

# Ems-Dollart Estuary

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## 1. Introduction

The Ems is Germany's most north-westerly river, rising near the town of Schloß Holte-Stukenbrock in Westphalia 134 m above sea level and – after 370 km – flowing into the North Sea near Borkum. Its largest tributaries are the Leda (tidal Ems) and the Hase. From Herbrum, the Ems and the Dortmund Ems Canal (DEK, 1<sup>st</sup> stage 1899) are influenced by the tide. Protection from storm surges and support for the transfer of newly-built ships has been provided by the Ems Barrier near Gandersum (Ems kilometre 32.2) since 2002.

The Ems serves as a drainage canal and shipping route, and its embankments offer space for habitation and agriculture. In its lower reaches, locks and pumping systems drain whole regions that are only very slightly above sea level and in some cases even below. The approach depth to Emden's sea port is guaranteed for shipping by maintaining the fairway depth at chart datum (LAT) – 8.5 m. Depending on the tide, ships can reach Emden with a draught of up to approx. 10.5 m. Inland navigation vessels up to the Europe ship class (length 85 m, width 9.5 m, draught 2.5 m) can travel through the Dortmund Ems canal to the Ruhr (Rhine region) or through the Mittelland canal to the waterway network of the rivers Weser and Elbe. The economic significance is defined primarily by the sea ports. Here worth mentioning vehicle transshipment with the VW works in Emden, major shipyards (Cassens, Nordseewerke, Meyer) and the handling of wood, paper and liquid chalk are worth mentioning. The handling of wind turbines is increasing, together with the significance as an energy hub, particularly on the electricity and gas sector. At the same time, the ecological significance of the Ems Estuary as a habitat for flora and fauna brings out competing uses. Tourism is assuming an increasing economic significance in the economically underdeveloped East Friesland. This is due to its high natural value, particularly with the extensive and specially protected Wadden Sea, the low population density and the authentic character of the East Frisian population. Fishing among others for shrimp also plays a role here. The fish stocks in the Ems Estuary can even be said to be good according to the so-called COFAD study.

In ecological terms, the Ems is a lowland river that flows essentially through low populated areas and bears great significance for animals and plants, providing a habitat for many protected species. The extensive marshlands and Estuary mudflats offer significant avifaunistic resting and breeding areas. As far as planning proceedings are concerned, it is significant that extensive areas are protected under the FFH Directive (Directive 92/43/EEC) as well as

under the regulations of the Lower Saxony National Park Wadden Sea (1986) and the Lower Saxony Biosphere Reserve Wadden Sea (1992).

The Ems Estuary is particularly relevant on account of its significance as being a frontier region to the Netherlands (STEEN, 2003). The exact course of the national frontier has still not been established. Thus, a treaty (Ems-Dollart treaty of 1962 and supplementary treaty of 1962) on the existence of so-called “disputed territory” had to be concluded between the Netherlands and the Federal Republic of Germany. This treaty stipulates in general the use of the Estuary, maintenance and participation of both parties in cross-frontier projects (referring to the disputed territory). The Ems Commission meets regularly for discussions.

## 2. Geomorphology of the Ems Estuary

In terms of its historical origins in the context of the continental shelf in the North Sea, the Ems Estuary is a relatively young hydro-morphological system (just a few thousand years old) which, therefore, has a highly dynamic character. The appearance of the present coastline, which is dominated by the East Frisian Islands, developed by transgression following an increase in sea level about 10,000 years ago. The oldest reliable charts of the region (sailing instructions) date back to the 1630s.

One striking morphological element is the Dollart, a bay to the south of Emden with an extension of about 100 km<sup>2</sup> today. The Dollart most probably resulted from the so called Marcellus Flood in 1362. It reached its largest expanse after the heavy storm tide of 1509. Around the same time, the Leybucht was created by the storm tides of 1374 and 1378 (MEYER, 2006) to the north-east of Pilsumer Watt and north of Greetsiel. A further major morphological effect of the storm tide of 1509 was the formation of the island “Nesserland”. The “old Ems” ran in a northerly loop straight past Emden, while the new branch of the river at Pogum drained the water due westwards. As a result, the “old Ems” at Emden was subject to increasing aggradation, which several attempts to keep the old fairway close to Emden failed to prevent. At this point in time, the main fairway ran to the west of Termunten through the bay of Watum. But the East Frisian Gatje, a branch of the river to the North-east of the bay of Watum, grew increasingly stronger as a result of the current forces. Consequently, in this period, the shore was subject to noticeable erosion, necessitating dyke realignments on both the German and the Dutch side. Numerous settlements had to be given up. At this point in time, the Western Ems was the main fairway, with maritime traffic being advised not to use the passage through the Hubertgat, the channel located to the South of the Western Ems on the same latitude with Borkum. Later, the channel through Hubertgat was partly used as the main fairway.

