S. II - 2-2

THE INFLUENCE ON THE ENVIRONMENT OF COASTAL STRUCTURES RECENTLY BUILT IN THE NETHERLANDS

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Part I

THE IMPACT ON THE ENVIRONMENT OF COASTAL STRUCTURES IN GENERAL

1. GENERAL

1.1. INTRODUCTION

In the Netherlands today much attention is paid to the effect of coastal structures on the environment. In the past it was usual to quantify the effect of such a structure on its environment solely with the purpose of deciding whether that effect could imply any hazard to the structure itself (or to structures in the neighbourhood).

Nowadays environmental impact studies are mainly carried out to see what possible changes the structure may bring about in the integral coastal system. However, changes in the coastal system can only be studied if information is already available regarding that coastal system. Therefore scientists and engineers from various disciplines, such as hydraulic engineering, sedimentology, geology, physical oceanography and marine biology have joined forces to describe and analyze the long-term and large-scale morphological evolution of the Dutch coastal zone as an integrated system.

1.2. THREE MAJOR PROJECTS

The above approach has been used in three major projects, viz :

- A pilot project to evaluate the effect of the big enclosure works in the southwestern part of the Netherlands;
- A programme focused on the coastal evolution of the Netherlands on historical and geological scales (Coastal Genesis) [De Vroeg et al., 1988], and
- A programme to provide information for the Coastal Memorandum, in which the Dutch government presents the national coastal policy to parliament.

1.3. COASTAL POLICY

The principles of the Dutch coastal policy [Verhagen, 1989], as laid down in the Coastal Memorandum, are :

(a) Responsibility for the safety of dunes (acting as a sea defence) rests with local, specialized authorities (polder boards). If erosion endangers the safety of water retaining dunes, these authorities are authorized by law to demand action by the national government in order to strengthen the dunes.

(b) Dunes are preferably strengthened by beach nourishment. This also keeps the coastline at its present location.

(c) If the coast is eroding and there is no danger of inundation of low lying polders, but only the danger of loss of dune area, a decision on coastal maintenance is made by the national government, depending on the value in the dunes (ecological, economical, etc.) and likewise on the costs of the works.

(d) Works to maintain the coastline for the above-mentioned second reason are paid for mainly by the national government. However, the decision to pay for such works depends also on the intention of local authorities to cooperate on a financial basis.

(e) Works in the coastal zone with an aim other than sea defence or erosion prevention require a coastal environmental impact statement.

The philosophy behind this policy is that it is our prime national aim to keep the sea defences at the required level of safety. However, we do not do this by suppression of the unwanted processes (erosion is not stopped by building sea walls) but by guiding and controlling them. By using an interdisciplinary, integrated approach we can prevent those processes from developing in an undesirable direction.

2. COASTAL STRUCTURES RECENTLY BUILT IN THE NETHERLANDS

2.1. THE DELTA PROJECT

After the storm surge disaster of 1953 it was decided to close the major tidal inlets in the Netherlands. This plan, known as the Delta Project, was completed in 1988. Figure 1 shows the plan.

Because the current pattern in the tidal area in the southwestern part of the Netherlands was completely changed by the Delta Project, the plan had a significant influence on the coastal area in front of the tidal inlets.

THE OPEN EASTERN SCHELDT

During the execution of the project it was decided not to close the Eastern Scheldt estuary by a dam, but to build a storm surge barrier. In this way the tidal influence in the estuary could remain, which had many ecological advantages. Because of inland dams, there is no longer any influx of (polluted) fresh water in this estuary. The water quality in the estuary has become very good, and this has resulted in an important aquatic ecosystem.

LAKE GREVELINGEN AND LAKE VEERE

The other estuaries are now salt water lakes (Lake Grevelingen and Lake Veere). The former sandbanks have become islands, which suffer from erosion. Many constructions have been designed and built to protect the shoreline.

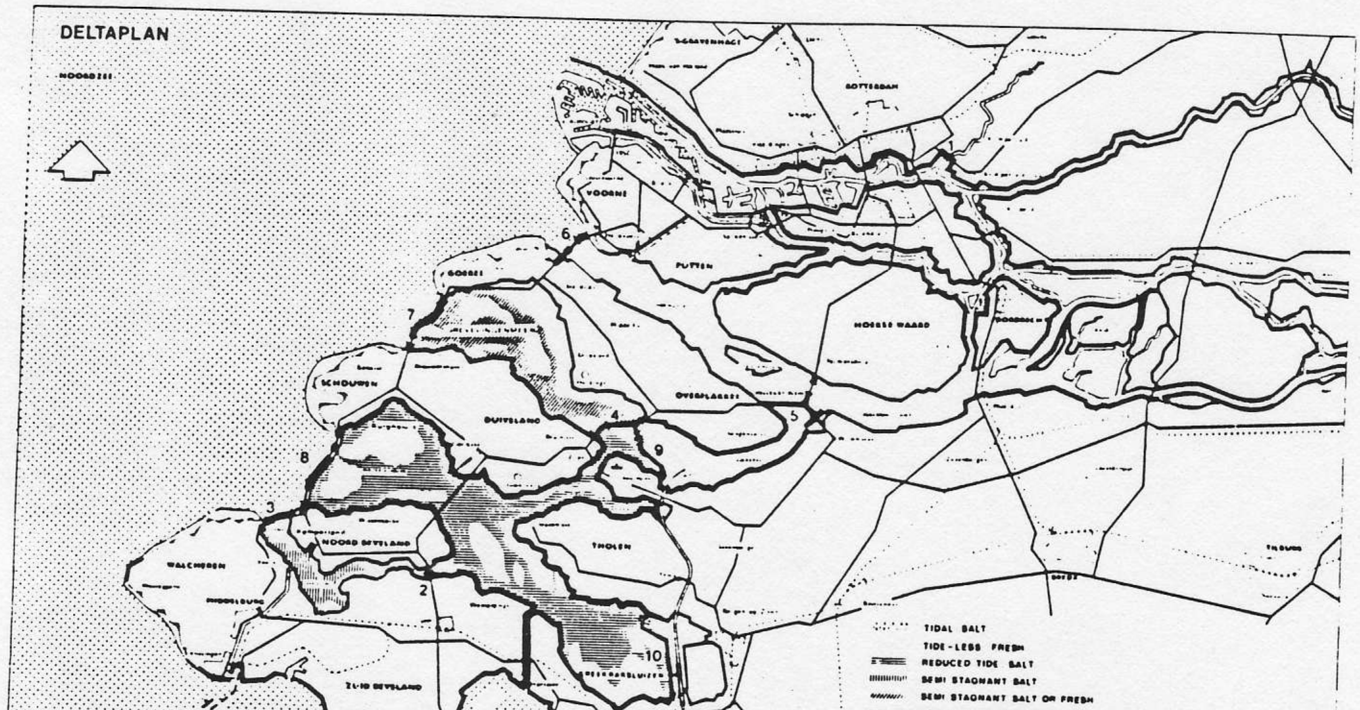

Figure 1 - The Delta Project (Deltaplan)

This has been done in such a way as to enable the shoreline to achieve a high ecological value (see Section 3.2.).

