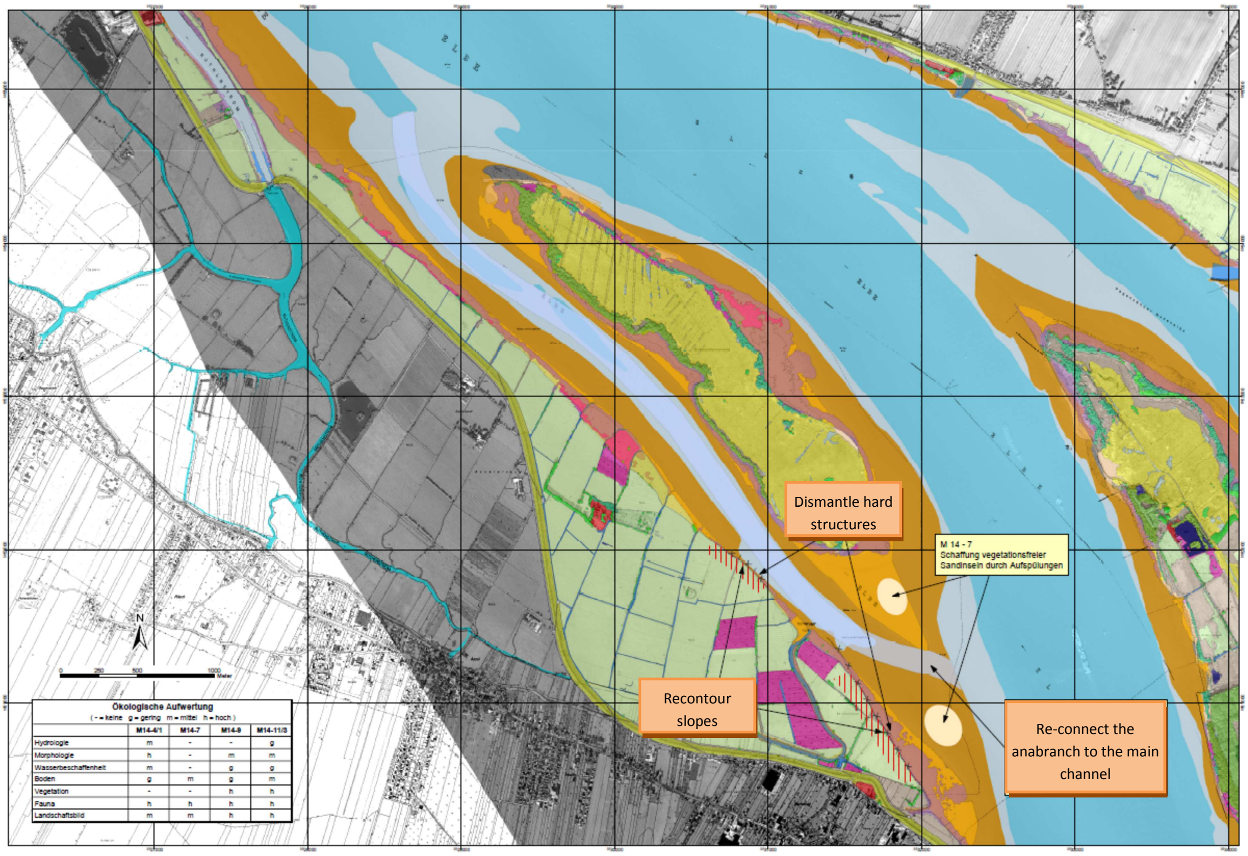

Fig. 18: Map of the options to improve the ecological status at the island Schwarztonnensand. Source: BfG (2003).

4.4.4 Sources

Websites

www.tideelbe.de
www.wsa-hamburg.wsv.de
www.hamburg-port-authority.de
www.portal-tideelbe.de
www.fahrrinnenausbau.de
www.zukunft-elbe.de
www.wasserblick.net
www.natura2000-unterelbe.de

Reports

BAW [Federal Waterways Engineering and Research Institute] (1996): Anpassung der Fahrrinne der Unter- und Außenelbe an die Containerschifffahrt. Zusammenfassendes Gutachten der Hydromechanik. Bundesanstalt für Wasserbau, Außenstelle Küste. BAW 9553 3417/34.

BAW [Federal Waterways Engineering and Research Institute] (2006a): Anpassung der Fahrrinne von Unter- und Außenelbe an die Containerschifffahrt. Gutachten zur ausbaubedingten Änderung der morphodynamischen Prozesse. BAW-Nr A 3955 03 10062.

BAW [Federal Waterways Engineering and Research Institute] (2010): Naturdatenanalyse und wasserbauliche Systemanalyse zur Ausgleichsrinne (A+E-Rinne) in der Hahnöfer Nebenelbe. BAW A 395 50 21 0099.

