CHAPTER 331

Dredging and Disposal within the Limits of a National Park

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Abstract

In coastal areas under tidal influence, recurrent dredging is an important part of the maintenance work to secure the nautical situation and the functionality of the harbors. In the past, the orientation of dredging activities was purely economic but since the early 80's, environmental concerns have rapidly increased and these concerns often define the limiting or determining factors that cover all parts of such operations in the marine region. At present, the sometimes quite different interests of engineering and ecological groups are becoming more gentle. Besides the natural learning effect from the changes in general, economic conditions are also an important factor.

This situation especially applies when maintenance dredging takes place within the limits of a national park where environmental concerns have the highest priority.

The scope of the engineering investigations was the estimation of the environmental capacity as a function of hydrology, sedimentation and biology leading to a specific management for dredging and disposal areas.

Introduction

Public awareness concerning the environment was highlighted at the United Nations Conference on the Environment in 1970. This triggered the development of legislation concerning the control of all kinds of waste. In Europe, a need for legal action ensued from the following international agreements, some of which were ratified by Germany:

- Oslo Convention of Feb. 15, 1972, with a supplement of June 12, 1991
- Helsinki Convention of April 9, 1972, with a supplement of June 6, 1992
- London Dumping Convention of Dec. 29, 1972
- Paris Convention of June 4, 1974

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The guidelines for the disposal of dredged sediments are designed to assiscontracting parties in the management of dredged sediments in a way that will prevent pollution of the marine environment. The relative importance of the dumping of dredged material within the containment arriving in the North Sea is estimated at approx. 1,600,000 t/y for nitrogen and approx. 10,000 t/y for lead (Neville-Jones 1994).
The guidelines and restrictions apply to the removal as well as the disposal of dredged sediments. A special question is hydraulic injection dredging and transport by the local current capacity.
When making an assessment in general, it will be necessary to consider the central factors as legal requirements, technical aspects, economic considerations, environmental aspects and more complicated subjective local knowledge and emotional aspects or estimations.

In fact, a very important stimulus for this investigation came from the observations of people who have been personally involved in local activities for a long time (even generations), e.g. the tourist guide.

In practice, environmental requirements are reflected in the individual permits which are only valid for a limited time (2-3 years). In Germany, such official permits actually specify the amount of dredging material (sand, mud), the dredging and dumping areas and the duration of dredging and disposal related to the season in the year (preference: winter) and the phase during the astronomic tidal cycle.

The need for investigation which is laid down by the valid guidelines is determined by the pollution load of the dredged material. Guide values r (mg/kg) are respectively defined for the individual heavy metals.
The guide value r results from concentration c related to the 20 μm fraction multiplied with an uncertainty factor α ($r = c \bullet \alpha$), at present $\alpha = 1.5$.
Within the maximum period of three years, the need for investigation is classified by three ranges of values ($c \leq r$, $r < c \leq 5 \bullet r$, $c > 5 \bullet r$).
In addition, permits can also define the need for and determine the scope of investigations on environmental effects as in this case.

Dredging in the National Park

The islands along the southern part of the German North Sea coast, which are predominately oriented to tourism, are located within the eco-system of the National Park's tidal mud flats and have been an important part of this young park, deserving special protection, since 1985.
Based on a mathematical model that gives a rough description of the current field (Dick 1992), the transport system under tidal effects is predominantly from West to East:

The protection status is to safeguard natural development and covers all activities in an area of approx. 2,400 km^2 with some exceptions within the framework of

coastal protection (dikes) and maintenance activities (dredging). In 1993, the National Park became part of the UNESCO-Program ''Man and Biosphere'' (MAB).
This status was the reason for some interesting economical and engineering requirements e.g. when an expensive tunnel was build for a standard pipeline with a diameter of approx. 1 m (Europipe-Project) or the work to raise a dike was suspended during the operation.

Within this protectorate, the navigable channels to the harbors along the coast and the islands lie mainly in areas with continuous sedimentation, the transport processes of which are defined by a regular average tidal range of approx. 2.6 m, superimposed by random storm surges. The consequence of these conditions is the substantial necessity for quasi permanent dredging activities inside the National Park and subsequent dumping. Alternatives, such as disposal outside the protected area or use of the material for beach nourishment in the vicinity are discussed and carried out in part.

