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Tidal River Elbe - a sediment budget for the grain size fraction of medium sand

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Human interventions have a historic and ongoing impact on estuarine sediment budgets across many estuaries worldwide. An early inference was the construction of embankments resulting in a constant loss of intertidal flats. Additionally, settlement activities and large scale land use changes in the upstream catchment areas had also an effect on sediment inflow rates. Today, the navigation channels in estuaries have been deepened for larger and more efficient vessels to reach a well-developed infrastructure of harbors and industrial areas often located far inland. In the past few years and just within the North-East Atlantic, the total annual amount of dredged sediments dumped at sea varied from 80 to 130 million tons (OSPAR Commission).
In most estuaries across Europe the resulting human impact on the sediment fluxes and morphodynamics is significant. A good understanding of estuarine processes is essential for determining useful and meaningful measures to mitigate negative effects and to improve the current situation. Maintenance dredging and its environmental effects are therefore in the focus of public attention.
Against this background, it is the aim of the presentation to identify and therefore to separate the particular effect that maintenance dredging has on sediment fluxes and budgets in the estuarine environment. Case study is the Tidal River Elbe in Germany, and here we set the focus on the grain size fraction of medium sand. In the past, river engineering measures forced the natural dynamics to form a concentrated stream flow along a fixed channel, except at a number of locations where side channels still exist. In addition to that, the main channel was deepened several times. The last deepening was in 1999/2000. The most significant deepening, however, took place from 1957 to 1962. Until then, an erosion-stable layer of marine clay (in German called “Klei”) formed a flat bottom along most sections of the main channel. After removal of this layer of marine clay by capital dredging, Weichselion sandy deposits, which formed the geological layer underneath, now became part of the sediment transport regime. Nowadays, most sections of the main channel are morphologically characterized by a medium sandy river bed and subaquatic dunes of several meters height followed by sections of a poorly structured river bed caused by the sedimentation of silty sediments.
By setting up the sediment balance for medium sand, the fluxes entering the estuary from the inland Elbe is one source term in the equation. The average annual load for the medium sand is estimated to be 110,000 m^3/year (1996 – 2008, measurement station Neu Darchau). Further downstream in the tidal part of the river there are no further measurement stations located, but the analysis of a time series of multibeam sonar data (2000 to 2014) shows that large amounts of medium sand episodically pass the tidal weir at Geesthacht only in the event of extreme flood. This is due to a significant increase in bed volume between Geesthacht and the Port of Hamburg in the aftermath of a singular extreme event. Until the next extreme event the bed volume (functions as temporary storage for medium sand) is eroding again, which is the second source term.
By comparing the information on bed load fluxes, the evolution of bed volumes over time and the dredging statistics we can conclude for the longer term that the total amount of medium sand that has been dredged and taken out of the system for constructional purposes is the same order of magnitude compared to the sum of both source terms. Hence, there is no or very limited net transport of medium sand passing the port area and entering the downstream river section. From the subsequent analysis of multibeam sonar data (2008 - 2014) we know for the river section from Hamburg to Brunsbuettel (total distance of 40 km) that there has been a continuous loss of about 1 Mio. m^3/a in bed volumes, which means a deficit situation for medium sand. Currently, the Weichselion deposit is the active source for medium sand, but due to the lack of medium sand fluxes from upstream this at the cost of having an ongoing deepening of the main channel.
The presumed cause for this deficit situation is the current management of the sandy dredged material. First of all, dredging and subsequent extraction of the dredged material is strongly affecting the longitudinal transport of medium sandy sediments from upstream through the Port of Hamburg in seaward direction. Further downstream in the river section in deficit, all dredged material, which is about 1 Mio m^3/a solely for the fraction of medium

sand, is transported by hopper dredgers over a long distance up to 40 km in seaward direction and disposed on a single site near Brunsbuettel. This 1 Mio m^3/a is a similar volume in comparison to the loss in bed volume. From an analysis of the geometry of the subaquatic dunes we know for sandy sediments a seaward net transport that exists for large parts of this river section. All in one, there is an irretrievable and ongoing loss of medium sandy sediments. Vice versa for the river section next to Brunsbuettel, which is the location of the disposal site, the data show an increase of bed volumes and dredging amounts at the same time.

For the Elbe case study we could demonstrate that maintenance dredging (and the subsequent disposal) could have a significant impact on the large scale sediment budget. Appropriate measures to stabilize the sediment budget in the inner part of the Tidal River Elbe for medium sand is (a) to dispose all medium sandy dredged material as close as possible to the location of dredging and (b) to reduce the extraction of medium sand in the Hamburg Port area.