From the 16<sup>th</sup>/17<sup>th</sup> century up to recent times, an expansion of the Dukegat and East Frisian Gatje channels can be observed, which would appear to be coming to an end through the almost complete aggradation of the bay of Watum. A map by LANG (1954) shows the situation around 1860 when the old loop of the Ems near Emden had disappeared completely, with an access channel connecting the port of Emden with the river Ems (later Emden fairway). The bay which had formed to the South of Emden on the one hand sedimented up on the other hand was part of land reclamation later on.

Fig. 2 shows present cross-sectional areas between Herbrum and the mouth to the North Sea (data from 2005), calculated for water levels approximately at LW (NN -1.5m), at NN and at HW (NN +1.5m). The significant break at Ems kilometre 48 appears due to the transition to the Emden fairway. The areas of the Dollart are not taken into account.

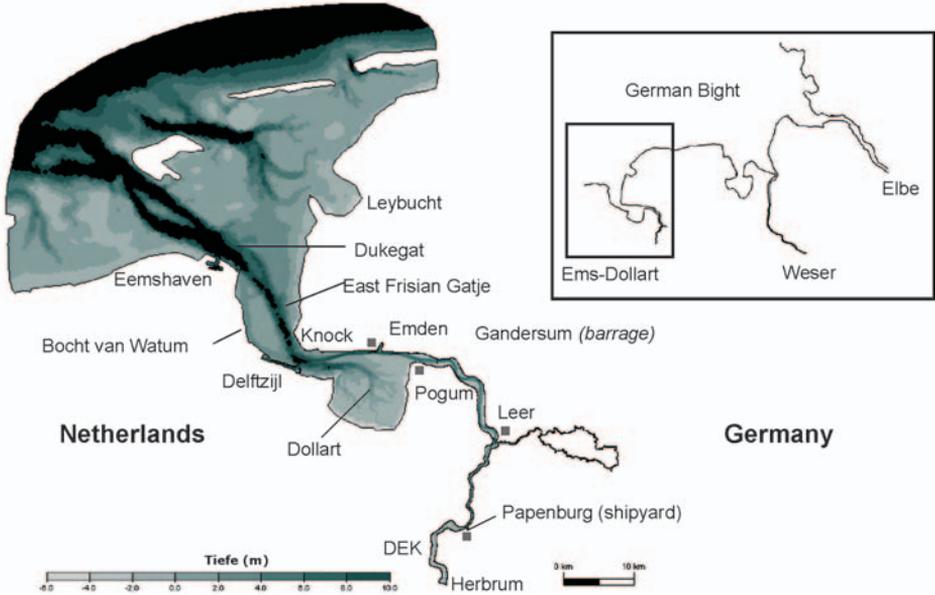


Fig. 1: Ems-Dollart Estuary

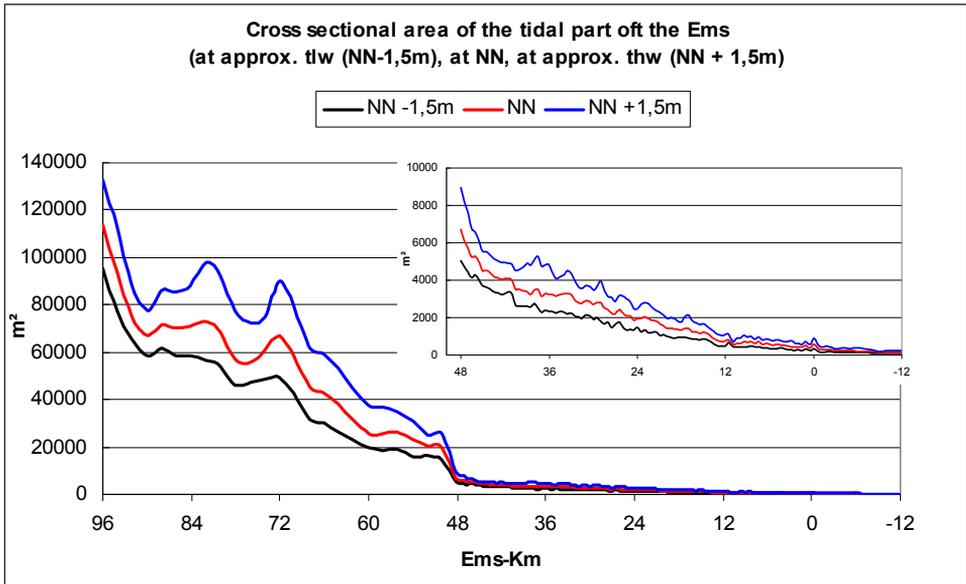


Fig. 2: Present cross-sections in the Ems Estuary as a function of the distance to the geographic origin of the system (tidal boundary)

### 3. Hydrological Characteristics

The catchment area of the Ems is 17,934 km<sup>2</sup> and thus less than 10 % of the catchment area of the Rhine or about 40 % of the catchment area of the Weser. The small size of the retention area means that there are phases with low freshwater discharge for six months in the summer. For the years 1941/2003, the maximum freshwater discharge (HHQ) is 1,200 m<sup>3</sup>/s (Feb. 12, 1946), the mean high value (MHQ) is 378 m<sup>3</sup>/s and the average discharge (MQ) 80.8 m<sup>3</sup>/s. The mean low-water discharge is 15.6 m<sup>3</sup>/s and the lowest value (NNQ) 5.2 m<sup>3</sup>/s (Aug. 01, 1947).