Within the National Park, annual dredging quantities of between 300,000 and 500,000 m^3 arise from the maintenance of navigation channels. Small suction hopper dredges with a cargo hold capacity of 150 t (mud) to 300 t (sand) are used for dredging and disposal, the limiting factor of which is the allowable draught with a maximum of 3 m determined by the shallow depth of the flat tidal area. As a rule, disposal is carried out gradually over the whole disposal area to achieve an even as possible distribution at the bottom and in the space of the water.
In connection with intensive monitoring of all dredging activities within the National Park, the measures are based on complete modernization of the position finding system based on the highest GPS technics in combination with the continuous recording of basic data to objectively document dredging activity.

With these measures, the efficiency of maintenance dredging is to be increased on the one hand and on the other, complete evidence on the executed dredging and disposal processes are to be ensured.

Effects of Dredging and Disposal

Due to the fact that the main problems concentrate more and more on the disposal of dredged material, the following description will focus on this question.
Dependent on material and area specific parameters, the introduction of dredged material into the water space may, as a result, have a variety of effects on the ecological boundary conditions (changes in the environment). This especially applies to the tidal mudflats.

In keeping with the knowledge we have today, an underlying, lasting and negative effect cannot be assumed a priori.
Area specific parameters such as e.g. current conditions, bottom material or sea conditions, are important boundary conditions for the transport and the dispersion behavior of the solid matter introduced into the natural tidal mud flat area by disposal.
The content of suspended solid matter is influenced by a number of parameters:

- Tide (current velocity, water level, turbulence, salinity)
- Meteorology (sea conditions, temperature,) and Climate (duration of ice covering)
- Topography (surrounding tidal mud flats, bottom material, artificial buildings)

In addition, there are chemical parameters such as e.g. oxygen or nutrient content which influence solid matter content, sedimentation behavior and turbidity conditions.

An urgent, independent problem is defining and selecting suitable parameters and characteristic quantities for describing or supplying evidence on the effects against a background of high, natural variance in tidal waters.

In the following, possible effects from the introduction of dredged material into the space of water and therefore the questions associated with it are presented for assessment:

- Local increase of solid matter content
  - Is there a correlation between solid matter content and turbidity?
  - Does a sandblasting effect occur at the bottom in the case of sandy material?
  - Can a natural turbidity or solid matter background be defined?
  - Are changes in light conditions to be evaluated vertically?
  - Is the influence on photosynthesis quantifiable?
  - Will the migration behavior of fish be influenced?
  - Will this reduce the recognition of danger (e.g. fishing nets)?
  - Are there accumulation effects?
- Reduction of oxygen content by introducing oxygen-depleting matter
  - Which material is considered oxygen-depleting?
  - Which depletion potential leads to a reduction in oxygen content?
  - How does the same depletion potential act under dynamic variability?

According to ESSINK (1993), the disposal of dredged material can, among other things, have the following ecological effects:

- Change of the nutrient balance

  Example: Phosphate redissolution can have the effect of increasing the growth of phytoplankton (Sea grass can be negatively influenced when algae cover the surface).
- Inhibition of growth

  Example: An inhibition of the growth of phytoplankton can occur through increased turbidity resulting in a reduced supply of food for zooplankton and filtering bottom organisms. Turbidity interferes with the search for food of visual predators (flat fish, ocean swallows)

- Inhibition of respiration
  Example: Increased content of suspended solids inhibit gill respiration of fish and invertebrates as well as food intake for zooplankton and filtering organisms (small crabs, mussels)

- Overtaxed adjustment
  Increased sedimentation rates have the effect of smothering bottom animals. Sedentary Benthos species have less chance of survival as opposed to mobile species. Fundamental changes in the composition of sediment can increase the damaging effect on bottom fauna.

The processes that take place in the water space and at the bottom are interdependent and have superpositioning effects. Colonization at the bottom can, for example, lead to increased erosion resistance and therefore influence the suspension content (Manzenrieder 1983).