2.2. SLUFTER ON THE MAASVLAKTE

For expansion of the port of Rotterdam more space was required and this was not available on the mainland. So it was decided to build a new harbour complex expanding as a peninsula into the sea, the so-called Maasvlakte.

Dredging the harbour basins results in huge quantities of mud. Most of this mud is polluted and cannot be dumped into the sea. It was not possible to find a location for a disposal area on the mainland, therefore one was designed in the form of a peninsula attached to the Maasvlakte. This plan is called the « Slufter-plan ». It became operational in 1988. Figure 2 shows the peninsula Maasvlakte / Slufter.

Figure 2 - Aerial picture of Maasvlakte/Slufter

2.3. MAN-MADE ISLANDS

The next step in the development of special storage areas could be the creation of land even further out at sea.

The idea of realizing land right out at sea goes back as far as the early seventies. The idea was born against the background of the scarcity of land in the densely populated delta region of the River Rhine.

Since then various projects have been developed, initially intended for the establishment of port and sea-bound activities, but later on for more specific applications, such as the storage of lightly contaminated dredged materials, energy supply, refuge harbours, etc. The main objective of all these projects was to create new large-scale areas relieving the pressure on the mainland in many ways and apt to being environmentally well controlled.

Two important reasons for hesitation before deciding to build such offshore islands are the cost of their realization and a possible consequent reduction in awareness of the need to solve pollution problems at the source of production.

In order to arrive at acceptable cost levels, the water depth should not be too great and the islands should be rather large (several kilometres in diameter). In other words, such islands can be reasonably considered, if the storage capacity is large and the location of the island is chosen in shallow water.

Various investigations have been carried out, but it has not yet come to the actual realization of such a project.

2.4. BEACH NOURISHMENT

The sandy coast of the Netherlands is eroding at several locations. The erosion is of the order of 0.5 - 5 m/year. Because the Netherlands are densely populated, any loss of land is always a difficulty. But in the case of dune erosion the problems are even more severe. At many places the dunes are the sea defence for the low-lying polders behind them, and this protective barrier is very thin, mostly only one row of dunes. Erosion endangers the sea defence and is therefore a direct threat to the survival of the Netherlands. As the dunes are of important ecological and recreational value, protecting them is therefore of the greatest significance in a densely populated country.

It has been decided at government level to call a halt to erosion. Erosion will always be stopped if there is any risk of inundation of polders due to a breakthrough in the dunes. In all other cases, the final decision to control erosion will depend on a cost-benefit analysis of the functions in the endangered dune area. On the basis of this policy, 30 beach nourishment projects have been implemented.

3. ASPECTS PARTICULARLY INVESTIGATED

3.1. INFLUENCE OF THE DELTA PROJECT ON THE MARINE ECOLOGY

Closure of the northern tidal inlets around 1970 meant that the velocity of inward and outward flow seaward of the dams was reduced by between 50 % and 90 %.

Erosion at the front of the deltas, which is caused by wave action and tidal currents and which was formerly compensated for by sediment originating from the tidal inlets, could now continue unabated. As a result, the shape of the ebb-delta began to change.

The eroded material settled in the former tidal channels and formed transverse bars. Mud, particularly, was deposited in the channels near the dams, in some places more than 0.50 m per year. The transverse bars developed mainly along the northern edge of the ebb-tidal deltas. They increase in height landward and also tend to move in this direction.

In less than 10 years these transversal bars developed into long intertidal longshore bars [Kohsiek, 1988]. Flood currents at high tide transported sand northwards over the banks, counterbalancing the wave activity. As a result, the level of the bars stabilized and the speed at which they moved landward was reduced (Figure 3).

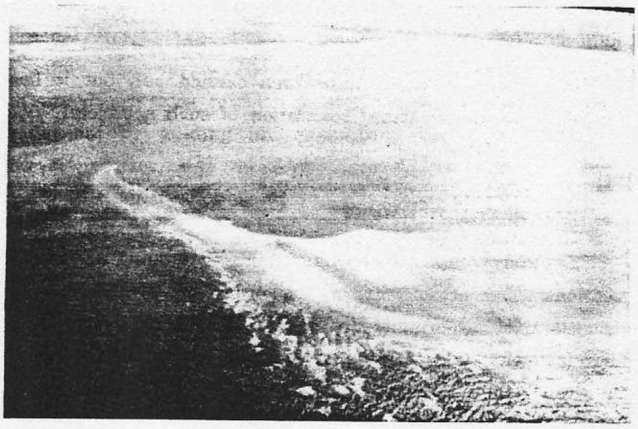

Figure 3 - Sandbanks developing in front of the Dutch Coast

Investigations aimed at quantifying these and future developments are in progress. The recently completed storm surge barrier in the Eastern Scheldt has reduced the tidal prism by 25 %. This is expected to cause developments similar to those in the other (fully closed) tidal inlets, although these changes will be less extensive.

Because of the geomorphological changes in the area, the natural environment is affected at all levels. The new hydraulic conditions and water quality affect the primary production of algae. Changes in bed level caused by shoal formation or erosion, siltation in deeper channel sections, and changes in bed composition due to the addition or removal of mud, greatly affect the development of benthic fauna. These areas, with their drying shoals and abundant food, fulfil an important function for many breeds of birds which migrate over them or winter there. The erosion of shoals in the Eastern Scheldt reduces its capacity to support birds and, by contrast, the capacity of the Outer Delta is increased by the growth of banks and shallow areas. As a result there will be changes in the types and number of birds in the area.

Large colonies of cockles have developed locally in the sheltered areas behind the new sandbanks. The cockle harvest by the commercial shellfish industry will increase. Mussels will also breed here. In the Eastern Scheldt, the erosion of shoals and the local increase in mud deposits will destroy some of the mussel breeding areas. By contrast, however, the reduction in current velocities enables mussels and cockles to establish themselves in the channels of the Outer Delta.

3.2. ENVIRONMENTALLY FRIENDLY EROSION CONTROL

The former sandbanks were automatically transformed into islands after the estuaries were closed off from the sea. However, the shorelines of these islands were not stable, and they eroded heavily. In order to prevent further erosion by wind waves, various protection systems were applied.

In all cases efforts were made to create a type of protection enabling the formation of an optimal ecosystem. In some cases the island was given a recreational function. For recreational shorelines different requirements were established, like safety for children, accessibility, etc. The main forms of protection were small detached breakwaters (mainly consisting of gravel), floating breakwaters and direct shore protection with gravel beaches.

The conclusions of this research were that unprotected shorelines in this area eroded by approximately 10 m/year in the early years. The erosion speed decreases slowly to about 1 m/year, a value which is reached when the shoreface plateau has a width of approximately 700 m. The depth of this plateau is of the order of 2.0 - 2.5 m. The maximum significant wave height in this area is of the order of 1 m. There were no indications that the remaining erosion speed of 1 m/year is decreasing any further. The process only stops when the island has entirely disappeared.

