Chapter 2
Background Information – Nature and Society

Contents

2.1 The Natural Environment of the North Sea Coastal Zones

2.1.1 Basic Information

The North Sea is a shallow sea adjacent to the northern Atlantic. The southern North Sea is divided into two parts: the Southern Bight and the German Bight. The mean depth of the southern North Sea is approx. 20–30 m. The recent shape of the North Sea is a result of fluvial and fluvio-glacial processes during and after the ice ages, Sindowski (1962), Streif (1982, 2002), Behre (2007).

The North Sea has a large variety of landscapes along its coast: e.g. cliffs, firths, Wadden Sea, dune areas, and fjords. The East Coast of England is characterised by estuaries such as Humber and Thames, and by further expanses of sand and mud flats in areas such as The Wash. Along the Channel the coastline of south-east England is dominated by low cliffs and flooded river valleys. From East to West along the French coast of the Channel the North Sea offers maritime plains and estuaries, cliffs, and the rocky shore of Brittany.

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From the Strait of Dover to the Danish West Coast, sandy beaches and dunes prevail with numerous estuaries (e.g. Scheldt, Rhine, Meuse, Weser and Elbe) and the islands of the Wadden Sea with their tidal inlets. In Denmark large lagoon-like areas exist behind long sandy beaches.

In main figures: the coastline is about 36,000 km long, the land-area within the 10 km zone is approx. 127,500 km^2, the population of this area is approx. 165 million. In comparison with other European coastal areas the North Sea has the highest level of urbanisation (17% of the coastal zone), the highest armouring of the coast including defences and harbours 20% of the North Sea coast is eroding and the highest level of protection in terms of the number of NATURA 2000 sites (EEA 2006, p. 20).

The following paragraph provides a short overview of the hydrography and meteorology of the North Sea with a focus on its southern part. The hydrographical and meteorological conditions are the main forces which create the great variety of landscapes along the North Sea coasts.

2.1.1.1 Hydrography and Meteorology

The different landscapes along the North Sea coast coincide with the existing tidal range (Fig. 2.1). Due to the long connecting line with the northern Atlantic the North Sea has significant tidal waves. Without this connection, there would only be micro tidal waves as in the Baltic Sea. The tidal range between Den Helder (The Netherlands) and Borkum (most western barrier island of the German Wadden Sea) increases from about 1.5 m up to 2.3 m (high meso-tidal). Further to the East (Inner German Bight) the tidal range increases up to 3.6 m near Wilhelmshaven (Jade Bay) and to approx. 4.2 m in the city of Bremen 70 km downstream the river Weser (low macro-tidal) (Niemeyer and Kaiser 1999).

The duration of a tide is 12 h and 25 min (semi-diurnal period). In general, the tidal wave in the Wadden Sea is influenced by the topography of the area, by the planet constellation, by meteorological conditions, by the amount of fresh water discharge of the rivers (Niemeyer and Kaiser 1999). “Tidal currents are the most energetic feature in the North Sea, stirring the entire water column in most of the southern North Sea and the Channel. In addition to its predominant oscillatory nature, this cyclonic propagation of tidal energy from the ocean also forces a net residual circulation in the same direction” (OSPAR 2000, p. 19).

The North Sea is situated in the temperate zone with a climate mainly influenced by the inflow of oceanic water from the northern Atlantic and by the large scale westerly air circulation which frequently contains low pressure systems. The climate development of the North Sea is directly linked to the large scale atmospheric circulation in the European-Atlantic system. The North Atlantic Oscillation index (NAO index) indicates the influence of high pressure at the Azores and of low pressure in the North of the Atlantic: a higher NAO index indicates the generation of a stronger west wind circulation and in consequence, stronger westerly winds creating higher water levels in the North Sea (Weisse and Rosenthal 2002). The strength

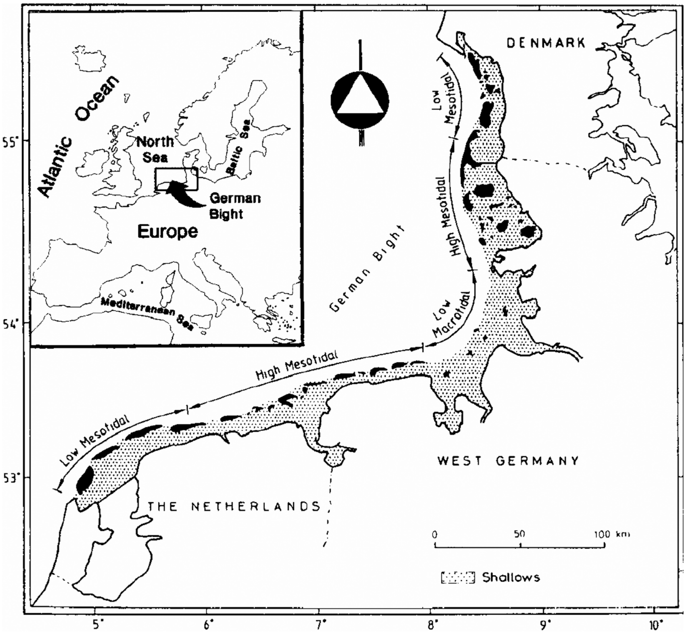


Fig. 2.1 Tidal range of the southern North Sea
Source: Dieckmann (1992).

of the westerly winds has a significant effect on water transport and distribution, vertical mixing and surface heat flux. This "atmospheric circulation" is also closely related to the cloud cover and therefore the light conditions in the water column and the coastal zones (OSPAR 2000). Moreover, other climatic-oceanographic features related to the NAO index include: temperature, salinity and circulation. A stronger NAO index causes a stronger influence of the northern Atlantic correlated with an increase of material transport, higher salinity and an increase of temperature (Weisse and Rosenthal 2002).

Finally, "the North Sea climate is characterised by large variations in wind circulation and speed, a high level of cloud cover, and relatively high precipitation. Rainfall data show precipitation ranging between 340 and 500 mm per year, and averaging 425 mm per year" (OSPAR 2000, p. 22).

A short description of typical landscapes in the southern North Sea Region is shown in Table 2.1. Selected landscapes will be described later in more detail providing a glimpse of the natural environment of the case study areas in Germany and the ComCoast partner countries.

2.1.2 Landscapes and Important Areas

The southern North Sea region is dominated by two landscapes: Dune Areas (mainland and barrier islands) and the Wadden Sea. They are the natural starting point

Table 2.1 Description of different landscapes along the southern North Sea

Elbe and Weser estuary, Jade Bay	The Elbe and the Weser discharge through their estuaries huge volumes of (contaminated) fresh water into south-eastern corner of the North Sea and into the Wadden Sea.The Jade Bay is a Wadden Sea-like tidal inshore basin connected to the open sea by a narrow channel. All three have important shipping lanes and are thus subject to intensive dredging and deepening. The Elbe and Weser have a strong and vertical salinity stratification although tidal and wave activity can be very strong. In the Jade Bay small fresh water input and very strong tidal currents suppress the development of stratification
Wadden Sea (including Ems-Dollart)	The Wadden Sea extends along the North Sea coasts of The Netherlands, Germany and Denmark, from Den Helder to the Skallingen peninsula near Esbjerg. It is a highly dynamic area of great ecological significance. With 500 km it is the largest unbroken stretch of mudflats in the world. According to the delimitation of the trilateral cooperation, the Wadden Sea covers about 13,000 km^2, including some 1,000 km^2 islands, 350 km^2 salt marshes, 8,000 km^2 tidal areas (sub-tidal and inter-tidal flats) and some 3,000 km^2 of offshore areas. Most parts of the Wadden Sea are sheltered by barrier islands and contain smaller or wider area of intertidal flats. During each high tide an average of 15 km^3 of North Sea waters enters the Wadden Sea, thereby doubling the volume from 15 to about 30 km^3. With the North Sea water also nutrients and suspended matter reach the Wadden Sea. In the North of Holland there is also a structural loss of sand from the Wadden Sea. There is a structural loss of sand from the offshore area to the tidal area causing erosion of the foreshore and beaches of several islands
Dutch coastal zone	The coastal zone along the entire western and northern half of The Netherlands can be considered as one of the most densely populated areas in Europe. The coastal zone is protected from the sea by natural sand-dunes (254 km) and sea dikes (34 km), beach flats (38 km) and 27 km of boulevard, beach walls and the like. The width of the coastal dunes varies between less than 200 m, and more than 6 km. The upper shore-face is a multi-barred system generated by normal wave action, while its lower part is dominated by storm sedimentation, down to the depth of about 16 m. At greater depths tidal currents play a significant role along with storm waves, keeping fine-grained sediment in suspension
Scheldt estuary	The Scheldt estuary is well-mixed with a yearly average upstream freshwater flow rate of 107 m^3/s. The total drainage area is 20,300 km^2. The estuary consists of an alteration of transition zones: deep ebb and flood channels, large shallow water zones, tidal flats and dry shoals

Source: OSPAR (2000, pp. 8–9).

for (sustainable) development in the coastal zone. The focus area of this dissertation in Germany is the mainland of Lower Saxony. The Wadden Sea of Lower Saxony consists of dunes on barrier islands, of estuaries, the sheltered (behind the islands) and the open Wadden Sea (without islands) – see Fig. 2.1. The partner countries of the ComCoast project have similar landscapes with slightly different conditions.