Relevant Publications

In the past years, several papers have been published on the problem of environmental effects caused by dredging and disposal of sedimentary material and International Conferences in particular have provided an opportunity for exchanging ideas and establishing relationships on a wide range, e.g.. DREDGING '94 by the ASCE in Orlando.
Some of the projects include the results of field studies and corresponding theoretical models. In Table 1, a partial list gives short information on selected studies based on the results of field programs covering typical engineering tools (sounding, sampling, sensor measurements, etc.) and an indication of extended results from natural science (Chemistry, Biology). The depth given indicates the depth at the dumping area.

The targets, size and executing institutions and - last not least - financial frame for such programs vary. In general, it can be stated first of all that every dredging and disposal area has its own behavior so that a direct transfer of results is not likely. Experience in engineering practice has often indicated that the respective research must be delegated to basic research and research with a direct reference, the latter of which often has narrow limitations on time and budget. Nevertheless, this is often the appropriate solution.

To answer basic questions concerning mud flats, a very large research program named ''Ecosystem-Research'' has been underway in Germany since 1989, the main phase expected to end in 1996. Beyond general statements, the results presented could not support the concrete questions formulated in the permits for maintenance dredging.

Table 1: Selected publications on dredging effects with field studies

Literature	Year	Country	Location	Chemistry	Biology
Hübner, H.-J. et al.	1996	Germany	Mudflats	yes	yes
Pejrup, M.	1995	Denmark	Mudflats	no	no
Netzband A. et al.	1995	Germany	Elb River	yes	yes
Borst, W.G. et al.	1994	Netherlands	Haringsvliet	yes	yes
Halka, J. et al.	1994	USA	Chesapeake Bay	no	no
Wiley, M. et al.	1994	USA	Connecticut	no	no
Marsh, J.	1994	U.K.	Cornwall	yes	yes
Stuber,L.M. et al.	1994	USA	Savannah Harbor	yes	yes
Tubman, M. et al.	1994	USA	San Francisco	no	no
Courtney, C.A. et al.	1994	USA	San Francisco	no	no
v. Oostrum, R. et al.	1994	Netherlands		yes	no
Bundesanstalt (BfG)	1993	Germany	Ems River	yes	no
Essink, K. et al.	1993	Netherlands	Ems, Mudflats	no	yes
Thevenot, M. et al.	1992	USA	Tylers Beach	no	no
Paul, J.H. (BfG)	1992	Germany	Weser River	no	no
Dammschneider	1992	Germany	Elb River	yes	no
Gallenne, B.	1989	France	Loire River	yes	yes
Vale, C. et al.	1989	Portugal	Tagus River	yes	yes
Bossinade, J.H. et al.	1988	Netherlands	Eemshaven	no	no
Truitt, C.L.	1986		Duwamish WW	no	no
van der Veer, et al.	1985	Netherlands	Mudflats	no	yes
Tavolaro, J.	1982	USA	NewYork Bight	no	no
Malherbe, B.	1980	Belgium		no	no
Bokuniewicz, H.J. et al.	1978	USA	Lake Erie/Ontario	no	no
			New York Bay		
			New York Bay		
			Saybrook		
			Elliott Bay		
Sustar, J.;Wakeman,T.	1977		Carquinez	no	no
McCauley, J.E. et al.	1976	USA	Coos Bay	yes	yes
Gordon, R.B.	1974	USA	Long Island	no	no
May, E.B.	1973	USA	Mobile Bay	yes	yes

The various public interests in the results of such (expensive) investigations which include social and political components are often much greater than the knowledge that has been established on the processes. The contrary explanations for the appearance of large areas with a oxygen deficit in the upper mud flat surface, so called ''black spots'' after a strong winter, was the last remarkable example.

Procedure

The main target of our investigation was and is compliance with the requirements that are a part of the permit, currently valid for a period of 3 years. To achieve this, an investigation program was started in 1994 which is still being executed, the areas of operation being:

- sediments in the subtidal and intertidal flats
- water column
- macrozoobenthos

For a pilot project, disposal sites are selected, which differ in respect to their location within the hydrological units, the quantity of material being disposed as well as the type of disposed material.
In compliance with the concrete time and economic terms of reference and under the responsible coordination of engineering sciences, a pilot study was developed for the interdisciplinary questions, the structure with long-term measurements and detailed surveys was selected as follows:

- Meteorological and hydrological surveys
- Static and dynamic sedimentological surveys
- Biological surveys

To describe biological processes, macrozoobenthos were selected as an indicator group.

