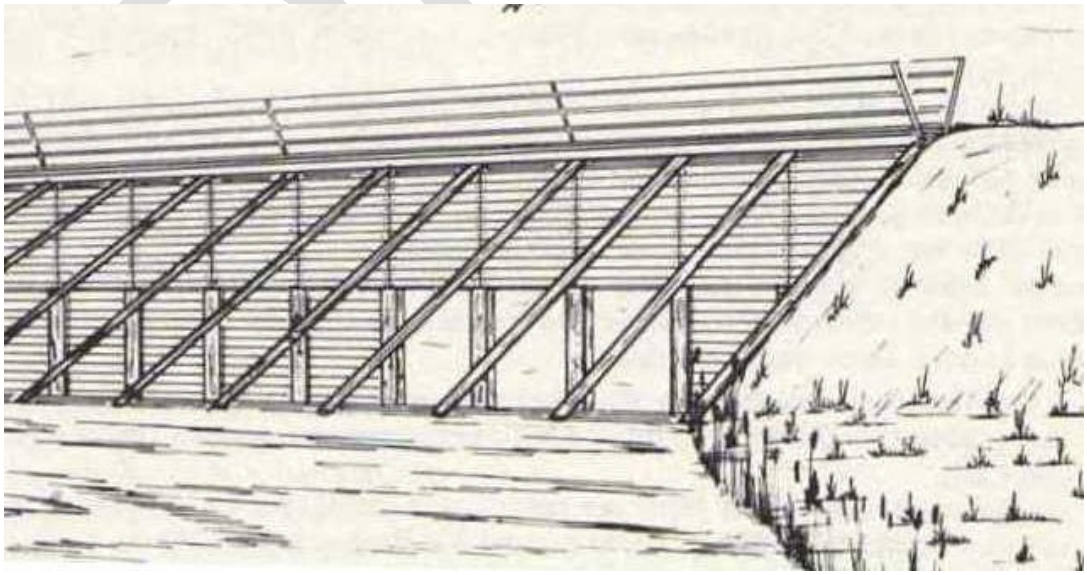
## Landward Solutions

# Landfills with dredged sediments

It is not clear when landfills started, but they took a huge flight in the 20th Century. Nowadays landfills with mud are mainly concentrated near the weirs of the estuaries. Mud is taken out to counter the infill of the fairways which occurs due to over-depths in combination with tidal pumping and locally the formation of fluid mud layers.

Enhancing sedimentation on inner-dike areas by allowing late autumn/winter-flooding of the diked lands was probably a standing practice from Roman times up to the Late Medieval period. This was done by either flooding of the low dikes or by opening sluices and such. Thereafter, diked lands had often subsided so strongly that draining the salt water became difficult; only locally flooding was still allowed. The main goal was probably to bring nutrients into the soil.



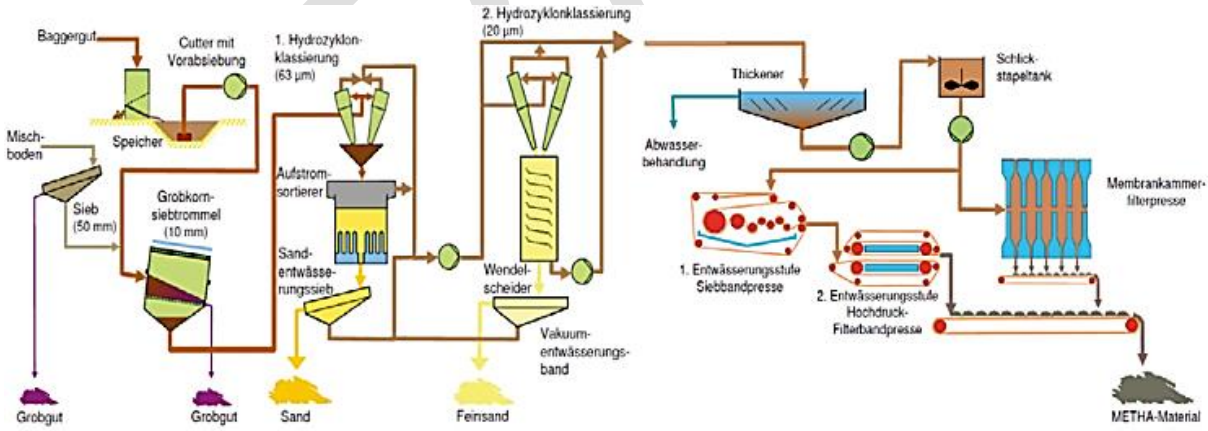
*Sketch of one of the inlet systems for the Bewässerungsfelder in the dike at the Oste (Fischer, 2011).*

However, in the 19th Century and up to the early 20th Century farmers along the Oste tidal river (brackish) in Lower Saxony strived to heighten their lands. They developed so-called “Bewässerungsfelder”, which could be flooded each high tide during wintertime by opening some special inlet devices. In in the Blumenthal polder resulted in sedimentation 4 1- cm/yr.