The Dutch Wadden Sea extends from the island Texel to the island Rottumer Oog, adjacent to the German border (the Dollart belongs to both countries). In Denmark only a small stretch is covered by the Wadden Sea with the islands of Rømø, Fanø and Mandø. North of the Danish Wadden Sea area there are dunes and sandy beaches.

Between Den Helder (NL) and the estuaries of the Rhine, Meuse and the Scheldt a long sandy coastline with dunes and beaches presents itself. In some places the chain of dunes is disconnected due to storm surge events in former times (e.g. in the proximity of the village Petten, the Hondsbossche and the Pettemer Sea Defence with a main dike between the dunes, see Sect. 3.4 on p. 71. In respect of England the dissertation concentrates on the region of Essex and Suffolk in East Anglia, because the pilot regions of the ComCoast project are located here. The region is dominated by several rivers and their estuaries with many salt marshes.

2.1.2.1 Dune Areas

In the southern North Sea Region dune areas extend on the West coast of The Netherlands between the Delta area (Hoek van Holland in the South) and Den Helder in the North. The coastline of The Netherlands is approx. 350 km long and approx. 250 km are dunes (Hillen and de Haan 1993). The dunes cover about 400 km^2 which is nearly 1% of the Dutch surface (Louisse and van der Meulen 1991). In the Delta area the islands have dunes at their seaward tips which are sometimes very narrow. The northern part, the Holland coast, consists of broader dunes with a length of up to 3.5 km and heights of up to 50 m. The shoreface consists of a breaker zone between Mean Sea Level (MSL) and 8 m depth line (Louisse and van der Meulen 1991). The Wadden Sea area of The Netherlands also features dunes. They cover an area of approx. 11,300 ha and are mainly located on the barrier islands (Petersen and Lammerts 2005).

All barrier islands of the Lower Saxonian Wadden Sea are covered by dunes, and in Schleswig-Holstein this applies to the islands of Sylt, Amrum and Föhr. The barrier islands are formed and sustained by the combined action of wind, waves and tides. Normally, a barrier island consists of a shoreface, beach, dunes and overwash areas. On the mainland side of some barrier islands salt marshes (polders) can be found. The dune area in Lower Saxony covers approx. 4,400 ha and in Schleswig-Holstein approx. 1,500 ha (Petersen and Lammerts 2005). In England sand dunes are rare and widely scattered, but with concentrations along the Lincolnshire and Humberside coasts and in North Norfolk between The Wash and Cromer. The dune area along the North Sea is about 25,000 ha (Doody et al. 1993).

"Dune formation occurs where a supply of dry, wind-blown sand is trapped by an obstacle such as shingle ridge, tidal litter or vegetation. This process often take place above a sand flat which is exposed sufficiently at low tide for the surface layer of sand to dry out. The dunes of the North Sea coast are characterised by the creation of front shore sand ridges formed by the opposing forces of prevailing and dominant winds which occur as offshore and onshore winds, respectively" (Doody et al. 1993, pp. 7–8). Shingle fringing beaches are highly mobile and may not support vegetation communities. Stable and semi-stable vegetated shingles are concentrated in Shetland, Orkneys and East Anglia. They can mainly be found in the south-east, from Norfolk to East Sussex. Altogether the shingle area is approx. about 2,750 ha (Doody et al. 1993).

2.1.2.2 Wadden Sea

The Wadden Sea area is divided into a Dutch, Danish and a German part. The seaward border is the 12-nautical-mile-zone and landwards the main dike line. The mainland adjacent to the Wadden Sea provides a living and working environment for approx. 3.3 million inhabitants (WSF 2005). The following section describes in brief important features and elements of the Wadden Sea from the perspective of the dissertation objectives. More detailed and comprehensive descriptions of the Wadden Sea can be found for example in Abrahamse et al. (1976), Reineck (1978), Ehlers (1988), Buchwald (1991), Lozán et al. (1994), Gätje and Reise (1998), NLP-V and UBA (1999), TERRAMARE (2001), Essink et al. (2005).

The Wadden Sea area is subject to tidal influence and therefore it is classified in several tidal areas (see e.g. Fig. 2.4):

Sub-Littoral: The area below the low water line. The sub-tidal area is divided in an upper and a lower sub-tidal area. The upper sub-tidal area covers the shallow sea in front of the barrier island, and the lower sub-tidal area includes the bigger tidal channels and tidal ebb deltas and is always covered by water. The environment above the water line is the living space for birds and seals.

Eu-Littoral: This area is flooded twice a day and includes the tidal flats and the shore-face. It mainly consists of flats with gentle slopes from the high to the low water line. The tidal flats are flooded and drained by numerous channels.

Supra-Littoral: This area is above the Mean High Tide Water (MThw) and is only flooded at very high water levels. The salt marshes of the mainland and in the mainland side of the barrier islands are a distinctive feature of this area. The salt marshes are carpeted with vegetation, mainly halophytes and in higher regions with salt tolerant plants.

Epi-Littoral: This area contains the dunes on the barrier islands and the area between the embankments and the pleistocene hinterland (until NN +10 m contour line in Germany).

The Wadden Sea area itself is also divided into an outer and an inner Wadden Sea area. The outer Wadden Sea area lies between the water bodies of high and lower salinity in front of the barrier islands. The inner area stretches between the barrier islands and the mainland, containing tidal flats, sand flats, channels and salt marshes. The Wadden Sea is a highly dynamic system with an energy input from the sun, wind, tides and waves. This highly dynamic system underlies natural changes through strong ice winters (e.g. risk for mussel beds), erosion and parasites (e.g. reduction of seals). The German Wadden Sea could be divided into three parts: the North-Frisian part, the East-Frisian part and the Inner Part with open tidal flats.

The North-Frisian part is about 40 km wide and ranges from the islands of Sylt down to the Eiderstedt peninsula. Four types of islands can be found in this area: islands with pleistocene core, marsh islands, Halligen and bigger sand flats. The open Wadden Sea lies between the Eiderstedt peninsula and the river Jade. Within this area the rivers Eider, Elbe, Weser and Jade discard into the Wadden Sea. The tidal flats mainly consist of sand flats and have a gently falling surface. The East-Frisian Wadden Sea stretches from the Jade to the river Ems in the western part of Germany to the border of The Netherlands. The barrier islands in front of the mainland are mainly dune islands, some of them have an older core from pleistocene ages. The Wadden Sea is 10 km wide and consists of 35% of mud and mixed falts. In this area the remnants of older bays can be found: the Jade Bay, the Ley Bay and the Dollart.

2.1.2.3 Tidal Area

The barrier islands are separated by tidal inlets. Tidal inlets are the mouths between the islands where the sediment transport is effected by tidal waters. Within each tidal cycle the water body goes in and out through these tidal inlets and fills and drains the tidal basin between the barrier islands and the mainland. A dynamic equilibrium exists between the tidal currents and the cross-sectional area of the inlet channel (Ehlers 1988, CPSL 2001). “The sediment that is transported by ebb-tidal currents is deposited at the seaward outlet, caused by decreasing current velocities. In result, an ebb-tidal delta develops. However, the erosive forces of deep water waves coming from the North Sea, limit the sediment volume of the deltas. A dynamic equilibrium exists between these erosive forces and the tidal accumulation (Ehlers 1988, Oost 1995, Hofstede 1999). Because the tidal channels of the inlet and the delta are strongly interrelated, they are normally treated as one element” (CPSL 2001, p. 16). On tidal flats the material may become settled as a result of decreasing current velocities. Because the (energy-rich) waves from the North Sea are almost completely dissipated at the shoreface and ebb-tidal deltas (Niemeyer 1986), only local (storm) waves limit the tidal accumulation on the tidal flats. “Similar to the ebb-tidal delta, a dynamic equilibrium seems to exist on tidal flats between the erosive forces of storm waves and tidal accumulation (mainly controlled by the time of tidal inundation)” (CPSL 2001, p. 16).

2.1.2.4 Bays

The Wadden Sea area features a range of bays. Many of them have been reclaimed over the last centuries, like Lauwersoog in the province of Groningen (NL) or the Harle Bay in the north-western part of Lower Saxony in Germany. Existing bays in the Wadden Sea from Lower Saxony to Schleswig-Holstein are the following (from West to North): Dollart, Ley Bay, Jade Bay, Meldorfer Bay and Tümlauer Bay. The historical development of most bays around the Wadden Sea is similar. Severe storm surges in the middle ages caused their largest extension. Afterwards, due to the natural processes of sedimentation and the increasing ability of the coastal community to protect themselves against flooding, land was reclaimed step by step over the years. To illustrate the historical development of German bays the box below (p. 14) contains an extract of the development of the Ley Bay.

Ley Bay – Part I

The Ley Bay witnessed its largest extension approx. 600 years ago, as a consequence of severe storm tides in the middle ages. Until the middle of the last century land reclamation works were executed to increase the arable area for the inhabitants. In the 1950s the Ley Bay was mainly shaped by economic drivers (Erchinger 1970, Hartung 1983, Janssen 1992, Kunz 1999b). Figure 2.2 shows the historical development of the Ley Bay. Approximately 10,000 ha were reclaimed and this new land was offered to inhabitants and refugees of the second world war. After the 1950s the effort to reclaim land from the sea decreased, because of the diversification of working fields after the second world war and the increase of the effectiveness in agriculture. On the other hand, the problems with water management in the hinterland around the Ley Bay intensified, the existing tidal channels silted up continuously. Until 1985 the problems also affected the harbours around the Ley Bay which were dependent on free access to the North Sea. Siltation had imposed increasing pressure on water management and shipping, resulting in the installation of pumping stations with continuously increasing performance (Janssen 1992).