Statistics show that the large freshwater discharges occur frequently in the period without vegetation i.e. in the months from January to April, followed by a transition to a distinctly smaller discharge during the summer months, as a rule. Mean monthly discharge values below 20 m<sup>3</sup>/s were only reached in 4 months over the last 20 years (towards the end of the 1980's and beginning of the 1990's). The median value (most frequent freshwater discharge) is approx. 60 m<sup>3</sup>/s.

The influence of upgrades of the navigational channel of the Ems on the tidal range (Thb), HW (Thw) and LW (Tnw) can be clearly demonstrated with the development of water levels at the tidal gauges Borkum Südstrand and Papenburg, shown in Fig. 3. The development of the mean annual tidal range for the seaward water gauge Borkum Südstrand in the mouth of the Ems shows a uniform variation through the Saros cycles (nodal tide: 18.61 years). The long-time mean of the tidal range is 225 cm, with a linearly increasing trend with a rate of currently 15 cm per century. Between 1958 and 1996, the tidal range at Borkum increased by 7 cm and at Papenburg by 165 cm. The development in water levels at Borkum is due to natural influences, while the increase at Papenburg is primarily influenced by construction measures. The time series show various trends; e.g. the tidal high water shows

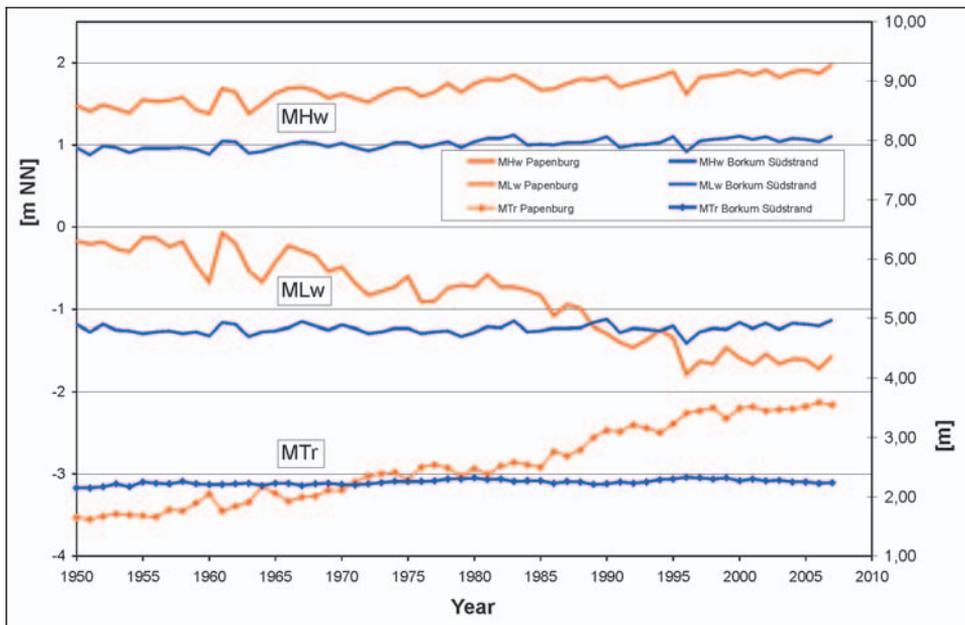


Fig. 3: Development of MLW, MHW and mean tidal range for selected water gauge sites