As for conditions in these lakes, gravel beaches were stable, but they had ecological disadvantages, and were not acceptable from a recreational point of view.

Detached breakwaters were effective in these conditions if they were not farther from the main shoreline than 80 m. Behind a detached breakwater the remaining erosion was of the order of a few cm/year.

Floating breakwaters were expensive and showed hardly any effect. From an ecological point of view, detached breakwaters are very good, provided the distance between the coast and the breakwater is 100 m or more. This is contrary to the morphological requirements. Detached breakwaters with gravel on the lake side and sand on the shore side have advantages from an ecological point of view. This construction favours the feeding and breeding of birds.

3.3. EFFECTS OF BEACH NOURISHMENTS

Beach nourishment has two aspects. Firstly, the sand has to be dredged somewhere and this dredging has an influence on the environment. Secondly, the deposition of the sand also has an influence on the environment. The influence of the transport of sand from the borrowing site to the beach can be neglected.

Placing the sand on a beach hardly affects the biological environment of the beach area, because of its high turbulence. Only one or two species of worms can be found on the beach. These worm populations recover quite fast after beach nourishment. The birds feeding on these worms are hardly influenced by the nourishment either.

Investigations of a nourishment at Schouwen (from 1986) (Figure 4) showed that after one season the quality of the biomass had recovered but that a change in the composition of specimens had occurred. However, it seems that this variation was not caused by the nourishment but was in fact a normal variation. The influence of the nourishment on the morphological environment is in all cases very positive.

Figure 4 - Nourishment at the Island of Schouwen in the southwestern part of the Netherlands

At the borrowing site the situation is somewhat different. If sand is borrowed from deep water (20 m deep) and dredged with a suction hopper dredge, the influence on the morphological system can be neglected. Benthic fauna is completely destroyed at the borrowing site, but usually recovers rather quickly. Of course breeding areas were not used as borrowing sites. Borrowing sand at such locations could be expected to cause ecological problems.

For some nourishments, sand was borrowed from the outer deltas. At those locations there is naturally a dynamic situation. If sand is borrowed correctly, it will not have very much influence on the system, especially as the beaches themselves are also part of the same morphological system. Sand should therefore not be borrowed from isolated pits without tidal currents. From an ecological point of view, borrowing sand from a dynamic area does not present very much of a problem, because at those locations life is very well adapted to changes.

Borrowing sand from lakes and from the Wadden area has hardly any influence on the morphology of the area itself, apart from the fact that isolated pits will mostly fill up with fine material instead of sand. From an ecological point of view, however, borrowing much sand from these sources is very often a problem. At the present time, borrowing sand from ecologically valuable areas like Lake Grevelingen and the Eastern Scheldt is no longer allowed.

3.4. STABILITY (AGAINST EROSION) OF LARGE STRUCTURES

At the moment « soft » sea defences are favoured in the Netherlands. An exposed construction such as the dredge spoil disposal area near the Maasvlakte (The Slufter) is also protected in this way. The dike around it is not protected against erosion by stone cladding, bottom protection etc., but a beach is created in front of the dike. Due to wave and current impact this beach will erode and must be regularly nourished.

The shape of the protecting beach has been optimized using advanced mathematical models. These models will be discussed in more detail in Chapter 4.

Economic analysis has proved that coastal maintenance by periodical beach nourishment is cheaper than defensive structures like seawalls. This implies however that relatively high maintenance costs must be met. For government agencies this may cause problems in the long term, because government money is always subject to political decisions of the moment.

3.5. EFFECTS ON ECOLOGY

Constructions in front of existing dunes do affect the ecology of the dunes, even if there is some distance between the construction and the (old) dunes. An important factor for the ecology of the dune area is the salt spray from the sea. This spray is influenced by constructions.

The construction of « The Slufter » depot in the estuary area will bring about changes in the interaction between the dune area and the open sea. This interaction finds particular expression in the salt particles which are sprayed into the air above the sea and then blown into the dunes. Since the depot will partly protect the Voorne coast from the sea winds, the quantity of salt particles carried into the dunes will decrease.

This is expected to lead to changes in conditions for the vegetation in the outer rows of dunes. Plants which can tolerate salt now have an advantage over plants which cannot tolerate it too well. A reduction in supply of salt following the construction of the depot will change the varieties of plants growing in the dune area. The salt-tolerating varieties will be less widely distributed and in smaller quantities.

In the outer delta of the estuarine area in the southwestern part of the Netherlands, the Delta Project has caused many morphological changes. Some of them are indicated above. Recently a detailed investigation was made of the relations between the various aspects of the area. Maps were drawn illustrating the wave climate, tidal currents, bottom topography, bottom composition (grain size, silt content, heavy metal content), composition of benthos, occurrence of fish and birds. The investigation revealed a significant correlation between some classes of benthic life and physical phenomena such as wave climate and current. Knowing these correlations and knowing, from morphological studies (see Chapter 4 below) the changes to be expected in the bottom topography, predictions were made of changes in marine life in this area.

The main conclusion from the investigation was that the changes occurring in this area are increasing its ecological value. It has therefore been decided not to interfere with these developments. Recreational development of the outer delta is not encouraged. No permits are granted for making constructions (like artificial islands for boating) in the outer delta.

4. ADVANCED INVESTIGATION METHODS

4.1. GENERAL

Solving environmental or engineering problems in the coastal zone requires a set of investigation tools, such as observation techniques and models.

Until recently, field campaigns or operational monitoring systems were the only way to gather quantitative data from the coastal zone. Because of the difficult logistics and the high costs involved, such data are usually sparse in space, time and conditions. Consequently, synoptic studies on the effects of human interference in the coastal zone can hardly be based on these field data only.

Models of some sort will therefore be needed for studies of this type, if not in the diagnostic phase (« how is the present system working ? »), then in the prognostic phase (« what will be the effect of the proposed measure ? »). These models should make optimum use of the available field data. In some cases, even hybrid prediction methods can be utilized, making use of models and phenomenological techniques at the same time.

4.2. MODELS FOR COASTAL INVESTIGATIONS

Roughly, there are two groups of coastal models, one describing physical aspects (tides, currents, waves, transport of material, morphology), the other describing chemical and biological aspects.

In principle, these descriptions are interconnected. In the case of coastal structures, however, the interrelation is almost entirely one-way : from morphological to chemical and biological factors.

The principal physical aspects in environmental impact studies of coastal structures are mostly morphology and the transport of material. Models of these two classes of phenomena will now be outlined.

4.3. MORPHOLOGICAL MODELS

Numerical models of coastal morphology can roughly be divided into the following four categories :

a. coastline models (single-line, multi-line), describing the cross-shore displacement of one or more points of the coastal profile over a given longshore stretch;
b. coastal profile models, describing the deformation of the cross-shore profile in the case of longshore uniformity;
c. dune erosion models, describing the storm profile or the dynamic evolution of dunes, beach and upper shoreface, assuming longshore uniformity;
d. coastal area models, describing the morphological evolution in two horizontal dimensions.