2.1.2.5 Salt Marshes – Extension, Morphology and Ecology

In general, the largest coherent salt marsh area of the world can be found in the southern North Sea region within the Wadden Sea area from Den Helder (NL) to Blåvands Huk (DK). For an overview of salt marshes in Europe see e.g. Dijkema (1987). Salt marshes will be explained in more detail, because they are important elements within the Wadden Sea in respect to both nature conservation and coastal protection as well as for other types of land use (multifunctional use). Salt marshes are the transition zone between sea and land and they fulfil several functions.

Salt marshes exist along most of the shallow coastal waters where marine sedimentation and erosion are balanced. The west coast of England features approx. 22,300 ha of salt marshes the equivalent of nearly half of the total amount of salt marshes in England. “The largest areas of salt marshes in [England] are concentrated around the Greater Thames estuary in Essex and Kent [...]” (Doody et al. 1993, p. 6). The total salt marsh area of the Wadden Sea is approx. 39,000 ha (Essink et al. 2005). Detailed information and data for each country around the Wadden Sea is shown in Fig. 2.3. The latest figures for Schleswig-Holstein in Stock et al. (2005) display a total area of 11,625 ha.

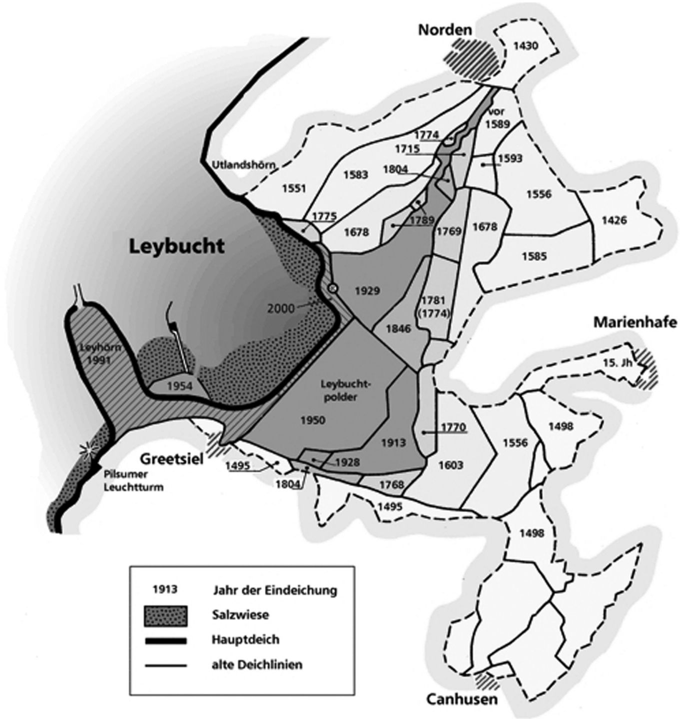


Fig. 2.2 Land reclamation works in the Ley Bay adapted after Homeier (1974)
Source: www.nlwkn.de

[ha]	The Netherlands	Denmark	Germany			Total
			Lower Saxony	Hamburg	Schleswig-Holstein	
Island	3,420	2,890	2,640	185	720	**9,855**
Main Land	2,190	4,590	5,460		7,500	**19,740**
Summer Polder	1,980		1,795			**3,775**
Halligen					2,300	**2,300**
Total	**7,590**	**7,480**	**9,895**	**185**	**10,520**	**35,670**

Fig. 2.3 Salt marsh areas in the Wadden Sea
Source: Stock (2002) and Ahlhorn and Kunz (2002b).

The present area of salt marshes around the Wadden Sea is in the main the remainder of larger former wetlands. Nowadays, almost all salt marshes are man-made or strongly influenced by human activities like coastal protection works, farming or other kinds of land use. In the middle of the last century salt marsh areas increased. This tendency was lowered up till the end of the 20th century, with a slow increase now detectable due to changes in foreland protection works (Dijkema 1987, Dijkema et al. 2001). Stock et al. (2001) concluded that from 1978 to 1996 the amount of salt marshes increased by about 1,700 ha. However, a large amount of salt marshes was lost by dike-building (approx. 1,500 ha). Today, neither a large decrease nor an increase of the salt marsh area can be detected, but within the groyne fields the tendency towards more erosion increases. Local loss can occur due to poor sediment conditions or erosion in the adjacent tidal flats (Stock et al. 2005). At certain places in Lower Saxony, the area of salt marshes has increased by about 2,747 ha and in other places it has decreased in the same period to 233 ha, so in total an increase of approx. 2,500 ha over the last 30 years can be determined. The recent investigation (in 2003) of the development of the salt marsh area in Lower Saxony gives a detailed overview of the changes, e.g. a detailed description of how the salt marshes have been restored or were lost due to dike-building or agricultural use. The increase of the salt marsh area in Lower Saxony is mainly in the sheltered bays of Jade Bay and Ley Bay (Bunje and Ringot 2003). In the Danish part no clear tendency could be established due to the lack of reliable data series. The comparison of the last available data and the latest investigation shows an increase of Danish salt marshes to approx. 8,710 ha. An increase can be found in some places on the mainland and in the proximity of the island of Fanø (Bakker et al. 2005).

A general tendency is the decrease of the pioneer zone and the increase of the older salt marsh parts which lie above the local mean high water level. This could be the consequence of higher energy input into the Wadden Sea and of the loss of space for natural salt marsh development e.g. due to land reclamation works in the last centuries (Dijkema 1987, Doody et al. 1993, Stock 2002). This effect is called *coastal squeeze*. Recent investigations in the Schleswig-Holstein Wadden Sea confirm these tendencies. The report states that these tendencies may accelerate under climate change: a progressive narrowing of the Wadden Sea, i.e. coastal squeeze will take place under an accelerated sea level rise, an increase of storminess will lead to higher hydrodynamical forces on the sand and mud plates. Consequently, this will lead to a significant loss of specific habitat such as mussel beds and eelgrass (Dolch 2008). The development and the behaviour of the Wadden Sea is essential for both nature conservation and coastal protection. Nature conservation might well get in conflict with the aims of process preservation and habitat conservation; the (natural) process is coastal squeeze; the consequence may be loss of habitat. Coastal protection needs the functions of the Wadden Sea and the salt marsh (foreland). The dissipation of wave energy from the North Sea increases if the sand and mud plates grow, retardation or even decrease will reduce this feature.

Coastal Squeeze

If the sea level rises, as it has since the last ice age, intertidal areas will naturally migrate landwards, maintaining the same position relative to the high and low tide marks in which the plants and animals thrive. If there is a fixed barrier, such as a dike or sea wall, this landward migration is interrupted. This means that the plants in existing areas of salt marsh will die, but no areas of replacement habitat become available further inland because of the barrier. The salt marsh is squeezed out between the sea and the barrier; erosion will appear and the salt marsh eventually may disappear – see for example Mai and Bartholomä (2000), Doody (2004).

van Duin et al. (1999) distinguished three morphological types of salt marshes:

Island Salt Marsh: Three sub-types of almost natural salt marshes can be distinguished on the islands. *Barrier-connected salt marshes* developed at the lee side of sand dune systems of barrier islands. A thin cover of clay-containing layers, starting from a former sandy beach plain, allows the establishment of salt marsh vegetation. The morphology shows an intricate pattern of creeks, levees and basins. Various transitions between salt marsh, beach plain, dune slacks, and dry dune occur and may show a relatively high species diversity. Seawards, they resemble foreland salt marshes. *Green beaches* develop on high and open beach plains. *Foreland salt marshes* develop in front of some island dikes. They are more clayish and richer in organic matter and the clay-containing layer is of a greater thickness than in barrier-connected salt marshes.

Mainland Salt Marsh: Along the mainland coast, two salt marsh types, mostly man-made, can be found. The first type are salt marshes situated in front of the mainland coastal plain, normally bordered by dikes at the landward side. The development has been stimulated by regulation of two key processes: enhancement of the drainage and reduction of wave/current energy. In Denmark and Germany, there are salt marshes along the mainland coastline which are not man-made or influenced by coastal protection measures [...]. The estuarine type resembles the foreland type, but the vegetation and invertebrate fauna show a brackish gradient, perpendicular to the normal zoning.

Halligen Salt Marsh: Halligen are splendid salt marsh islands on dwelling mounds. They have been naturally accreted on surviving parts of marshes flooded in the past, and are highly exposed to wave energy.

In terms of vegetation salt marshes itself are divided into six types. Here the TMAP (Trilateral Monitoring and Assessment Programme) classification is used – see Bakker et al. (2005) and Fig. 2.4:

Pioneer Salt Marsh: This zone lies approx. 40 cm below mean high water level with *Spartina anglica* and *Salicorna* spp. (Samphire) as main vegetation types.

Low Salt Marsh: This zone is inundated during mean spring tide, approx. 100–400 floods per year. The main vegetation is *Puccinella maritima* and *Aster tripolium* (beach aster).