a greater increase at Papenburg than at Borkum. LW elevations at Borkum range between  $-1.5$  m and  $-1.0$  m (gauge ref. datum) for the period from 1950 to 2005. The curve for Papenburg gauge is subject to greater fluctuations than at Borkum because of the deformation of the tidal wave by the narrowing river cross-sections and freshwater discharge from upstream. There is a striking decrease in LW during the observed period.

The Ems is characterized by a large gradient in salinity reaching a maximum in the vicinity of Emden with a mean freshwater discharge. The variation of discharge and tidal current means that the conditions in the brackish water zone are subject to constant change. For mean conditions, a salt level of less than 0.5 PSU (PSU almost equivalent to ‰) can be found near Papenburg and Weener, less than 3 PSU for Terborg (Ems kilometre 24.5) and 7 PSU for Gandersum. At Gandersum (Ems kilometre 32), it is possible for salinity levels to exceed 16 PSU at slack water during longer periods with low discharge volumes during the summer. In 1951/1952, comparative measurements of salinity showed a very low level of approx. 2–3 PSU for a discharge of  $30 \text{ m}^3/\text{s}$  at the Terborg water gauge, and about 10–12 PSU at Gandersum (slack water on the surface and on the bottom of the river). Today, comparable marginal conditions show a salinity level of about 6–8 PSU for Terborg and 14–16 PSU for Gandersum, indicating an increase of 4–6 PSU (SPINGAT, 1997).

One particular phenomenon can only be detected by special measurements (MAUSHAKE, 2003 and TALKE, 2006). These are situations where close to the river bed lower salinity concentrations than in the layers above can be found. Fig. 4 shows salinity concentrations measured during one tide, clearly indicating the time phases of instable salinity stratification. Sometimes, the vertical gradient in salinity concentration is more than 3 PSU. The cause of this is to be found in the interaction of the prevalent extremely high particulate matter concentrations and the resulting current and turbulence conditions.

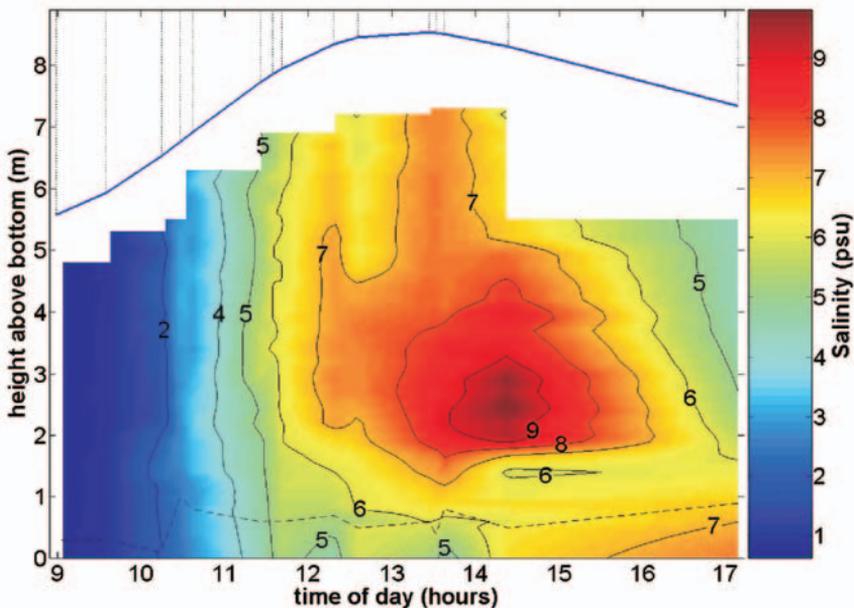


Fig. 4: Salinity concentrations measured during one tide (TALKE, 2006)

Typically current velocities are recorded by continuous measurements in one location, at a constant distance either to the water surface or to the river bed. The velocity measurements are made at the edge of the fairway and are therefore only conditionally representative for the current regime in the cross-section. It is presumed that the maximum current velocities in the fairway will be around 20–30 % larger than the measured values discussed below. Comparative statements for the Ems can be made on the basis of continuous current measurements carried out since 1986.

