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TERRA ET AQUA

Maritime Solutions for a Changing World

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Guidelines for Authors

Terra et Aqua is a quarterly publication of the International Association of Dredging Companies, emphasising "maritime solutions for a changing world". It covers the fields of civil, hydraulic and mechanical engineering including the technical, economic and environmental aspects of dredging. Developments in the state of the art of the industry and other topics from the industry with actual news value will be highlighted.

- As *Terra et Aqua* is an English language journal, articles must be submitted in English.
- Contributions will be considered primarily from authors who represent the various disciplines of the dredging industry or professions, which are associated with dredging.
- Students and young professionals are encouraged to submit articles based on their research.
- Articles should be approximately 10-12 A4s. Photographs, graphics and illustrations are encouraged. Original photographs should be submitted, as these provide the best quality. Digital photographs should be of the highest resolution.
- Articles should be original and should not have appeared in other magazines or publications. An exception is made for the proceedings of conferences which have a limited reading public.
- In the case of articles that have previously appeared in conference proceedings, permission to reprint in *Terra et Aqua* will be requested.
- Authors are requested to provide in the "Introduction" an insight into the drivers (the Why) behind the dredging project.
- By submitting an article, authors grant IADC permission to publish said article in both the printed and digital version of *Terra et Aqua* without limitations and remunerations.
- All articles will be reviewed by the Editorial Advisory Committee (EAC). Publication of an article is subject to approval by the EAC and no article will be published without approval of the EAC.

COVER
Aerial photo of Amager, a new beach park recently built in Copenhagen, Denmark (courtesy of Jan Kofod Winther). This thoroughly planned location and layout of urban elements integrates recreational demands with the natural dynamics of artificial beaches and lagoons using the principle of exposing new beaches to wave action by placing them out in deep water (see page 21).

CONTENTS

TERRA ET AQUA

EDITORIAL

In the present "age of sustainable development", the virtues and vices of human intervention is often a topic of discussion. Indeed, almost everywhere in the world, on every beach in the world, so to speak, people have left their footprints. Dredging is of course part of this intervention process, and though it is sometimes seen as controversial, intervention can also result in farsighted innovation, creating changes which play an important role in achieving sustainable growth. Practical, applicable innovation is at the core of every enduring business and this is true of dredging as well. The dredging industry depends on talented people with a wide variety of skills and imagination.

The ability of the dredging industry to provide safe harbours and ports, quality reclaimed land, sandy beaches and coastal protection is the ultimate purpose which drives the companies, and the people working for them, to perform at the top of their game. In the dredging industry, innovation is not the domain of the few, hidden in an ivory tower. It has been integrated into every aspect of the industry. Sometimes dredging experts are at work in their own backyards, but often work takes them far from home. Wherever they find themselves, for countries with extensive coastlines like Denmark, the Netherlands, Singapore and the UK, the question of preserving coastlines, coastal development and coastal protection are daily public policy concerns.

The articles that appear in this issue are focused on innovative human intervention – looking for the best solutions, finding further data and information to apply to a dredging or maritime construction challenge. The first article is the paper that received the IADC Award at the PIANC COPEDEC. It describes the ongoing efforts to evaluate the quality of the waters surrounding the Wadden Islands. These sandy islands provide a vacation and recreation area for many tourists and yet their tidal basins are vulnerable to water currents and erosion. This is an old problem that demands new insights.

Innovation also means asking, "What does the client need?" In the case of the Port of London the client needed assistance in finding suitable uses for dredged material as is stipulated by UK regulations. The second *Terra* article describes how, by the developing a new innovative form of contract, a partnership between the Port Authority and the dredging company was formed so that dredged material from a maintenance project was used to clean up a brownfield site for a new riverside project. Similarly, the final article on "waterfront developments built in harmony with nature" is an example of creative, determined minds, developing projects that improve people's lives, such as the new beaches at Amager in Copenhagen.

All these articles demonstrate that innovation does not occur in isolation. It is a team effort and depends on harnessing the collective intelligence in a company. Innovation and well-planned change can indeed be made part of the philosophy of a company, with all employees contributing on various levels. Many ideas will be tried, and some ideas will not be feasible, but it is only by trying, by modelling and trials, that the next leap forward can be made. In the dredging industry, the people who "play" on the team, whatever their role may be, the engineers, dredgers, researchers, financial planners, contract lawyers and project managers, work together with a common goal: To create innovative products, to effect change, which will improve the community's quality of life through long-lasting maritime solutions.

Koos van Oord
President, IADC

ALI DASTGHEIB

PROCESS-BASED MODELLING OF MEGA-SCALE EQUILIBRIUM CONDITIONS IN THE DUTCH WADDEN SEA

ABSTRACT

The equilibrium condition in tidal basins, especially in the Dutch Wadden Sea, which is a multi-basin tidal system, has been the subject of numerous studies in recent decades. This concept is more important when the tidal basin imports sediment from the adjacent coastline and its ebb-tidal delta. In the Dutch Wadden Sea the construction of the Afsluitdijk in 1932 affected the behaviour of tidal basins, especially Marsdiep, to a large extent and disturbed its equilibrium condition. In this study a process-based model (Delft3D) based on the shallow water equations is used to simulate the morphological changes of the Western Wadden Sea for a sufficiently long period for achieving equilibrium (2100 years). The main forcing which is included in the simulations is tidal forcing and different simulations with different initial conditions of the model are carried out. The main parameters of tidal basins are calculated and checked with suggested empirical equilibrium relations in the literature. It is shown that such a process-based model can simulate the morphological evolution of the tidal basins in the Western Dutch Wadden Sea and can model a stable (equilibrium) condition in these basins. This stable condition is however strongly dependent on the initial condition of the model as well as the forcing conditions. Comparing all the results of the simulations in this study, it is concluded that the process-based model results show the morphological evolution towards empirical equilibrium equations suggested in the literature, mainly in line with the relations rather than in terms of exact coefficients.

The work presented here was carried out in the framework of the project, "Interaction between the long-term developments of Dutch Coast and the tidal basins Marsdiep and Westerschelde", conducted by Rijkswaterstaat (Directorate-General of Public Works and Water Management of The Netherlands) at WL|Delft Hydraulics. The author wishes to acknowledge the contributions of Z.B. Wang, WL|Delft Hydraulics, J. de Ronde, Rijkswaterstaat (RIKZ), and J.A. Roelvink, UNESCO-IHE Institute for Water Education. This paper was published in the proceedings of PIANC COPEDEC VII and is reprinted here in a slightly revised version with permission.

Above, The construction of the Afsluitdijk in 1932 affected the behaviour of tidal basins surrounding the Dutch Wadden Islands. Shown here, the Eierlandse dam on the northwest corner of Texel, the most western of these islands.

INTRODUCTION

Barrier islands and tidal inlets are found in many places along the coastlines in the world. A tidal basin system consists of three main morphological elements: a tidal basin, tidal inlet and ebb-tidal delta. These three elements, affected by meteorological and hydrodynamic forces, interact with each other to gain and maintain a (dynamic) equilibrium. Sometimes as a result of human intervention and/or natural phenomena, the effecting forces on the tidal basins change. These changes lead to morphological changes in different elements. First sediment is re-distributed within the elements, and sand is exchanged between elements. But if these changes are larger, the sediment exchange may take place between the tidal basins and adjacent coast and in its turn this causes some morphological changes (and problems) in nearby coastlines.

In the last decades, efforts have been undertaken to identify equilibrium and stability of tidal inlets, and to model different morphological time scales and spatial scales of tidal basins using behaviour based models (De Vriend *et al*., 1993). These include, for instance, empirical relationships, such as tidal prism-cross sectional area relationship, (e.g., O'Brien, 1931; Jarret, 1976) and closure criteria (e.g., Escoffier, 1940), and semi-empirical long-term models such as ASMITA (Stive *et al*., 1998; Stive and Wang, 2003). But better understanding of the underlying processes allows process-based models to find their role in the modelling of tidal basins. These models have been used to simulate the morphological evolution of tidal basins in different time scales (Wang *et al*., 1995; Hibma *et al*., 2003; Marciano *et al*., 2005; Van der Wegen and Roelvink, 2008). These studies show that the process-based morphological models, describing the flow field, resulting sediment transport and bottom changes, perform well in the complicated morphological situation in tidal basins. In this study the Western Dutch Wadden Sea, one of the most investigated tidal basins in the world, is used as a case study and a process-based model based on shallow water equation is used to simulate the morphological evolution of the main morphological features form different initial conditions. The result of this process-based model is compared to the well-known empirical equilibrium equations.

STUDY AREA

The Wadden Sea, located at the south-eastern side of the North Sea, consists of 33 tidal inlets system along the approximately 500 km of The Netherlands, Germany and Denmark coastlines.
The barrier islands of these tidal basin systems separate the largest tidal flat area in the world from the North Sea (Elias, 2006). The part of the Wadden Sea which is along The Netherlands coastline (Dutch Wadden Sea) is shown in Figure 1.
The ebb-tidal delta shoals in Dutch Wadden Sea are relatively large while they are associated with relatively narrow and deep channels; the back barrier basins of these tidal inlet systems consist of extensive systems of branching channels, tidal flats and salt marshes. The main area of interest in the current study is the Western part of the Dutch Wadden Sea.

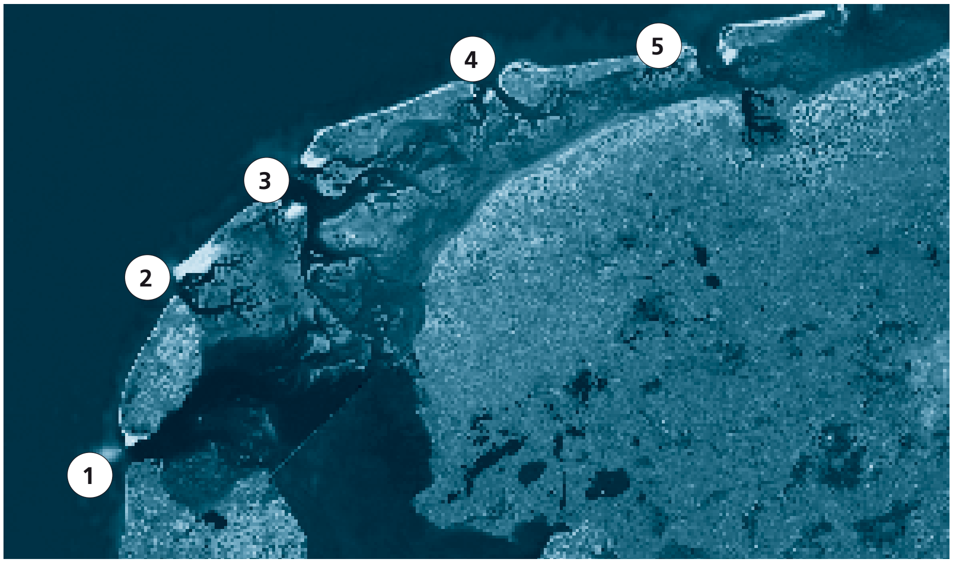

Figure 1. Satellite image of Dutch Wadden Sea: 1) Texel-Marsdiep Basin; 2) Eierlandse Gat; 3) Vlie Gat; 4) Amelander Zeegat; 5) Frisian Gat.

The Wadden Sea is a young geological landscape, which has been subjected to numerous, large- or medium-scale human interventions such as closure of basins, land reclamation, coastal defense structures, sand nourishments and so on. The largest human intervention, which affected the morphology of the Dutch Wadden Sea the most, was the closure of the southern part of the basins, the Zuider Sea. Elias *et al*. (2003) summarise the effects of this construction on hydrodynamic and morphodynamic behaviour of the Wadden Sea.

Several studies have shown that as a result of all the interventions and natural disturbances, the Wadden Sea in its current situation is not in an equilibrium or stable condition; for example, Stive and Eysink (1989) note that the cause of structural large sand losses from the North-Holland coastline is mainly the demand of sand in Wadden Sea tidal basins; Elias (2006) shows that the Marsdiep basin imports a large volume of sediment from the adjacent coast and ebb tidal delta every year (3-5 Mm^3/year). Based on theoretical knowledge and analysis of bathymetry data, a conceptual model for development of the Wadden Sea tidal basins is introduced by Elias *et al*. (2003). This model describes the morphological development of the Wadden Sea in four different stages (see Figure 2).

In stage 1, which is before the human intervention, it is assumed that the whole system of the Wadden Sea is in a dynamic equilibrium. In this stage the characteristics of morphological elements of tidal basins can be described with empirical relations.

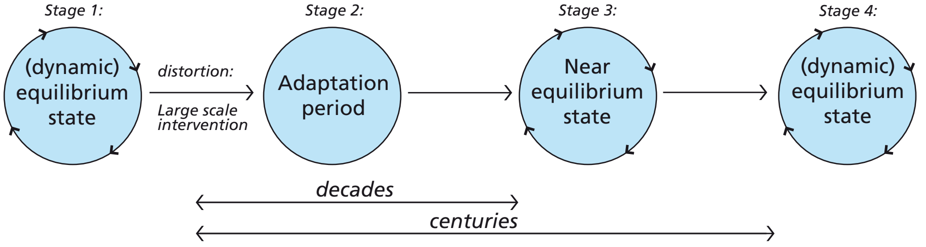

Figure 2. Conceptual model for Wadden Sea tidal basins (Elias *et al*., 2003).

Ali Dastgheib received the IADC Best Paper Award for a young author at PIANC-COPEDEC VII in Dubai, UAE.

IADC AWARD 2008 PRESENTED AT PIANC COPEDEC VII, DUBAI, UAE, FEBRUARY 24-28 2008

An IADC Best Paper Award was presented to Ali Dastgheib, who since October 2007 has been working at UNESCO-IHE as a lecturer in port planning and coastal engineering while doing a PhD in tidal basin morphodynamics. Ali Dastgheib graduated with a BSc in Civil Engineering from Shiraz University, Iran in 1999 and received a MSc (Gold Medalist) in Hydraulic Structures from Amir Kabir University of Technology (Tehran Polytechnic), Iran in 2001. He then worked for Port and Shipping Organization of Iran as a researcher and in late 2002 joined Pouya Tarh Pars Consulting Engineers as a design manager dealing with port planning and design of coastal structures. In April 2007 he graduated with a second MSc in coastal engineering and port development from UNESCO-IHE, Delft, The Netherlands after carrying out his research at WL|Delft Hydraulics.

Each year at selected conferences, the International Association of Dredging Companies grants awards for the best papers written by younger authors. In each case the Conference Paper Committee is asked to recommend a prizewinner whose paper makes a significant contribution to the literature on dredging and related fields.
The purpose of the IADC Award is "to stimulate the promotion of new ideas and encourage younger men and women in the dredging industry". The winner of an IADC Award receives €1000 and a certificate of recognition and the paper may then be published in *Terra et Aqua*.

This dynamic equilibrium was disturbed as a result of the effects of the closure of the Zuider Sea in the 1930s. Stage 2 or the "Adaptation period" is the period of large changes. In this stage the natural behaviour of the tidal basin systems is dominated by the human intervention. Therefore, the empirical relations of equilibrium cannot describe the morphological development of the tidal basin systems. This stage has a time scale in the order of several decades and leads the system to reach a stage of "Near equilibrium state". In this stage (stage 3), the adaptation continues but on a long-term time scale. Finally, after centuries, the whole system will gain its new dynamic equilibrium state, clearly different from its original one (stage 4).

It seems that now 75 years after the closure of the Zuider Sea, the condition of the Wadden Sea is somewhere at the end of stage 2 and beginning of stage 3.