Middle/High Salt Marsh: This zone is inundated less than 100 times per year. The vegetation is dominated by *Festuca rubra* (red fescue) and *Juncus gerardi* (salt rush).

Green Beach, Sandy Pioneer Zone: Mainly found on the barrier islands with vegetation like *Elytrigia juncea*.

Brackish Marsh: Salt marsh zone found in the estuaries influenced by salt and fresh water, with *Phragmites australis* (reed).

Fresh (anthropogenic) Grassland: Former salt marshes truncated by salt water influence due to building of embankments, with *Lolium perenne* (perennial ryegrass).

For the case study Nessmersiel these salt marsh types have been aggregated to three Design Elements (see Sect. 5.2.4): pioneer zone, salt marsh and marsh.

Salt marshes exhibit about 40 typical plant species that are 90% dependent on the special situation of salty ecosystems; i.e. on good nutrition support and also good sun conditions. About 1,650 terrestrial animal species and approx. 350 marine animal species live in the salt marshes, half of which are strongly connected to salt marshes (Heydemann and Müller-Karch 1980). Decreasing influence of salinity and flooding causes an increase in plant species (Heydemann and Müller-Karch 1980). Salt marshes are a roosting, feeding and moulting area for many birds (see Box on p. 19). Some of these birds are listed in the Red List of Lower Saxony and Bremen, e.g. the lapwing and the redshank are classified as endangered or highly endangered (Südbeck and Wendt 2002). Besides that, salt marshes fulfil other important functions such as filtering North Sea water and they have an asthetic value (Heydemann 1987). To evaluate the quality of salt marshes Dierßen (1987) recommended five criteria: representativeness of areas, the sparseness of existing or resettled species of plants and animals, the diversity and variety of existing or new spatial structures and the status-quo of each area. The importance of the salt marshes for nature conservation and coastal protection in respect of the functional value have been thoroughly investigated by Meyerdirks (2008) and Wittig (2008). A detailed explanation of the functional value is given in Sect. 4.3 on p. 110: the functional

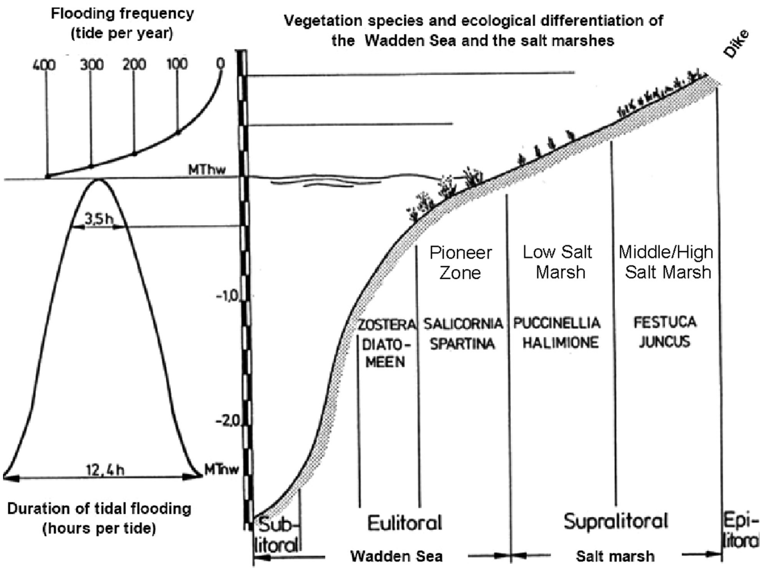


Fig. 2.4 Interaction of tide level and salt marsh vegetation
Source: Bretschneider et al. (1993).

value describes the services which a natural unit (here the salt marsh) provides for different types of land use.

The quality of the salt marsh and the effects of coastal protection schemes on salt marshes have been investigated within several projects. Within these projects different items have been investigated e.g. protection of biotopes, protection of species and the potential for development of areas with regard to changes in reclamation efforts and land use (Michaelis 1968, Arens and Götting 1997). The importance and the quality of salt marshes has been comprehensively investigated, e.g. as conservation of evidence following coastal protection projects see e.g. Heydemann (1987), Blindow (1991), Arens (2000), Götting et al. (2002) and within the German research programme "Climate Change and the Coast" see e.g. Kinder et al. (1993), Cordes et al. (1997) or Vagts et al. (2000).

The interest of nature conservation in maintenance and development of salt marshes are described in the "mission statement" for the Wadden Sea National Park in Schleswig-Holstein: A salt marsh not used by human beings with natural channels and ditches, characteristic and geomorphological structures and a characteristic distribution of plant and animal species regarding the natural dynamics – see Stock et al. (1994). For Lower Saxony the salt marshes are very important in the Wadden Sea area and are highly protected, but no "mission statement" for the salt marshes has been developed.

The Wadden Sea Region – Important Bird Area

The Wadden Sea attracts about 50 bird species with more than 10 million individuals which breed, rest and some of them stay over winter-time. The Wadden Sea is attractive for birds because of the high production rates of biomass and a good availability of nutrients. The common breeding birds are black-headed gull, herring gull, arctic and common tern and avocet (Exo 1994).

Breeding Birds

> . . . The Wadden Sea is a hot-spot within the European breeding range and which represent Species of European concern. Furthermore, 14 species are included in Annex I of the EC Birds Directive (EC 1979) and several breeding birds are listed in national Red Lists for Denmark, Schleswig-Holstein, Niedersachsen or The Netherlands. The distribution of breeding birds within the Wadden Sea is mainly determined by geographical range, feeding opportunities, available nesting habitat, predation pressure and level of human disturbance. High densities of breeding birds are especially found in salt marshes, the dunes on the islands and the higher outer sands (Koffijberg et al. 2005, p. 275).

Several factors influence the occurrence of breeding birds in the Wadden Sea: climate change, pollution, recreation and tourism, fisheries and agricultural use of salt marshes and adjacent resting and breeding areas. The effects of climate change and the accompanying consequence of an accelerated sea level rise might have negative influences on breeding birds, especially on species which breed in the surf zone of beaches and salt marshes. The influences of milder winters might have positive as well as negative effects. Recreation and tourism will have a negative influence, since it takes place in the area of breeding birds, especially at the surf zone. Changes in management have dampened the influence in some places. Fisheries have caused an ambivalent effect on breeding birds. On the one hand, the population of some species has grown because of the increasing fishery discard, and on the other hand the negative effects of harvesting mussel beds. Ambivalent influence can be determined for agricultural use of salt marshes. The change of salt marsh management has led to a more natural development of salt marshes accompanied by higher vegetation. Consequently, the composition of the species has changed to birds which are more adapted to higher vegetation like redshank and meadow pipit (Koffijberg et al. 2005).

Migratory Birds
The Wadden Sea area plays an outstanding role for migratory birds enroute to their breeding range or on the way back to their wintering areas. Within the Quality Status Report 2004 (Essink et al. 2005) 34 species were included in an evaluation of the state of migratory birds in the Wadden Sea: 44% showed a significant decrease in the 1990s, another 21% showed a decrease which is statiscally insignificant. These are not common tendencies, in adjacent areas like the UK and France these tendencies were not observed, thus the reason for decline of species might be found in the Wadden Sea. A few species have increasing trends, like barnacle goose and eurasian spoonbill. Others have fluctuating trends, because of low abundance (Blew et al. 2005). Most migratory birds do not only roost, but also moult in the Wadden Sea. Within this moulting time the birds are highly vulnerable, because many of them can not fly. "Case studies in several parts of the Wadden Sea have pointed out that recreational activities are among the most frequently observed sources of anthropogenic disturbance. This is confirmed by the recent inventory by Koffijberg et al. (2003), which points out that 29 to 42% of all roosting sites are subject to an estimated moderate to heavy recreational pressure." (Blew et al. 2005, p. 292). The highest abundance of moulting shelducks can be found in the southern part of the Schleswig-Holstein Wadden Sea with about 200,000 individuals. The moulting areas of the common eider is not concentrated like the moulting area of the shelduck, but account for about 170,000–230,000 individuals. Remarkably, in the East-Frisian region between the barrier island of Juist and Wangerooge there are no roosting sites for these species. Blew et al. (2005) concluded that within this area the recreational pressure and activities are too high to provide undisturbed areas for roosting and moulting birds. Other disturbances for roosting and moutling birds are commercial fishery, boat and air traffic and oil spills. Additionally, in the future, near-shore wind farms within the 12-nautical-mile-zone might prove potential elements for disturbance.

2.2 Sea Level Curves and the Flood-prone Areas

2.2.1 Sea Level Curves

In this section a brief description will be given of the recent findings related to the extent and the reasons for sea level rise. The morphological structure of the southern North Sea coast is mainly dependent on these processes. The iso-static movements in the southern North Sea are mainly caused by the retreatment of the ice mass since the last ice-age and reflect the balancing of the earth's crust. The eu-static sea level rise is also caused by the retreatment of the ice mass, since the melting ice led to an increasing sea level. Many investigations have been carried out world wide and documented in a wide range of publications. A current overview is given by the Intergovernmental Panel on Climate Change (IPCC) – e.g. IPCC (2007). A frequently cited curve which visualises the quaternary history of sea level changes in the North Sea has been published by Jelgersma (1979).