BfG [Federal Institute of Hydrology] (2002): Untersuchung des ökologischen Entwicklungspotenzials der Unter- und Außenelbe (Ökologische Potenzialanalyse) Teil 1. Gutachten für Projektgruppe Potenzialanalyse des WSA Nord, HPA und Behörde für Wirtschaft und Arbeit, Hamburg. BfG – 1346.

BfG [Federal Institute of Hydrology] (2003): Untersuchung des ökologischen Entwicklungspotenzials der Unter- und Außenelbe (Ökologische Potenzialanalyse) Teil 2 – Konkretisierung von Maßnahmen. Gutachten für Projektgruppe Potenzialanalyse des WSA Nord, HPA und Behörde für Wirtschaft und Arbeit, Hamburg. BfG – 1388.

BfG [Federal Institute of Hydrology] (2004): Untersuchung des ökologischen Entwicklungspotenzials der Unter- und Außenelbe (Ökologische Potenzialanalyse) Teil 3 – Ökologische Bewertungsgrundlagen für den Strombau. Gutachten für Projektgruppe Potenzialanalyse des WSA Nord, HPA und Behörde für Wirtschaft und Arbeit, Hamburg. BfG – 1412.

BfG [Federal Institute of Hydrology] (2008a): WSV-Sedimentmanagement Tideelbe – Strategien und Potenzial – eine Systemstudie. Ökologische Auswirkungen der Umlagerung von Wedeler Baggergut. Untersuchung im Auftrag des Wasser- und Schifffahrtsamtes Cuxhaven. BfG – 1584.

Boehlich, M.J. (2006): Hydrologische und morphologische Entwicklungen an der Tideelbe. Presentation at the symposium Tideelbe, 6./7. November 2006. Source: www.tideelbe.de – access April 2012.

Eichweber, G. (2005): Hydromorphologie des Elbeästuars. Federal Waterways Administration North. Source: www.natura2000-unterelbe.de – access March 2012.

Frässdorf, J. (1999): Morphologische Veränderungen der Nebenelben von ca. 1950 bis 1995. Presentation at the Colloquium „Kenngrößen der Ästuardynamik - Analyse und Darstellungsmethoden. Source: vzb.baw.de – access April 2012.

FFH-Lenkungsgruppe (2005): FFH-Gebiete im Elbästuar. Ziele für die Erhaltung und Entwicklung. Technical Report. Source: www.natura2000-unterelbe.de – access March 2012.

Freitag, C., Hochfeld, B., Ohle, N. (2007): Lebensraum Tideelbe. Coastline Reports (9): 69 – 79.

GKSS (2007): Sedimenttransportgeschehen in der tidebeeinflussten Elbe, der Deutschen Bucht und in der Nordsee. Technical Report GKSS 2007/20.

Heyer, H. (2006): Überlegungen zur Beeinflussung des Sedimenttransports in Ästuaren. Presentation at the „Gemeinsames Kolloquium BfG und BAW", 8./9. November 2006. Source: vzb.baw.de/digitale_bib/kolloquien.php?id=6738d8bfb34db7368497eee636432a57 – access April 2012.

HPA & WSA [Hamburg Port Authority & Federal Waterways Administration] (2008): Strombau- und Sedimentmanagementkonzept für die Tideelbe. Technical Report. Source: www.fahrrinnenausbau.de – access April 2012.

Project Group Fairway Adaptation (2004): Machbarkeitsstudie – Arbeitsfassung. Source: www.fahrrinnenausbau.de – access April 2012.

Schlüter, K. (1988): Die Strombauarbeiten an der Unter- und Außenelbe. Jahrbuch der Hafenbautechnischen Gesellschaft (43): 187 – 195.

WSA [Federal Waterways Administration] (2008): Anpassung der Fahrrinne der Unter- und Außenelbe an die Containerschifffahrt 1999. Kompensationsmaßnahmen und Erfolgskontrollen. Übersicht und Statusbericht 2008. Source: www.fahrrinnenausbau.de – access April 2012.

WSA [Federal Waterways Administration] (2010): Anpassung der Fahrrinne von Unter- und Außenelbe an die Containerschifffahrt. Planfeststellungsunterlage nach Bundeswasserstraßengesetz. Planänderung III. Umweltverträglichkeitsuntersuchung für die Kohärenzmaßnahme „Schwarztonnensander Nebenelbe mit Ufer Asseler Sand" und die Maßnahme „Barnkruger Loch". Planänderungsunterlage III Teil 12c. Source: www.fahrrinnenausbau.de – access April 2012.

WSA [Federal Waterways Administration] (2012): Anpassung der Fahrrinne der Unter- und Außenelbe an die Containerschifffahrt. Bericht 2011. Abschlussbericht Erfolgskontrollen. Source: www.portal-tideelbe.de – access April 2012.