Long-term measurements gradually broaden our knowledge and are therefore a part of extended basic research. In view of the investigations listed for the disposal site area, these are primarily oriented to stabilizing the respective causal analysis:

- Analysis of the dredged material (grain distribution, pollutants)
- High resolution topographical surveys using state-of-the-art techniques
- A rough sedimentological and biological survey of the disposal sites
- Taking samples from monitoring stations in the subtidal and intertidal flats
- Sedimentological characterization of surface samples from the mudflats
- Assessment of macrobenthic fauna on the mudflats

The detailed investigations include a great number of individual measurements and are continuously coordinated to developments. Previous investigations have concentrated on the natural variation of turbidity and the change and extension during disposals as well as the changes in oxygen content during disposals.

Previous Results

Part 1: Dredged Material

All objective reflections on the effects of disposal arise from the potential load potential and therefore from the properties of the dredged material with following results:

- The results of laboratory measurements confirm pronounced material-dependent differences.
- As opposed to fine sand, silt (coastal marsh sediments) shows continuously higher depletion rates.
- Silt samples show an up to 45 times higher average depletion activity related to mass than fine sands.
- Depletion curves of the silt samples show a high initial depletion at the beginning which can exceed mean oxygen depletion by 10 times.
- Quantitative results of stabilized laboratory results cannot be directly confirmed by the natural measurements during disposal.
- In individual measurements during the disposal of coastal marsh sediments and sand, no changes in oxygen content beyond the fluctuation margin of measured values before disposal were determined in the space of water over a period of approx. one hour after disposal.
- Heavy metal concentrations determined in the grain size fraction $d < 20\ \mu m$ all range below the defined limiting values in the guidelines used (Figure 1).
- On the basis of this assessment, the examined dredged material can be rated as non-polluted.
- At present, there is no uniform assessment concept for the evaluation of heavy metal content and organic pollutants in dredged material.
- In regard to the area-specific loads from sediments, there is a need for uniform recording of data as a basis for documentation and the evaluation of trends while isolating anthropogenetic intervention

Part 2: Disposal Sites

Previously determined results of the engineering and natural science work fields will be presented in abbreviated form.

- Sediment composition and seasonal changes are different at every disposal site.
- Fine and medium grain sands dominate in the sublitoral, the highest variation being shown by the fine grain size fractions.

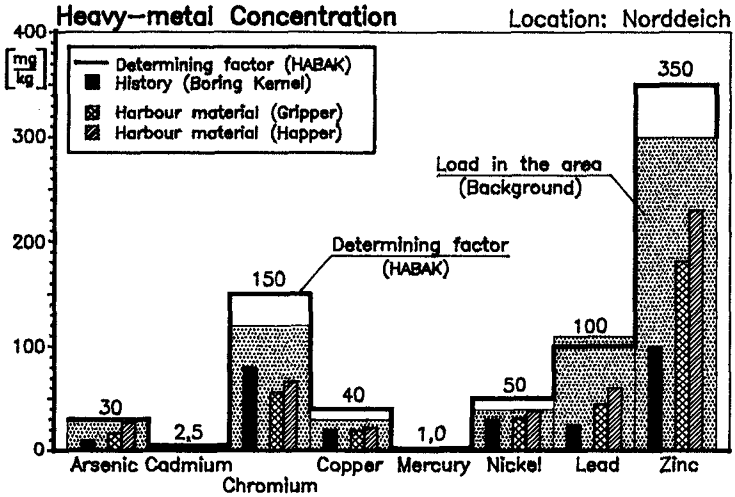

Figure 1. Heavy Metal Concentration and Determining Factors

- With mostly constant main sediment types, changes also occurred on the examined mudflat surfaces during the low-energy summer months in the fine grain areas.
- A sorting of grain size takes place within the immediate disposal site.
- The fine sediment part rises to the edges of a hydraulic/morphological unit (tidal mudflat watershed).