A new sea level curve for the southern North Sea by Behre (2007) is shown on Fig. 2.5. The sea level curve is mainly deduced from archaeological data. The sea level rise amounted to 1.25 m per century from 7,000 to 5,000 BC, and was reduced to 0.14 m per century until 1,000 BC. Between 1,000 BC until today the curve shows many oscillations. These oscillations are explained by information and data on settlement activities in the low-lying areas of the German Bight. In mean, the curve shows over the period of the last 3,000 years a sea level rise of about 0.11 m per century.

Bungenstock (2006) investigated the sea level curve of the barrier island of Langeoog (Lower Saxony) using the sequence-stratigraphy method. This curve is inserted into Fig. 2.5. The sea level curves show more or less the same rates, although two different approaches were used, the natural-scientific approach by Bungenstock (2006) and the archaeological approach by Behre (2007).

The sea level curves presented give an impression of the sea level rise for the last 10,000 years. However, the determination of the sea level rise and thus these curves are imprecise due to different reasons. Behre (2003) refers to these aspects and discussed these reasons, e.g. determination of the age using archaeological data, e.g. elevation of settlements, or determination of the height using peat. The age of archaeological data is subject to estimations. The height of the mean high water level has to be determined carefully by using the peat horizon, because some turfs can develop between 0.5 m below mean high water level (MHW) and MHW and others between MHW and 0.8 m above MHW. So, there is a potential divergence of approx. 1.3 m. Using the elevation of settlements on ground level is also imprecise because these settlements represent more or less storm surge level rather than MHW, and have been set as 1 m above MHW (Behre 2003). The same problems of interpretation e.g. of the heights of peat apply to Bungenstock's approach. Behre (2003) concludes at present a tectonic decrease of less than 0.1 cm per century and that a further iso-static movement is unlikely. Bungenstock (2006) concludes that the coast of the southern North Sea is – in terms of geological time scales – a sedimentation

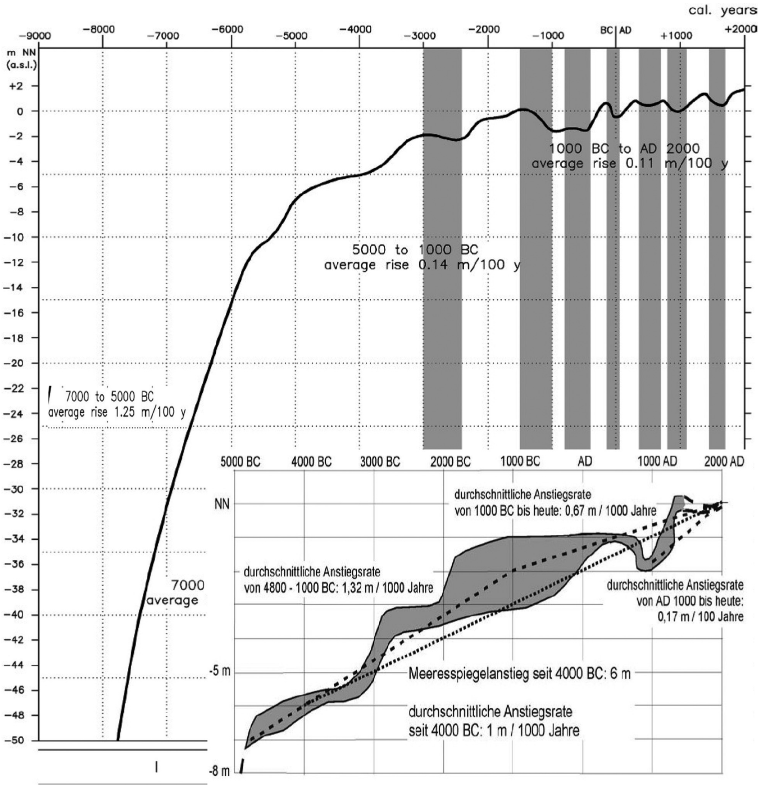


Fig. 2.5 Sea level curve for the southern North Sea
Source: Bungenstock (2006) and Behre (2007).

coast. However, short periods (about a generation of human live) of sea level rise cannot be ruled out.

2.2.2 Todays Flood-prone Areas

In Germany the States are responsible for coastal protection. An overview of the flood-prone area in the German Bight is given in Fig. 2.6. In *Schleswig-Holstein* the existing Master Plan for Coastal Protection Management defines the area between the −15 m NN on the sea-side and +5 m NN on the land-side as the coastal protection planning area. The flood-prone area is about 3,400 km^2 with approx. 250,000 inhabitants. The sea-side area covers approx. 3,000 km^2 including the islands, Halligen and the off-shore island Helgoland. The Master Plan of Schleswig-Holstein covers both the land and the sea side. The flood-prone area is determined by the area which will be inundated by the highest storm surge level without protecting elements. The sea side border was chosen because of the influence of waves and currents (MLR 2001).

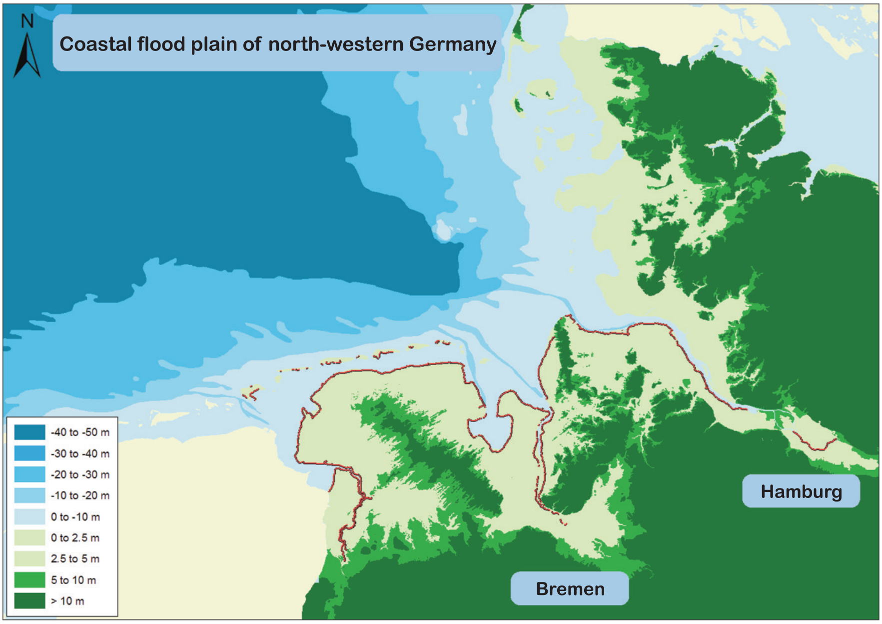


Fig. 2.6 The coastal flood plain of north-western Germany
Source: Ebenhöh et al. (1996).

Regarding the State Law on Dikes for *Lower Saxony* the protected area (=flood plain) is the area which will be inundated by the highest storm surge level (§6, NDG 1963). This area is the area of the dike boards along the Lower Saxonian coast and covers approx. 6,500 km^2 (MELF 1973, BR W-E 1997) with approx. 1.2 million inhabitants. On the sea side, the area is limited by the MHW, because it is the natural border between the fore land and the Wadden Sea which is flooded by normal tide twice a day (Lüders and Leis 1964). In Lower Saxony the area for coastal protection ranges from the MHW to the NN +8 m contour-line in the hinterland. The barrier islands are located in this area, but they are outside the scope of this dissertation.

The flood-prone area of the state of *Bremen* is also determined by the highest storm surge level. For some parts of the city of Bremen the river discharges (run off) have to be taken into account (e.g. River Weser, Ochtum and Lesum). The flood-prone area is approx. 340 km^2 with approx. 410,000 inhabitants (NLWKN 2007b). In *Hamburg* one third of the city is lying below MHW, approx. 250 km^2, with approx. 180,000 residents and 140,000 employees (Otto 2004, LSBG 2007).

The figures summarised in Fig. 2.7 are mainly taken from the technical reports of the EUROSION project – see EUROSION (2004a,b). Within the EUROSION project a "Radius of Influence of Coastal Erosion := RICE" was defined: the area within 500m from the coastline that can be extended to areas lying under +5 m MSL. In England the flood prone area is determined as an area possibly affected by a 1 in 5 year storm event and a 1 in 200 year storm event, respectively, which might exceed the +5 m contour-line (EUROSION 2004b).

Country / Items	Germany: Lower Saxony[1]	Germany: Schleswig-Holstein[2]	Germany: Bremen[3]	Germany: Hamburg[4]	East of England[5]	Netherlands[5]	Denmark[5] (North & Baltic Sea)	Total [approx.]
Flood Prone Area [km²]	6,500	3,400	340	270	3,714	13,900	13,300	40,373
Inhabitants [approx.]	1.2 Million	252,000	410,000	180,000	855,000	7.1 Million	2.1 Million	12.1 Million
Border of the protected area	up to + 8m contour-line	+ 5m contour-line	+ 5m contour-line	+ 5m contour-line	Line determined by 1:200 storm event	+ 5m contour-line	+ 5m contour-line	X

Fig. 2.7 Figures about the coastal flood plain of the southern North Sea region
Sources: 1: MELF (1973), BR W-E (1997), NLWKN (2007b) 2: MLR (2001), 3: NLWKN (2007b), 4: Otto (2004), LSBG (2007) and 5: EUROSION (2004b).