More and detailed information can be found on the websites mentioned above. Especially the website www.tideelbe.de is a profound starting point to get and collect information on the development and current plans for the Elbe. The responsible authorities for the Elbe are the Hamburg Port Authority and the Federal Waterways Administration.

4.5 River Management and Anabranches in European Estuaries

European rivers and estuaries have undergone several engineering works over centuries, but these works accelerated considerably during the last 120 years (called “channelization”; see e.g. Gregory 1977; Brookes et al. 1983; Franzius 1888; Wetzel 1988; Gregory 2004; Gregory 2006; Simon & Rinaldi 2006; especially for the European *TIDE* estuaries described in Ducrotoy 2010). These engineering works were conducted in order to improve and to maintain accessibility of harbours and ports to the sea. These works started already centuries or even thousands of years ago. The main driver for regulating and straightening of rivers was the increasing trade between nations (Gregory 2006). This development is going on, the vessels for containers and bulk cargo are getting bigger and bigger (Table 4).

Generation	TEU	Length (m)	Width (m)	Draught (m)
1972	up to 1,500	225	24,5	9,00
1980	up to 3,000	275	27,5	10,00
1987	up to 4,500	300	32,2	11,50
1997	up to 6,600	320	40,0	14,30
1999	up to 8,000	347	42,6	14,50
2006	up to 11,000	398	56,4	16,00

Table 4: Development of vessel size. Source: ISL (2000) and www.forschungsinformationssytem.de (access April 2012)

In many cases this led to a single channel system of the estuary whereas existing branches suffer from regulation and straightening of the main navigation lane (for the river Weser e.g. Franzius 1888; for the *TIDE* estuaries e.g. Ducrotoy 2010). As a consequence, most of the naturally meandering and branching rivers have disappeared in developed countries, most of the rivers and estuaries are “channelized” for transport issues (Gregory 2004, 2006). In some rivers with tidal influence this channelization has led to a different hydrodynamic and morphological characteristic. Those regulations resulted in adaptation processes within the river itself, the current velocities and tidal ranges changed until an almost equilibrium between all hydrological parameters has been achieved. In some cases this equilibrium will not be achieved due to specific reasons (Gregory 2004,

2006) and continuous dredging and river works are the consequences. Jeuken et al. (2003) investigated the relation of the periodic change of the mean tidal range and the morphological development of two tide-dominated estuaries, i.e. the Scheldt and the Humber. "The nodal cycle is known as hydrodynamic cycle with a period of approx. 18 years which is able to strongly influence tidal currents in tide-dominated estuaries. […] An increase of the tidal range is associated with an increase of the tidal prism and velocities and results in a larger estuarine water volume (i.e. erosion), whereas a decrease of tidal range is followed by temporal reduction of the water volume (sedimentation)" (Jeuken et al. 2003, p. 170). They conclude that the nodal cycle as an external force should be considered in the monitoring programmes for estuaries and sediment balance studies (Jeuken et al. 2003, p. 172).

The "channelization" of river led to the loss of habitats and increased the risk at flooding too (e.g. Gregory 2006). Many cities along the rivers experienced higher floods than in history, for example the tidal range in the city of Bremen has increased from 20 cm in 1885 up to 4.20 m nowadays (Lucker et al. 1995). The consequences are that huge efforts have to be taken to protect the city and their inhabitants against flooding (e.g. NLWKN 2007). On the other hand, straightening of rivers reduces the ability of old channels to persist, because the current velocity is concentrated on the main channel to increase the self-sustaining effect of sediment mobilisation. Thus, old branches or anabranches were cut-off from the main channel. In most cases these old branches suffer from siltation, and after a certain time they have been reclaimed (e.g. IECS & Shell UK 1987, IECS 1994).

During the last decades many investigations were conducted concerning the biological and ecological status of rivers. The poor water quality has been recorded and measures were taken to tackle this problem. Consequently, the loss of habitats and species in rivers and other water bodies led to national and European approaches to stop or even to turn these trends. In Germany, for example, the Federal Nature Conservation Act (Bundesnaturschutzgesetz) was put into force at 24th December 1976. On the European level the Birds Directive is the oldest European nature legislation adopted in 1979 (79/409/EC). Nowadays, together with the Habitats Directive, adopted in 1992 (92/43/EC), these two directives are the "centrepiece of EU nature and biodiversity policy" called NATURA 2000. As shown in this chapter almost all parts of the selected estuaries are designated under the NATURA 2000 legislation. The Humber Estuary is completely covered by the NATURA 2000 directives, for the rivers Weser and Elbe some areas are excluded. Consequently, the ecology and biodiversity in estuaries are commonly seen as of high value.