The Dutch Wadden Sea is one of the best-monitored coastal regions in the world. Some depth measurements especially in Marsdiep were recorded in the 16th century. Since 1987 Rijkswaterstaat (The Netherlands Directorate-General of Public Works and Water Management) have frequently measured the bed level in the Wadden Sea. The ebb-tidal deltas are measured every 3 years, while the basins are measured every 6 years. Rijkswaterstaat defined the borders between different basins, and the data for each basin is stored in a 20 x 20 m resolution database called *Vaklodingen*. The available data before that time are less frequent and also less accurate; those data are stored in a 250 x 250 m grid.

MODEL DESCRIPTION AND SETUP

Model description

The model which is used in this study is the 2DH version of the Delft3D model, described in Lesser *et al.* (2004) in detail. Basically the governing equation of the same model is integrated over depth. This model is a finite difference-scheme model which solves the momentum and continuity equations on a curvilinear grid with a robust drying and flooding scheme. For this exploratory study, the simplest possible physics (depth-averaged shallow water equations, simple transport formula) are applied. In this study, the empirical relation of Engelund-Hansen is used for sediment transport.

$$S = S_b + S_s = \frac{0.05\alpha U^5}{\sqrt{g C^3 \Delta^2 D_{50}}}$$

in which

U [m/sec]:	Magnitude of flow velocity
Δ [-]:	Relative density
C [$m^{0.5}$ /sec]:	Chézy friction coefficient
D_{50}[m]:	Median grain size
α [-]:	Calibration coefficient *(O(1))*

The approach for morphological modelling in this study is called the "online approach" (Roelvink, 2006). In this approach the flow, sediment transport and bed-level updating run with the same (small) time steps (Lesser *et al*., 2004; Roelvink, 2006). Since the morphological changes are calculated simultaneously with the other modules, the coupling errors are minimised. But, as described in Lesser *et al*. (2004), because this approach does not consider the difference between the flow and morphological time step, a "morphological

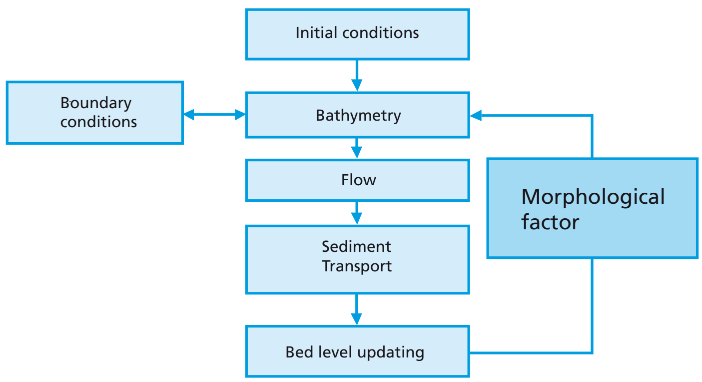

Figure 3. Model flowchart.

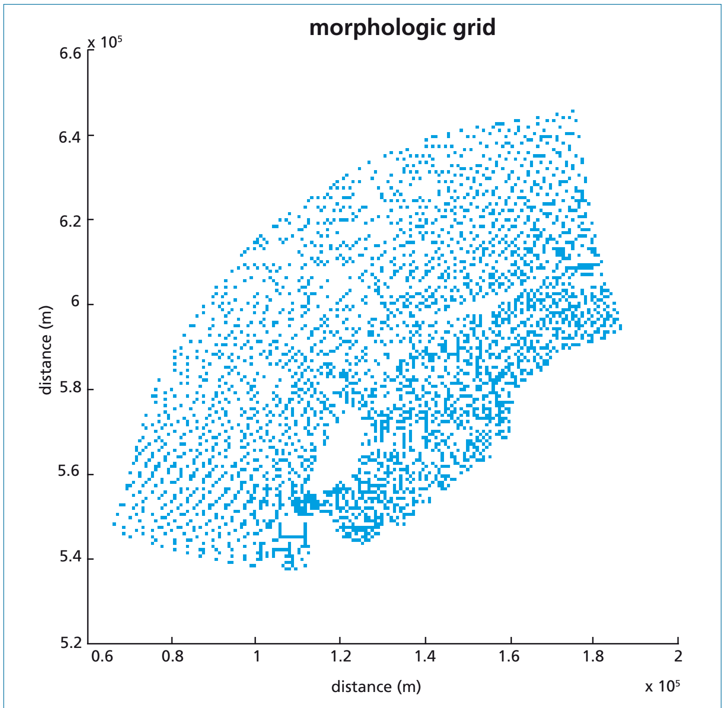

Figure 4.
The computational mesh generated for the study area.

The ZUNO model is based on the "ZUidelijke NOordzee model" from the Dutch Ministry of Public Works and constructed by WL|Delft Hydraulics.
A detailed description of the calibration and validation of the model can be found in Roelvink *et al*. (2001). The ZUNO model has approximately 20,000 computational grids. In the coastal zone the grid sizes are approximately 1.5 km alongshore and 400m cross-shore. The model is forced by the boundary conditions on two open boundaries: The southern boundary situated south of the straight of Dover and the northern boundary between Scotland and the north of Denmark. At these boundaries water levels are specified as astronomic components by tidal constants, amplitudes and phases of tidal constituents. The calibration of the model was based on the comparing the water levels resulting from the model and observations in 47 locations. The ZUNO model is shown in the Figure 5.

factor" to increase the depth changes rate by a constant factor (n) should be applied (Roelvink, 2006). So after a simulation of one tidal cycle in fact the morphological changes in n tidal cycle are modelled. In this model even if a large value is chosen for n, the bed level changes are computed in much smaller time steps than in other approaches.

The drying and wetting areas are also treated in a more straightforward way than, e.g., in the classical tide averaged approaches. Examples of the practical usage of this approach can be found in Lesser *et al*. (2003, 2004). This method has been used for detail event-scale modelling also (Roelvink *et al*., 2003) for a case of breaching of a sand dam or narrow barrier island. In the case of long-term morphological modelling of tidal basins and estuaries, this method is used by Van der Wegen and Roelvink (2008). The flow chart of the model is shown in Figure 3.

Grids

A local model for the Western Dutch Wadden Sea was set up. Although the main area of interest is Marsdiep, Eierlandse Gat and Vlie, to avoid the effect of boundaries, the model is extended to the tidal divide between Amelander Zeegat and Frisian basins. In this study the aim was to set up a model with a reasonable computational time that can simulate long-term (~ 2000 years) morphological changes. The grid that was generated is a compromise between enough resolution in the inlets (at least 10 at the gorge) and having as few cells as possible (~ 7000 cells total) In this study the average spacing between grid lines inside the basins is about 350 m. The grid cells are smaller inside the basins and they are much bigger at the offshore boundary. The grid mesh covers only the area under the high water and the other parts of the barrier islands are excluded from the model. Based on these considerations the mesh shown in Figure 4 was generated for the study area.

Forcing

The main forces acting on a hydro-morphological model for coastal regions are tides, wind, waves and gravitational circulations. However, in this exploratory study the focus was on the effect of tidal forcing and neglects other processes.
In order to determine the boundary conditions of this local model, a calibrated model for the vertical tide in the North Sea, called ZUNO, is used.

Referring to Van de Kreeke and Robaczewska (1993), the spring neap cycle was neglected and the dominant forcing by M2 and over-tides was considered. Therefore the ZUNO model was run with the forcing boundary conditions of M2, M4 and M6 until a periodic solution was reached. During this run the tidal level variations at the boundaries of local model were recorded.

From the results of the ZUNO model, the recorded tidal variations at local model boundaries were analysed and M2, M4 and M6 were extracted for these boundaries. These components were used to form boundary conditions for the local model. The boundaries for the local model consisted of three boundaries: One boundary at the seaside and two other lateral boundaries. The seaside boundary was chosen to be a water level boundary, while the lateral boundaries were Neumann boundaries, where the alongshore water level gradient is prescribed (Roelvink and Walstra, 2004). Figure 6 shows the local model configuration.

Initial bathymetry

The other parameter that can affect the hypothetical equilibrium condition of a tidal basin in a process-based model is the initial bathymetry. In this study besides the real bathymetry, two other types of schematised bathymetries also were modelled. The most important point in choosing the bathymetries is the available sediment in the model. The amount of available sediment in all the bathymetries should be reasonably similar to the available sediment in the real bathymetry. For runs with real bathymetry, the bathymetry data for 1998 were used; these data are projected on the grid using triangular interpolation. This bathymetry is shown in Figure 7.

Flat bathymetry
An other interesting way to model a tidal basin is to use a flat bathymetry inside the basin without any kind of ebb-tidal delta outside the inlet and to let the model show the mechanism of building and changing the ebb-tidal delta outside the basin and channel and shoal patterns inside. So it was decided to make some schematised bathymetries with flat bed inside the Wadden Sea. The following steps were taken to make such a bathymetry:

- Inside the Wadden Sea was assumed to be flat.
- The effects of tidal basins on the seaside such as ebb tidal deltas were omitted.
- The slope of coastal shelf was made uniform.
- The offshore side of the model was assumed to be flat.

A sample of this bathymetry with the same depth scale of Figure 7 is shown in Figure 8.

To determine the depth of the flat Wadden Sea some analysis on the availability and the distribution of the sediment inside the model was carried out and, based on different criteria, different depths are chosen:

- Depth = 3.62: The volume of sediment inside the basins is equal to the real bathymetry plus the available sediment in the ebb-tidal deltas.
- Depth = 4.54: The volume of sediment inside the basins is equal to the real bathymetry.
- Depth = 5.02: The volume of sediment inside the Marsdiep basin is equal to the real bathymetry plus the available sediment in its own ebb-tidal deltas.

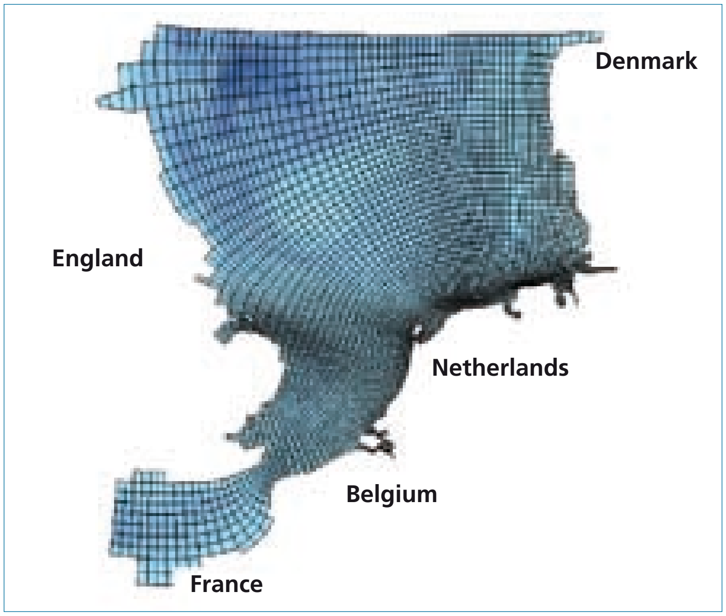

Figure 5. ZUNO (Zuidelijke Noordzee) model grid lines from the Dutch Ministry of Public Works as constructed by WL| Delft Hydraulics.

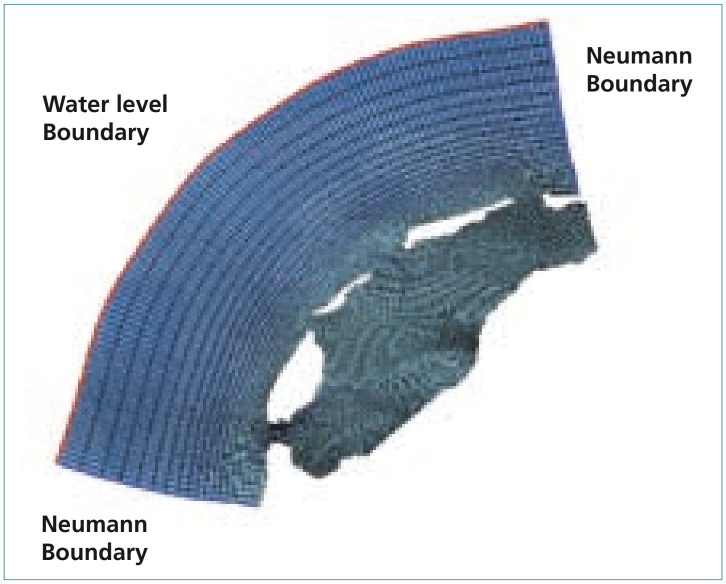

Figure 6. Local model boundaries: The seaside boundary is a water level boundary, while the lateral boundaries are Neumann boundaries.

Sloping bathymetry
During the attempts to model the morphological evolution of the tidal basins with process- based models in recent studies, sometimes a sloping bathymetry toward the inlet is used as the initial bathymetry (e.g. Wang *et al*., 1995; Marciano *et al*., 2005). In this study also, a schematised sloping bathymetry is made for the Wadden Sea. The procedure of this schematisation is as follows:

- The tidal basins are separated based on the borders defined by Rijkswaterstaat in *Vaklodingen* database.
- In each basin the depth of each grid point is plotted versus the distance from the middle point of the inlet.
- The depth of grid points are classified and averaged according to the distance from the inlet in 2.5 km groups.
- Using the average values, the depth of each point is defined as a function of the distance from the inlet.
- The available sediment of each ebb-tidal delta is distributed uniformly inside the corresponding basin.
- The slope of the coastal shelf is made uniform.
- The offshore side of the model is assumed to be flat.

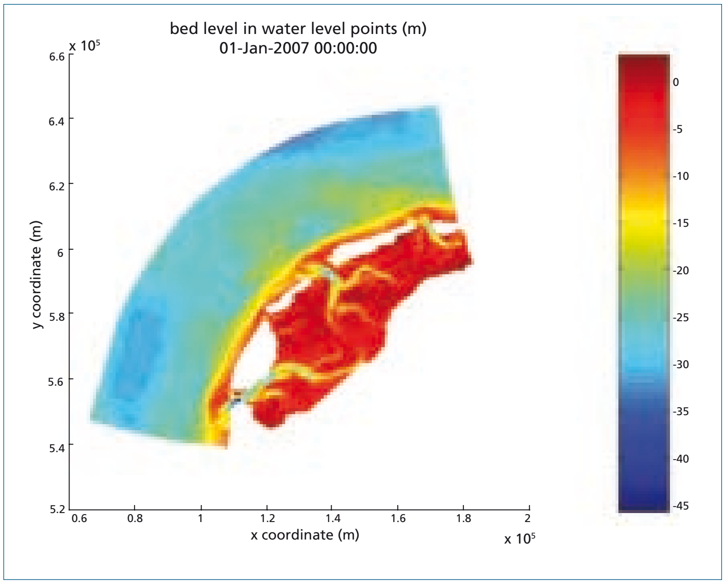

Figure 7. Bathymetry of 1998 projected on the grids.

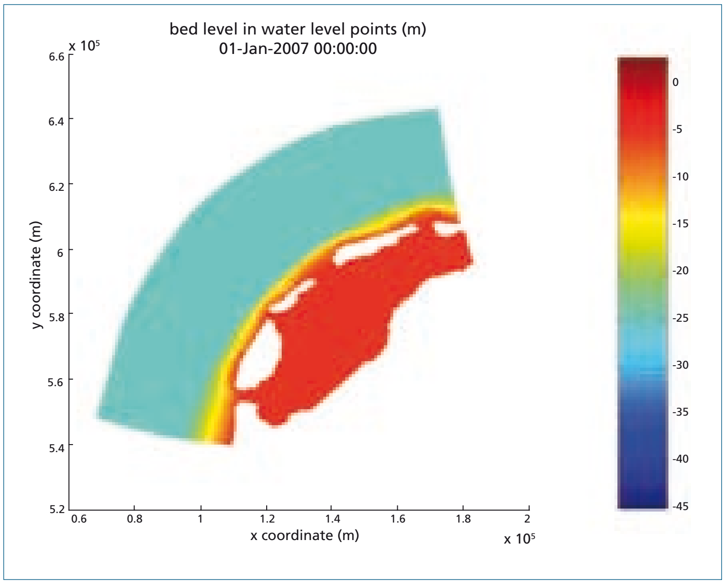

Figure 8. A sample of schematised bathymetry with flat bed level inside the Wadden Sea.