Part 3: Turbidity and Suspension

In order to determine the value range and variation of the natural suspended matter content in connection with current behavior, selective measurements were made over one tide respectively. These results form the basis for an evaluation of concentrated measuring results that were made during the disposal of sand and coastal marsh sediment. The results are characterized as follows:

- The suspension content measured fluctuated during a natural tide cycle (without disposal) in a wide range between 120 mg/l and 660 mg/l. The result over the whole tide was a mean suspension content of c=225 mg/l with the maximum values near the bottom.
- Drogues and continuous current measurements in the area of the examined disposal site support a current potential with the highest velocities close to the surface of up to 1.5 m/s at ebb current which, as a whole, dominates over the flood current.
- The measurements made immediately before disposal at lower current velocities comprised recorded values of 2.5 to 30 TE/F (turbidity unit related to Formazin) with respective suspension samples with solid matter contents of 50 to 200 mg/l.

- During disposals, stationary and dynamic measurements were made at a mean water depth of 15 m and in depth steps of 5 m and 10 m in the disposal site and adjacent lee area to survey the spreading cloud of turbidity.
- In Figure 2 a passage of the turbidity cloud during a disposal of sand (d_{50} ca. 0,15 mm) giving a current velocity and water level above the probe is presented. Distance to the input point was approx. 200 m.
  It was observed that the disposal "trail" clearly stands out against the background values of turbidity. Just a few minutes after input, turbidity values at the selected measuring position rise to approx. 100 TE/F.
  The mean basic turbidity of approx. 15 TE/F is significantly exceeded over a period of approx. 11 minutes with up to 150 TE/F. After that, the level returns to the level before disposal. At a mean current velocity of 40 cm/s, an extension in the length of the turbidity cloud to approx. 270 m results which corresponds to doubling.
- After the disposal of coastal marsh sediment, the maximum level in the turbidity cloud over a range of 3,000 m was reduced to a third of the measured maximum value.
- The oxygen content within the detected turbidity cloud consistently ranged within the measured natural fluctuation margin.

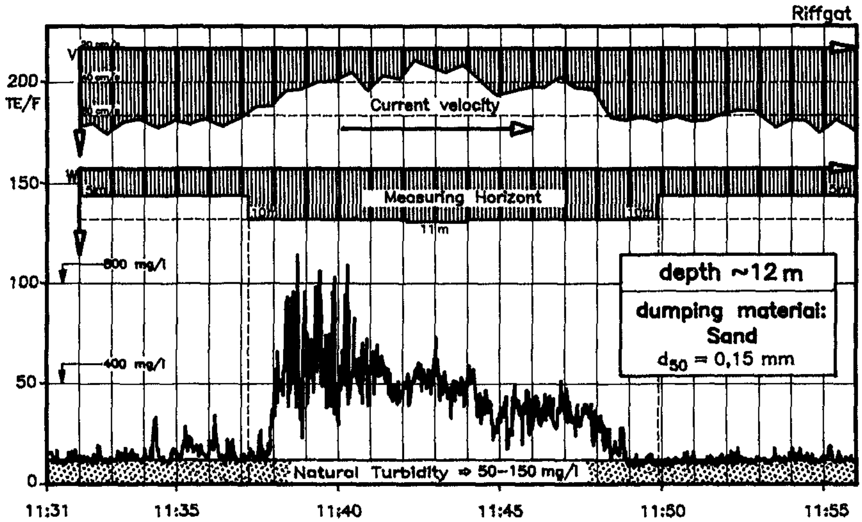

Figure 2. Turbidity Cloud during Dumping passing in the central Lee Side

The newest version of a modern self-sufficient instrument, a so called sand-surface-meter (Manzenrieder 1995) was placed during the disposal of sand and mud direct under the hopper dredger. The real-time history of the stationary measurements is concentrated on Figure 3.

During the observation the disposal of sand is predominant indicated by a stepwise change in the bottom position. The dominant effect of mud disposal is the transient formation of a cloud with very low particle movement. The stability of the mud clouds was detected between 2 and 6 hours during the measurements.