The other side of the coin "channelization" is an increasing risk at flooding. Many cities along the rivers experienced higher tide and faster fluvial run-off which may lead to flooding events. In The Netherlands and the UK these events led to a revised strategy of dealing with rivers. The new strategy is called "Ruimte voor de Rivier (Space for river regions)" (e.g. RvdR 2012) or "Making space for water" (e.g. DEFRA 2004). Within these strategies different approaches were developed and on specific places implemented to reduce the risk at flooding (for The Netherlands see e.g. Provincie Overijssel 2007). One of the measures taken into account for the purpose of making space for the rivers is the lowering of floodplains or the depoldering of old river marshes to create a wider cross-section. Within these measures the creation of side channels beside the main channel is one option which has been implemented in the rivers Lek and Meuse in The Netherlands (Schoor 2007, 2010). Consequently, after straightening and regulation of rivers over centuries to enhance the accessibility for shipping the negative experiences of higher and faster run-off led to a turning point in river engineering. The current strategy for German rivers is called "Integrative River Engineering" which means that also other aspects will be taken into account such as the ecological value of specific habitats (e.g. Heyer 2006; see for the river Danube e.g. www.donau.bmvit.gv.at, Schiemer et al. 1999). As an example, the ideas of "Integrated River Engineering" the river Danube will be explained. At the river Danube this "Integrated River Engineering" project was launched to combine traditional river engineering works with ecological requirements. Several measures are taken into account, e.g. "riverbank renaturation" and "waterway linkage". With the measure "waterway linkage" it is aimed at increasing the erosion in side channels of the river. Until today these side channels suffer from the infiltration of sediment and siltation. Executing these measures former morphological and hydrological conditions should be re-established.

At the European level several directives are valid for the rivers and their ecological status, e.g. Water Framework Directive, Marine Strategy Framework Directive, Flood Risk Management Directive and NATURA 2000. The aim of this study is not to compare these directives and to elaborate on their overlaps, gaps and bottle-necks, but it is important to recognise that desirable measures implemented by one directive could be contradictory to another one. For example, to improve the quality status of a tidal river it could be beneficial to remove a weir upstream. The dismantling of the weir may lead to a tidal influence which is going beyond the former (artificial) barrier. Consequently, the fresh water habitats which have been developed behind the artificial barrier (weir) will be affected by tides and may be affected by brackish or salt water. The fresh water habitats are designated habitats under the Habitats Directive and have to be conserved. On the other hand, the quality of the river water could be improved by dismantling the weir, but the measure contradicts the aims of the Habitats directive.

Finally, anabranches as such don't play an important role within the environmental legislation. Despite this, anabranches which are mostly remainder of an old multiple channel system of rivers, have the potential to fulfil the requirements of different directives by e.g. providing special habitats for rare species. On the other hand, recently the value of anabranches or side channels is reflected not only in the light of habitat creation or conservation, but also for "making space for water" or as one part of an "Integrated River Engineering" concept.

Lessons-learned for the anabranches of the Weser

Comparable to the situation of the anabranches in the Weser estuary is more or less the situation of the anabranches in the Elbe estuary. Most of the islands in the Elbe are former sand plates and have been artificially heightened, fixed and partially lengthened. These islands and the islands within the Weser fulfil different functions. These conversions of the islands were aiming at regulating and straightening the main channel in order to minimise the effort for dredging. One of the main conclusions drawn from the Elbe estuary with regard to the Weser estuary is that the relation between the length of the anabranch and the current velocity in the main channel are important factors for siltation, i.e. the faster the current velocity in the main channel the shorter the anabranch should be in order to achieve a minimum of maintenance measures. Each situation has its specific boundary conditions and is depending on various factors, but the length of the anabranch was indicated as one important factor for the morphological stability of the anabranch (Eichweber 2005). At the Hahnöfer Nebenelbe and the Schweiburg various options were investigated to solve the problem of siltation. The main result for both anabranches is that the future development is depending on the fundamental decision of keeping them accessible or not. If the decision is positive, for example for the Schweiburg there is a mandatory duty to keep the northern part on a certain depth, than it seems that only human action can guarantee this decision. Thus, the question “if” these anabranches should be kept open has been answered, especially for the Schweiburg, the question on “how” to achieve this has to be tackled. One part of the second question is which environmental aims and goals should be achieved, e.g. which habitats should be created or at least maintained by the selected option.

The studies conducted by the BfG (2002, 2003, 2004) for the ecological potential of the Elbe estuary are also of great importance for the Weser estuary. The identification of deficits and the development of various options to improve the ecological status in the anabranch as well as on the river islands and at their shore line can facilitate the process in the Weser.

Finally, the available studies on the morphological development of these anabranches indicate a tendency of siltation (see sections 4.4.2). On the other hand, another important aspect is the relation between the current velocity in the main channel and the length of an anabranch, i.e. the faster the current velocity in the main channel the shorter the anabranch should be in order to achieve a minimised effort of maintenance measures. This statement has been drawn for some of the islands in the Elbe estuary. Hence, the option of improving the self-sustaining forces of anabranches in relation to this aspect should be taken into account. It seems that human action of maintaining the system of anabranches could be reduced, but might be indispensable.