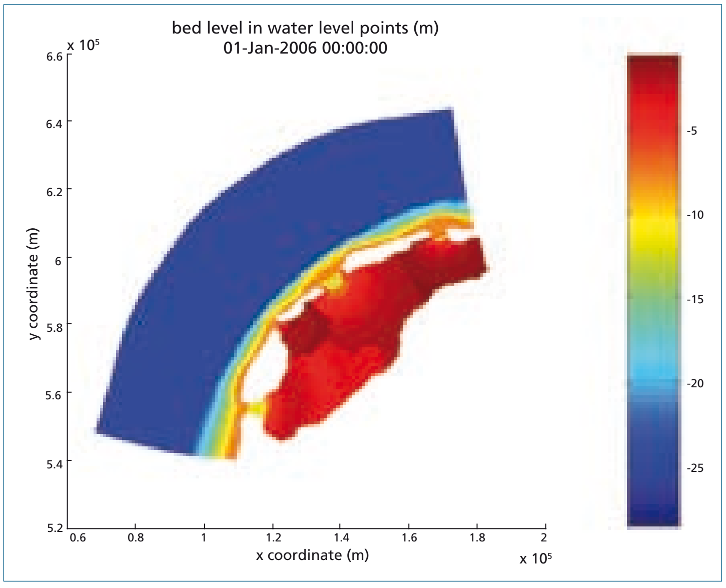

Figure 9. Simulation with sloping bathymetry.

Different runs

Considering different initial bathymetry conditions, 5 different simulations were carried out, 3 with flat bathymetry with the depths of 3.62, 4.54 and 5.02 m, one with sloping bathymetry (Figure 9) and finally one with the real bathymetry. The bed material in all cases consists of uniform sand with D_{50} = 200 µm. For bottom roughness a Chezy value of 65 m ½/sec is used.

To choose the morphological factor, it is referred to the Van der Wegen and Roelvink *(*2008*)* study. This study shows that in the long-term simulations using high values of morphological factor (up to 400), the main morphological characteristics of the basin are maintained. In this study the morphological factor of 300 is used and by running the model for 7 years of hydro-dynamic time, 2100 years of morphological time is simulated.

RESULTS AND DISCUSSION

Relative inter-tidal flat area

The inter-tidal flat area (flat area) is defined as the area of the basin between MLW and MHW. In the literature there are some suggestions for the flat area in equilibrium condition. De Vriend *et al*. (1989) showed a general relation between the flat area and the total area of the basin:

$$A_f = A_b - \beta \frac{2a}{h_c} A_b^{\frac{2}{3}}$$

in which

A_f [m²]	Flat Area at MLW
A_b [m²]	Total Area of basin
β [-]	Constant
h_c [-]	Characteristic channel depth
a [m]	Tidal amplitude

Renger and Partenscky (1974) worked on the same form of relation for inlets in the German Bight. Later Eysink (1991) re-wrote their relation as:

$$\frac{A_f}{A_b} = 1 - 0.025 \cdot A_b^{0.5}$$

A_f [Km²]	Flat Area at MLW
A_b [Km²]	Total Area of basin

Eysink (1991) uses the same form of relation (A_f/A_b as a function of A_b) to analyse the available data in tidal inlets and estuaries in The Netherlands. He summarised his result as shown in Figure 10.

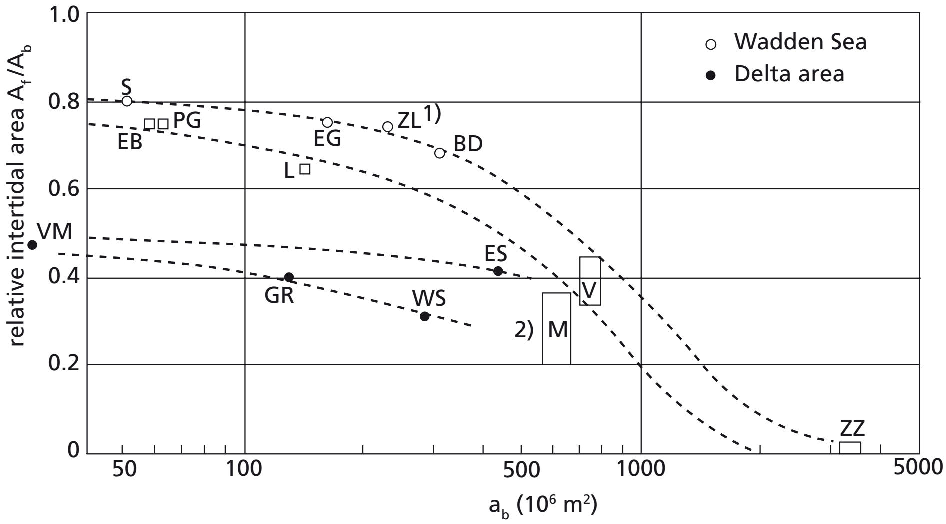

Figure 10. Relative flat area in Dutch Wadden Sea and Delta Area (Eysink, 1991).

The result of the model for A_f/A_b is plotted against the Renger and Partenscky (1974) relation and suggested graph for Wadden Sea basins by Eysink (1991) in Figures 11 and 12 during 2100 years of modelling. Figure 11 shows the results for the simulations with schematised initial bathymetry and Figure 12 shows the results for the simulations with real initial bathymetries for all the basins. This shows that regardless of the initial bathymetry the A_f/A_b tends to a stability near the range which Eysink (1991) suggested. But the final value of A_f/A_b in Marsdiep and Vlie basins is far from the value suggested by Renger and Partenscky (1974). This is mainly because of the size of the basin. The relation of Renger and Partenscky (1974) is based on the data of smaller basins than Vlie or Marsdiep.

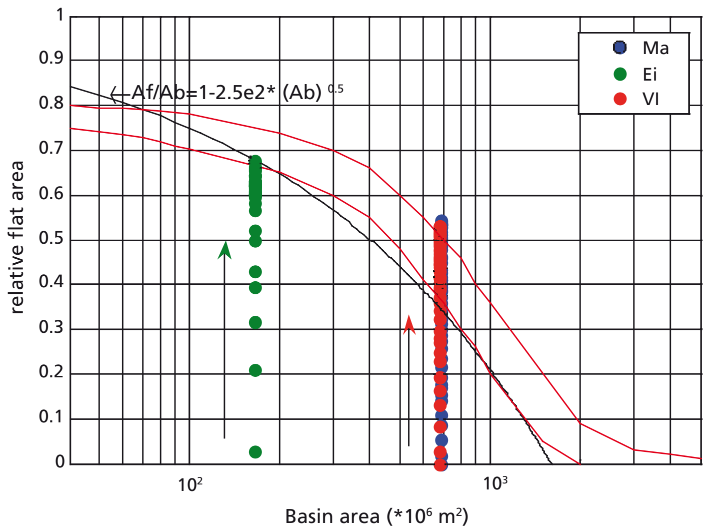

Figure 11. Development of relative flat area of basins during the simulation plotted on Eysink (1991) graph for Wadden Sea, for simulations with schematised initial bathymetry.

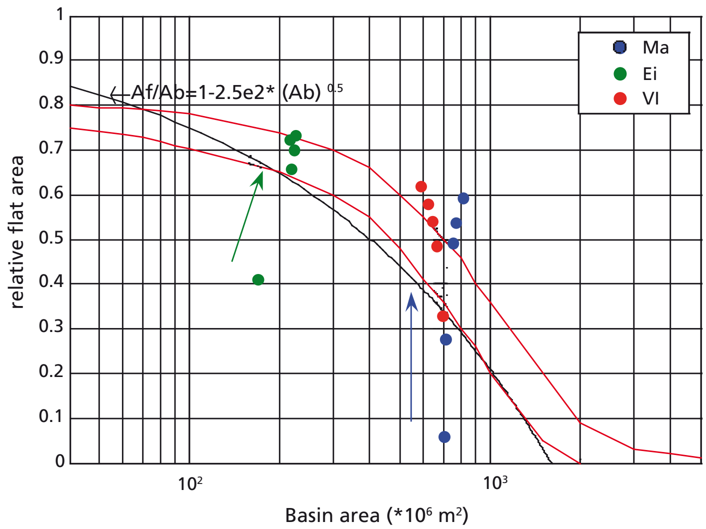

Figure 12. Development of relative flat area of basins during the simulation plotted on Eysink (1991) graph for Wadden Sea, for simulations with real initial bathymetry.

Height of flats

Eysink (1990) claims that one of the first parameters which aims for equilibrium, in relatively short time, is the height of flats which is related to the tidal amplitude. Height of flats, which is usually used in the equilibrium situation, is defined as the average height of the flat areas calculated by the following relation:

$$h_f = \frac{V_f}{A_f}$$

in which

A_f [m²]	Flat Area at MLW
V_f [m²]	Volume of flats i.e. volume of sediment in the region between LW and HW
h_f [-]	Height of flats

To check this hypothesis in the results of process-based modelling, the development of flats from different initial bathymetries in different basins are shown in the Figures 13, 14, and 15. The same results for all three basins simulations from real initial bathymetry are presented in Figure 16.

Figures 13 to16 show that flat characteristics tend toward some equilibrium values but the flat height is not adjusted as fast as Eysink (1990) claims. In addition, it is shown that these equilibrium values are also dependent on the initial condition. This dependency is less pronounced in flat height but in volume of flats obviously the initial sloping bathymetry developed more flat volume and also it developed more flat area. Therefore the longitudinal distribution of the sediment in initial bathymetry also affects the results for flat characteristics. The final height of flats in all the simulations with flat initial bathymetries are almost the same but far from the equilibrium value suggested by Eysink (1990), which is around 0.4 m. The main reason for this difference is the lack of wave effect in the basin, which leads the channels to be deeper and the flats to be higher.

Friedrichs and Aubrey graph

Friedrichs and Aubrey (1988) use a 1-D numerical model to study the influence of geometry and bathymetry of short, friction-dominated and well-mixed estuaries. They suggest that two non-dimensional parameters can be used to characterise the tidal basins. These parameters are responsible for different types of asymmetries.

The first one is a/h, tidal amplitude over the depth of the channel with respect to MSL, which shows the relative shallowness of the estuary. The second parameter is Vs/Vc

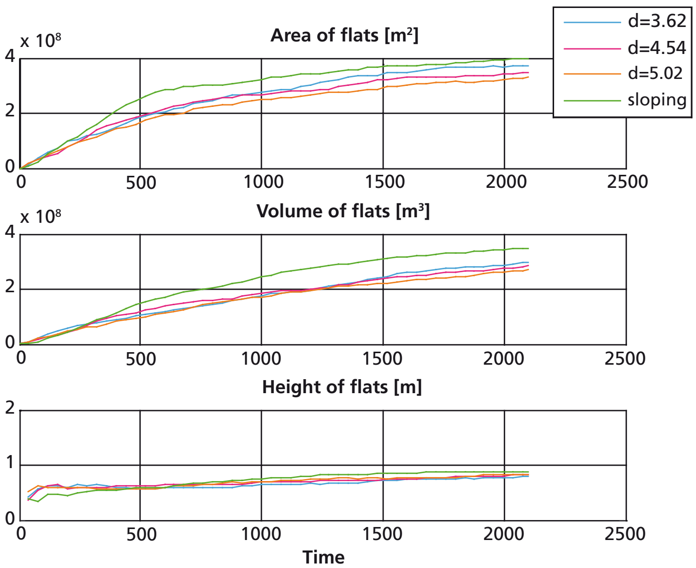

Figure 13. Development of flat characteristics in Marsdiep from different initial conditions.

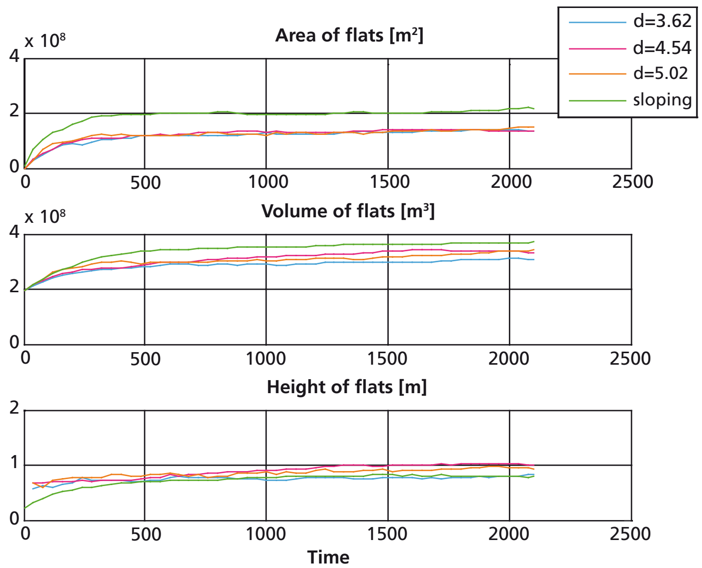

Figure 14. Development of flat characteristics in Eirlandse Gat from different initial conditions.

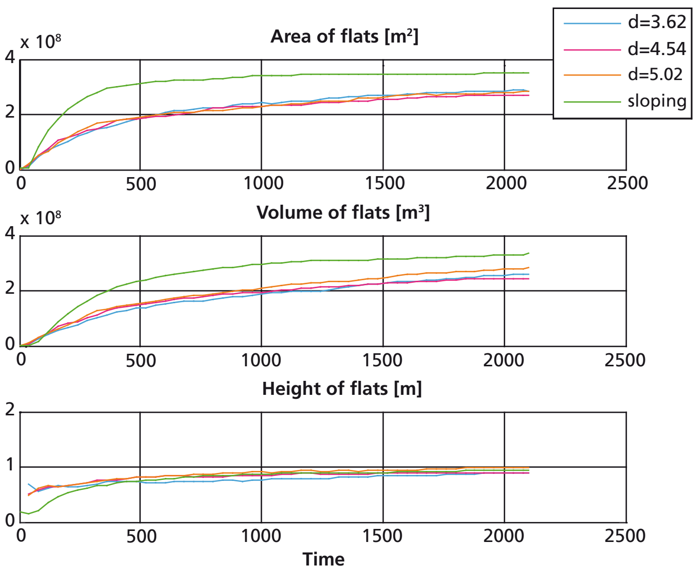

Figure 15. Development of flat characteristics in Vlie from different initial conditions.

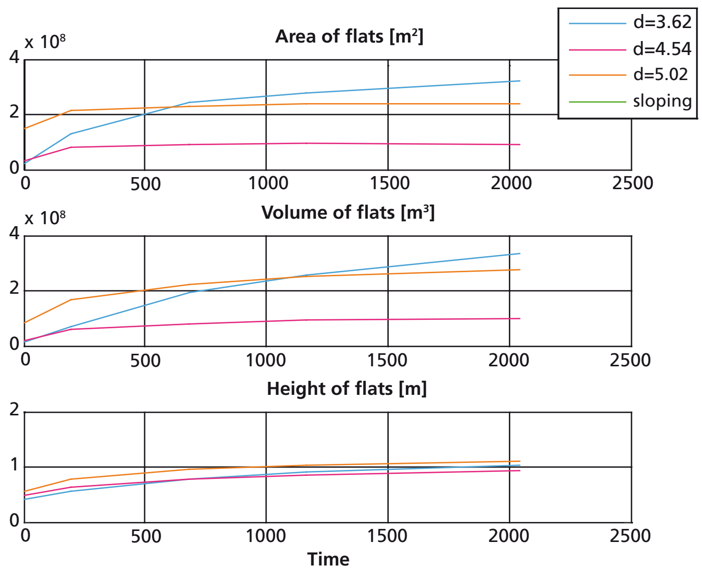

Figure 16. Development of flat parameters for different basins during the simulations with real initial bathymetry.