2.3 Service for Society: Coastal Protection

2.3.1 Retrospective – Coastal Protection until Yesterday

The purpose of this section is not to repeat the description of the historical development of the organisation and engineering techniques of coastal protection. A comprehensive description of the dike-building techniques can be found in e.g. Kramer (1992). But, to understand the development of coastal protection in north-western Germany, especially in Lower Saxony it is necessary to describe roughly the historical changes until the severe storm surges in the middle of the last century. Comprehensive descriptions of the historical organisation and the circumstances of coastal protection along the coasts of the southern North Sea can be found e.g. in van de Ven (1993). The historical development in Germany, especially in the States of Lower Saxony and Schleswig-Holstein has been treated in several reports and articles. For the purpose of this report it is sufficient to refer to some old literature like Brahms (1754), Auhagen (1896), Tenge (1898), von Gierke (1901/1917), Tenge (1912), Wöbcken (1924, 1932) and Breuel (1954), which most of the following and recent publications are based on. Nevertheless, the research and investigations into early settlements in the coastal zone has provided a deeper insight into the challenges for living and working in low-lying areas – e.g. Krämer (1984), Hofmeister (1984), Brandt (1984), Prange (1986) and Behre (1987).

People settled down in the low-lying areas of the southern North Sea region and tried to provide for their livelihood. The first settlers in the low-lying areas of the north-western part of Germany constructed their settlements according to the sea level (i.e. intuitive storm surge level). This defensive strategy (or adaptation), i.e. moving inland with rising water and moving towards the sea with falling water, was reconstructed by excavations in the lower marsh (Brandt 1992). The settlements in the early middle ages were limited to the higher grounds along channels and rivers. Afterwards, in times with low changes in sea level, the re-settlement of the area led to the protection against storm surges of the sea by building dwelling mounds – e.g. Brandt (1984, 1992). In the last period of the 12th century and with the beginning of the 13th century the first embankments were built, to protect the land around settlements (Brandt 1992). These embankments displayed a very poor construction in comparison to today's, and can perhaps be compared to current summer dikes, which are only capable of protecting the farmland against lower high-tides occurring during summer time and autumn (Peters 1992).

To conclude: The first embankments were built in the earliest mid-ages around the southern North Sea (e.g. van der Linden 1981, Blok 1984 and van de Ven 1993 for The Netherlands and Ravensdale 1981 for England) to reclaim land for settlement. Thus, the fight against the sea was the main task for these low-lands, expressed by the Frisian settler: "Frisian people should protect their land with three weapons: spade, pushcart and pitch-fork" (p. 6 after Wiarda 1805 in Meyer 1926). The contract in the year 1106 between settlers from The Netherlands and the archbishop of Bremen seems to be the first hint of dike-building to enable settlement at the river marshes of the Weser (von Gierke 1901/1917) and thus to reclaim arable land.

For the purpose of this dissertation, especially for the issue of participation, it is of special interest how the alliances or unions to protect and to maintain the reclaimed land were established and how they were organised and managed. These characteristics provide a deeper insight in the traditional identity and mission of dike boards today. The land reclamation works in the fenland's of The Netherlands, the area between Utrecht, Rotterdam and Amsterdam, had in earlier times led to the generation of local organisations to commonly maintain the already installed constructions (i.e. dams, sluices and dikes). These organisations consisted mainly of the aldermen of the settlements. These organisations developed over time and grew with the reclamation works and the interests of maintenance and drainage of a much bigger area. The water boards in The Netherlands were established and officially commissioned by a count or a bishop in the 13th and 14th century. Afterwards, these water boards also became important for the creation of polders, which were mainly designed to control the water level of the arable land inside a dike-ring; the oldest polder can be found in Zeeland. Starting in 1840, the management board of the water boards underwent several changes until the end of the 19th century. At that time the provinces became more powerful and published new laws and regulations. These changes led to more democratic structures, based on assemblies of representatives elected by the landowners (van der Linden 1981). The number of water boards in The Netherlands was reduced from over 3,500 to 2,500 by 1950 and after the devastating storm surge in 1953 to about 120. Nowadays, there are 26 big water boards in The Netherlands with comprehensive duties such as the maintenance of dikes and other embankments (in The Netherlands about 3,500 km), water management, water quality and to some extend for waste water treatment (UvW 1992).

The establishment and the historical development of the dike boards in Germany are outlined by Kramer and Rohde (1992), and e.g. for the Oldenburg-area by Meyer (1926). The dike boards in north-western part of Germany were established in different ways, but the result was always the same: the dike boards were organisations set up for a special reason: protection of settlements and arable land. The early dike boards were associations like municipalities with obligatory membership within a specific area. During the 16th and the 18th century the organisation of the dike boards was reformed, the associations were compelled to transfer more and more responsibilities to state agencies. Hand in hand with these changes manual dike construction work was replaced by machine-assisted techniques. Also a system of fees was introduced. After the storm surge of 1825 these developments were rebirth of the adoption of the co-management. The decisive step in the re-reform process was the dike order of 1855, which was based on four principles (Meyer 1926, p. 101):

1. Establishment of a common dike law for the entire state.
2. Reduction the number of dike boards: from 15 to 4.
3. Annulment of exoneration of dike obligations.
4. Annulment of the deposit on the past of the inhabitants protected by main dikes, and adoption of the “Kommuniondeichung” (which distributed dike maintenance duties among all people living in the flood-prone area of a dike board).

The latter principle was a reaction to the bad experiences made in earlier times, when the responsibility for a line lay solely with the people living directly behind a certain stretch of dike with the maintenance and reconstruction was based on a system of deposits. The old approach led to the desolate economical state of the dike boards. Finally, the process was stopped in the last century with a democratic organisation of the dike boards, run by a committee, where members were elected (Meyer 1926). To conclude, the result of joint work for coastal protection was the generation of marsh-land, which led to economical growth.

The difference between the dike boards in Germany and the water boards in The Netherlands today lie in the distribution of the responsibilities and their place within the government/authority hierarchies: the “water boards” are also responsible for water management of the area, whereas the “dike boards” are solely responsible for the dikes. The water boards in The Netherlands have an equal status to that of the municipalities, in Germany the dike boards are public corporations with a special duty, which in Lower Saxony is laid down in the State Law on Dikes (NDG 1963).

2.3.2 The Consequences of the Storm Surges in 1953 and in 1962

The storm surges in 1953 in The Netherlands/England and a few years later in 1962 in Germany led to both organisational and technical changes, i.e. in the fields of engineering and the strategic orientation of coastal protection. The following section summarises the circumstances, experiences and the consequences of these devastating storm surges. Again, many publications are available on the consequences of these storm surges and in the light of the recent storm surges at the German coast, these aspects have been reviewed in several documentations. A comprehensive overview is given e.g. in Kramer (1989), Kunz (2004a) or DHV (2007).

2.3.2.1 Northern Germany – Lower Saxony in 1962

In Germany, especially in Lower Saxony, the strategy for the mainland can be summarised as “hold the line”. As a reaction to the storm surge of 1953 in The Netherlands an Engineering Commission was established to investigate and to improve the existing strategy of coastal protection – see e.g. Lorenzen (1955), Tomczak (1955). The recommendations led to higher crests on some coastal stretches which, later withstood the water heights and the wave run-up of the 1962s storm surge (Ingenieur-Kommission Niedersachsen 1962). The storm of 1962 led to extreme water levels in the area of the rivers Elbe and Weser, especially in Hamburg and Bremen, and in the river Ems area. The “Lower Saxonian program for coastal protection 1955–1964”, installed after the Dutch disaster, was not completely implemented by February 1962. The consequences were loss of life of people and animals and devastating damages, mainly in Hamburg. The water levels at the East Frisian coast were less than expected. The main dike line extended approx. 870 km along the Lower Saxonian coast; about two thirds of which were not damaged, but the consequence of 61 dike breaches was an inundated area of approx. 37,000 ha (Ingenieur-Kommission Niedersachsen 1962). The Engineering Commission acknowledged that older dike lines, which had been built with a different mission (i.e. to protect the polder against inland waters from the peaty area), had protected the hinterland against devastating inundations. Thus, the recommendation was given to maintain and improve the older dike lines, and where possible to build new second dike lines. Also, it was recommended that the second dike line should be installed within a certain distance of the main dike to enable better emergency management in the case of a storm surge and a dike failure. The experiences in 1962 have shown, that the response time in some cases was too short to rescue the inhabitants of the polder areas (Ingenieur-Kommission Niedersachsen 1962).

The experiences of the 1962-disaster led to the installation of the Advisory Committee for Coastal Protection for the North and the Baltic Sea (Lorenzen 1966). The comprehensive recommendations of this Committee were published in Engineering Committee for North and Baltic Sea (1962). These recommendations cover the design of dikes, the design of the outer and inner slope, the quality and conditions of the soil and the subsoil of dikes, and the maintenance and contingency planning. The results of the research programmes and the recommendations of the committee led to the first-ever State Law on Dikes in Lower Saxony – see NDG (1963), a detailed description of which will be given in Sect. 4.1.1.

The coastal protection authority is obliged to prepare a special plan describing and elaborating the strategy and concepts of coastal protection (Master Plan for Coastal Protection – German: Generalplan Küstenschutz). The first Master Plan, published in 1973, included a comprehensive description of the consequences of the storm surge in 1962, objectives of coastal and island protection in Lower Saxony and the design of main dikes and their heights, and also the work programme for the coming years – see MELF (1973). The intention of the Master Plan is to fix mandatory directives and to provide information for both the general public and the people and institutions affected.