5 Conclusions

The terms “anabranch” and “secondary (side) channel” are not consistently used in literature. There are differences between a secondary channel and an anabranch. A definition has been provided in chapter 1, which distinguish between a multiple channel system at the mouth of an estuary, where secondary channels exist and their location vary due to the morphological and hydrological conditions. An anabranch is a side channel of the river, which leaves the river at a certain place and re-enters it further downstream. This description is mainly used in Australia, but it fits best with the situation given at the river Weser estuary.

This study has shown that today anabranches rarely exist in European estuaries (see Table 1). Secondary or side channels exist mainly in the mouth of estuaries and are part of multiple channel system. In morphological active systems where channels are shifting such as in the Humber one can find secondary channels. Furthermore, the Scheldt (Westerschelde) has secondary channels. One channel is used by the flood and the other channel by the ebb current. This situation is different to the situation found in the Weser. The disappearance of anabranches or a multiple channel system in the fairway of rivers is caused by river engineering works concentrating on the accessibility of harbours and the safety for shipping. This led to the “channelization” of rivers, i.e. regulation and straightening of the main navigation lane. Consequently, anabranches and secondary channels suffer from reduced current velocity in the branch and higher rates of sediment deposition. A relevant boundary conditions for robust anabranches that are not suffering from high deposition rates is the length of the branch in relation to the main navigation lane (e.g. Eichweber 2005). Due to the increased current velocity in the main channel the flow rate in the branch is too slow and therefore the water can enter the branch from both sides, up- as well as downstream, if the branch is too long. This effect leads in estuaries where the direction of flow is changing to impounded water and reduced current velocity in some parts of the branch and, finally, to appropriate conditions for accretion.

Only today in the estuaries Elbe and Weser anabranches exist which are of similar characteristic. The anabranches in the river Weser are the remainders of the multiple channel system before river engineering works have started at the end of the 19th century. The original (not anthropogenic) channels and anabranches of the river Elbe were reclaimed due to decrease the risk at flooding and to gain new farm land. Almost all former branches of the Elbe were cut-off or reclaimed, the branches which currently exist are more or less artificially constructed. All European rivers investigated in this study have designated areas under the different environmental directives such as the Habitats or the Birds Directive. After centuries of prioritising the economical function of rivers as navigation lanes for shipping the ecological functions and services were put on the agenda. Despite this, drivers for river development are still nowadays mainly river engineering works imposed by an increasing demand for trade leading to bigger vessels.

Recently, the concept of "Integrated River Engineering" emerged where ecological requirements shall be taken into account in the planning process and during the phase of implementation. On national level the Federal Waterways Administration in Germany is aiming at executing the current river engineering works in the Elbe and the Weser by applying an "integrated river engineering" concept. For example, in the river Weser the currently planned adaptation of the main channel is accompanied by intensive investigations on ecological effects and opportunities to avoid impacts on the anabranch Schweiburg. On the European level projects were launched which are exchanging knowledge and experiences in river management (European Interreg IVB project *TIDE*) or applying measures of the integrated river management concept, e.g. at the river Danube (Integrated River Engineering Project on the Danube East of Vienna co-financed by Trans-European Transport Networks (TEN-T)).

Taking the idea of an "Integrated River Engineering" and the existing environmental legislative such as the Water Framework Directive, NATURA 2000, the Flood Risk Management Directive into account, the revitalisation of anabranches could provide several benefits. Possible benefits could be as follows:

- The intertidal habitats existing in anabranches can serve as reserve for species which are not able to adapt to the "channelized" river system, e.g. macrophytes.
- The anabranches and side channels will serve as spawning and nursery habitat for several species such as fish and macro invertebrates and, in general could improve the ecological status of selected sections of a river or estuary (e.g. Schoor 2010; BfG 2002, 2003).

- The revitalisation of old branches can support the way to an appropriate tidal regime of the river (e.g. BAW 2006a; Heyer 2006; Freitag et al. 2007).
- Re-connecting branches to the main channel could increase the discharge capacity of the river (e.g. Buijse 2010; Heyer 2006), i.e. creating retention basins.
- Where appropriate the current velocity in the main channel could be reduced by increasing the flow rate through a branch and, thus, decrease the erosion in the vicinity (IECS 1994).

Big fluvial flood events in Germany (Elbe 2002 and 2006) and The Netherlands (Rhine 1993 and 1995) led to new river basin management strategies. In The Netherlands in 1995 the programme "Ruimte voor de Rivier (room for the river region)" was launched and strives to protect approx. 4 million people against flooding. The UK launched the programme "making space for water" due to the devastating experiences of flooding events in the beginning of the 21st century (e.g. EA 2001; DEFRA 2004). The view on rivers slightly changes and besides economic issues also ecological issues will be taken into account. This process started by the experiences of flooding events with high loss of lives and properties could be assisted and furthermore improved by the current European environmental legislation if the mutual benefits of an integrated approach will be fully exploited.