In-situ measurement during disposal (20.-22.06.1995)

(Below hopper dredger, depth at disposal site: ~8 m below chart datum)

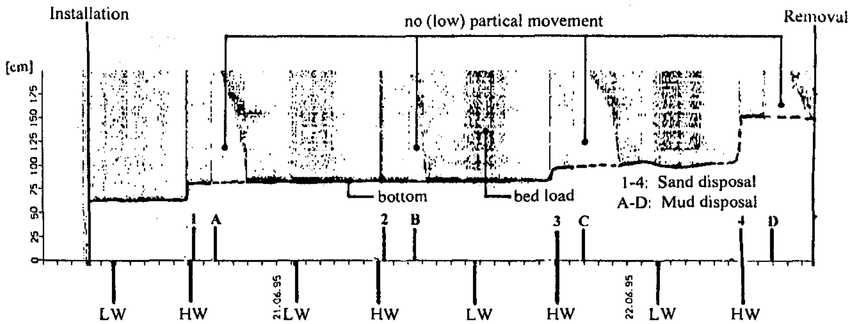

Figure 3. Direct Measurements under a Hopper Dredger during Disposal

Part 4: Benthos Investigations

In the subtidal flats, quantitative samples were taken using van Veen grab sampler supplemented by trawl net catches from a research dredge which were to give a qualitative overview of the epibenthic animal species.

In the intertidal flats, surface samples up to 30 cm in depth were taken respectively. A presentation of the complicated types of analysis and the different extensive groups of results will not be dealt with in this paper.

Assessment (Example)

Since the natural measurements carried out and the model approaches that are available do not form a stable basis for a closed solid matter balance, continuous current and suspension measurements were carried out for a rough model of solid matter loads.

For a defined cross-section in the middle of the disposal site, corresponding suspension loads of 5,800 to 7,700 t per tide phase result for suspension contents of 150 to 200 mg/l. Independent analyses on local bed loads carried by currents show that with an order of magnitude of approx. 10 % of the suspension load, this is a clearly smaller part of the total solid matter load. In Figure 4 the increase of the above presented (natural) suspension transport caused by the input of two dredged material disposals with a quantity of 300 t each is presented for the cross-section of the disposal site. In this case, the first disposal is assumed at approx. 2 hours after the turn of the tide and the second disposal 2 hours before. Under the assumptions made here, both disposals lead to an increase in the quantity of solid matter transported in suspension during the course of a tide of approx. 10%. This value lies within the documented natural fluctuation margin for the location.

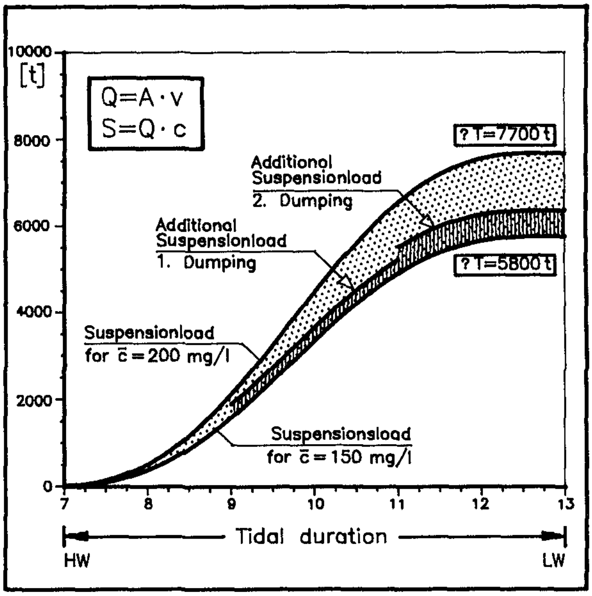

Figure 4. Increase of the natural suspension transport due to 2 disposals (example)

The conditions presented are based as an estimate on assumptions stabilized by measured data and describe the order of magnitude of the solid matter transported.
Greater knowledge about natural variation as a result of seasonal fluctuations or meteorological influences as well as secured data concerning the transport of sediment and suspended solids and their distribution for individual tide phases separately are needed for a secured, quantitative assessment of the effect of dredged material disposal. For this, a corresponding picture of current and transport must be described for the area.

Disposal Site Management

Because of the great number of influencing factors that are to be taken into consideration when managing dredged material, especially in shallow water areas, individual disposal site management is to be connected with corresponding ecological requirements. Here, the qualitative and quantitative assessment of specific boundary conditions provides an opportunity to combine the relevant economic and ecological interests into solutions capable of reaching a consensus.
Sufficient knowledge on the load potential in connection with the tolerance potential forms the basis for such disposal site management.