2.3.2.2 The Netherlands since 1953

The consequences of the storm surge of 1953 (or "de ramp") were the loss of life of about 1,800 people and many animals, because of several dike failures and the resulting devastating damages (e.g. Slager 1992, TAW 1998, Seijffert 2001). As a reaction the strategy of coastal protection was totally re-worked for The Netherlands (TAW 1998). A master plan to increase the safety of the low-lying areas was established in the 1960s. The basis of these coastal protection works is the Flood Defence Act (FDA) established in 1953. Up until the 1950s the risk of flooding was estimated on the basis of intuition and experiences, as (complex) simulations or calculations to determine the risk of flooding were not possible (TAW 1998). The first step of the advisory board of the Delta Committee was to investigate whether the water level of the 1953 flood (NAP +385 m, Hoek van Holland) could be exceeded and the second step was to investigate the costs of increasing the safety level in comparison with the expected economic benefits (TAW 1998, 2000). The result was the classification of the Dutch coastline and the rivers into four safety levels, i.e. ranging from 1 to 10,000 for highly populated areas with high economic values from 1 to 4,000 at the Wester Schelde delta and the north-east of The Netherlands, and 1 to 1,250 at the rivers (e.g. de Ronde et al. 1995, TAW 2000). The proposed coastal works, called "Delta Works", were largely completed in the late 1980s. This approach was based on the suggestions to strengthen the embankments as a result of the experiences of the storm surge in 1953 in the light of the state-of-the-art in engineering, i.e. the prime goal was to retain the water from the hinterland. Hence the embankments were constructed to withstand one major flood every 10,000 years.

This probability-based approach of exceedance has been applied to the entire coast of The Netherlands. Over the past 30 years many dikes, sluices and storm surge barriers have been improved – and to some extent newly installed – to increase safety against flooding. However, the design of the embankments was subject to the lack of experience and knowledge of the various failure mechanisms, which could lead to a dike failure (TAW 2000). The Technical Advisory Committee for Flood Defence published comprehensive guidelines for the maintenance and the construction of embankments and the consideration of different values and functions in the coastal zone and along the rivers – see TAW (1998). Shortly after the completion of the Delta Works a new policy of dynamic maintenance was established, accompanied with the base-line concept for the sandy coast in The Netherlands (RWS 1990, Hillen and de Haan 1993). The new strategy was a reaction to the enduring coastal erosion along the coasts of The Netherlands and the anticipation of possible consequences of an accelerated sea level rise. In general terms: if the base-line concept was applied; erosion can be allowed to take place to a limited extent, but will be prevented on highly vulnerable coastal stretches. The main technique deployed to implement this strategy was the application of sand nourishment and this has led to reasonable results. The concept of the coastal defence strip was introduced from the −20 m depth-line on the sea-side to the polder on the land-side (MVenW 1990).

The Netherlands applied a scenario-driven approach for an accelerated sea level rise, which is based on the IPCC scenarios and ranges from 20 cm/100 years (minimum scenario) to 85 cm/100 years (maximum scenario) with 10% more winds (MVenW 2002). The safety level of the embankments will be re-assessed every five years. The Technical Advisory Committee recommended that the failure mechanisms and the probability of embankment-failure be investigated and included in the planning measures (TAW 1998).

2.4 Protection Against Flooding – Today's Concept

2.4.1 Lower Saxony

Coastal Protection in Germany is based on the Constitution of the Federal Republic of Germany (German: Grundgesetz). In article 74 section 1 coastal protection is an integral part of the concurrent legislation between the Federation and the States (Deutscher Bundestag 2007a). In practise, the responsibility lies with the States (principle of subsidiarity). All coastal States have a special legislation for water management and all of them have incorporated coastal protection into this framework with the exception of Lower Saxony with its State Law on Dikes (NDG). The Federation contributes financial support to this task, established in article 91a of the Constitution (Deutscher Bundestag 2007a). The contribution is established as "Federal Objection for the Improvement of the Agrarian Structure and Coastal Protection". The present version refers to the main principle for the enhancement of the agrarian structure and coastal protection for the period 2007–2010 (Deutscher Bundestag 2007b). The fields of enhancement encompass e.g. improvement of rural structures, improvement of production and distribution structures, forestry and coastal protection. The aim for coastal protection is as follows: "Defence against natural hazards and enhancement of safety in coastal zones, on the islands and on river basins in tidal areas against inundation and loss of land by storm surges and sea attack" (Deutscher Bundestag 2007b, p. 62). Other provisions are included, such as strategy development and investigations in combination with measures, to reconstruct, strengthen and heighten coastal protection structures, fore land work within a range of 400 m and sand nourishment. Limited support is given for coastal protection measures, which affect areas of ecological value. These are only eligible if e.g. the required safety can not be achieved by another justifiable measure. Measures which are not covered by the Federal Objection are e.g. the maintenance of coastal protection structures and the construction of pumping stations. The federal contribution is limited to 70% and the State contributes 30% (Deutscher Bundestag 2007b).

The recommendations of the Engineering Committee for Coastal Protection of the North and Baltic Sea are still valid (Engineering Committee for North and Baltic Sea 1962) and have been amended in the light of recent findings in 1993 (EAK 1993) and 2002 (EAK 2002). The latest Master Plan for Coastal Protection in Lower Saxony in combination with Bremen (Mainland) was published in 2007 (NLWKN 2007b, a detailed description of which is given in Sect. 4.1.1).

The concept and the strategy of coastal protection has not been changed since the Master Plans of 1973 and 1997. Hence, the current Master Plan is an extension of former Master Plans, describing mainly the financial stipulations and the agreed programmes for the next years. The budget claimed by Lower Saxony is approx. 500 Mio. € (NLWKN 2007b). The necessary projects will be described in more detail in Sect. 3.4, because these projects relate directly to activities in Lower Saxony.

The methodology for calculating and determining the height of the dike is recommended by the Advisory Committee for the North and Baltic Sea and combines two approaches: (a) Single Value Proceeding and (b) Composition Proceeding (Fig. 2.8).

Although Lower Saxony features second or older dike lines, these are not adequately considered and to some extent they have not been integrated into the concept of the protection by the dike boards (Kunz 2004a). Examples of different second dike line conditions are demonstrated by Fig. 2.9: a second dike line of the Norden Dike Board is shown in Fig. 2.9a; the dike board responsible for the coastal stretch around the western Jade Bay (III. Dike Board Oldenburg) has improved and maintained the existing second dike lines over the last years – see Fig. 2.9b.

The amendments of the Master Plans conducted and published after the storm surge of 1962 follow the recommendations of the Advisory Committee for Coastal Protection (Kunz 2004b). The aims of safety for coastal protection at the North and Baltic Sea are summarised as follows:

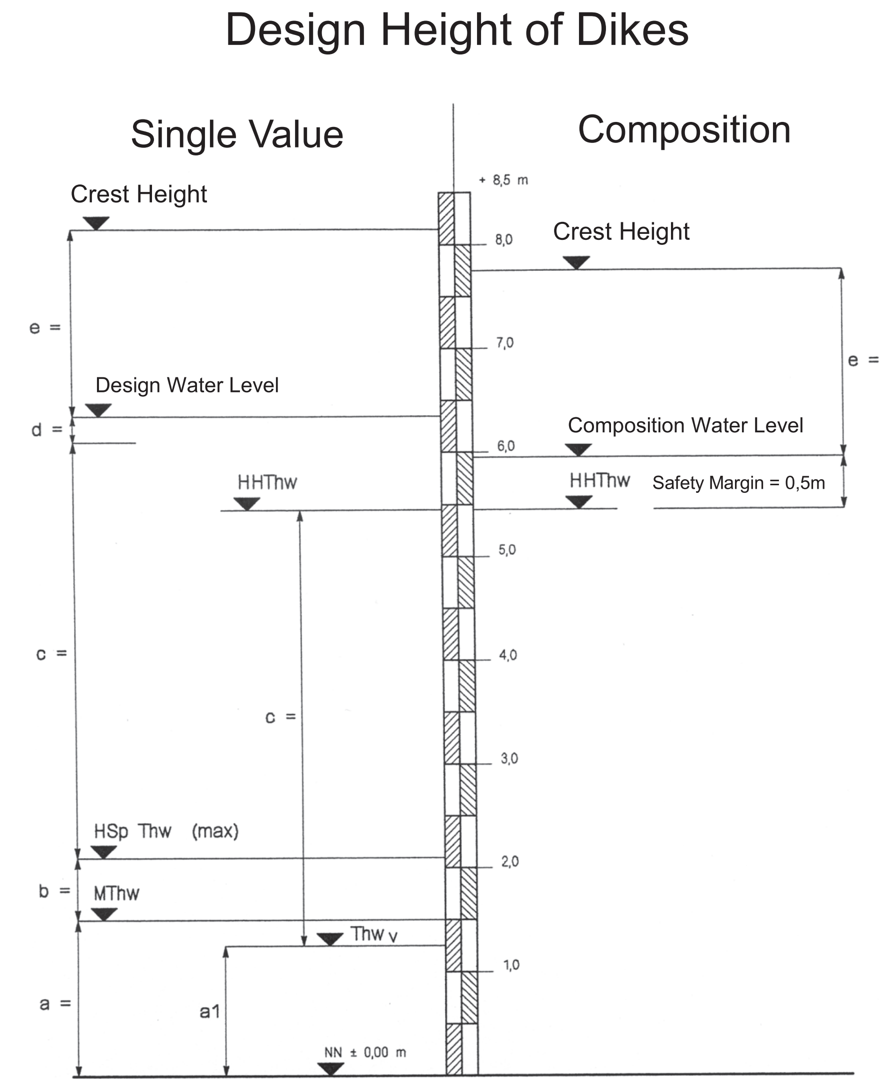
> The basic findings of the Advisory Committee for Coastal Protection – see EAK (2002) – are as follows:
>
> - The absolutely highest storm surge can not be determined.
> - Certain specific astronomical, meteorological and oceanographical circumstances coincide may leading to higher storm surges as anticipated today.
> - It is questionable whether dikes should be built which will hold back flooding water under all perceivable conditions.