6 References

ABPmer (2008): Humber Holocene Chronology (13 p.). Summary prepared for the Environment Agency "Humber Estuary Geomorphology Study – Stage 2", Final report 2000. Found on www.estuary-guide.net – called April 2012.

Aubry, A., Elliott, M. (2005): The use of Environmental Integrative Indicators to assess anthropogenic disturbance in the estuaries and coasts. Application to the Humber Estuary, UK. Dissertation at the Institute of Estuarine and Coastal Studies (IECS) – University of Hull. Reference No.: YBB094-F-2005.

BAW [Federal Waterways Engineering and Research Institute] (1996): Anpassung der Fahrrinne der Unter- und Außenelbe an die Containerschifffahrt. Zusammenfassendes Gutachten der Hydromechanik. Bundesanstalt für Wasserbau, Außenstelle Küste. BAW 9553 3417/34.

BAW [Federal Waterways Engineering and Research Institute] (2006a): Anpassung der Fahrrinne von Unter- und Außenelbe an die Containerschifffahrt. Gutachten zur ausbaubedingten Änderung der morphodynamischen Prozesse. BAW-Nr A 3955 03 10062.

BAW [Federal Waterways Engineering and Research Institute] (2006b): Fahrrinnenanpassung der Unterweser – Fahrrinnenanpassung der Außenweser an die Entwicklungen im Schiffsverkehr sowie Tiefenanpassung der hafenbezogenen Wendestelle. Summationswirkungen der Anpassungen von Unter- und Außenweser. Gutachten zur ausbaubedingten Änderung von Transportprozessen und Morphodynamik. BAW 5.02.10048.00–2.

BAW [Federal Waterways Engineering and Research Institute] (2010): Naturdatenanalyse und wasserbauliche Systemanalyse zur Ausgleichsrinne (A+E-Rinne) in der Hahnöfer Nebenelbe. BAW A 395 50 21 0099.

BAW [Federal Waterways Engineering and Research Institute] (2012): Öffnung der Nebenarme der Weser – Systemstudie Schweiburg. BAW A 395 50 21 0122 im Auftrag des WSA Bremerhaven.

BfG [Federal Institute of Hydrology] (2002): Untersuchung des ökologischen Entwicklungspotenzials der Unter- und Außenelbe (Ökologische Potenzialanalyse) Teil 1. Gutachten für Projektgruppe Potenzialanalyse des WSA Nord, HPA und Behörde für Wirtschaft und Arbeit, Hamburg. BfG – 1346.

BfG [Federal Institute of Hydrology] (2003): Untersuchung des ökologischen Entwicklungspotenzials der Unter- und Außenelbe (Ökologische Potenzialanalyse) Teil 2 – Konkretisierung von Maßnahmen. Gutachten für Projektgruppe Potenzialanalyse des WSA Nord, HPA und Behörde für Wirtschaft und Arbeit, Hamburg. BfG – 1388.

BfG [Federal Institute of Hydrology] (2004): Untersuchung des ökologischen Entwicklungspotenzials der Unter- und Außenelbe (Ökologische Potenzialanalyse) Teil 3 – Ökologische Bewertungsgrundlagen für den Strombau. Gutachten für Projektgruppe Potenzialanalyse des WSA Nord, HPA und Behörde für Wirtschaft und Arbeit, Hamburg. BfG – 1412.

BfG [Federal Institute of Hydrology] (2008a): WSV-Sedimentmanagement Tideelbe – Strategien und Potenzial – eine Systemstudie. Ökologische Auswirkungen der Umlagerung von Wedeler Baggergut. Untersuchung im Auftrag des Wasser- und Schifffahrtsamtes Cuxhaven. BfG – 1584.

BfG [Federal Institute of Hydrology] (2008b): Unterweser. Unterhaltungsplan für den Abschnitt von km 44,0 bis km 52,0 – Berücksichtigung ökologischer Belange bei der Unterhaltung. Study prepared fort he Federal Waterways Administration. BfG – 1588.

Boehlich, M.J. (2006): Hydrologische und morphologische Entwicklungen an der Tideelbe. Presentation at the symposium Tideelbe, 6./7. November 2006. Source: www.tideelbe.de – access April 2012.

Bosschap (ed., 2011): Nevengeulen in uiterwaarden als kraamkamer voor riviervissen. Technical report 2011/OBN 143-RI, Bosschap, bedrijfsschap voor bos en natuur, Driebergen-Rijsenburg.

Brookes, A., Gregory, K.J., Dawson, F.H. (1983): An assessment of river channelization in England and Wales. Science of the Total Environment (27): 97 – 111.