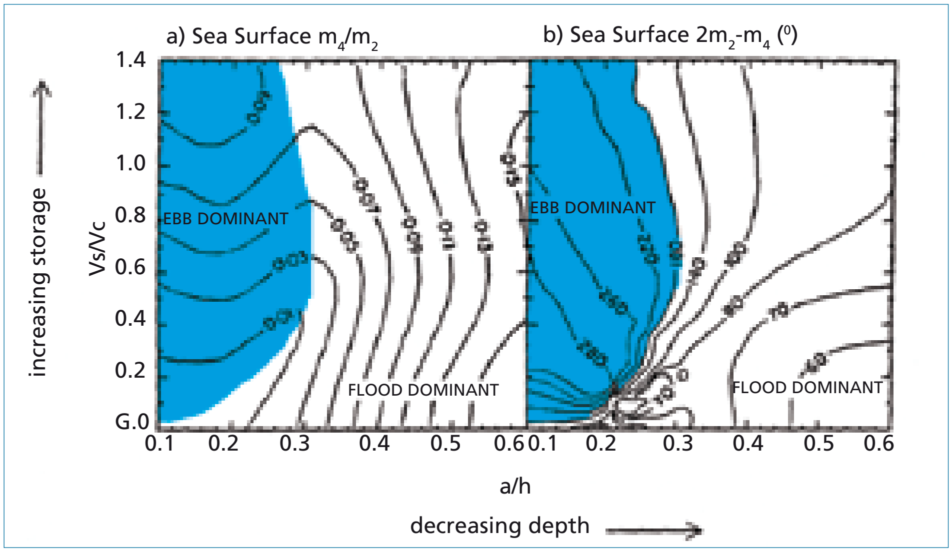

Figure 17. Diagram based on Friedrischs and Aubrey models (Speer *et al*., 1991).

where Vs is the Volume of inter-tidal storage and Vc is the channel volume. Speer *et al*. (1991) translated the Friedrichs and Aubrey (1988) results to a graph (Figure 17) which distinguishes the flood or ebb-dominant tidal basins. It is suggested that the border between these two regions can represent the equilibrium condition of the basins (Friedrichs and Aubrey, 1988).

The parameters for the Friedrichs and Aubrey graph are calculated from the result of the model for different basins. These results are shown in Figures 18-21. In all the simulations and all the basins the development of the basin according to this graph is toward the ebb and flood dominant separation line; this development is faster in early years of modelling than at the end. When the basin condition is near that line, it begins to scatter and develop almost parallel with the line. This is shown in the case of Marsdiep for the simulation from initial real bathymetry, Vlie for the simulation with sloping and real initial bathymetry and Eierlandse Gat in all the simulations.

This line in the Friedrichs and Aubrey graph is suggested to be some indicator of equilibrium, so it can be concluded that all the basins from all initial conditions are going toward this equilibrium.

The difference between the value of *a*/h in different simulations is a result of different initial depths (h) rather than the difference in tidal amplitude (a).

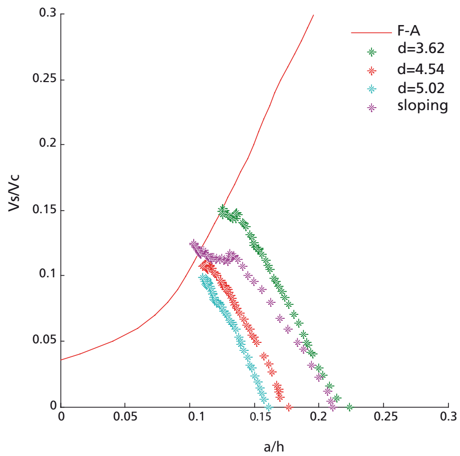

Figure 18. The Friedrichs and Aubrey diagram for Marsdiep in the simulations with different initial condition.

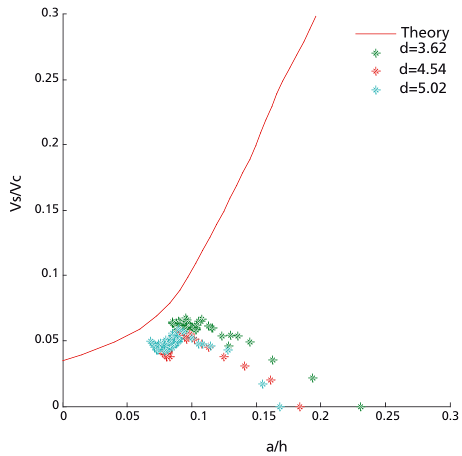

Figure 19. The Friedrichs and Aubrey diagram for Eierlandse Gat in the simulations with different initial condition.

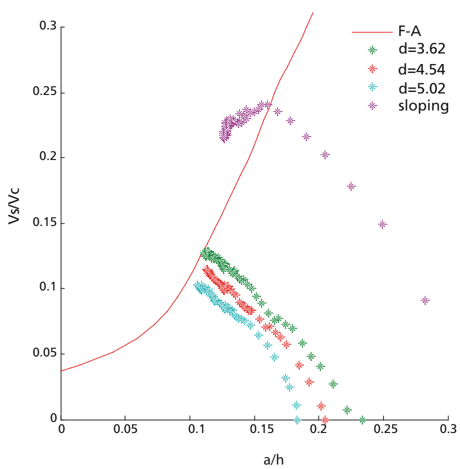

Figure 20. The Friedrichs and Aubrey diagram for Vlie in the simulations with different initial condition.

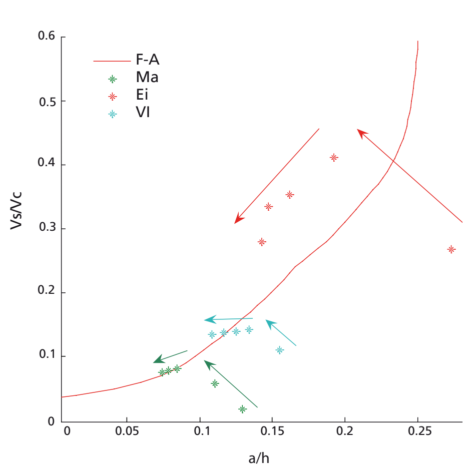

Figure 21. The Friedrichs and Aubrey diagram for the basins in the simulations with real initial bathymetry.

CONCLUSION

The process-based model which is used in this study does not simulate one single *mega-scale* stable (equilibrium) condition in the Western Wadden Sea for all initial conditions for the *duration of the simulations*. But with each initial condition in many aspects such as some basic characteristics of tidal basins, a *mega-scale* stable (equilibrium) condition is simulated, which is dependent not only on the given boundary condition but also on the initial condition.

In this study it is shown that the results of this process-based model followed the empirical equilibrium equations for flat characteristics and relative flat area qualitatively, while the results are in very good agreement with the equilibrium suggested based on the Friedrichs and Aubrey graph (1988) in the case of Marsdiep Basin.

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NICOLA CLAY, NICK BRAY AND PAUL HESK

MAXIMISING BENEFICIAL REUSE THROUGH THE USE OF A NOVEL DREDGING CONTRACT

ABSTRACT

The Port of London Authority (PLA) has a statutory responsibility for maintaining safe navigation within its port limits, which includes the dynamic sandbanks of the Thames Estuary. The potential long-term instability of one of the southern access routes into the port led PLA to consider the provision of improved access by the navigational dredging of Princes Channel. In accordance with Government guidance and international requirements, the PLA is committed to using dredged material in a beneficial manner wherever possible.

By working in partnership with the dredging industry, the PLA sought sustainable options for using the dredged sediments, such as infrastructure development, habitat creation, coastal defences and recycling within the estuary system. To facilitate this approach, the PLA employed Dredging Research Ltd to develop a Contract incentivising dredging contractors to explore and acquire opportunities for the beneficial reuse of this material, but without commitment if no such needs existed.

The Rochester Riverside Development, part of the Government promoted and funded Thames Gateway Regeneration, is improving a brownfield site to a standard where commercial, residential and leisure development can be instigated. A key element of these enabling works was the improvement of the site's flood defences, this being partly achieved through land-raising. Van Oord UK Ltd was awarded the Contract for supplying 340,000 m^3 of sand fill, using material from Princes Channel in accordance with the PLA's Pro-Forma Contract. The seemingly ideal use of this material was not straightforward; the designation of dredgings as waste resulted in protracted discussions between the PLA/ Van Oord partnership and the regulatory authorities before the works could commence. The successful completion, in August 2006, demonstrates that estuary dredgings can legitimately be used within the construction sector providing cost savings and environmental benefits when compared to the use of virgin aggregates.

This article appeared as a paper in the Proceedings of the CEDA Dredging Days, Rotterdam, in November 2007 and is reprinted here in a slightly adapted form with permission.

Above, Under the provisions of a unique dredging contract, sand material dredged from Princes Channel was imported by the TSHD Ostsee to improve a brownfield site at the Rochester Riverside.

INTRODUCTION

The Port of London Authority (PLA) is responsible for ensuring the safety of navigation on the River Thames whilst protecting the diverse environment of an estuary which includes many National, European and International conservation designations. After having successfully completed Phase 1 of their project to deepen the Princes Channel (the southerly access into the Port of London) in 2003, the PLA decided to investigate ways in which these works could be completed at low cost, with a minimal impact on the existing environment, and simultaneously in which maximum opportunities could be ensured for the dredged material to be reused beneficially rather than being deposited at sea.

This article describes how the PLA worked in partnership with the dredging industry to identify and develop a form of Contract that would incentivise Contractors to acquire opportunities for the beneficial reuse of the material to be dredged from Princes Channel. The success of this approach was demonstrated in the autumn of 2005 when a Contract for the Preparatory Engineering Works of the Rochester Riverside Development was awarded by Medway Council to an Edmund Nuttall/Van Oord Joint Venture. Included within the scope of the project was a requirement to improve the site's flood defences; this would be achieved by a combination of new or refurbished river walls and the raising of the land by approximately 1 metre. A key factor in the Council awarding the Project to this Joint Venture was Van Oord UK Ltd's proposal to undertake the land-raising by beneficially reusing the Princes Channel material. Whilst keen to support the beneficial use of this material, the Council also benefited financially from this proposal as it provided a cheaper source of fill than alternative sources such as the Outer Thames Estuary's Crown Estates Licensed Dredging Areas.

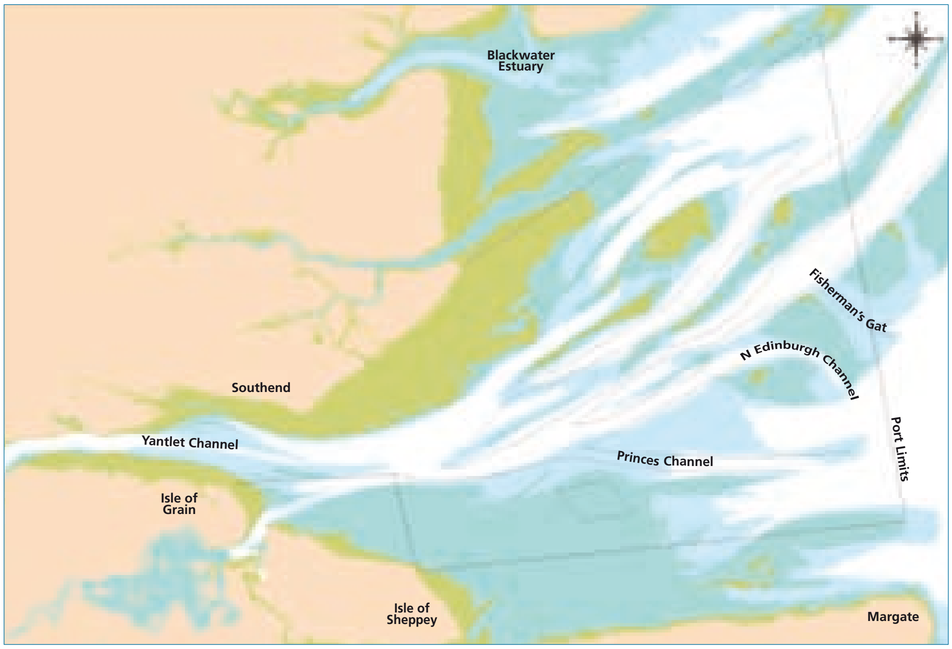

Figure 1. Location of the Princes Channel, Outer Thames Estuary.

THE PLA REQUIREMENT FOR THE DREDGING OF PRINCES CHANNEL

The PLA is a self-financing public sector trust which manages a range of responsibilities along the tidal River Thames.
Its operations cover 95 miles of the River Thames, which, in broad terms, can be broken down into the following three main sections:

- Teddington to Putney: principally recreational uses, including rowing and sailing and some occasional, special-project cargoes.
- Putney to the Thames Barrier: mainly tourist and commuter passenger vessels with some smaller boats/barges, predominantly carrying aggregates and wastes.
- Thames Barrier to the sea: the main centre for the commercial Port operations, handling the larger sea-going vessels.

The PLA's primary responsibilities are the safety of navigation and protection of the environment of the River Thames, an area which is recognised for its environmental importance, but with differing characteristics along its length. The wide expanses of the mudflats in the lower Thames are noted for their bird interest, with National, European and International conservation designations including Sites of Special Scientific Interest (SSSI), Special Protection Areas (SPA), Special Areas of Conservation (SAC) and Ramsar sites.

Project overview

For many years the southerly access into the Port of London has been provided by the North Edinburgh Channel, Princes Channel and, more recently, the Fisherman's Gat (see Figure 1). However the seabed in these areas has been in a state of constant flux, with water depths and channel centrelines continually changing. Historically, there has always been a southern access route into the main entrance channel of the Thames with a minimum depth in the region of 7 to 8 m. Whilst this is currently provided by the Fisherman's Gat, the combination of the instability of this access together with the necessity for vessels to cross busy shipping lanes when entering from this point has required the PLA to consider alternative routes including the Princes Channel.

In order to comply with the recommendations derived from a Navigational Risk Assessment that studied the above factors, the PLA committed to deepen a section of the Princes Channel to –8.0 m CD.
The deepening project was planned to be undertaken in two discrete phases. The first was a trial that was completed in the summer of 2003. The purpose of this trial was to deepen a narrow part of the western section of the Channel to approximately –7.0 m CD (marginally below the existing regime depth) and then study its stability and rate of infill. The subsequent intensive regime of bathymetric survey demonstrated that a deepened channel was sustainable and confirmed the PLA's intention to complete the project and provide an alternative stable access from the South.

Phase 2 of the deepening project would therefore complete the development of the Princes Channel to provide a 300 m channel with maintenance dredging zones of 75 m to either side to facilitate uninterrupted passage for shipping. This would require approximately 2,500,000 m^3 of dredging.

In line with Government Regulations, and in accordance with the London Convention and OSPAR requirements, the 350,000 m^3 of dredged material from the first phase of the Project was used beneficially in a

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NICK BRAY
is a director and founder of Dredging Research Ltd, which is now part of HR Wallingford. He has 40 years of experience in dredging and reclamation and maritime civil engineering. He has written numerous technical articles and is editor of the new IADC/CEDA book, "Environmental Aspects of Dredging". He has developed several computer-based dredging production and cost-estimating models and also has experience in the field of underwater rock removal by drilling, blasting and dredging. He has provided expert opinions on a variety of dredging disputes, acted as a mediator as well as an expert witness in various arbitration proceedings.