The above described examples are based on temporal flooding of the mainland area. One of the earliest known examples of actively transporting mud to the land comes from farming practices. In the early 20th Century (and probably earlier) farmers living near the Wadden Sea, spent their spare time to dredge mud from the Wadden Sea and to spread it over their lands. Most likely this was mainly to bring nutrients on the fields and not so much to heighten the lands.

Starting in the late 19th Century landfills with mud have taken a flight in the 20th Century as harbors were extended and fairways were deepened. This is especially true for the three big estuaries of the Ems, Weser and Elbe, each showing their own developments. Especially the riverine sediments from the Elbe and Weser are heavily contaminated (although concentrations are going down). Environmental considerations made storage on land unavoidable.

Traditionally, the dredging material from the Port of Hamburg is stored on land, to heighten areas. At the end of the 1970s, the environmental impacts of this practice became clear. A small part is relatively clean and will be dewatered in the Moorburg Entwässerungsfeldern. The rest is strongly contaminated. For these sediments a dredging material treatment was developed and implemented in the 1980s, the so-called METHA-Anlage (Mechanische Anlage zur Trennung von Hafensedimenten). The METHA-Anlage, an industrial separation operation, processes some $1*10^6$ $m^3/y$ of the most contaminated dredging sludge (Figure). Annually some 550 000 ton of dredged material (after drying 1 000 000 $m^3$) is processed. The sand is separated from the mud fraction (silt and clay). The sediment is flushed to remove the salts and is subsequently dewatered.




*Overview of the production process METHA Anlage Hamburg (Hamburg Port Authority, NY).*

The possibilities to use the sediments of the METHA Anlage are limited due to the high costs and the ecological limitations. Sand can be used among others as drainage sand. The mud fraction is mostly contaminated and must be stored in two depots which are especially adapted to that end. The fine fraction which is not contaminated is used for clay cover of dikes and such.

In harbors of Bremen and Bremerhaven produce dredged sediments, mainly consisting of clayey mud which is contaminated with heavy minerals and the antifouling agent tributyltin (TBT). Before 1994 contaminated fine-grained material from the harbors was deposited on disposal sites on land and on a placement site in the Wurster Arm (Outer Weser). Since 1994 Bremen stores on land at the integrated dredged material disposal site in Bremen-Seehausen (Figure). Since 2001 also Bremerhaven uses the site. First, the sediment is being pre-processed in 16 dredging depots of 100*200 m each (max sediment depth: 2.6 m). In the process the sludge will dewater and ripen. On a regular basis the sediment will be turned over by means of a "Mietenumsetzer". After about one year, the most contaminated mud is placed in a specially adapted landfill of Bremen-Seehausen. The part of the sediment which meets environmental standards is used for various purposes.

*Dredging depots Bremen-Seehausen (www.Bremenports.de)*

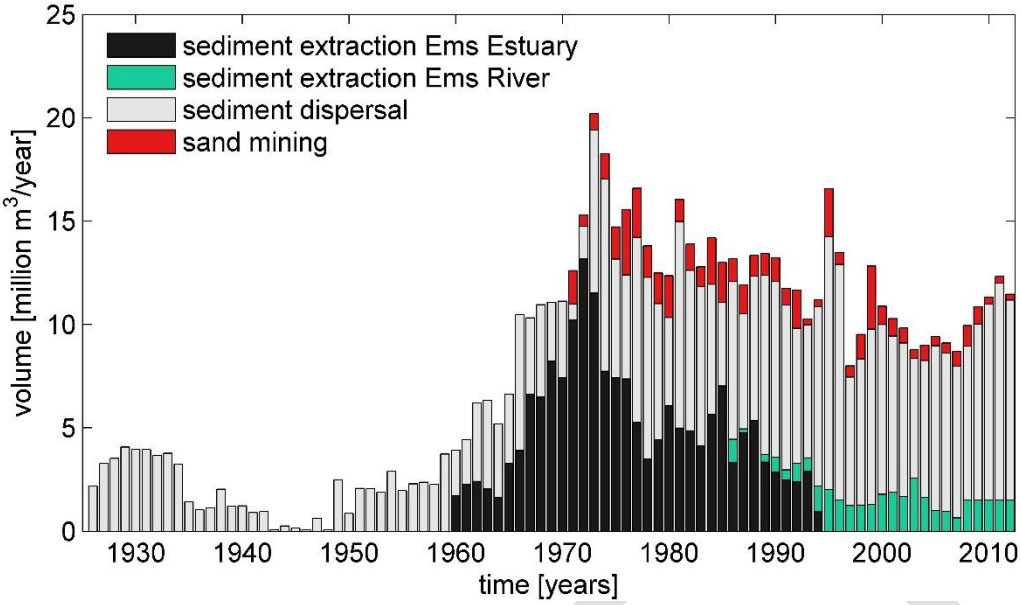
At the Ems, dredging and land storage started probably at the end of the 19th Century. Already in the 1930-ies substantial amounts of mud were stored in landfills. Quantities of sediment extracted before 1960 are not exactly known. Between 1960 and 1994, $5.1*10^6$ $m^3/y$ was dredged from the port of Emden ($1.5*10^6$ $m^3/y$) and fairway ($3.6\ 10^6$ $m^3/y$) and brought on land (Figure). Another $5*10^6$ $m^3$ of sediment was dredged from the estuarine approach channels and ports, and subsequently dispersed within the estuary. Approximately $1.5*10^6$ $m^3$ of the extracted sediment was sand: the remaining $3.6*10^6$ $m^3/y$ (or $1.8*10^6$ tons/y) was mud. On many sites east of the Ems landfills were developed heightening the land and improving the agricultural quality. Furthermore, sediment was used to heighten tidal marshlands which were formed behind dams, such as the Rysumer Nacken over the period 1949-1995.