For Papenburg measuring station, the maximum flood current velocity values averaged over the year 2000 were approx. 1.2 m/s; ebb currents were 0.7 m/s. On the other hand for 2007, the flood and ebb values were between 0.8 and 1.0 m/s. Both periods are outside any dredging activities and in a phase with a freshwater discharge of less than 50 m<sup>3</sup>/s. In the year 2000, maximum flood and ebb current velocities of about 1 m/s were measured at Leerort, without any change until 2007. The measurements near Weener and near Terborg typically show higher flood than ebb current velocities.

These statements can be confirmed by an analysis of characteristic tidal values obtained from a calibrated three-dimensional model of the Ems-Dollart-Estuary. The results of a model run for time periode in May 2005 were stored for cross-sections at each Ems kilometre and analyzed in several post-processing steps regarding characteristic ebb and flood quantities. Fig. 5 shows calculated mean maximum ebb and flood current velocities and their ratio. The dominance of the flood current, which was already found in the measurements, is clearly visible. Due to the relatively small cross-sectional areas in the upstream part of the Ems, this ratio is strongly dependent on the prevailing freshwater discharge.

Fig. 6 shows suspended matter concentrations measured at various stations of the Ems. The data are from 2004 but can be considered representative for the Lower Ems. Discharge

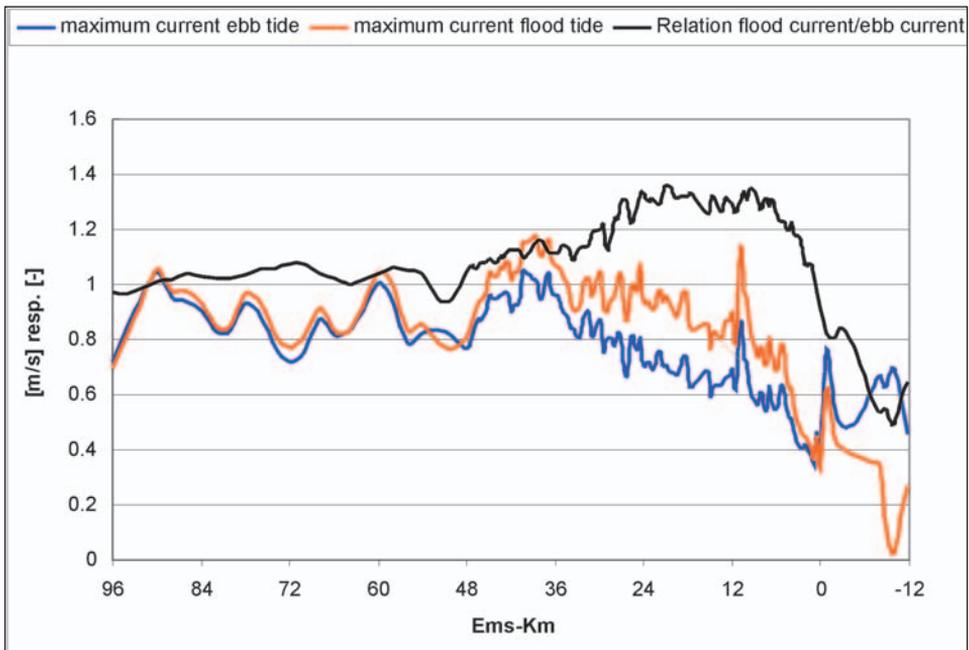


Fig. 5: Flood and ebb current velocities, mean values for cross-sections (model results)