PAUL HESK
is Contracts and Business Development Manager at Van Oord UK Ltd.
His primary responsibilities include identifying and securing projects in the UK and Ireland. He acted as tender coordinator for the Rochester Riverside Project and led the liaison with the PLA regarding opportunities for the beneficial reuse of material dredged from Princes Channel. He is also responsible for Quality, Health, Safety and Environmental Management in the UK and Ireland and coordinates all of Van Oord's works under their second generation, four-year Framework with the Environment Agency.

construction scheme on the East Coast.
The PLA decided that they should continue to seek beneficial uses for the material from Phase 2 of the Project, for example, land reclamation, maritime construction, coastal protection and environmental enhancements. However, in recognising the difficulties in coordinating the requirements and timescales of the various projects they were aware might require large quantities of sand fill, they realised this aim might not be fully achievable. Therefore a fall-back strategy of placing dredged material in a marine disposal site was developed.
The designation of a new location within the dynamic regime of the estuary, the North Edinburgh Channel, was suggested.

Environmental assessment

The general position around the coast of England and Wales is that dredging undertaken for navigational purposes is regulated by the Department for Transport (DfT) (via the Marine Consents and Environmental Unit) under Section 34 of the Coast Protection Act (CPA). However, within the PLA's Port limits the situation is different as they have the powers to both license and undertake dredging operations. These powers have been given to the PLA under successive Port of London Authority Acts (most recently PoLA 1968, sections 60 and 73). The CPA recognises these powers, Section 35 of the Act exempting dredging on the Thames from the requirements for consent.

Whilst, therefore, exempted from the requirements of the CPA, Section 48A of the Harbours Act requires the PLA to "have regard to" a number of environmental issues whilst fulfilling its functions such as the licensing of dredging operations. For example the PLA must pay regard to:

a) the conservation of the natural beauty of the countryside and of flora, fauna and geological or physiographical features of special interest;
b) the desirability of preserving for the public any freedom of access to places of natural beauty;
c) the desirability of maintaining the availability to the public of any facility for visiting or inspecting any building, site or object of archaeological, architectural or historic interest.

In addition, as a public body, the PLA must comply with the following environmental legislative requirements when licensing or undertaking dredging operations:

- Conservation (Natural Habitats &c.) Regulations 1994;
- Countryside and Rights of Way Act 2000;
- Environmental Impact Assessment (EIA) Directive (97/11/EC);
- Shellfish Waters Directive (79/923/EEC); and
- Surface Waters (Dangerous Substances) (Classification) Regulations 1997 and 1998.

Therefore the PLA undertook an environmental assessment of the likely affects of the Phase 2 Dredging operations which considered the following:

- Coastal Processes
- Sediment Quality
- Water Quality
- Marine Biology
- Natural Fisheries
- Birds
- Designated Conservation Sites
- Marine Archaeology
- Commercial Fishing
- Navigation
- Recreational Activity
- Other Seabed Uses
- In-Combination Effects

The conclusions of this assessment were as follows:

- Whilst the dredging operation would cause localised changes to the hydrodynamic properties of the Princes Channel, areas outside of this would be unaffected.
- The seabed sediment was considered chemically clean and therefore suitable for either beneficially reuse or disposal at sea.
- Water quality was unlikely to be impacted owing to the low levels of contaminant, organic material and fines in the dredged sand.
- The marine biology within the dredging area was impoverished and no species of conservation importance were identified.
- Whilst the Thames estuary is important to fisheries as both spawning and nursery areas for a variety of fish, there was no evidence to suggest that the dredge site

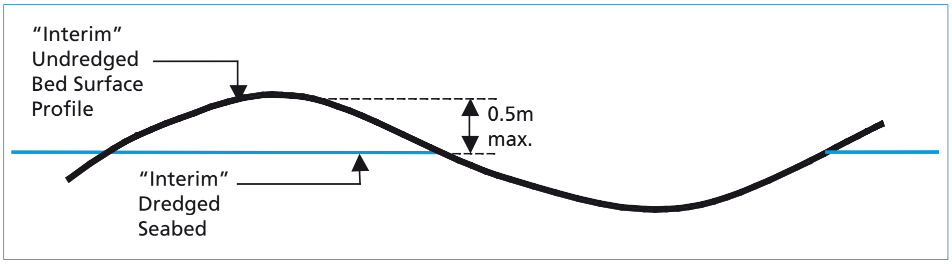

Figure 2. Dredging Tolerance during the deepening process.

was of any specific importance.
- The presence of dredging vessels in an already busy shipping channel was unlikely to affect bird activity that is geographically widespread and variable from year to year.
- The nearest designated conservation sites were over 20 km from the dredging area; no impacts on these were therefore predicted.
- An archaeological assessment found evidence of a historically important wreck within the Princes Channel. This was investigated further and subsequently lifted in accordance with a mitigation strategy agreed with English Heritage.
- The local fishing community indicated that the Princes Channel was of limited importance for fishing, therefore negligible impacts were expected.
- The dredging operation could be effectively managed by the Harbour Master to avoid any interference with the interests of commercial and recreational navigation.
- Whilst a number of other infrastructure projects were either ongoing or planned for the area, no interference was predicted.
- Geographical separation limited the potential for any in-combination effects.

In conclusion the PLA concluded that the Phase 2 dredging project was unlikely to have any significant effects on the natural environment in the vicinity of the Princes Channel.

The loss of the limited biological community was considered to be only a temporary effect as recovery would commence upon completion of the dredging operation.
The next step was to work in partnership with the dredging industry to find viable solutions.

THE DREDGING CONTRACT

Having demonstrated that Phase 2 of the Princes Channel Deepening Project was unlikely to have significant environmental effects, the PLA consulted with the dredging industry to both seek their views on the options available for the sustainable utilisation of the dredged material and the type of Contract required to promote its use to the mutual benefit of the End User, the Contractor and themselves. To facilitate this approach, PLA employed Dredging Research Ltd to develop a Contract incentivising dredging contractors to explore and acquire opportunities for the beneficial reuse of this material, but without commitment if no such needs existed.

The Requirements

The essence of the contract was that it should provide a win-win outcome for both the PLA and the dredging contractors.
The PLA needed the dredging to be carried out in a specific way in order to gain the benefits of the dredging in terms of navigational improvement. The dredging contractor needed the reassurance of being able to take the requisite volume of material for its project, at a time to suit its programme and for a known cost.

In more detailed terms the PLA required:
- A way of ensuring that the full width of the channel was dredged and that the shallowest zones were lowered gradually to give a continuously improving navigable depth;
- A method of directing the final dredging operations to ensure that no parts of the channel contained high spots;
- A contract form that encouraged use of the material rather than disposal;
- A contract form that would encourage the dredging contractors to use the Princes Channel material rather than other competing sources of fill; and
- A contract that would be reasonably easy to administer.

The dredging contractors were understood to require:
- A sand source of a quality that could be used for future reclamation projects;
- A known cost (i.e. material cost plus royalty) of obtaining this material from Princes Channel;
- An arrangement that permitted use of the Princes Channel sand but that did not tie them exclusively to using this sand; and
- An assurance that sufficient material would be available, but that this material did not have to be taken if, for instance the quality became too poor or the reclamation contract was curtailed.

The Solution

The solution adopted was to develop a Pro-Forma Contract that all interested dredging contractors could sign up to in principle. This ensured a level playing field and gave all parties the confidence that all potential users were being treated equally. The Pro-Forma Contract was based on the FIDIC Conditions of Contract for Dredging and Reclamation Works and contained the following provisions for any contractor who had signed up to the pro-forma:

a) Within reason, sand could be dredged from the channel by a contractor at a production rate to suit any intended reclamation project and its programme.
b) The contractor was not obliged to use the exact amount of sand specified in the contract, but could excavate any volume that was convenient for the given purposes. In effect the contractor had no obligation to dredge at all. Dredging was entirely at the contractor's discretion.

c) If the contractor carried out dredging, there was an obligation to dredge the channel in relatively thin layers, to maintain a steady increase in navigable depth (see Figure 2). In practice, the specification stated that the deepest part of the dredged footprint should be no greater than 500 mm deeper than the shallowest part of this footprint.
d) Contractors would have to take account of the fact that more than one company might be dredging at any one time. In such cases, the channel would be split longitudinally into strips of equal width and each contractor would be allocated a strip in which to dredge.
e) Whilst the PLA would neither make nor receive payment for any sand dredged, the contractor would have to pay the Crown Estate a royalty for the removal of the seabed.

The Incentive

As a means of encouraging the contractors to favour the Princes Channel as a suitable source, rather than obtaining the required sand from a licensed area offshore, an incentive was built into the contract. This incentive was that:
"For every 100 m^3 of sand removed, in hopper, from the site and reused in a reclamation project, the contractor would be paid to dredge another 25 m^3, in hopper, and this material would be taken to a licensed placement site in the North Edinburgh channel".

The incentive dredging was to be carried out at the end of the contract, when the total volume of reclamation dredging was known. The contractor was not obliged to carry out all, or any, of the incentive dredging if it did not suit.

The advantage of the incentive dredging was threefold:

- It increased the size of the project for the contractor by 20%.
- It increased the amount of channel dredging for the PLA by at least 20%.
- It permitted the PLA to target the dredging in the final period to removing high spots or the toe of slopes, to gain the maximum navigational advantage from the works carried out.

In addition to these advantages, the movement of sand from Princes to the North Edinburgh Channel, where it was carefully placed in the deeper water according to a prescribed grid system, had the effect of keeping the sand in the same sedimentary system.

Other aspects of the Contract

Apart from the provisions of the Contract described above, there were a number of others relating to environmental effects, both around the dredging site and at the placement site in the North Edinburgh channel. These included:

- The responsibility of the contractor to monitor a number of water quality parameters at a designated location near the dredging site, including temperature, salinity, current speed and suspended sediment levels;
- Bathymetric surveying at the dredging and placement sites on a prescribed frequency; and
- Arrangements for dealing with obstructions and patches of sub-soil that were clearly not classified as sands and gravels, such as stiff clay.

The operation of the Contract

The forerunner of the contract operated successfully in 2003, when some 350,000 m^3 of sand were dredged from the channel and taken to Felixstowe for reclamation. Subsequently, the incentive arrangements were added and the full Pro-Forma was issued in December 2004. Since then, the Rochester project has been carried out using the contract and approximately 340,000 m^3 of sand was taken to reclamation and another 85,000 m^3 to the North Edinburgh channel (see below).

A review of the workings of the contract has demonstrated that it has worked well. Improvements for the future might include:

- nominating the sub-contractor that executes the environmental monitoring to ensure that the data collected is of a high standard and presented in a consistent manner, and
- allowing a little more flexibility in the timing of the incentive dredging.

THE ROCHESTER RIVERSIDE DEVELOPMENT

The aim of the Rochester Riverside Development, a 30 hectare site on the River Medway (see Figure 3) and part of the UK Government promoted and funded Thames Gateway Regeneration, is to create a sustainable development of a mixed-use community of around 1800 homes with a hotel, primary school and other community facilities and employment opportunities. As part of this development an Edmund Nuttall/Van Oord Joint Venture was awarded a Preparatory Engineering Works Contract by Medway Council in autumn 2005 which included the following scope:

- Land-raising (to provide improved flood defences);
- Contamination Remediation; and
- Inter-Tidal Habitat Creation.

A key element of the Contract was the improvement of the site's flood defences, to be achieved by a combination of approximately 2.5 km of new sheet-piled or refurbished river walls and the average raising of the land by approximately 1 m. The improvement of the flood defences to the standards required in the UK Govern-

Table I. Responsibilities for contracting parties.

Van Oord UK Ltd	Edmund Nuttall Ltd
Importation of sand fill for Land Raising Material into Reception Lagoons	Onward movement of sand fill from Reception Lagoons and subsequent placement into the Works
Installation of Vertical Drains to accelerate consolidation of the underlying strata	Construction of new and refurbishment of existing River Walls
	Remediation of Contaminated Materials

ment's Department for Environment, Food and Rural Affairs (Defra) Planning Policy Statement 25: Development and Flood Risk (PPS25) was critical in securing Environment Agency approval for the scheme.

A key part of the Edmund Nuttall/Van Oord Joint Venture's success in being awarded this Contract had been their positive promotion to the Client and their Consultants of the benefits, both economically and environmentally, of using land-raising material obtained from the navigational dredging of the Princes Channel.

In bidding for and subsequently being awarded this Contract the parties within the Joint Venture had agreed to the split of responsibilities for the Works shown in Table I.

Included in Van Oord's responsibilities were the negotiations with the appropriate Regulatory Authorities in order to gain consent for the dredging and importation of the Princes Channel material.

Regulatory approval

Immediately following Contract Award, Van Oord commenced negotiations with both the PLA and the Environment Agency regarding the dredging and subsequent reuse of the Princes Channel material for the Project.

The negotiations with the PLA were straightforward, the principles of the agreement to dredge having been agreed in advance through their Pro-Forma Contract. However, gaining the necessary approvals from the Environment Agency was a more protracted process.

In developing their proposed methodology for the sand importation at tender stage, the Joint Venture had recognised that the direct placement of the material into its required location would involve a significant risk owing to the presence of contaminants throughout the site. The risk of the transportation water being contaminated by contact with these materials was considered too great and therefore a methodology was developed of importing the sand into sealed reception lagoons before its subsequent onward movement and placement using conventional earthmoving equipment. The use of these lagoons meant that the large volumes of transportation water, used by a trailing suction hopper dredger (TSHD) to facilitate pumping the dredged material onto the site, could be effectively managed prior to its eventual discharge back into the River Medway.

The early discussions with the Environment Agency identified that by using this proposed methodology they would require the licences in Table II to be in place prior to works commencing.

The requirement for the Waste Management and Site Recovery Licences emanated from the Environment Agency's designation of the material dredged at Princes Channel as a Waste. This designation resulted in protracted discussions with the Environment Agency by both the Client and the PLA /Van Oord partnership. Despite

Figure 3. The Rochester Riverside Development, River Medway.

continuing to disagree with their interpretation, it was recognised that, save for seeking a court ruling, the only practical way forward was to apply for these licences in line with this classification. However, Van Oord did continue to contend that an Abstraction Licence was inappropriate for this application and the operation was completed without one.

Despite the Environment Agency being supportive in principle to this beneficial reuse of dredged material being transported by sea, each licence application took approximately four months to process. Extensive negotiations were required to agree the levels of suspended solids permitted to be discharged back into the River Medway, with variations appropriate for times of spring and neap tides respectively.

Importation of the land-raising material

Prior to the final agreement and receipt of the Waste, Site Recovery and Discharge Consent Licences, Van Oord commenced construction of the Reception Lagoons. The layout shown in Figure 4 had been conceived at tender stage, but owing to a number of constraints identified following the award of the Contract an amended arrangement (see Figure 5) was used.

The overall lagoon layout accommodated two sand reception lagoons and a single sediment settlement and discharge pond. The size of each reception lagoon was sufficient to receive and store up to 3 days sand supply from the dredger. Two reception lagoons were used on an alternating basis; whilst one was being filled by the dredger the other was emptied using conventional earth-moving equipment. The size of the settlement pond was dictated by both the quantity of discharge water and the length of time it was anticipated this would have to be retained until its quality (i.e. suspended solids content) was of a level that complied with the requirements of the Discharge Consent Licence.

Table II. Licences necessary to proceed with the project.