*The Niederung Eden Riepe is being filled via a 13 km long pipe transporting the dredging sludge over the Ems-Jade channel (period 1946-1989). (Source: Creative Commons Attribution 4.0 International License Photo HB01395.jpg )*

Since 1994, sediment is no longer dredged from the port of Emden, but regularly re-aerated, thereby preventing consolidation. The resulting poorly consolidated bed remains navigable, and consequently the port no longer requires maintenance dredging. At the same time, sediment dredged from the approach channel to Emden is no longer extracted but dispersed in the estuary. No dredged sediment is disposed in marine waters outside of the estuary.

Since its last major deepening in 1994, the lower Ems River requires regular dredging. Around $1.5*10^6$ $m^3/y$ ($0.8*10^6$ ton/y) of fine sediment are extracted annually from the lower Ems River and brought on land. These are clean sediments. They are deposited in the landfills near Ihrhove (top figure), which are relatively quickly filled up. Just below the top soil peat layers of 2 to 3 m thick are sometimes present and care should be taken not to compact these peats. Furthermore, it appeared that the drainage of the newly established fields is not sufficient, leading to negative changes in plant species composition, slower nutrient release in spring and slower soil-ripening processes. The landowners press currently for subsurface drainage pipes.

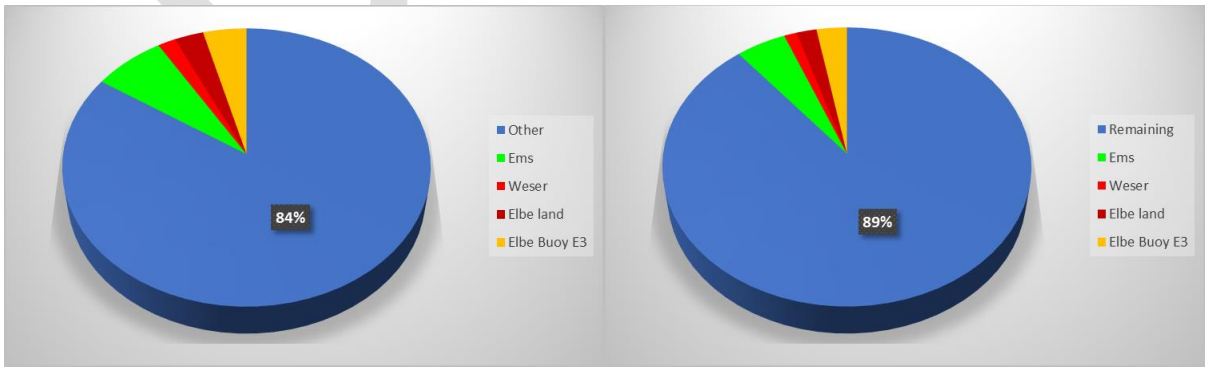
Plans are being developed for the Ems estuary to reduce the suspended matter concentrations by artificially enhancing sedimentation over larger areas which will be opened to deposit sediment (managed retreat), using it for diking, or withdrawing muddy sediment to heighten inner dike polders. The last two approaches are already used in Lower Saxony (see above and factsheet on clay pits). The first approach envisages managed retreat on a very large scale of the order of 10 $km^2$ (see factsheet on managed retreat).