This led the Advisory Committee to the following recommendations for a main dike (Kunz 2004b, pp. 256–257):

> - The height of the dike is crucial for the safety of the protected marshes.
> - The crest of the dike should be as high as the design water level, which is based on a defined level of safety taking into account a certain probability of exceedance and the height of wave run-up, which should prevent frequent and powerful overtopping.
> - The decision not to determine a "highest storm surge", has to be considered by designing dikes with a certain cross-section able to withstand strong and long-lasting overtopping.

For the design of main dikes the Committee recommends:

- For every stretch of the coast the "design water level" has to be determined – verified by scientific research and clearly defined – which either will never or at least within a manageable risk level – be exceeded within a certain time period. The currently applied procedures (in Schleswig-Holstein with regard to the frequence



a = Mean High Tide Water (MThw, 10 year mean),
a1 = Forecast Tidal High Water (Thw) with max. wind surge (Windstau)
b = Difference between High Spring Tide Water (Hsp Thw) and Mean High Tide Water,
c = Difference between highest High Tide Water (HHThw) and Mean High Tide Water,
d = Secular trend of Sea Level Rise,
e = Max. wave run-up

Fig. 2.8 Proceedings to calculate the design water level and the crest height of the main dike, *left*: single value, *right*: composition
Source: BR W-E (1997).

(a) Second dike line dike board Norden (b) Second dike line III. dike board Oldenburg

Fig. 2.9 Second dike lines in Lower Saxony
Source: Ahlhorn (1997, 2005) @ Frank Ahlhorn.

of a certain water level, and in Lower Saxony to the single value procedure) produce approximately the same values, but are not verified by science and are more or less the result of empirical studies.

- Identification of a "design height for wave run-up", which will only be over topped by a certain wave level or only allow a defined amount of water to flow over the dike crest (overflow).

These guidelines of the Advisory Committee are reflected in the current procedure to determine the height of the dike crest and, thus, in the accepted safety standard, incorporated in the procedure applied in Lower Saxony as shown in Fig. 2.8. Differentiated discussion and criticism has been provided by Kunz (2004b) and can be summarised as follows: Since no absolutely safe coastal protection against flooding is guaranteed, the risks have to be limited and managed. There are many uncertainties which have to be considered to determine the safety level of embankments. As mentioned above, for example, the highest storm surge can not exactly be determined, e.g. because of uncertainties in projecting water levels into the future (see box in Sect. 3.1.3). There is no question, that the existing safety concept has to be enhanced, however, step by step and not immediately by introducing new approaches before they are ready for implementation, e.g. it is necessary to enhance the knowledge of failure mechanisms and the failure probability of dikes and other structures (Kunz 2004b).

Taking these remarks into account, the recent enhancement of the safety margin for the secular sea level rise from 25 up to 50 cm announced at the conference on climate change and coastal protection in Oldenburg (July 2007) by the Minister of the Environment, responsible for coastal protection, is a postponement of the issue at stake and does not solve the described basic problems and challenges. However, it serves as an approach to address the consequence of increased sea level rise in Lower Saxony (and Bremen).

2.4.2 The Netherlands

The Technical Advisory Committee in The Netherlands has stimulated an investigation of the failure mechanisms of coastal protection elements. Consequently, a large research project has been launched called VNK (Veiligheid Nederland in Kaart, Flood Risks and Safety in The Netherlands, Floris). The approach taken in this project is described as: "From probability of exceedance to probability of flooding" (TAW 2000, MVenW 2005a–c). This means, that the safety margins established by the Delta Commission are still valid, but the design water level as criteria for the dike height will be substituted by an acceptable risk.

The definitions are as follows (TAW 2000, p. 8):

Exceedance Frequency: The exceedance frequency of a water level is the probability that the design water level is reached or exceeded. The design water level is used to design a safe dike or hydraulic structure.

Flood Probability: The flood probability is the probability, that an area might be inundated, because the water defence around that area (i.e. a dike ring) fails at one or more locations.

The background of the conceptual shifting in The Netherlands refers to the fact, that about 50 dike rings around polders have been installed to protect people against flooding and at the rivers against inundation (some stretches of these dike rings are on rivers and some at the coast). The safety of the dike ring is provided by different constructions like dikes, sluices and locks. Every element has its own failure mechanism and its specific failure probability, especially, that of human error, as the experiences of 1953 have shown (Slager 1992). The aim of the research project was to determine as exactly as possible the probability of failure of these components. This was done by assuming that, a chain is as strong as its weakest link. Thus, the VNK project identified the "Weak Spots" (see Fig. 3.18). In the first phase of this project pilot studies were conducted, see e.g. Provincie Noord-Holland (2005) or RIKZ (2006). This approach and the paradigm shift had been integrated as early as possible in a much wider approach to coastal development – see MVenW (2002). For that purpose, a detailed research programme called SBW (Sterkte Belasting Waterkeringen, Extent of Hydraulic Impacts to Embankments) has been initiated – see e.g. RWS (2008a–d). This programme encompasses six projects:

- Wave overtopping and the strength of the inner slope
- Dune erosion
- Protection of the dune foundation
- Hydraulic boundary conditions at the Wadden Sea
- (Macro) stability of dikes with regard to increased water pressure under the dike
- Wind- and wave statistics.

The new concept of The Netherlands can be summarised as follows: It is important to consider the requirements of water management adequately in spatial planning. The new water management law will strengthen the relationship between water management and spatial planning. This will be implemented by the national and regional water management plans which are part of the new law for spatial planning (Wet over Ruimtelijke Ordening, Wro), which came into force 1. July 2008. With the implementation of this law the spatial aspects of water management will be mandatory at national and provincial levels (description of the integration of water management and spatial planning on www.helpdeskwater.nl of April 2008).

2.4.3 Outlook

The descriptions and explanations in this chapter show that the people living and working in the flood-prone area can protect themselves against flooding. The experiences of the last decades provide evidence, that devastating consequences of storm surges can be avoided. Protection strategies have been revised continuously, e.g. in The Netherlands over the last 20 years, and further aspects have still to be considered. The present strategies will protect people and their property against flooding, but absolutely safe protection against natural hazards is unachievable. Thus, the concepts and strategies have to and will be continuously revised and adapted to new challenges and problems. One of today's widely accepted challenges is linked to the consequences of climate change. Climate change will impose different threats and changes to parameters which are important for the safety of people in low-lying areas and for coastal protection.

Sea level rise itself is not a new challenge for the people living in flood-prone areas, as the discussion of the sea level curves has shown. But, how fast will the sea level rising be? Over the last centuries, we have increased settlements in coastal zones, for the purposes of trading, recreation etc.; but how will the future risks to settlements develop? And what about the Wadden Sea, the enormous nature reserve in front of the dikes? How will the plates react to sea level rise? Bungenstock (2006) assumes that the southern North Sea is in the stage of a sedimentation coast, but this trend is defined in geological time scales.

The next chapter will deal with the new challenges people have to face resulting from climate change. A new approach in dealing with nature was introduced with the acknowledgment of the phenomenon of climate change that of sustainable development. The mutually consideration of social, economic and ecologic aspects for development. The Earth Summit in 1992 initiated a process called Agenda 21, and furthermore the concept of ICZM has been introduced. The growing awareness of nature conservation has led to a more comprehensive view on projects and programmes in the coastal zone. So, in consequence, coastal protection projects have been influenced by the interests and needs of nature conservation and this will continue.

What are the challenges imposed by climate change? What might the consequences be for coastal protection? The summary of the recommendations of the Advisory Committee for the North and Baltic Sea and the conclusions of Kunz (2004b) have led to the establishment of basic safety principles (p. 259):

- . . . The existing philosophy of safety installed under the impression of the storm surges in 1953 and 1962 provides an overall concept for coastal protection which is still valid. The philosophy of safety is a sound basis for the enhancement of aims for coastal protection with regard to spatial protection concepts and strategies, which lead from reaction to adaptation and from solidification to flexibility.
- Coastal protection has to consider interests and needs which are derived from the principle of sustainable coastal development. [. . .] These cross-sectoral and multifunctional interests are asking for societal agreements about the desired safety in flood-prone areas. This stimulates a paradigm shift: From the principle of "security of failure for the dike line" to the principle that for certain areas a defined risk will not be exceeded (acceptance of risk) and that the remaining risks are manageable (risk management).

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