Licence	Details
Waste Management Licence	Control of the importation of the sand material into the Reception Pits
Site Recovery Licences	Control of the subsequent onward movement and placement of the sand material from the Reception Pits to its required location on site, including the effects of this on the underlying soils and ground water (which included contaminants)
Discharge Consent Licence	Control of the quality and quantity of transportation water being discharged back into the River Medway
Abstraction Licence	Control of abstraction of water from the River Medway by the TSHD for the pumping of the sand material into the Reception Pits

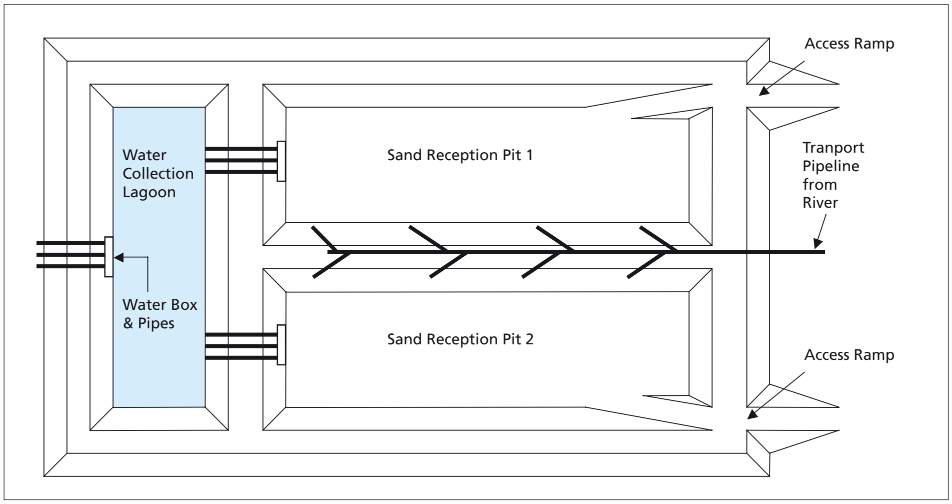

Figure 4. Tender stage layout of the reception lagoons.

Figure 5. Actual layout of the reception lagoons as amended.

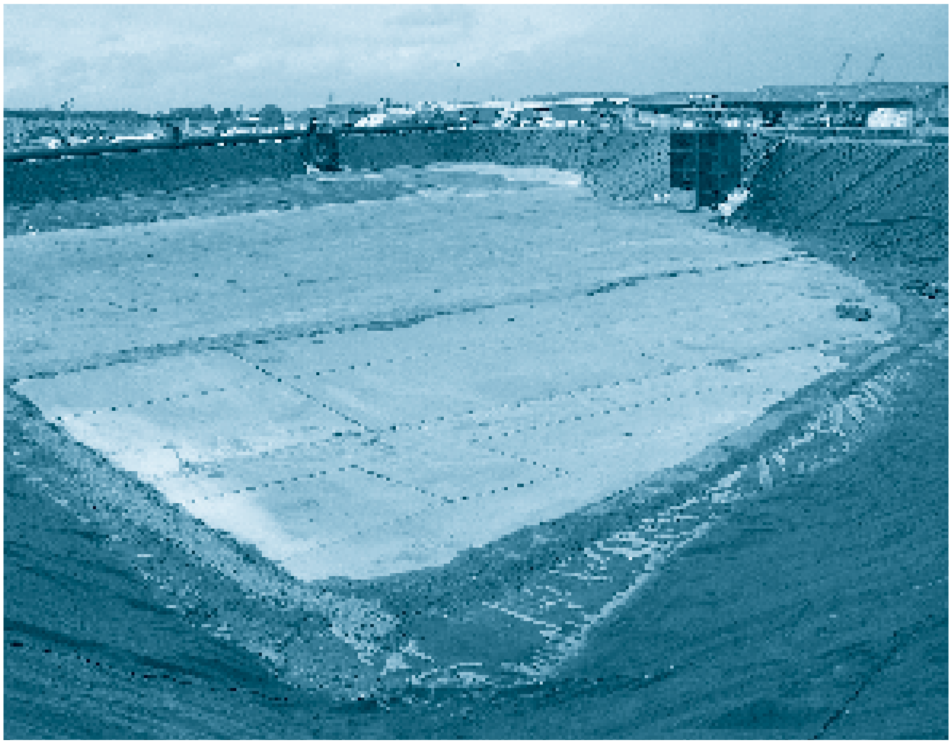

Figure 6. Reception lagoon and weir box.

The reception lagoons were constructed from sand dredged from a Crown Estates Licensed source in the Outer Thames Estuary and was delivered to site by an Aggregate Dredger, from which it was dry-discharged using conveyor belts and an elevator.
The use of this material and methodology for the construction of the lagoons was planned to allow the works to proceed in parallel with the licence applications, thereby saving time on the overall construction programme. Whilst the lagoon sides were lined with an impermeable membrane, the bases were formed on existing concrete ground-slabs. These slabs were deemed sufficiently impermeable for the purpose, and the risk of damage to a base membrane during the filling and recovery operations was considered too great for one to be of any long-term practical use.

All three lagoons were connected by pipelines and weir boxes (see Figure 6) in order that the discharge water from the reception lagoons could be transferred, by gravity, into the final settlement lagoon. The rate at which the water moved from the reception lagoons into the settlement lagoon and from there subsequently discharged back into the River Medway was controlled by the heights of the weirs between the lagoons and preceding the final discharge pipe work. This methodology and the real-time monitoring undertaken of the water discharged back into the Medway ensured that its quality (i.e. the suspended solids content) complied with the requirements of the Discharge Consent Licence.

The importation of the sand material dredged from Princes Channel commenced in late April 2006 using the TSHD Ostsee which carried an average load of 2,000 m^3 per trip. Owing to navigation constraints, the dredger's access to the Rochester site was only possible around times of high water. The sand discharge generally commenced 1 hour before the high tide and lasted for approximately 1.5 hours.

These constraints led to the dredging operation at Princes Channel being undertaken around times of low tide. There was however sufficient available time in the tidal cycle to allow, towards the end of the operation, some of the "incentive" dredging work to be undertaken in parallel with the sand supply operation.

The movement and incorporation of the sand from the lagoons into the permanent works was undertaken by Van Oord's Joint Venture partner since they were considered to be more experienced in conventional earth-moving operations. The sand material was also used as a surcharge to accelerate consolidation of the underlying strata; this process being aided by the installation of over 1,000,000 m of prefabricated vertical drain. Various monitoring methods were used during the placement of the sand fill. These included real time measurements of the underlying pore water pressure and settlement monitoring using both settlement plates and electronic methods.
The sand supply to the Rochester Riverside site was completed in September 2006 when approximately 340,000 m^3 had been delivered.

CONCLUSION

By working in partnership with the dredging industry, the Port of London Authority and Dredging Research Ltd have produced a form of Contract that incentivises Contractors to acquire opportunities for the beneficial reuse of dredged material.

The use of this Contract has allowed the PLA to undertake a significant part of Phase 2 of their Project to deepen Princes Channel in compliance with Governmental, London Convention and OSPAR requirements.
In addition, both they and Medway Council have benefited commercially from the beneficial reuse of this material.

The successful completion of the import of approximately 340,000 m^3 of sand fill from the Princes Channel for land-raising at the Rochester Riverside Project has demonstrated that estuary dredgings can legitimately be used within the construction sector; providing cost savings and environmental benefits when compared to the use of virgin aggregates.

KARSTEN MANGOR, IDA BRØKER AND DAN HASLØV

WATERFRONT DEVELOPMENTS IN HARMONY WITH NATURE

ABSTRACT

The main development theme in many coastal countries is to utilise the attractiveness of water in a broad context. The emphasis has shifted from coastal protection to the development of coastal communities, with coastal resorts along existing coastlines. Waterfront developments as such are considered to be artificial pieces of new nature. The artificial beaches and lagoons, however, do not know that they are artificial. Consequently, these landscape elements will follow the natural marine and coastal processes resulting from the characteristics of the hydrodynamic forces on the coastal sediments, flushing and pollution loading to which they are exposed following construction. Therefore, understanding the prevailing natural processes responsible for creating attractive waterfront, beach and lagoon environments as a basis for the design of well-functioning artificial coastal and marine elements is essential.

This article focuses on providing a basic understanding of how to develop well-functioning coastal and offshore developments with regard to the hydraulic issues – for some the most desired elements in the modern waterfront developments, beaches and lagoons. Design guidelines for *artificial beaches* and for *artificial lagoons* will be presented as well as guidelines for *recreational and landscape elements of coastal developments*. A holistic design of the new Amager Beach Park in Copenhagen is presented as an example of how a successful collaboration between the coastal engineer and the architect can lead to a sustainable new coastal landscape. Finally, a new type of offshore development scheme is presented, where the main idea is the development of an exposed crescent-shaped bay with a high quality beach, which could form the backbone for development of a coastal promenade.
All photographs accompanying this article are by DHI or Hasløv & Kjærsgaard.

INTRODUCTION

The art in developing waterfront projects is to utilise the possibilities provided at a specific site to the benefit of the project, i.e., to integrate the possibilities provided by the marine environment with the demands of society. The art is to perceive the marine forces, such as waves and tides, as external opportunities to be used to maintain high quality artificial beaches and lagoons, contrary to the traditional approach of perceiving these external forces as problem generators, against which protection is required. The article is divided in the following sections:

- Characteristics of natural landscape elements
- Design guidelines for artificial beaches
- Design guidelines for artificial lagoons
- Landscape elements of coastal and offshore developments and their hydraulic design
- Example of beach park development
- Presentation of a new concept for an offshore development scheme

Above, Attractive natural, beaches such as the Skaw Spit in Denmark benefit from the natural wave action that keeps them clean and sandy.

CHARACTERISTICS OF NATURAL LANDSCAPE ELEMENTS

Characteristics of natural beaches

Attractive and safe recreational beaches are always characterised by their exposure to moderate wave action, the tide is micro to moderate (tidal range < ~1.5 m), clean and transparent water, no rock outcrops, well sorted medium sand and minimal amounts of natural and artificial debris.

Figure 1. Other examples of attractive natural beaches with exposure to waves. Left: NW Mediterranean coast in Egypt. Right: Sunset Beach in Dubai, UAE.

Examples of attractive natural beaches are presented in Figure 1. These beaches are all characterised by their exposure to waves, their clean beach sand and their clean water. The type and colour of the sand is different, but all types are natural beach sand of great beauty and recreational value. The exposed beaches have a sandy and clean appearance owing to the wave action which prevents settlement of fine sediments and organic matter. However, there are also many examples of good quality beaches along coasts, where the water contains high amounts of suspended sediments, at least during the rainy season and/or during rough weather. This is, e.g., the situation along Malaysia's East coast and along Sri Lanka's entire coastline. These beaches also remain clean and sandy, because they too are exposed to waves.

Natural beaches develop differently when they are lacking wave exposure. This is clearly seen in the examples presented in Figure 2 and Figure 3. These examples of exposed and protected natural beaches demonstrate that wave exposure is of paramount importance for the type of natural beach which develops in an area.

Clearly, one of the main hazards in relation to developing attractive artificial sandy beaches is lack of wave exposure. Lack of wave exposure on an artificial beach will allow settlement of suspended matter on the seabed and on the beach, also in cases where the beaches have been built of clean sand. This will, with time, lead to the seabed being covered with a layer of soft sediment. Though this is a natural process, it is the main reason for poor quality of beaches found in protected environments. Such beaches feel muddy when walking on them, which is unattractive for recreational beaches.

Characteristics of natural lagoons

Natural lagoons are attractive from a recreational point of view owing mainly to the open water body they offer and not their beaches, which are normally of poor

Figure 2. Beaches lacking wave exposure. Left: Beach in a natural lagoon in the UAE, which suffers from algae and deposition of fine sediments. Right: "Beaches" in Dubai Creek.

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quality. Coastal lagoons are characterised by the following elements:

- One or more so-called tidal inlets which connect the lagoon and the sea.
- Tidal exchange of water between the lagoon and the sea known as the tidal volume.
- Rich flora, such as sea grass beds, mangroves and meadows.
- Rich fauna such as mussel banks, nursery areas for many fish species and rich bird life.
- The openings are sometimes stable and sometimes suffering from sedimentation; this is dependent on the balance between the tidal range and the wave exposure.
- The lagoon environment is protected and is therefore often characterised by the settlement of fines, which in many cases leads to the formation of mudflats.

These natural conditions offer the following attractions:

- Protected water environment, which are traditionally used by coastal societies as a natural location for communities based on natural harbour facilities.
- Possibilities for a great number of commercial activities such as fishing, hunting, aquaculture, location for water intakes/outlets of different kinds and salt production for example.
- Recreational activities such as water sports, navigation in protected waters, fishing, bird watching and so on.

On the other hand, however, these communities as well as the many associated activities in the lagoons also contribute to the high risk of impacts on the lagoons, such as:

Figure 3. Examples of correlation between type of beach and wave exposure. Below left: Location "Map", North Beach in Doha, Qatar. Note, the southern part is protected by an island and associated reefs and has a muddy tidal flat beach (photo lower right) whereas the northern part is exposed and has a sandy beach (photo upper right).

Figure 4. Above: Marsa Matrouh Lagoon, NW Mediterranean coast of Egypt; red dot is photo location for photos below. Lower left: Semi-exposed sandy beach looking towards NW. Lower right: semi-exposed beach towards SE.

- Pollution leading to degradation of the water quality and associated degradation of flora and fauna.
- Installation of sluices leading to changes in the salinity and such.
- Reclamations leading to changes in the tidal volume.
- Regulation of inlets and dredging of navigation channels leading to changes in the tidal volume, which may lead to local erosion or general siltation.
- Navigation, which may lead to pollution and erosion and other impacts.

An example of an attractive lagoon environment is the semi-open Marsa Matrouh lagoon located at the NW Mediterranean coast of Egypt (Figure 4). This lagoon offers attractive sandy beaches because of the wide opening towards the sea, which allows some wave penetration and good water quality. The breaking waves over the reef and shoals ensure a good exchange of waters.

DESIGN GUIDELINES FOR ARTIFICIAL BEACHES

The most important landscape elements in many waterfront developments are *attractive sandy beaches*. An artificial beach is the construction of a new beach by the supplying of sand, so-called beach fill. The design requirements for a good quality recreational beach are outlined below.

Beach exposure to waves

A beach will be exposed to waves in order to obtain a good quality beach. However, a recreational beach should not be too exposed, as this endangers bathing safety. This means that there are two opposing requirements:

- A certain degree of exposure to ensure a self-cleaning beach.
- The exposure should not be too great in order to ensure safe bathing conditions.

In order to safeguard an attractive sandy beach the yearly wave exposure should be moderate to exposed, which means that the significant wave height ($H_{s,\ 12h/y}$), which is exceeded 12 hours per year, should be higher than 1.0 m. This consistent movement of the sand during rough conditions by the wave action is what naturally maintains a nice sandy beach and shoreface by preventing settlement of the content of fines, which are often present in seawater, on the beach and shoreface. Furthermore, the wave exposure prevents sea grasses from growing on the shoreface.

The difference between two artificial beaches in a beach park in the UAE area, where the first beach is exposed to waves and the second beach is a protected lagoon beach, can be seen clearly in Figure 5.

No internationally agreed criteria exist as related to wave height relative to safe bathing conditions. Bathing safety is mainly related to the occurrence and type of breaking waves and the wave-generated currents in the breaking zone. These conditions are discussed below.

Breaking waves

Spilling breakers are often associated with the formation of bars and rip currents, which can carry both adults and children out into deep water. This situation is typical for strong wind and storm conditions at sandy (ocean) coasts. Plunging waves are dangerous because the violent breaking can hit a person who is swimming. Plunging breakers typically occur on ocean coasts with moderate wave conditions, such as under monsoon and trade wind conditions on coasts with relatively coarse sand. Based on the above, obviously ocean coasts are

Figure 5. Left: An exposed artificial beach in the UAE is a nice clean beach owing to the wave action. Right: At an artificial beach in an artificial lagoon in the UAE, note the muddy seabed, which is caused by the lack of wave exposure. The lack of freshness can be clearly seen.