(a) COASTLINE MODELS

Single-line and double-line models are in operational use in the Netherlands [Pilarczyk and Van Overeem, 1987]. The time scale of the morphological processes described by these models ranges from years to centuries. De Vroeg et al. describe a state-of-the-art application of a double-line model to the evolution of the Dutch coast.

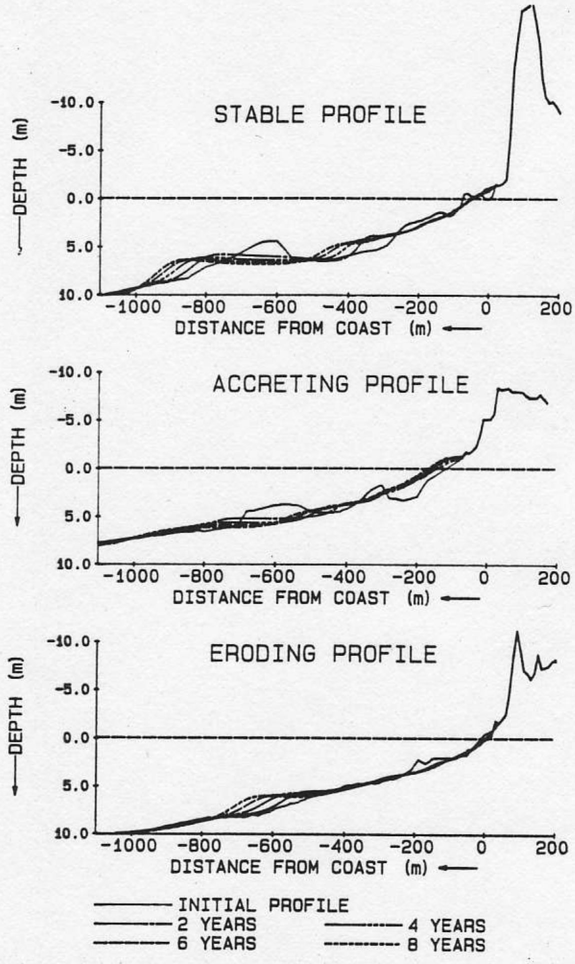

Figure 5 - Development of the coastal profile at some locations along the Dutch coast (stable, accreting, eroding as observed), simulated with a CROSTRAN model [Roelvink and Stive, 1988]

(b) COASTAL PROFILE MODELS

Using cross-shore models of waves, currents and sediment transport, the deformation of the coastal profile is simulated on a real time basis (e.g. with the CROSTRAN-model; See Figure 5 and [Roelvink and Stive, 1988]). A typical time scale of the processes described is several years.

(c) DUNE EROSION MODELS

One category of dune erosion models uses a semi-empirical description of the upper coastal profile after a storm. They are in operational use in the Netherlands, e.g. for security assessment of the dune-coast [TAW, 1984].

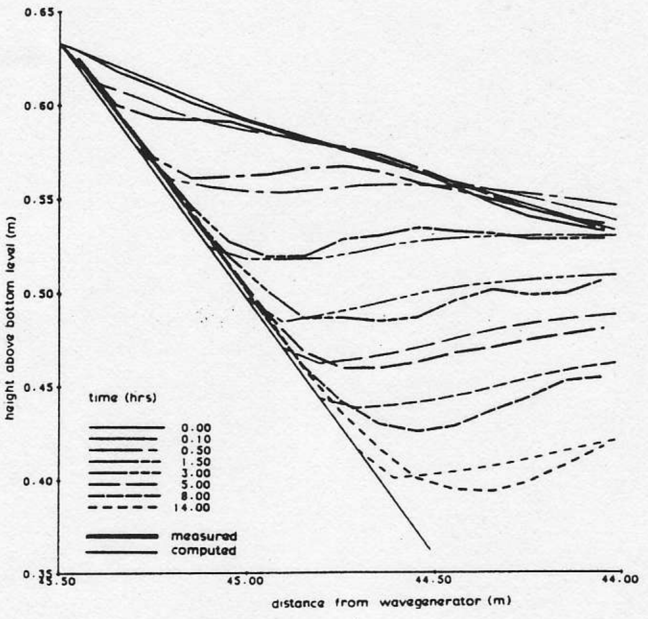

Figure 6 - Beach scour in front of a dune revetment, simulated with a DUROSTA model and measured in a laboratory flume [Steetzel, 1987]

Another category concerns models describing the dune and beach erosion process on a real time basis, with a typical time scale of a few storms. The DUROSTA model [Steetzel, 1987] (Figure 6) belongs to this category.

(d) COASTAL AREA MODELS

Coastal area models are meant to describe morphological evolutions in complex situations without a predominant orientation in the horizontal plane. Often they only give the residual sediment transport field and the attendant rate of erosion/deposition.

Compound model systems to describe this « initial » transport field are in operational use now (e.g. the COMOR system; See [Boer et al., 1984]). They have proved their worth in impact assessment studies of coastal engineering works (harbour entrances, inlets and outlets, breakwaters, artificial islands, etc.; see also figure 7). A model of this type was also applied in the Slufter project, to optimize the shape of the ring dike from a maintenance point of view [Van Orden, 1989].

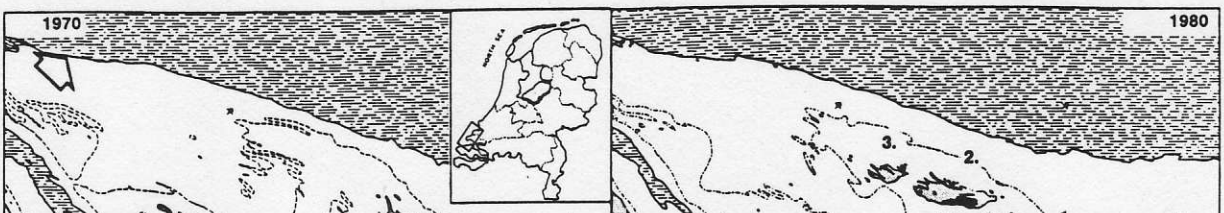

Figure 7 - Evolution of the Grevelingen ebb-tidal delta after closure of the estuary, observed and hindcasted with a COMOR model [Steijn et al., 1989]

4.4. TRANSPORT MODELS

Apart from the sand, the water transports other materials as well, such as :

- passive contaminants, conveyed and dispersed by the water motion but without any autonomous behaviour;
- silt, which is not only conveyed and dispersed but also stirred and deposited (flocculation, settling), and
- matter (chemicals, biota) that exhibits its own autonomous behaviour (motion, reaction, decay).

A typical application of versatile advection/diffusion solver for these transport phenomena [DELWAQ; see Postma, 1984] is shown in Figure 8.

5. CONCLUSIONS

In the Netherlands, big works have been undertaken and completed and these continue to have an enormous influence on the environment. That influence has been monitored and evaluated. Based on the experience gained and on integral scientific research, models have been developed to quantify the environmental effect of coastal works. For recent coastal works these models were used in order to determine which of the various alternative plans had an acceptable impact on all aspects of the environment. A coastal environmental impact statement is presently required for all major coastal works. The tools to make such a statement are available.