Buijse, T. (2010): Prospects and challenges to ecologically improve riparian zones along the large European rivers. Presentation held at the Colloquium of BFG & BAW in Magdeburg, March 23rd and 24th 2010 (vzb.baw.de/digitale_bib/kolloquien.php?id=078332c892d9a88fa904a234942987e – access at April 2012).

Burningham, H., French, J. (2011): Seabed dynamics in a large coastal embayment: 180 years of morphological change in the outer Thames estuary. Hydrobiologica (672): 105 – 119. DOI 10.1007/s10750-011-0760-y.

DEFRA [Department of Environment, Food and Rural Affairs] (2004): Making Space for Water. Developing a new Government strategy for flood and coastal erosion risk management in England.

Ducrotoy, J.-P. (2010): Ecological restoration of tidal estuaries in North Western Europe: an adaptive strategy to multi-scale changes. Plankton & Benthos Research (5 Suppl.): 174 – 184.

EA [Environment Agency] (2000): Planning for the Rising Tides. The Humber Estuary Shoreline Management Plan.

EA [Environment Agency] (2001): Lessons Learned: Autumn 2000 Floods. Technical Report.

EA [Environment Agency] (2009): Habitats Regulations Assessment of the River Basin Management Plan for the Humber River Basin District.

Eichweber, G. (2005): Hydromorphologie des Elbeästuars. Federal Waterways Administration North. Source: www.tideelbe.de – access April 2012.

Elsebach, J., Kaiser, R., Niemeyer, H.-D. (2007): Spatial Balance of Habitats in the Weser Estuary. HARBASINS Report.

EstProc (2003): The transport of fine sediment in the Humber estuary. Report 4 of Estuary Processes Research Project (EstProc) – www.estproc.net (access April 2012).

FFH-Lenkungsgruppe (2005): FFH-Gebiete im Elbästuar. Ziele für die Erhaltung und Entwicklung. Technical Report. Source: www.natura2000-unterelbe.de – access March 2012.

Franzius, L. (1888): Die Korrektion der Unterweser: auf Veranlassung der Bremischen Deputation für die Unterweserkorrektion. Guthe, Bremen.

Frässdorf, J. (1999): Morphologische Veränderungen der Nebenelben von ca. 1950 bis 1995. Presentation at the Colloquium „Kenngrößen der Ästuardynamik - Analyse und Darstellungsmethoden. Source: vzb.baw.de – access April 2012.

Freitag, C., Hochfeld, B., Ohle, N. (2007): Lebensraum Tideelbe. Coastline Reports (9): 69 – 79.

GKSS (2007): Sedimenttransportgeschehen in der tidebeeinflussten Elbe, der Deutschen Bucht und in der Nordsee. Technical Report GKSS 2007/20.

Gregory, K.J. (1977): River channel changes. Wiley, Chichester.

Gregory, K.J. (2004): Human activity transforming and designing river landscapes: a review perspective. Geographia Polonica (77): 5 – 20.

Gregory, K.J. (2006): The human role in changing river channels. Geomorphology (79): 172 – 191.

Hamer, K., Liedke, N., Saathoff, S. Jürgen Schröter, J. (2012): Development of the Weser Estuary: Historical Changes to shallow water areas, anabranches and shore areas -Integrating aspects of human Activities. TIDE report published on the URL: www.TIDE-project.eu (in prep.).

Heyer, H. (2006): Überlegungen zur Beeinflussung des Sedimenttransports in Ästuaren. Presentation at the „Gemeinsames Kolloquium BfG und BAW“, 8./9. November 2006. Source: vzb.baw.de/digitale_bib/kolloquien.php?id=6738d8bfb34db7368497eee636432a57 – access April 2012.

Homeier, H. (1967): Das Wurster Watt – Eine historisch-morphologische Untersuchung des Küsten- und Wattgebietes von der Weser- bis zur Elbmündung. In: Jahresbericht Forschungsstelle Norderney, Band XIX: 31 – 120.

HPA & WSA [Hamburg Port Authority & Federal Waterways Administration] (2008): Strombau- und Sedimentmanagementkonzept für die Tideelbe. Technical Report. Source: www.fahrrinnenausbau.de – access April 2012.

IECS & Shell UK (1987): The Humber Estuary. Environmental Background. ISBN 0-90538-11-4.

IECS [Institute of Estuarine and Coastal Studies] (1994): Humber Estuary and Coast. Technical Report prepared by IECS at the University of Hull commissioned by the Humberside County Council.

ISL [Institute of Shipping Economics and Logistics] (2000): Entwicklungstendenzen der deutschen Nordseehäfen bis zum Jahr 2015. Studien aus dem ISL, ISSN: 0942-0975.