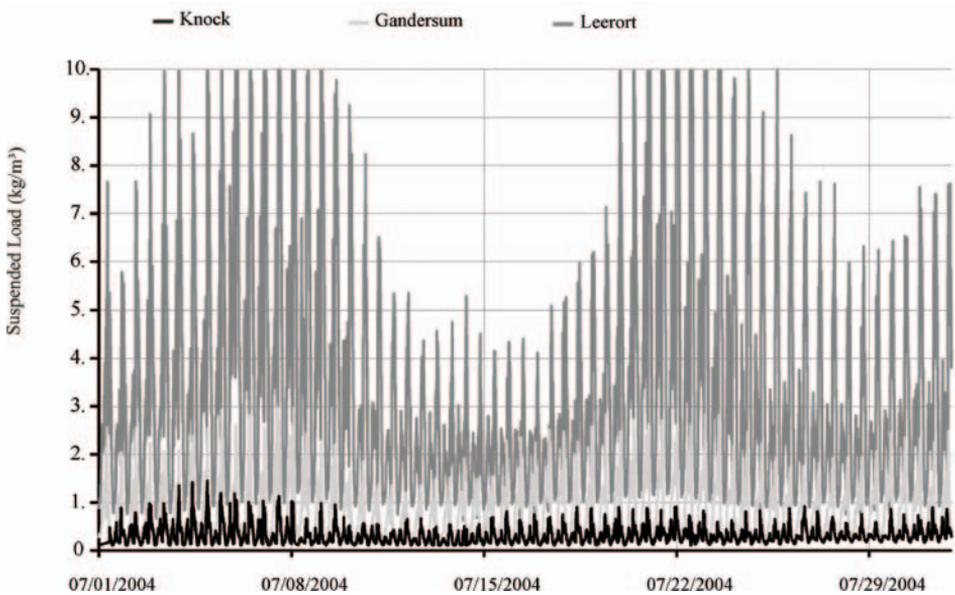


Fig. 6: Suspended matter concentrations measured at the Knock, Gandersum and Leerort stations in 2004 (WEILBEER, 2005)

volumes and tidal conditions are seen to have a particularly clear influence in the area of the Lower Ems. At Knock station (mouth of the Dollart) the concentrations are below 1 g/l. Further upstream near the Ems Barrier at Gandersum, the particulate matter concentrations reach values of approx. 3 g/l. The influence of the 14-day neap/spring tide cycle is also clearly apparent at this station. During the spring tide, concentrations reach far higher values than during the neap tide. Another 18 kilometres upstream at Leerort station, the same pattern can be seen in even greater clarity, with concentrations exceeding 10 g/l during the spring tide.

Fig. 7 shows suspended matter concentrations in the Ems resulting from measurements in a longitudinal profile in the Lower and Outer Ems. These measurements were carried out at low freshwater discharge ( $Q = 20 \text{ m}^3/\text{s}$ ) in August 2006 (TALKE, 2006). There is a significant transition to higher concentrations in the Lower Ems. Concentrations exceeding 10 g/l can already be found in a medium level of the water column and increase further towards the river bed. At this point in time a distinctive “fluid mud” layer along the entire Lower Ems exists.

#### 4. Structural Measures to Adjust the System

After the Second World War, inland navigation increased with an even greater increase in ocean-going shipping, the latter using the river Ems primarily from Emden to Leerort. Water depths in this stretch were 4.80 m below mean HW (MThw). Overseas maritime traffic calling the port of Papenburg had to lighten their load in the port of Emden or Leerort above the Jann-Berghaus Bridge, with part of their cargo being transhipped to inland navigation vessels.

In the section Leerort-Papenburg, depth of the fairway was only 4.0 m below HW. Dredging was necessary at a few points to maintain these depths. The work was carried out

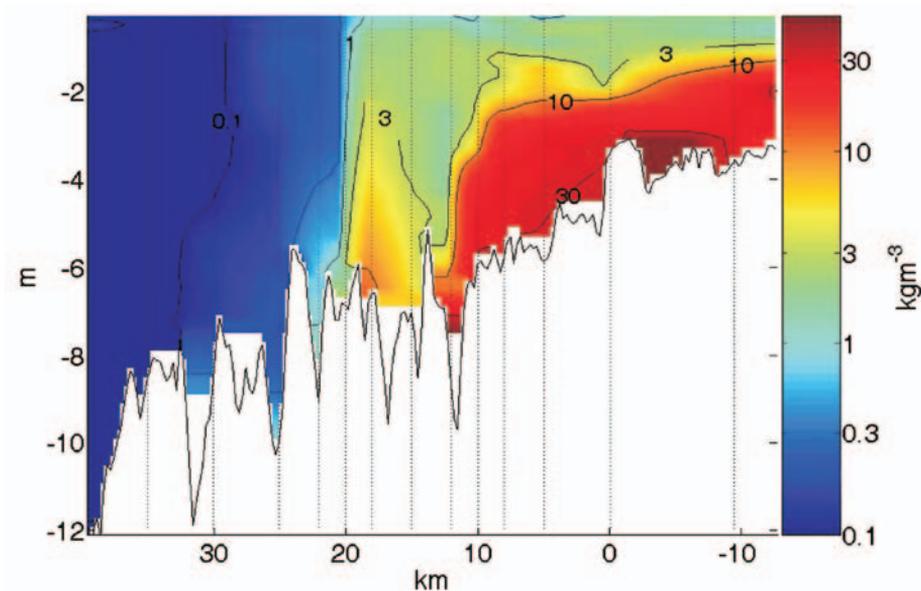


Fig. 7: Suspended matter concentrations (field measurements) in a longitudinal profile in the Lower and Outer Ems at low freshwater discharge ( $Q = 20 \text{ m}^3/\text{s}$ ) in August 2006 (TALKE, 2007). The kilometres refer to Papenburg (Lower Ems KM 0)