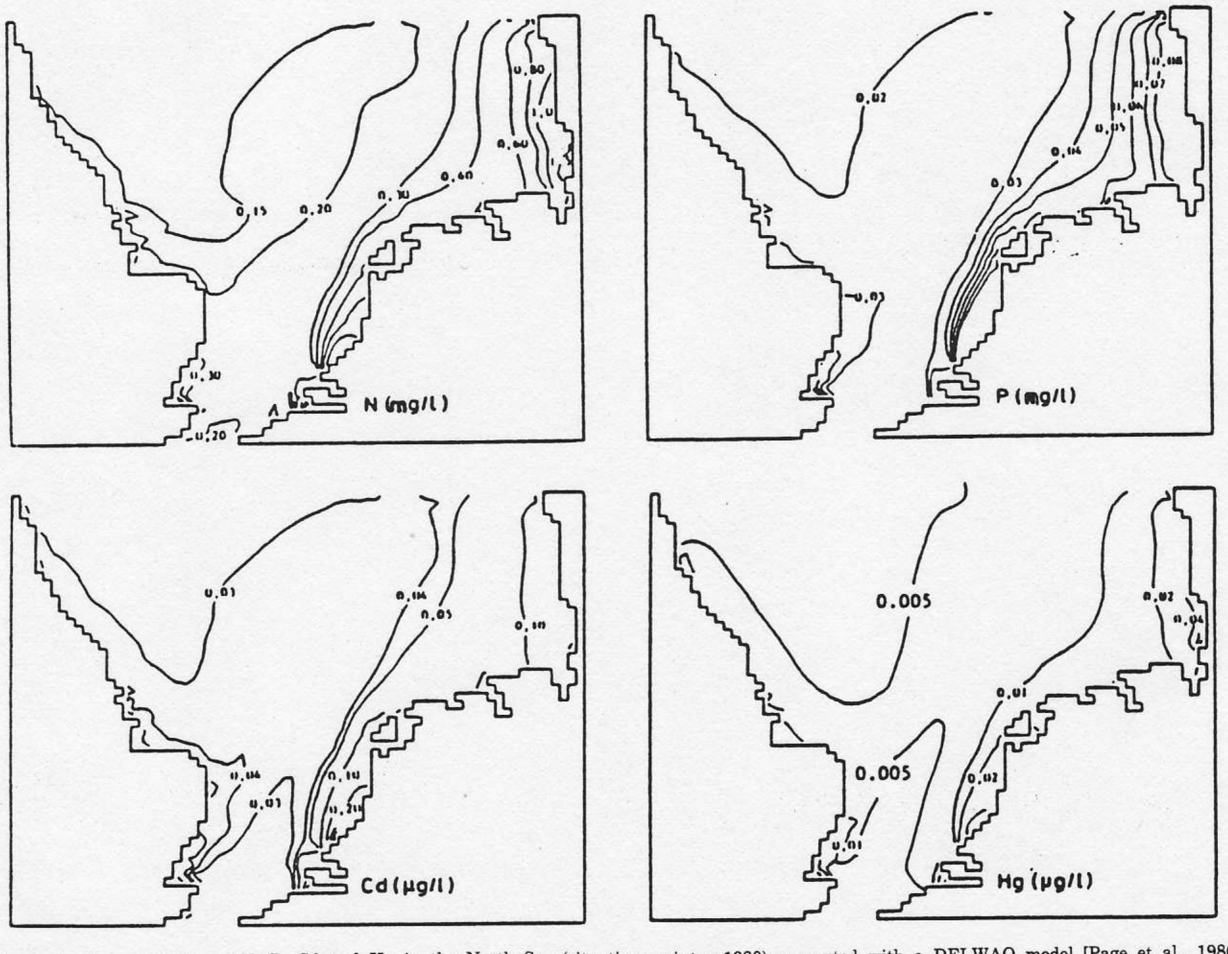

Figure 8 - Concentration of N, P, Cd and Hg in the North Sea (situation : winter 1980), computed with a DELWAQ model [Page et al., 1986]

4.5. ECOLOGICAL MODELLING

As part of the chain « structure + water motion + transport + water quality and biological conditions + functions, biota », transport modelling is an indispensable tool in the environmental impact assessment of coastal structures.

The last step in the biological branch of this chain, the transformation of biological conditions into quantities of biota, requires descriptive ecological models. Given the environmental conditions, these models describe the growth, displacement and decay of a population [Van Pagee et al., 1986].

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Part II

COASTAL STRUCTURES TO MITIGATE THE ENVIRONMENTAL IMPACT OF CONTAMINATED DREDGED MATERIALS

1. INTRODUCTION

Given the great amount of silt to be annually dredged in the Dutch harbour areas (37 million cubic metres, with an extra of 10 million cubic metres from the Western Scheldt Estuary) it is evident that the disposal of the contaminated part of it calls for large-scale solutions.

2. THE PROBLEM OF DISPOSAL OF CONTAMINATED DREDGED MATERIAL IN THE NETHERLANDS

In this chapter a description will be given of the way in which the storage problem was solved for the dredged material originating from the lower reaches of the River Rhine. The greater part of the amount to be dredged in Dutch harbour areas comes from this region: 23 million cubic metres every year. The location of the largest port in the world at the mouth of the same River Rhine, with its enormous economic interests, is one of the reasons why the « Policy Plan » with its detailed classification system was drafted especially for this area.

Apart from the big depots for dredged material in the Netherlands: « The Slufter » and « The Parrot Beak », a description will also be given of other disposal areas in Germany, Belgium and the Netherlands.

2.1. SHOALING PROBLEMS IN PORTS

Nearly all ports in the Netherlands have shoaling problems. Constant dredging in ports and navigation channels is necessary.

2.2. SOME EXAMPLES OF DISPOSAL OF HARBOUR SLUDGE

All Port Authorities struggle with a lack of appropriate dumping areas for contaminated sludge. The most important harbour areas in the Netherlands are:

(a) EEMS HARBOUR DELFZIJL

Annual quantity of maintenance sludge to be dredged is about 1.5 mln m^3. Conventional dumping areas are situated offshore. Solutions for dumping about 0.5 mln m^3 Class 4 sludge have been found in a special land location.

(b) AMSTERDAM - NORTH SEA CANAL AREA

Annual quantity of maintenance sludge to be dredged is about 3.5 mln m^3. Until 1985 the Port Authorities were allowed to dump this quantity in open sea. Afterwards an exception was still made for contaminated sludge (in total about 0.5 mln m^3) dumped in a former harbour, especially isolated.

(c) ROTTERDAM

For this area reference is made to Chapter 3 below.

(d) GENT-TERNEUZEN CANAL AREA

Annual quantity of maintenance sludge to be dredged is relatively small, till now dumped in the Western Scheldt Estuary. In a restricted area, the contamination of the canal bottom turned out to be a more serious problem.