*Dredging volumes for the Ems estuary since 1925: sediment extraction (mainly mud) in the Ems estuary and the lower Ems River, sediment dispersal, and sand mining (from van Maren et al. (2016). Total dredging volumes before 1960 are from de Jonge (1983); dredging volumes after 1960 are from Mulder (2013) for the Ems estuary and from Krebs (2006) in the lower Ems River (until 2006; after 2006 a constant value of 1.5*10⁶ m³ is assumed).*

**Lessons learned**

All old harbors in the three big estuaries were medieval in age and were founded when these locations were the cross points between roads and sea-going ships at that time which had much smaller dimensions. As dimensions of ships increased, especially during the past 100 years, fairways had to be deepened and harbors had to expand. This led to a massive increase in maintenance dredging. Storage on land of the dredged material seemed like a good idea and due to this, large amounts of mud and sand were retrieved from the harbor. As a result, large areas around the estuaries were heightened considerably, which made them less vulnerable to flooding. In the 70-ies the realization came that part of especially the muds were heavily contaminated and had to be stored under controlled conditions. Another part of it is clear mud which could also be left in the estuary.




*Comparison of landfill volumes as part of total sedimentation (left) and total influx of suspended matter (right; excluding supply by the East Anglia Plume)*

Some 3000*$10^6$ $m^3$ of mud must have thus been stored on land along the Ems in the past 120 years: this is comparable to the total net sedimentation in the western part of the Dutch Wadden Sea area in the same period. How this is for the Weser and Elbe is not well known. Recently it became clear that especially the long-term (over a century) and large-scale retrieval of mud from the Ems estuary is significant if compared to the estimated 8-20 *$10^6$ ton of mud which is annually transported from the West into the Wadden area. Given the large internal buffers in the Wadden Sea possible effects will probably go unnoticed for a long time. At the moment, it is unclear whether such extraction influences the sedimentary and ecological development of the Wadden Sea area more to the east of the estuary.

### Stakeholder process

Two of the three estuaries are largely part of two German States (Bundesland): Freie und Hanzestadt Hamburg and Freie Hansestadt Bremen. As these sea harbors are important to Germany the influence of the harbors and industry on the development and management of the area is large. For the Elbe the stakeholders are Hamburg and to some extent Schleswig Holstein and Lower Saxony on a state level. Next to that the Harbors of Hamburg, Cuxhaven and Brünsbuttel have a strong say in the development. Furthermore, environmental groups influence the discours. The ever-continuing deepening of the fairway meets with stiff resistance of the environmentalists. Furthermore, part of the estuary is part of nature protection areas which also leads to discussions considering the development of the harbors and fairways. In the Weser estuary the land of Bremen and the harbors of Bremen and Bremerhaven are quite influential. Another stakeholder is Lower Saxony which has also to take care of the National Park of the Lower Saxon Wadden Sea. During the past decennia much effort has been given to managed realignment measures to compensate the effects of the harbor and fairway measures. As for the contaminated mud retrieval there seems to be no objection from environmental groups to take this out of the estuary.

The Ems Estuary is bordering both the Netherlands and Germany and is an important local motor for the economy of the surrounding region. Also here, the influence of the economics and industry is considerable. States and harbors and the shipyard of Papenburg have a relatively large influence in the development of the estuary. Environmental groups are pushing to improve the quality of the estuary via measures such as restoring connectivity for fish migration, managed realignment and decreasing the turbidity of the water to enhance primary production and fish migration. The turbidity is thought to have increased considerably due to the lack of permanent sedimentation sites and the ending of landfills from the dredging of the main part of the estuary and harbors by Germany since 1994. A part of the plans aims at annually retrieving large amounts of mud either via land storage, dike clay production or deposition in tidal marsh areas (ED2050 projects).

### Discussion points

Clearly a part of the mud stored on the mainland is so contaminated that it cannot remain in the estuaries of Elbe and Weser. The question arises: are the current contaminated landfills sea-level rise proof enough for the coming centuries?

The amount of uncontaminated fine sediments which is taken from the Ems is significant when compared to the annual import in the Wadden Sea. At the moment it is not known if there are any adverse effects for the Wadden area east of the Estuary from retrieval of such amounts of mud over such an extended period. The question arises: is it not more prudent to keep these dredged sediments in the system and for instance to dump it east of the estuary? Or should we instead take out more material to improve the water quality (reducing turbidity) and heighten the landscape so that it becomes more resilient against sea-level rise?

By the same token: $1.5*10^6$ $m^3/y$ ($0.8*10^6$ ton/y) of fine sediment could allow an area of $150*10^6$ $m^2$ to keep up with 1 cm/yr of sea-level rise, rates foreseen for the end of the century. Extra tidal marshes and mudflats could be created, either via Foreland Tidal Marsh creation in the Wadden Sea or via managed realignment. Would it be more interesting to choose for helping to establish extra tidal marsh where it is absent in front of existing dikes and adding to their safety (wave breaking), or to create more tidal marshes on a large scale by managed realignment to create natural values and add to the touristic appeal than to concentrate on land-fills with uncontaminated muds?

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