with chain-and-bucket dredgers, and the dredged soils were loaded into barges to be transported to the old river branches resulting from breakthroughs made between 1911 and 1928. Here, they were dumped or flushed ashore.

In February 1962, the German North Sea coast suffered from a heavy storm surge. Consequently, all dykes along the Ems had to be reinforced and raised, starting in the mid 1960's. The design of new dykes was modified to consist a sand core covered with clay. Today, crest elevations of the dykes along the lower Ems are between NN + 6.60 and 7.30 m. The necessary sand was mined in the lowlands behind the dyke, resulting in large lakes along the river Ems. On the other hand, approx. 4.5 million  $\text{m}^3$  material was taken by hopper dredgers along various sections of the Lower Ems where insufficient fairway depths prevailed. These measures also supported the necessary maintenance measures up to the early 1980's, when the depth of the navigational channel had to be adapted to the growing drafts of vessels.

The main river and coastal engineering measures changing the appearance and system behaviour of the present Ems-Dollart Estuary are listed in a chronicle below:

- |           |  |
|-----------|--|
| 1872      | Start of river construction work in the Ems to erect groynes, among others on the Geise near Emden   |
| 1901      | Emden sea port is opened as the terminal point of the Dortmund Ems Canal, Dredging of the Gatjebogen and deepening of the East Frisian Gatje to improve access from the sea to Emden |
| 1914–1923 | Dyke construction Knock – Emden West Mole for fortifying Emden's fairway   |
| 1930–1932 | Construction of the Knock training wall (later also boundary of former containment areas)  |

1930–1939	River structures to strengthen the Gatjebogen and construction of Geise staging to straighten Emden's fairway and achieve a depth of 7 m below chart datum
1958–1964	Regulation of Emden's fairway and deepening to 8 m below chart datum. Construction of the Geise training wall and sea dyke training wall; fairway of the Outer Ems deepened to 8.5 m below chart datum
1971/72	Approach from offshore deepened to 12.5 m below chart datum
1973–1977	Sea locks in Papenburg and Leer widened from 18 to 26 m
1976	Fairway moved from the Old Ems to the Randzelgat
1983/84	Lower Ems deepened for ships with 5.70 m draught
1988/89	Fairway moved from Hubertgat to the West Ems
1991–1994	Lower Ems deepened (temporarily) for ships with a draught of 6.30 m (basic depth) or 6.80 m
1994/95	Lower Ems deepened (temporarily) for ships with a draught of 7.30 m.

The currently planned measures (as of 2nd quarter 2008) are listed in the following table.

Section	Measure	Status
Lower Ems	Adaptation of parts of the federal waterways river Ems and Dortmund Ems canal	Planning approval procedure in progress
Lower Ems	Creation of summer dykes near to the shore to make the summer backwater flexible	Feasibility study
Lower Ems	Ems action campaign	Conceptual considerations
Outer Ems	Deepening the approach to Emden port	Feasibility study
Outer Ems	Deepening the approach to Eemshaven	Ongoing process

## 5. Maintenance of the Fairways

As far as dredging in the Ems Estuary is concerned, a distinction must be made between dredging the Lower Ems and the Outer Ems. The reason for this distinction consists primarily in the use of the waterway and what to do with the dredged material. While the Outer Ems has to be maintained for uninterrupted maritime traffic to Emden, the maintenance of the Lower Ems is geared primarily to the transfer of ships from the shipyard in Papenburg. The boom in the cruise business has intensified the depth requirements and the intervals between necessary dredging measures in recent years. Since September 2002, the storm surge barrage at Gandersum has been in operation; the passage can be used for the transfer of large ships from the shipyard and the weir as a water retaining structure. It is operated by the Lower Saxony State Agency for Water Management, Coastal Defence and Nature Conservation (NLWKN).