(e) WESTERN SCHELDT ESTUARY AREA
(INCLUDING THE ANTWERP HARBOUR AREA)

Annual quantity of maintenance sludge to be dredged is about 10 mln m^3, till now dumped in restricted (surface water) areas in the Western Scheldt Estuary. Contamination of sludge urges the construction of appropriate disposal areas, both estuarine and land-based (about one fifth the size of the disposal area for the Rotterdam Harbour area).

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Various policy documents (publication is in progress).

2.3. POLICY PLAN FOR THE LOWER REGION OF THE RHINE DELTA

Until the nineteen seventies, dredged material was generally used as filling material for low-lying areas (polders). It then became clear that the major part of the silt was polluted with a variety of more or less hazardous chemicals, heavy metals, etc. These pollutants originate from upstream and harbour linked industries.

As the disposal problem was most immediate for the lower reaches of the River Rhine, with an annual amount of 23 million m^3 to be dredged, a committee was formed to draft a plan (« Policy Plan ») to solve the problem.

According to this plan, the real solution for the problem was to reduce the degree of pollution to such an extent, that the silt could be disposed of in the North Sea or usefully recycled. However, this could not be achieved at short notice. It would take years before the silt would be of such quality that it could be classified as « clean ».

2.4. CLASSIFICATION OF CONTAMINATED DREDGED MATERIALS (a local classification system)

An important part of the « Policy Plan » was the classification of the silt, based on geographical grounds. Three categories or classes were distinguished, with a fourth non-geographic category for the most heavily polluted silt occurring locally in different parts of the region.

(a) CLASS 1 : (13 mln m^3 annually)

(hardly contaminated / of marine origin), located in Rotterdam-Europoort and the western part of the Rhine. Is being dumped into the North Sea.

(b) CLASS 2 : (together with Class 3 : 10 mln m^3 annually)

(slightly contaminated) located in the Botlek area, west of the mouth of the River Oude Maas. For its disposal a medium form solution has to be found. See Section 3.1.

(c) CLASS 3 : (together with Class 2 : 10 mln m^3 annually)

(polluted) in the river and harbour basins located east of the River Oude Maas. For the disposal of this class of material see Section 3.1.

(d) CLASS 4 :

(heavily polluted) caused by local discharges of waste water into the harbour basins and rivers. The solution for the disposal of this class of material is described in Section 3.2.

At a later stage, a more sophisticated classification system, based on degree of pollution (standards), should be designed in order to make the system applicable to other regions in the Netherlands as well.

2.5. SLUDGE QUALITY (A NATIONWIDE CLASSIFICATION SYSTEM)

(a) LEVELS OF SLUDGE QUALITY

Three levels of sludge quality (real quality standards)

Base quality = minimum quality level to strive for (transition measurements between Class 1 and Class 2);

Testing values = quality level used for judging the free allocation of sludge (under certain conditions) or the undesirability of the latter (transition measurements between Classes 2 and 3);

Signalizing value = indicational level. Exceeding this level calls for examination to accessory sanitary measurements (transition measurements between Classes 3 and 4).

(b) RELATION BETWEEN DISPOSAL OF SLUDGE AND REAL QUALITY STANDARDS

* 'Release into surface waters', principally permitted for sludge quality levels between 'Base quality' and 'Testing value'.
* 'Controlled disposal' is permitted for sludge exceeding the 'Testing value'.
* 'Isolated disposal' is required for sludge exceeding the 'Signalizing values'.

3. SOLUTIONS FOR HANDLING AND STORAGE OF CONTAMINATED DREDGED MATERIALS FOR RHINE DELTA

3.1. THE SLUFTER

According to the above-mentioned Policy Plan, a large-scale depot (150 mln m^3, on the basis of the disposal of 200 000 m^3/week) for the storage of Class 2 and 3 polluted silt promises to be the best way to solve the problem for the next two decades.

All sorts of possible locations for such a large-scale depot were investigated, on land, off the coast and at sea. After an Environmental Impact Statement (EIS) [van Orden, 1986] the choice fell upon a site linked to the Maasvlakte, viz: « The Slufter » (Figure 9).

Figure 9 - THE SLUFTER: Large-scale depot for the storage of contaminated dredged materials on the Maasvlakte near Rotterdam

The Slufter covers 260 hectares, is 28 metres deep, with an enclosing dam 23 metres above Mean Sea Level. The volume of the silt is reduced by consolidation. Due to the effect of the weight of the upper layers, the water is pressed out to the surface of the silt layer into the subsoil of the depot. This water has been in close contact with the polluted silt and is therefore also polluted.

Chemical reactions in the depot also determine the degree of pollution of the water. A particularly important role is played in this respect by the breakdown of the organic matter in the silt. One result is the formation of gas. It is expected that during the storage period 10 % of the space will be taken up by gas bubbles (methane and carbondioxide). Due to the chemical reactions, the degree of pollution of the water will be variable during the first 10 years. Thereafter the situation will be more balanced.

After the total storage has been completed, the quantity of water filtering through the bottom of the depot into the subsoil will gradually decrease and even reach zero after a few hundred years.

The way in which the water draining out of the depot is distributed into the subsoil depends largely on the subsoil's geological structure and the difference between the relatively fresh water in the depot and the salt water in the subsoil. This difference will give rise to a fresh water lens, floating on the brackish ground water (see Chapter 5 below). All the water brought to the surface in this lens disappears along the sides without spreading any further into the neighbouring subsoil. It is uncertain whether a fresh water lens will occur and continue to exist under the deep part of the depot. Such a lens will certainly exist under the enclosing dam and the adjacent area, because of the surplus precipitation on this dam (400 mm/year).

The following conclusions can be drawn from various ground water distribution pattern calculations:

(a) Most pollutions occur over a period of several thousands of years at a relatively high level in the ground water at a limited distance from the sludge in the depot.
(b) Two pollutants (cadmium and zinc) will have moved noticeably further during this period.
(c) In the immediate vicinity of the dam (50 metres) the presence of the fresh water lens tends to limit the rise in cadmium and zinc concentrations to 10 to 20 % compared with the present natural levels.
(d) In the area lying further away, a further rise in the concentrations of cadmium and zinc can be expected over a period of several thousand years. A rise moreover, which stays within the naturally occurring concentrations in ground water.
(e) The ground water in the nearby dunes will not be affected by polluted water draining from the depot.
(f) No effects are expected on marine life on the sea bed.

Because of the above conclusions measures such as sheeting or sealing layers in the depot were not taken into consideration. If things should turn out differently in practice, a pumping system around the depot can be established to pump up the polluted water in the subsoil. By taking regular samples of the ground water, data can be assembled and used as a basis for deciding whether the distribution of pollution actually taking place corresponds with what was predicted.

3.2. THE PARROT BEAK

A special solution had to be found for the disposal of Class 4 silt. An inventory of the material in this category in the Lower Rhine Delta revealed that an amount of about 1.5 million m^3 had to be stored. As soon as the silt has been dredged and stored, no more silt of this category will be allowed to form. Discharge permits are linked with strict legislation in this field. A plan was developed to create a temporary site on a peninsula in the northernmost part of the Maasvlakte. Because of its shape this site was given the name « Parrot Beak » (Figure 10).