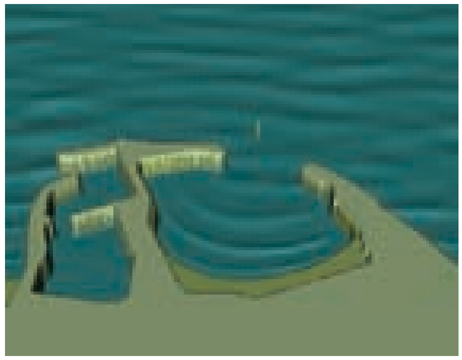

Figure 6. Modelled wave conditions at an artificial beach in Alexandria, Egypt. The design is made by DHI, Hasløv & Kjærsgaard and ECMA.

the most dangerous. However, if an upper limit for wave heights were to be recommended in relation to safe bathing conditions, an estimated criterion will be H_s < 0.8-1.2 m during the swimming season. The low limit is valid for long period waves (swell) and the high limit for steep waves (wind waves). This means that protective measures are required if a site is more exposed during the bathing season than given in the above rough criteria, e.g. in the form of specially designed coastal structures.

Rip currents generated as a result of the presence of coastal structures can also be very dangerous. This danger occurs because during a storm situation waves will be partially sheltered behind the coastal structure, but in the same area strong currents, which can carry poor swimmers out into deep water, will arise owing to eddy formation. Such areas with partial shelter provided by coastal structures generate a false sense of safety and such arrangements should consequently be avoided.

The principle of providing safe partial shelter and shoreline stability at an exposed coast is presented in Figure 6, which shows a project for an artificial beach and a marina in Alexandria, Egypt:

- Large breakwaters provide partial shelter; the width of the opening has been adjusted to provide suitable wave exposure to fulfil the requirements of moderate exposure for securing a good beach quality and semi-sheltered conditions for providing safe swimming conditions.
- The beach is designed to be stable under the resulting wave conditions, and a nice curved shape is obtained by the diffracting waves.
- No dangerous rip currents are created because of the long distance between the breakwaters and the beach and because of the equilibrium shape of the beach.

Minimum wave exposure

A recreational beach should have an active profile out to a water depth of about 2.0 m relative to low tide. This recommendation of a depth of 2.0 m relative to low tide results from the requirement that swimmers walking on the seabed should experience an attractive clean sandy seabed without deposition of fines, which causes a muddy seabed. The clean and active seabed is ensured by the requirement that the active coastal profile should extend out to a water depth of 2.0 m, that is, $d_l \geq 2.0$ m or in terms of wave height: $H_{s,12h/y} \geq 1.0$ *m.* This means that the seabed out to this water depth will regularly be exposed to waves which will prevent fine sediments from settling on the shoreface. Furthermore, the growth of sea grasses will also be prevented.

If the natural shoreface does not allow these requirements to be fulfilled, e.g., if the shoreface is shallower than the equilibrium profile, then two possibilities may fulfil the requirements:

- The beach is shifted seaward.
- The existing coastal profile is excavated to accommodate the equilibrium profile.

Beach exposure in relation to tidal range

A certain tidal range and storm-surge activity will cause a wide beach. However, a tidal flat may develop if the mean spring tidal range is much larger than the yearly average breaker wave height H_b. A high tidal range may also cause a danger to bathers. Thus, a good quality recreational beach is normally characterised with a micro to moderate tidal regime, which means a tidal range smaller than approx 1.5 m.

Beach plan form

The beach should be stable in plan form (horizontally) in order to ensure minimum maintenance. This means that the orientation of the beach must be perpendicular to the direction of the prevailing waves, or in other words, the orientation of the beach will be in the equilibrium orientation, which is the orientation providing net zero littoral transport. This often leads to the requirement of supporting coastal structures for stabilising the beach in an orientation, which is different from the natural orientation of the coastline in the area of interest.

At an exposed beach with oblique wave attack, the supportive coastal structures for an artificial beach should be designed to fulfil the following conditions:

- Provide support for a stable lateral shape of the beach and prevent loss of sand out of the artificial beach area.
- Provide partial protection against wave action.

- Must not lead to dangerous currents near the beach.
- Structures will have a streamlined form to minimise trapping of floating debris.
- All coastal structures should also have recreational functions.

Beach profile form

The beach profile should be stable, which means that a beach will be built in the form of the equilibrium profile. A beach adjusts to the equilibrium profile in the active littoral zone. The shape of the profile is mainly dependent of the grain size characteristics of the sand. The equilibrium shape, Dean's Equilibrium Profile, follows the shape $d = A\ x^{2/3}$ where d is the depth in the distance x from the shoreline, both d and x in metres. A is Dean's constant, which is dependent on the grain size of the sand according to the directions given in Table I.

The equilibrium profile concept is valid only for the active littoral zone, i.e., out to the Closure Depth d_l. As a rule of thumb $d_l \sim 2H_{s,\ 12h/y}$ can be used for normal wind waves.

Beach fill material

The beach fill material for artificial beaches should fulfil the following criteria in order to provide a high quality recreational beach:

- Characteristics of the fill sand should be similar to that of the natural sand in the area if the new artificial beach is connected to an existing beach, however, as a rule slightly coarser.
- Sand should be medium, i.e., 0.25 mm $< d_{50} <$ 0.5 mm, preferably coarser than 0.3 mm, which minimises wind loss.
- Minimum content of fines, i.e., silt content less than 1-2%.
- Gravel and shell content less than 3%.
- Well-sorted sand, $u = d_{60}/d_{10}$ less than 2.0.
- Colour shall be white, light grey or yellow/golden.
- No content of organic matter.
- Thickness of sand layer will be at a minimum1 m, preferably thicker.

The reason for the requirement for the beach sand to be medium, well-sorted sand with minimum content of fines is discussed below. If this requirement is not fulfilled, i.e., if the sand is graded (the opposite of well sorted) with some content of fines, the permeability is low, which means that the beach will drain very slowly at falling tide. This implies that the beach will be wet at all times and will have a tendency to be swampy, and thereby unpleasant to walk on. This criterion is especially important for artificial beaches built at protected locations, as there will not be enough wave action to wash the fine sediments out of the beach. Furthermore, algae may grow on the beach, which makes it greenish in colour and un-aesthetic. Finally, in such environments the beach will attract beach crabs and their pellets. Especially at protected sites, the use of clean sand with zero content of organic matter is important, because the combination of lack of wave exposure and content of organic matter may lead to anoxic conditions resulting in formation of hydrogen sulphide, which causes a bad smell and dark colouring of the sand (see examples in Figure 7).

The requirement for a small content of gravel and coarse fractions is important for the quality of the beach surface as the action of the waves will wash away the fine fractions leaving the beach armoured with the coarse fractions. Such a beach surface is unpleasant to walk on (see examples in Figure 8).

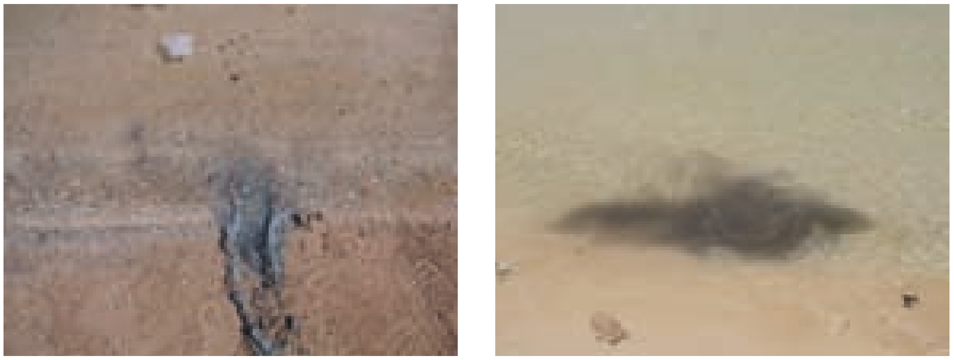

Figure 7. Examples of anoxic conditions and the formation of hydrogen sulphide at protected artificial beaches. Left: Dark substance suspended in the water when seabed at shallow water is disturbed, artificial beach in lagoon environment at the Egyptian NW coast. Right: Dark substance at beach in artificial lagoon in the Red Sea.

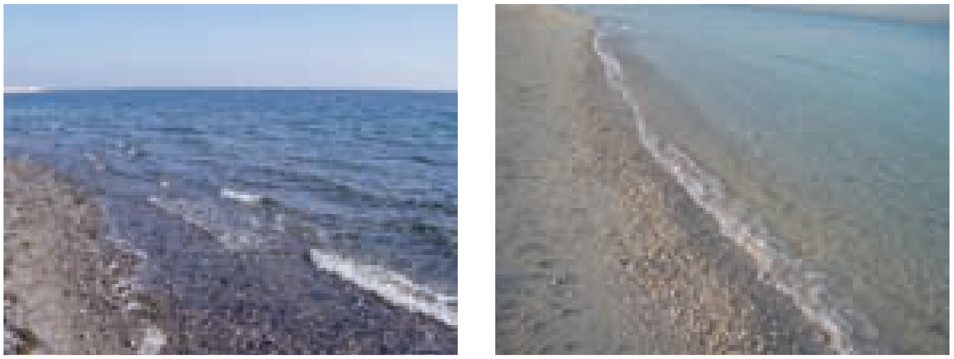

Figure 8. Artificial beaches with too much coarse material. Left: Beach Park in Copenhagen. Section where the content of gravel and pebble is too high. Right: Artificial beach in the UAE where the content of shells and coral debris is too high.

Table I. Correlation between mean grain size d_{50} in mm and the constant A in Dean's Equilibrium profile equation. For typical beach sand.

d_{50}	0.20	0.25	0.30	0.50
A	0.080	0.092	0.103	0.132

Clearly, from the examples in Figures 7 and 8, the use of very good quality fill sand for the construction of artificial recreational beaches is very important.

DESIGN GUIDELINES FOR ARTIFICIAL LAGOONS

The most important landscape elements in many coastal development schemes are attractive tidal lagoons. Such lagoons provide an attractive protected marine environment – but also major technical challenges. Design guidelines for elements of artificial lagoons are discussed below.

Lagoon mouth and channel sections
The stability of tidal inlets is a science in itself, which is not be discussed in detail here. Suffice it to say that at littoral transport coasts the stability of tidal inlets is a major issue, which means that careful studies are needed. The required cross sections will be dependent on the tidal volume in the lagoon. No specific criteria can be given. However, the cross section area of mouth and channel sections of artificial lagoons should be large enough that peak tidal current velocities are less than ~ 0.8 m/s. The width and depth should also be designed according to guidelines for safe navigation if the lagoon is to accommodate boating by motor and sailing yachts.

Open water body
The main purpose of introducing artificial lagoon and channel elements is to add attractive landscape elements adjacent to an urban development area. The lagoon may be designed to accommodate water sports, navigation and swimming, but swimming in a lagoon will never be as attractive as in the sea. The most import function is to provide the inherent attraction of water to an area which does not have this in its native condition. The lagoon therefore should be properly designed as an important landscape element.

A requirement for maintaining good water quality is the proper flushing of the lagoon. Flushing can be expressed in terms of a characteristic "flushing time" T_{50}, which is the time it takes before 50% of the water in the lagoon system has been exchanged with clean water from the sea outside the lagoon during a design scenario. The design scenario should be a calm and warm period, as this is most critical for flushing and water quality. No required criteria are specified for the flushing time. An acceptable flushing time for a natural lagoon will normally be 5–7 days but the flushing time for artificial recreational lagoons should preferably be shorter.

Under many conditions, more than one opening is recommended in order to accommodate sufficient flushing; sometimes forced flushing circulation by gates or additional pumping may be required. Other rules of thumb are:

- Water depths shall not be larger than 3–4 m.
- There must be no local depressions in the seabed.
- There must be no discharge of pollutants to the lagoon, such as sewage, storm water, brine, cooling water, pesticides and nutrients.

The above-mentioned flushing guidelines are imperative for obtaining good bathing conditions. Fulfilment of international bathing water quality standards must be ensured, e.g. the EU Standard, Ref. /2/.

Perimeters
Normally it is difficult to obtain a good quality beach inside a lagoon for the reasons discussed in the previous section. The following guidelines should be followed to obtain the best possible lagoon beaches if lagoon beaches are embarked on despite the above "warnings":

Figure 9. Pictures from Amager Beach Park, Copenhagen. Right: Middle pier functions as terminal structure for the two beach sections and as viewing and bathing facility. Below: Seawall along the southern beach section has multiple functions: Coast protection, separation between promenade and beach and sitting furniture.

Figure 10. Aerial photo of Amager Beach Park, Copenhagen (courtesy of Jan Kofod Winther), which consists of the following main elements: Island with terminal structures north and south and a separating headland between northern and southern beaches and a lagoon. Designed by DHI, Hasløv and Kjærsgaard and NIRAS.

- Use only high standard beach sand as explained under the design guidelines for beaches.
- Construct the desired beach profile from the beginning.
- Build only beaches at exposed locations in "large" lagoons with dimensions preferable > 2–5 km and water depth not less than 2 m.
- Build only beaches if the amount of suspended substances in the lagoon water is very small, say in the order of less than 5–10 mg/l.

It is strongly advised to consider other alternatives than beaches inside lagoons.

LANDSCAPE ELEMENTS OF COASTAL AND OFFSHORE DEVELOPMENTS

The recreational and landscaping requirements in relation to design of the marine elements of waterfront developments are discussed below.

The characteristic elements are:
- Beaches
- Other types of shoreline perimeters
- Landscape behind the shoreline perimeter
- Lagoon areas/body lines

Far too many coastal projects are developed without a clear understanding and respect for the natural hydraulic and coastal processes which are decisive for the overall layout of the marine elements of a development. Consequently, many projects are developed without a clear idea of which layouts are feasible and of how the different elements can support each other.

This may lead to unsuitable shoreline perimeter solutions of poor quality and consequently major expenses for maintenance – often resulting in poor results.

The planning process for a waterfront development should consequently ensure a balance between the objectives of the developer and the possibilities that the specific development site offers in terms of artificial marine elements, taking environmental impacts into consideration. The main objectives of the developer, being a public authority or a private company, are typically some of the following:
- Enhancing of economic development possibilities in an area.
- Expanding the length of water perimeter through establishment of artificial water bodies.
- Developing recreational and service facilities.
- Providing balanced public and private access.
- Providing sandy beaches and other shoreline perimeters types.
- Establishing optimum internal functionality and causing minimum environmental impacts.

These objectives must be balanced against the possibilities and constraints offered by the natural conditions in the development area: Where can beaches be located and how should they be orientated? How can good flushing and water quality be ensured in artificial lagoons and so on? These conditions are already discussed in the previous sections where design guidelines for artificial beaches and artificial lagoons are presented.

It is especially important to ensure that necessary coastal structures are planned and designed as multifunctional facilities. Examples of such layouts could be:

- A terminal structure is designed as a viewing headland.
- A groyne structure is designed as a headland which can be utilised for recreational facilities.
- A lagoon opening can be designed as a marina.
- A seawall can be designed as an integrated part of the beach furniture (see Figure 9).

Landscaping principles for the layout of artificial beaches should focus on as long and uninterrupted beach sections as possible, with a minimum number of structures, as this will enhance the natural appearance of a beach section.

An integrated plan based on workable marine elements will make it possible for developers and planners to create unique and sustainable coastal developments where the possibilities and requirements of nature are utilised optimally according to the needs of society.

AN EXAMPLE OF A SUCCESSFUL BEACH PARK DEVELOPMENT

A new beach park was recently built in Copenhagen using the principle of making the new beaches exposed to waves by moving them out to deep water thereby avoiding the shelter provided by the existing shallow shoreface. An aerial photo of the new beach park just after finalisation of the civil works is presented in Figure 10. The main wave directions at the site are NE and SE, which have been utilised to make two sections of beach separated by a headland, one facing towards NE and one facing towards SE. Note the Y-shape of the headland structure providing a smooth transition between the structure and the beaches, which secures minimum trapping of floating seaweed and debris in the transition areas. The new beaches have been constructed on an island and a new lagoon (excavated) has been built between the island and the old shoreline. There is always a good current just off the beach park as it is located in the Sound, the strait between Denmark and Sweden, where the water exchange between the Baltic and the North Sea takes place. This results in a good flushing of the lagoon.