In the course of fairway deepening work in the early 80's, quantities of up to 200,000 m<sup>3</sup> p.a. were dredged at some points in the Lower Ems. In some years no dredging was carried out at all. Given the restricted conditions in the Lower Ems, only small dredgers can be used. In 1995, work was carried out for the last time with chain-and-bucket dredgers during dee-

pening the river for ships with a draught of 7.3 m. Nowadays maintenance dredging is carried out by hopper dredgers. The machines have a hold capacity of between 800 and 1,000 m<sup>3</sup>. It is worth mentioning that presently the fairway of the Lower Ems has to be maintained for the transfer of ships from the shipyard with draughts of up to 8.0 m (regular-traffic vessels have draughts of up to 5 m). The possibility of increasing the water depth for ship transfers due to the Ems Barrier has resulted in considerable reductions in the dredging quantities necessary for such large ships.

Until 1978, maintenance dredging in the Outer Ems was carried out with chain-and-bucket dredgers, usually with several units operating at the same time. As from 1978, the federal hopper dredger “Nordsee” operated in the Ems Estuary. The “Nordsee” was redeployed in 1995 and was replaced by commissioned dredgers.

In the period between 1965 and 1980, material dredged from the Lower Ems was used primarily for dyke construction; because dredged soils consisted of approx. 80 % sand, another area of utilization for road and settlement area construction was opened up in 1984, with the corresponding share declining successively since 1995. The sand was hydraulically washed onto areas near the river Ems, and containment areas were raised up to 6 m. After drying up, the material was removed and used for various applications, thus fulfilling both economical and ecological aspects. This permitted good synergetic effects between the Life-Cycle Resources Management Act and utilization of dredged material.

Today the dredged material from the Lower Ems, consisting almost completely of silt and clay, is pumped into former gravel and quartz sand pits. It is too expensive to transport the material to dumpsites of the Outer Ems because of the long transport distances and time involved. Since 2006, several hundred hectares of land for containment areas have been made available to the North of Papenburg where dredged soils can be deposited.

Between 1954 and 1994, dredged material from fairway maintenance in the Outer Ems, primarily for Emden’s fairway and the port of Emden, was dumped on agricultural areas to the North-east of Emden. This, however, soon became subject to criticism because of the high costs involved as well as nature protection aspects. Until the end of the 1980’s, sandy dredged material was hydraulically washed onto “Rysumer Nacken”. Meanwhile all the material dredged from Emden’s fairway and from the Outer Ems is transported to dumpsites in the Estuary, based on sustaining the natural material cycles.

Dredging quantities in the Ems Estuary are caused by the different structures of the Outer Ems and the Lower Ems. Particularly, in the Lower Ems, not only the dredged volumes but also the quality of the sediments has changed drastically over the last three decades (considerable share of silty sediment).

## 6. Ongoing Activities for Observation and Analysis of the System

Long-term observations include the ongoing registration of water levels at the gauges at Papenburg (since 1895), Weener (since 1899), Leerort (since 1895), Terborg (since 1899), Pogum (since 1923), Emden New Sea Lock (since 1919), Knock (since 1970) -site has been moved; originally Fiscal Lock (since 1907) and Borkum Fischerbalje (since 1961); former landing stage (from 1907 to 1959). Moreover, echosoundings for the morphology supplemented by additional permanent current measuring devices and secured in the context of the data gathering required for preserving the evidence for the structures in the Lower Ems were carried out. Furthermore, since 2004 regular sediment studies have been conducted in the Lower Ems

and in Emden's fairway. The evaluations yield important findings about the physical changes of the system. All data were transferred to databases to permit decentral evaluation.

At present, tidal gauge locations are being investigated under the aspect of long-term geological movement in the context of the IKÜS research project. This has revealed initial indications of significant geogenic or anthropogenic effects (such as extraction of natural gas) and will have to be given some consideration in the future.

Some German and Dutch institutes maintain and run hydrodynamic-numerical models covering partial areas or the entire Ems-Dollart Estuary to study the hydrodynamic processes and ecological issues (HARTSUIKER et al., 2007). For several years, the Federal Waterways Engineering and Research Institute (Bundesanstalt für Wasserbau – BAW) has been operating 2D and 3D models with high local resolutions to examine the effects of upgrade measures in the Ems on water levels and currents, salinity and sediment transport. The corresponding model technology is subject to ongoing developments in order to include relevant physical effects within the simulations to predict the movement of dumped soils and long-term morphodynamic development.

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