The site lies at a level of 5 m above Mean Sea Level with dikes 3.5 m in height. Thus a depot of about 30 ha was created. The slopes of the dikes and the bottom of the depot are covered with « plastic » (HDPE = High Density Poly Ethylene) sheeting, 2 mm thick, to prevent the infiltration of the highly polluted water into the subsoil.

This HDPE sheeting was one of the main conditions for getting legal permission to build the depot in this area. In order to make the maximum use of the storage capacity, the silt will be pumped into the basin in thin layers.

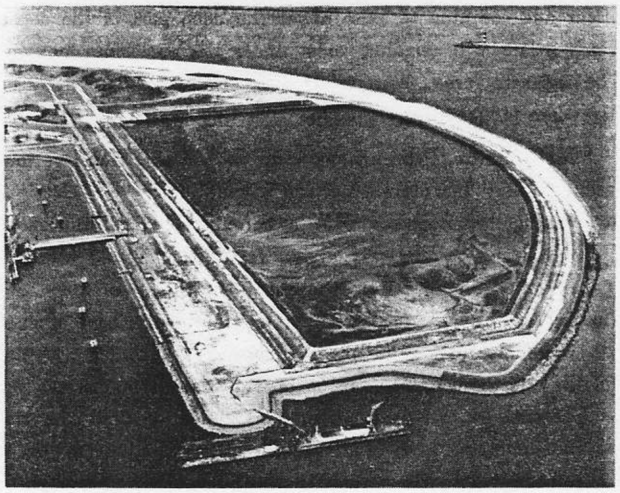

Figure 10 - THE PARROT BEAK : Disposal area for heavily contaminated dredged material on the Maasvlakte near Rotterdam

4. SOLUTIONS FOR HANDLING AND STORAGE OF CONTAMINATED MATERIALS IN THE FUTURE

As shown, the realization of the reservoirs « The Slufter » and « The Parrot Beak » provides solutions for the storage of respectively lightly and heavily polluted dredged material for the Rotterdam region for the rest of this century. However, other large-scale storage areas still have to be considered for two main reasons :

- For other regions, such as the southwestern region of the Netherlands (Antwerp, Western Scheldt Estuary), such solutions do not exist.
- In the Netherlands at this moment a quantity of more than 100 mln tons of waste and dredged materials is generated annually. As it will take a considerable time (probably some decades) before the pollution is stopped at the source or reduced to an acceptable level, large amounts of these materials still have to be stored somewhere.

The pressure of the continuous flow of, in particular, lightly contaminated materials will demand large-scale solutions which can be quickly realized. In view of the scarcity of socially acceptable sites on land, fresh consideration should be given to the possibility of creating large-scale, well controlled and isolated areas in the sea itself, such as :

- disposal into pre-dredged holes in the sea bed which can be covered over after completion of the disposal or, in other words, sealed off in order to guarantee isolation, and
- disposal in man-made island type storage basins.

In order to reconsider these possibilities, in November 1988 the Netherlands Royal Institute of Engineers (K.I.v.I.) organized a symposium in Rotterdam, where presentations and contributions were made by the various ministries concerned, by the Public Works Department of Rotterdam and by environmental and industrial (chemical and construction industry) organizations.

With respect to the possibility of using man-made island type reservoirs it was shown that, for water depths of about 10 m, islands with a diameter of at least 3 km are economically viable, and, for water depths of 20 m, islands with a diameter of 5 km or more.

Further investigations into the possibilities of such solutions will concentrate not so much on their construction possibilities, but more on the influence such island schemes may have on coastline development and the surrounding sea (bed).

5. STEP BY STEP INTEGRATION OF CIVIL AND ENVIRONMENTAL TECHNIQUES

5.1. GENERAL CONSIDERATIONS

The basic design principles of disposal sites have been derived from conventional risk analysis techniques, which require consideration of the problem from three interconnected starting points :

(a) A source of potentially dangerous chemicals.
(b) A target in the surroundings in which the environment is considered to be at risk.
(c) A pathway connecting the source to the target.

In practice it is usual to have to consider multiple sources and targets connected by several pathways. These include :

(a) Wind erosion of dry material and the transport of adsorbed or free phase contaminants;
(b) Water erosion of material and the transport of adsorbed and free phase contaminants, as well as the dispersion of any associated pore water contaminants;
(c) Percolation of water through the depot and advection into the surrounding geo- and hydrospheres. This can also include ejected consolidation water;
(d) Direct uptake into the biosphere and the food chains.

In the long-term safety assessments, attention also has to be paid to more remote failure scenarios.

Reliance can often be placed in natural (in situ) barriers and in the long term these are the only ones available. In the short term, it is possible to enhance the near-field barriers by civil engineering techniques, such as cut-off walls, guard and scavenging well points and capping.

Prediction of the effects of the site design on the environmental impact of the site and of the most cost-effective strategies for mitigating these effects together form the basis of the Dutch approach to the design of disposal sites.

5.2. STORAGE FACILITY IN ZELZATE-BELGIUM

Chronologically, the first major facility to be designed on these lines was the landfill site to hold the contaminated dredged material from the ship canal between Ghent in

Belgium and the Western Scheldt Estuary in the Netherlands. The site is located in a highly permeable sand aquifer in the agricultural buffer zone between two highly industrialized conurbations at Zelzate in Belgium. The potential for the migration of toxic chemicals in the aquifer was judged to be severe and the almost non-existent natural barriers were upgraded by adding a bentonite-cement curtain wall around the site, anchored in a deep clay stratum of low permeability and high integrity.

The migration pathways are such that in the short term the (polluted) transport and consolidation waters will be collected in a control ditch on the site. Beyond that time span, it was calculated that the permeability of the dredged material would be so low that further emissions into the surroundings, even after a significant failure of the cut-off wall, would be environmentally acceptable.

5.3. STORAGE FACILITIES IN ROTTERDAM AND HAMBURG REGIONS

The major facility in the Rotterdam area, « The Slufter », has been described above. Of importance for the safety analysis is the fact that the site is located on top of a salt water aquifer, which could allow migration of the more mobile toxic components to areas of ecological value within 2000 m of the site. However, it was not necessary to enhance the near-field natural barriers, reliance being placed in the properties of the fresh water lens that would be created under the site by the pore water expelled in the initial consolidation phase. In the long term, when this barrier will no longer be available, the fluxes will have been reduced to such a level as to pose no significant threat to the environment.

Finally, two sites have been considered where it has been thought necessary to reduce the potential for erosion and percolation to the absolute minimum, in both the long and the short run. These are the pesticide-contaminated sediment site in one of the Rotterdam harbours and a proposed site in the Waddenzee, a major nature reserve, to hold the highly contaminated dredged material from the Hamburg port area.