Jeuken, M.C.J.L., Wang, Z.B., Keiller, D., Townend, I., Liek, G.A. (2003): Morphological Response of Estuaries to nodal Tide Variation. Proceedings of the International Conference on Estuaries and Coasts 2003 (IRTCES), Zhejiang Institute of Hydraulics and Estuary, Hangzhou, China, November 9-11, 2003: 166 – 173.

Lucker, T., Busch, D., Knötzel, J., Schirmer, M. (1995): Unterweserausbau, Entwicklung des Schiffsverkehrs und Auswirkungen auf das Flusssystem. In Gerken, B., Schirmer, M. (eds.): Die Weser. Limnologie aktuell Vol. 6: 301 – 312.

NLWKN [Lower Saxonian Agency for Water Management, Coastal Protection and Nature Conservation] (2007): Generalplan Küstenschutz – Festland. Bremen – Niedersachsen.

NLWKN [Lower Saxonian Agency for Water Management, Coastal Protection and Nature Conservation] (2008/10): Integrierter Bewirtschaftungsplan Weser. Konzept der niedersächsischen Planungsgruppe.

Project Group Fairway Adaptation (2004): Machbarkeitsstudie – Arbeitsfassung. Source: www.fahrrinnenausbau.de – acces April 2012.

Provinice Overijssel (2007): Ijssel. Handreiking Ruimtelijke Kwaliteit. Technical Report.

RvdR [Ruimte voor de Rivier] (2012): Room for the River. From higher dykes to river widening. Working together towards a safe and attractive river region. www.ruimtevoorderivier.nl - access April 5th 2012.

Schiemer, F., Baumgartner, C., Tockner, K. (1999): Restoration of floodplain rivers: The Danube restoration project. Regulated Rivers Research Management (15), 1-2: 231 – 244.

Schirmer, M. (1995): Eindeichung, Trockenlegung, Korrektion, Anpassung: Die Abwicklung der Unterweser und ihrer Marsch. In Gerken, B., Schirmer, M. (eds.): Die Weser. Limnologie aktuell Vol. 6: 35 – 53.

Schlüter, K. (1988): Die Strombauarbeiten an der Unter- und Außenelbe. Jahrbuch der Hafenbautechnischen Gesellschaft (43): 187 – 195.

Schoor, M. (2007): Environmental Perspective of the Rhine. Navigation and EU Water Framework Directive. Presentation held at the Smart Rivers Conference (PIANC USA) Sept 17th 2007 (smart07.pianc.us/proagenda.cfm – access at April 2012).

Schoor, M. (2010): Ecological benefits of side channels in relation to their hydro-morphological characteristics. Presentation held at the Colloquium of BFG & BAW in Magdeburg, March 23rd and 24th 2010 (vzb.baw.de/digitale_bib/kolloquien.php?id=078332c892d9a88fa904a234942987e – called at April 2012).

Schoor, M. (2011): Nevengeulen langs de grote rivieren. Leren van de prektijk. Presentation held at the Platform beek- en rivierherstel, Dec 14th 2011 (http://www.watermozaiek.nl/images/8/8a/Presentatie_Margriet_Schoor.pdf – access at April 2012).

Simon, A., Rinaldi, M. (2006): Disturbance, stream incision and channel evolution: The roles of excess transport capacity and boundary materials in controlling channel response. Geomorphology (79): 361 – 383.

Simons, J.H.E.J., Bakker, C., Schropp, M.H.I., Jans, L.H., Kok, F.R., Grift, R.E. (2001): Man-made secondary channels along the river Rhine (The Netherlands); Results of post-project monitoring. Regulated Rivers: Research and Management (17): 473 – 491.

Wetzel, V. (1988): Der Ausbau des Weserfahrwassers von 1921 bis heute. Jahrbuch der Hafenbautechnischen Gesellschaft Hamburg 42: 83 – 105.

WSA [Federal Waterways Administration] (2008): Anpassung der Fahrrinne der Unter- und Außenelbe an die Containerschifffahrt 1999. Kompensationsmaßnahmen und Erfolgskontrollen. Übersicht und Statusbericht 2008. Source: www.fahrrinnenausbau.de – access April 2012.

WSA [Federal Waterways Administration] (2010): Anpassung der Fahrrinne von Unter- und Außenelbe an die Containerschifffahrt. Planfeststellungsunterlage nach Bundeswasserstraßengesetz. Planänderung III. Umweltverträglichkeitsuntersuchung für die Kohärenzmaßnahme „Schwarztonnensander Nebenelbe mit Ufer Asseler Sand“ und die Maßnahme „Barnkruger Loch“. Planänderungsunterlage III Teil 12c. Source: www.fahrrinnenausbau.de – access April 2012.

WSA [Federal Waterways Administration] (2012): Anpassung der Fahrrinne der Unter- und Außenelbe an die Containerschifffahrt. Bericht 2011. Abschlussbericht Erfolgskontrollen. Source: www.portal-tideelbe.de – access April 2012.