The load potential (stress factors) comprises all effective area and material specific effects concentrated in disposal.

The tolerance potential (ecological elasticity) describes the available reaction options of the water ecology and especially the bottom of the body of water under natural and/or anthropogenic loads.

A sensitivity classification as a basis for making decisions which defines limit criteria by stabilized guide parameters and therefore contains e.g. statements on allowable sedimentation dynamics (height, duration) should be the goal for selecting main areas for disposal or disposal sites.

When defining possible disposal sites, the question of whether selective or gradual disposal presents the more economical and ecological solution in the course of a year and for different energy input must be answered.

All of the known or the yet to be determined area and material specific parameters supply a contribution to the effect processes which define the eco-system.

Tolerance potential >> Load potential → Mostly uninfluenced environment
No prolonged change or damage to water ecology and little utilization of loading capacity

Tolerance potential > Load potential → Stable environment
No long-term change or damage to water ecology to be expected for high utilization of loading capacity

Tolerance potential = Load potential → Unstable environment
Unstable limit state of water ecology is reached by full utilization of loading capacity

Tolerance potential < Load potential → Destabilized environment
Prolonged changes or damage to water ecology occur when loading capacity is exceeded

Tolerance potential << Load potential → Changed environment
Comprehensive ehanges or damage to water ecology by clearly exceeding loading capacity

In the following, an evaluation matrix for the individual monitoring stations has been compiled for a disposal site within the National Park (example).

Based on a measuring program carried out over a period of several years in the area of the disposal site, short-termed, local changes could be quantitatively determined. Long-term changes or damage to the environment which can be directly attributed to the disposals could not be documented in the dynamic ocean area so far.

A valid assessment of the project dream - "stable environment" - was undertaken according to the presented assessment scheme for the evaluation of intervention in the eco-system which forms the basis for the pending decision of the responsible permit authorities.

Parameter	Retake stations in/around the disposal area in relation to LW												
	above (mudflats)											below	
Bottom Sediments	-	-	/	-	-	/	/	-	/	/	+	/	n
Sedimentary Material	n	n	-	-	-	-	-	+	+	n	-	n	n
Oxygen Content	n	n	/	/	/	/	/	+	/	n	+	n	n
Topography	n	n	+	-	/	-	-	-	-	+	+	n	n
Benthos fauna	n	n	+	-	/	/	n	-	-	/	-	/	n
Turbidity	n	n	n	n	n	n	n	n	n	n	n	+	+
Suspension	n	n	n	n	n	n	n	n	n	n	n	+	+
Values in relation to the natural variation: +:above,/:boundary,-:below,n:not determined													

When objectively viewing the (required) state of knowledge on the manifold influencing factors (cluster), it can be determined that there are considerable deficits. Therefore, qualitative natural observations and quantitative natural measurements will still supply the central contributions.

Conclusion

The quantity of the actual dredged material in the National Park is relatively small in relation to the average annual amount in Germany of 35 million m^3.
By complying with the defined requirements, the unit price for dredging in the National Park - up to US $ 13 - has nearly doubled in the past few years. When compared internationally, for example with the United States which has an annual average of 230 million m^3, the relation of costs for 1995 is approx. 10:1 (Hales 1995).

The type and nature of the sediment is often different from that in the harbors (mud) and the connecting navigable channel (sand). This is important for dredging and the area influenced by disposal. The strategy and collected results were used as input for characterizing the environmental behavior of each region as a part of a morphological and hydrological unit. To do this, the natural background needed to be described in its seasonal variation, also with regard to the effect of single, extremely energetic storm periods. The assessment will resume on the central question concerning the following relation between the natural tolerance potential and the additional artificial load potential due to dredging and disposal with the simple effects for the concerned environment:

Tolerance potential > Load potential = Stable environment
Tolerance potential ~ Load potential = Unstable environment
Tolerance potential < Load potential = Destabilized environment

Experience from such investigations with an ecological orientation show that not only the formulated requirements and limit values but also the relevant investigations are to be objectively adjusted to the respective questions. In this connection, the results from natural measurements are of central importance with increasing duration of observation.

In this process, the engineering sciences with their optimizing work methodology must actively shape these projects in a major way, also searching for overlapping areas in other sciences as they proceed.

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