In both these cases it has been decided to excavate deep into the river- or sea bed, to landfill the material in question in the pit so formed, and to cap to sea bed level with an unpolluted barrier material. In the former case capping was effected immediately after filling and in the latter case capping will be improved by the long-term collapse of the surrounding dikes over the site by wind and wave action. This last site is illustrated in Figure 11.

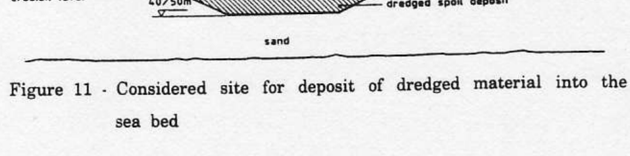

Figure 11 - Considered site for deposit of dredged material into the sea bed

In the long term, the emission scenarios from both sites will be diffusion and redox-dominated, with very low emission levels. In the short term, care must be taken to avoid major emissions and Figure 12 illustrates the expected concentration development in the surrounding sea bed at the Hamburg site, again for cadmium. The concentrations shown are of the order of the current background levels and are to be taken as worst-case estimates.

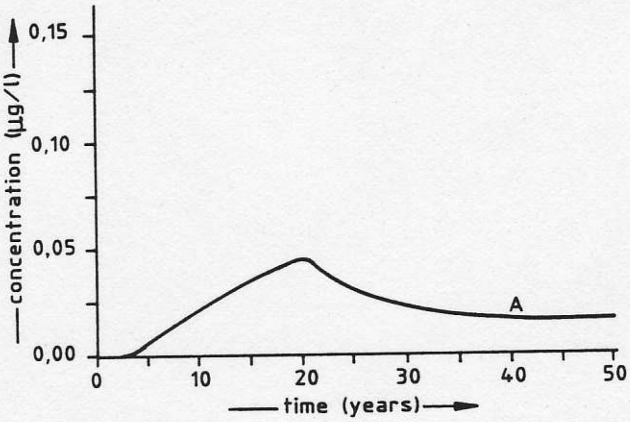

Figure 12 - Expected cadmium concentration development in the surrounding sea bed at the Hamburg site

6. CONCLUSIONS

Given a lot of effort and money it is possible to solve the storage problems for contaminated dredged material for the short and medium term. The cases discussed in this part of the presentation demonstrate the importance of an integrated approach to the environmental and civil engineering design tasks involved.

However, the disposal of large quantities of contaminated material results in a concentration of significant amounts of toxic and potentially harmful chemicals in a relatively small area. Large areas of land and/or water are concerned and to date all efforts to solve the problem of storing dredged material still fail to bring the ultimate solution nearer.

For the long term, efforts have to be made to limit the discharges of polluted waste water into rivers and harbour basins in the Netherlands as well as in the neighbouring countries.

In the Netherlands, technical and legal studies are being carried out in order to solve the problem before the necessity arises for building a second Slufter or Parrot Beak. The Municipality of Rotterdam is discussing the problems with industries, water quality controllers and other municipal authorities along the River Rhine.

Part of the legal study will be concerned with the question as to whether the Municipal Authority of Rotterdam can charge the additional silt disposal costs due to the pollutants to one or more of the industries causing this pollution and whether it can institute civil procedures to achieve this.

The aim of the technical study is to identify the sources from where the various pollutants are being discharged and to calculate what contribution each individual discharger makes to the total pollution of the silt.

In the opinion of the Rotterdam authorities, all these efforts should finally result in the river silt being of such a quality that it can be transported to the sea without any problem, employed again - as it was in the past - to raise the level of polders, or put to some other good use.

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RESUME

Au cours des dernières décennies, plusieurs ouvrages d'ingénierie côtière ont été réalisés aux Pays-Bas, dans le but de protéger le littoral et d'améliorer la protection contre les inondations, pour améliorer les routes de navigation maritime et pour créer des bassins d'eau douce assurant une réserve suffisante en eau de bonne qualité.

Le principal problème rencontré lors du développement et de la création de ces projets était la conception d'ouvrages capables de résister aux éléments (environnement), répondant aux objectifs précités au plus intéressant prix de revient.

Cependant, au moment même où ces projets de grande envergure (Projet Delta, Port en eau profonde de Rotterdam) étaient en cours de développement et de réalisation, d'autres phénomènes apparurent, tels que la croissance explosive de l'industrie en général et du bassin du Rhin en particulier. De plus, l'augmentation de la production couplée à l'amélioration généralisée du niveau de vie se traduisaient par une sollicitation beaucoup plus élevée par personne des ressources naturelles (telles que l'eau, les produits agricoles, l'économie etc.) et par l'augmentation de la production de produits de déchet.

Les Pays-Bas, situés à l'embouchure du bassin du Rhin, très peuplé et industrialisé, et engagés dans l'exécution de plans d'aménagement à grande échelle dans des zones côtières et des estuaires du delta du Rhin où l'équilibre écologique est délicat, étaient un des premiers pays à être confrontés à la nécessité de concevoir des ouvrages capables non seulement de résister aux éléments (environnement), mais aussi de protéger l'environnement lui-même d'interférences humaines trop radicales. En d'autres termes, le développement de deltas et de plaines côtières devait se faire non seulement en fonction de critères purement techniques, mais aussi en tenant compte de beaucoup d'autres aspects.

La prise de conscience grandissante de ce processus a mené à la modification du Projet Delta au cours de son exécution. Ainsi le bras de mer de l'Escaut Oriental n'a pas été fermé complètement, mais reste en jonction ouverte avec la mer. Une porte marée-tempête n'est fermée que lorsqu'il y a danger d'inondation.

Ce qui précède n'est que le contexte du présent rapport comportant deux parties :
1. L'impact écologique des ouvrages côtiers en général,
2. Ouvrages côtiers destinés à atténuer l'impact sur le milieu de produits de dragage contaminés.

La première partie contient une brève description de quelques grands projets de génie civil en cours aux Pays-Bas. L'accent est mis sur les conséquences de ces projets qui n'appartiennent pas au domaine de l'ingénierie et sur les mesures prises pour y faire face. Afin d'aboutir à une approche multidisciplinaire intégrée, des modèles numériques avancés, décrits dans le rapport, ont été developpés.

Dans le cadre de cette philosophie nouvelle, les solutions « douces », tels que l'ensablement des plages, sont à préférer aux ouvrages rigides. Il est aussi tenu compte de solutions favorables au milieu pour la protection des rivages.

La deuxième partie du rapport traite des solutions, déjà réalisées ou à l'étude, à la contamination des fonds des bassins portuaires et des voies navigables. Après une description de la classification des produits de dragage contaminés, suit une description de sites de déversement pour matériaux contaminés déjà réalisés ou à l'étude en Belgique, dans la République Fédérale d'Allemagne et aux Pays-Bas. Une attention spéciale est accordée à quelques solutions réalisées aux Pays-Bas pour l'entreposage respectif de produits de dragage peu et fortement pollués.

L'intention et l'espoir des auteurs est de montrer avec ce rapport, à l'aide de projets déjà réalisés, comment les régions côtières peuvent être gérées efficacement et utilement à partir d'une approche multidisciplinaire intégrée des problèmes soulevés.