The beach park has been very well received by the residents of Copenhagen and in an opinion poll it was nominated as the best beach in the Copenhagen area. It has also received a reward from the "Society for the beautification of the Capital", and people are enjoying all the facilities in the park (see Figure 11).

A NEW CONCEPT FOR AN OFFSHORE DEVELOPMENT SCHEME

A new concept for an offshore development plan utilising the principles presented in this article has been developed by DHI and Hasløv & Kjærsgaard, Planners and Architects, Copenhagen. The plan is universal because it can be implemented at any location where a coastal development is

Figure 11. Recreational activities in Amager Beach Park, Copenhagen. Upper: Beach activities. Lower: Kayaking and kite surfing on the Lagoon; the beach islandis in the background (courlesy Adrian Saly).

needed and where wave exposure is present. The plan has been created under the motto, "Work with Nature", meaning that the wave exposure at the site should be considered a valuable natural gift, to be utilised for developing a significant recreational facility, namely a high-quality exposed beach.

The centre of the plan is the unique half-moon-shaped ocean bay providing an excellent sandy beach. The plan thus offers the possibility for developing an extremely high quality urban beach which can be equipped with an attractive cornice along which most of the important recreational and leisure functions of the new city can be developed, such as promenades, retail downtown areas, advanced apartment schemes, hotels, marine sport facilities, entertainment facilities, parks and other amenities.

Figure 12. "The Universe" concept for an offshore development scheme. Artist's impression of the beach in "The Universe" and a possible concept for a marina. © DHI and Hasløv & Kjærsgaard. All rights reserved.

CONCLUSIONS

It is clearly crucial for a successful design of beach and lagoon elements in waterfront developments that the hydraulic, coastal and environmental aspects are included in the planning from the earliest planning stage. The design of these elements has to follow the "rules of nature", which imposes certain restrictions on the design. The main issues to observe are:

Artificial beaches:
- Good quality recreational beaches should be moderately exposed to waves; they should be orientated towards the direction of the prevailing waves to be stable and terminal structures should be constructed to prevent loss.
- Artificial beaches should be constructed by good quality beach sand: medium, i.e. 0.25 mm < d_{50} < 0.5 mm, well sorted, attractive colour, minimum content of fines and minimum content of coarse fractions and no content of organic matter.
- Coastal structures adjacent to beaches should be designed so that no dangerous currents are generated.

Artificial lagoons:
- High water quality standards should be ensured in recreational lagoons; the "flushing time" T_{50} should be better than 5 to 7 days, which may require special precautions.
- The lagoon mouths should be stable and free of sedimentation.
- Water depths should be between 2 m and 4 m.
- There must be no local depressions in the seabed.
- There must be no discharge of pollutants to the lagoon, such as sewage, storm water, brine, cooling water, pesticides and nutrients.

Waterfront developments in general:
- A thoroughly planned location and layout of the urban elements integrating recreational demands with the natural dynamics of artificial beaches and lagoons are important.
- Coastal structures should also have recreational functions.

REFERENCES

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Mangor, Karsten, 2004. *Shoreline Management Guidelines*. Published by DHI Water & Environment, ISBN 87-981950-5-0.

Mangor, Karsten, 2005. *Successful Waterfront Developments* – Work with Nature. Keynote Speech at ArabianCoast 2005, Dubai, UAE.

BOOKS/PERIODICALS REVIEWED

Sediment Dredging at Superfund Megasites: Assessing the Effectiveness
NATIONAL RESEARCH COUNCIL
Published by the National Academies Press, Washington DC. 2007. 316 pages.

The U.S. National Research Council (NRC) published its report on *"Assessing the Effectiveness of Dredging Superfund Megasites"* in 2007, which summarises the findings of an NRC committee charged with conducting an independent evaluation of the effectiveness of dredging contaminated sediments at large Superfund sites. In general, the report does a good job of providing a concise overview of the various aspects of remedial dredging projects and presents some useful conclusions and guidelines. The report tries to provide an objective analysis of the data available from major contaminated sites in the United States, acknowledging that most sites are data limited in that either data was never collected or made available to the public.

The summary at the beginning of the book provides a well-founded set of conclusions and recommendations that are useful for regulators and responsible parties contemplating remedial dredging. The rest of the report is organised as follows: Chapter 1 provides a good review of the issues surrounding contaminated sediment sites. Chapter 2 outlines overall concepts of sediment management at Superfund sites (including a discussion of the Superfund process, an evaluation of risks in contaminated sediments, and an impression of remedial dredging, its effectiveness and the technical challenges). Chapters 3 and 4 discuss the evaluation framework (for remedial dredging projects) and the lessons learned from these sites. Chapter 5 presents an objective analysis of monitoring approaches and practices, and suggests approaches to improve monitoring. Finally, Chapter 6 provides some recommendations on improving future decision-making aspects of contaminated sediment dredging projects in a Superfund context. Appendix C of the report is a useful compendium of major sediment sites and lists Remedial Action Objectives (RAOs), clean up levels (Numerical Remedial Goals) and their overall effectiveness/performance at those sites.

The committee evaluated "megasites" or sites where the total clean up cost is expected to exceed US$50 million. Accordingly, the committee considered eleven NPL (National Priorities List) sites and three Non-NPL sites. The committee concluded that while dredging is a good tool for mass removal, it appears that it has encountered systematic difficulties in achieving specified clean up levels. Long-term monitoring data appear to be generally lacking for any meaningful long-term trends analysis.
A powerful method would have been to evaluate long term-system recovery trends in the absence of dredging and compare it to the case post-dredging. Interestingly, not many sites have even contemplated such a systems-wide approach to evaluating remedial effectiveness. One recommendation of the report is that the US Environmental Protection Agency (EPA) take steps to ensure that adequate monitoring is conducted at all contaminated sediment sites to evaluate remedial effectiveness. This would be a valuable tool to plan future sediment management decision-making processes.

The committee noted that remedies should be designed to meet long-term risk-reduction goals, and not necessarily focus on other criteria not strictly related to risk, such as mass removal. Since most dredging projects are aimed at achieving mass reduction in some sense or other, the dilemma and debate about whether mass removal is an appropriate target continues. The committee's evaluation of surface concentrations prior to and following dredging was somewhat inconclusive, i.e., some sites showed increases, some showed decreases and some had no significant changes. However, the committee did find that dredging alone achieved the desired clean up goals in only a few of the 26 projects it evaluated: At most sites, capping or a post-dredge cover was needed to bring the surface concentrations in compliance with the clean up goals. Further, the committee noted that environmental conditions that limit the effectiveness of dredging should be fully evaluated before a decision to dredge is made. This makes sense as some of the most inefficient remedial dredging projects have occurred under conditions that are not ideally suited for dredging to begin with – such as hard rock and shale beds, fluid bed layers, sediment interlaid with debris and high flow/current conditions.

One limitation of the report is that it only considers dredging as a stand-alone remedy, with mass removal apparently being the objective. The value of the report would have been increased tremendously had the committee ventured to provide analyses and summaries pertaining to efficiencies of dredging:
a) as related to other remedies such as Monitored Natural Recovery (MNR) and capping; and
b) addressing the effectiveness of dredging as part of a hybrid remedy scenario (i.e., one or two passes of dredging followed by a sand cover or an engineered cover). While that was no doubt beyond the charge of the committee, it leaves the decision process somewhat muddled as no clear-cut analyses on such scenarios have been performed by a national body with the stature of the NRC.

Another aspect where the report could have provided useful direction was in the remedial action monitoring area. An effective monitoring process should aim to determine if the assumed relationship between the clean up levels in the Record of Decision (ROD) and the remedial action objectives (RAOs) have been achieved. While such data may not determine remedy effectiveness, it would help verify the underlying assumptions of the clean up level-exposure relationships, and thus help inform the long-term monitoring and review/re-opener scenarios during USEPA process, as well as help in developing future sediment management decisions.

The committee concluded that dredging, in the context of mass removal, may be effective, but it may present surface contamination issues that will need to be handled some other way – such as through a post-dredging cover or cap. The committee seems to advocate the use of pilot studies where possible for identifying adverse site conditions and logistic problems. However, a pilot study should be undertaken with appropriate conditions that are either comparable to full scale application, or can be easily scalable to the full-scale application. Otherwise, it would not be a true "pilot" and thus will be unable to replicate the same process-related choke points. Several recommendations are provided for future management of sediment sites, including carefully planned pre-remedial baseline monitoring in order to facilitate comparisons with post-remedial data; during and post project monitoring to evaluate effectiveness; planning, evaluation and adaptive management based on monitoring data; and research to develop rapid field monitoring techniques to make real-time adjustments as needed. Perhaps the committee's most useful observation is that contaminated sites should be evaluated using the principles of adaptive management – particularly for sites where there is a large degree of uncertainty regarding contaminant distribution and the effectiveness of remedial technologies. This includes a tiered remedial approach, where the least conservative (yet, environmentally effective) remedy is implemented first, followed by a robust monitoring programme, with triggers that may move it towards a more conservative remedy if certain threshold effectiveness criteria are not met through monitoring.

Another aspect the report notes is the increasing popularity and utility of hybrid remedies – a concept where dredging is typically undertaken to address hot spots (or areas with higher chemical concentrations) or other specific needs (such as navigation or habitat restoration), followed by backfilling, capping or habitat creation or restoration.

The report advocates a risk-based clean up decision-making process, with due consideration of the 4Rs of dredging – ie., residuals, resuspension, releases and risks. While the report intended to review only "megasites", they also reviewed several smaller projects (mainly because of the volume of sediment remediation resulting in multiple years of dredging). The report rightfully concludes that a "basin-wide" cleanup goal is essential to effective environmental remediation. This approach, plus the adaptive management concept mentioned earlier, makes a phased remedial approach ideal for remediation of such contaminated megasites. That way, lessons learned from the initial years can be applied painlessly to future years of remedy implementation.

The report is a good summary of publicly available information from a wide range of projects and a good reference for academics, site managers, practitioners and regulators alike.

DR. RAM MOHAN, PE
ANCHOR ENVIRONMENTAL, LLC.

SEMINARS/CONFERENCES/EVENTS

International Symposium on Sediment Management
LILLE, FRANCE
JULY 10-12 2008

Over the ages, river estuaries have given economic prosperity to those who live on their embankments. Much of this prosperity is based on the sediments brought by the rivers, which carry with them contaminants. Even if regulations and a better control of contaminants have been established to reduce their emission, many contaminants are still present in bottom sediments. In fact, some of them are persistent and continue to pose a risk to the environment. Since the contaminated sediment problem is extended throughout the world, this symposium will be international event, reviewing recent advances on sediments management related research and focus on engineering aspects including:

- Management of dredging operation and storage of sediments
- Treatments and transport of contaminated sediments
- Ecotoxicological approaches and developments of biotests
- Analyses and water treatments
- Beneficial uses of dredged marine and river sediments in civil engineering and in other fields

All papers and presentations will be in English. Official languages of the symposium are English and French, with simultaneous translations provided during plenary sessions.

For further information contact:
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CEDA Dredging Days 2008
CONFERENCE CENTRE 'T ELZENVELD
ANTWERP, BELGIUM
OCTOBER 1-3 2008

With the title "Dredging Facing Sustainability" CEDA Belgium intends to raise a wider awareness of the stakeholders to the efforts of the dredging world – contractors, shipyards and consultants – to sustainable development.

Topics include: How to tackle sea level rise – dredging for coastal flood protection; Dredging as a key player in the energy discussion; Creating estuarine wetlands – vital ecosystems for sustainable development; Dredging in sensitive areas – balancing between socio-economic development and nature conservation – improving technology to achieve "no impact"; Efforts to reduce emissions in the dredging industry; sustainability concerning decision process.

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www.dredgingdays.org/2008

Port & Terminal Technology 2008
5TH INTERNATIONAL CONFERENCE & EXHIBITION
ROTTERDAM, THE NETHERLANDS
OCTOBER 16-17 2008

Millennium Conferences International announces the 5th International Port & Terminal Technology 2008 Conference & Exhibition. The event is aimed at those involved in the effective development and operations of container port and terminal facilities. The conference examines new trends and technologies to successfully develop and operate ports and terminals around the world. Topics at the conference will include: Port Automation - Simulation (of cargo handling equipment) - terminal design - maintenance - security - terminal lighting - increasing productivity for cargo handling - impact of larger ships on port infrastructures - paving - increasing capacity - fender systems - port & terminal efficiency - environmental issues.
The conference will be supported by an (technical) exhibition and exhibition stands can be reserved on-line.

For further information contact:
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Hydro8 Symposium
BRITANNIA ADELPHI HOTEL
LIVERPOOL, UK
NOVEMBER 4-6 2008

The Hydrographic Society UK, on behalf of the International Federation of Hydrographic Societies, is to stage the 16th International Hydrographic Symposium, Hydro8, in Europe's 2008 Capital of Culture, Liverpool. To be held at the City's historic Britannia Adelphi Hotel, the three-day event will feature a main conference and an exhibition of equipment and services in addition to a series of workshops, equipment demonstrations, mid-afternoon technical visits and a social programme highlighted by a special Symposium Dinner in Liverpool's celebrated Georgian Town Hall.

Conference proceedings will cover a wide range of contemporary survey and environmental-related issues under the theme, New Opportunities. Scheduled topics include Deep Water Terminal Challenges, Sediment Hydraulics/Dynamics for Dredging, ENCs, Tidal Predictions, the EU Water Framework Directive & Its Hydrographic Implications, Wind Farm Development, and Latest Acoustic & Multibeam System Developments and Applications. Hydro8, which is expected to attract a worldwide delegate audience and over 50 major exhibitor companies and organisations,

For further information and general details contact:
www.hydro8.org.uk

31st International Seminar on Dredging and Reclamation
ABU DHABI, UAE
NOVEMBER 2008

Aimed at (future) decision makers and their advisors in governments, port and harbour authorities, offshore companies and other organisations which are involved with the execution of dredging projects, the International Association of Dredging Companies organises the International Seminar on Dredging and Reclamation each year in various locations.

Since 1993 IADC has provided this week-long seminar especially developed for professionals in dredging-related industries. These intensive courses are often given in co-operation with local technical universities and have been successfully presented in Delft, Singapore, Dubai, Buenos Aires, Bahrain and Mexico. The Seminars reflect IADC's commitment to education, to encouraging young people to enter the field of dredging, and to improving knowledge about dredging throughout the world.

This five-day course strives to provide an understanding through lectures by experts in the field and workshops. Some of the subjects covered are:
- the development of new ports and maintenance of existing ports;
- project phasing (identification, investigation, feasibility studies, design, construction, and maintenance);
- descriptions of types of dredging equipment and boundary conditions for their use;
- state-of-the-art dredging techniques as well as environmentally sound techniques;
- pre-dredging and soil investigations, designing and estimating from the contractor's view;
- costing of projects and types of contracts such as charter, unit rates, lump sum and risk-sharing agreements.

An important feature of the seminars is a trip on a trailing suction hopper or a cutter suction dredger to a nearby dredging project. A visit to a dredging yard is also included.

For further information, please contact:
Mr. Frans-Herman Cammel,
cammel@iadc-dredging.com or
IADC Secretariat: + 31 70 352 3334

Gulf Coast Hurricane Preparedness, Response, Recovery and Rebuilding
MOBILE, ALABAMA
NOVEMBER 11-14, 2008

The Gulf Coast Hurricane Preparedness, Response, Recovery & Rebuilding Conference is being organised by PIANC USA. This is a "must attend" conference for all professionals interested in sharing knowledge and experience in post storm ecosystem restoration and coastal infrastructure protection.

The conference is co-sponsored by American Association of Port Authorities (AAPA), Association of Floodplain Managers of Mississippi, Coasts, Oceans, Ports and Rivers Institute of ASCE (COPRI), Dredging Contractors of America, EPA Gulf of Mexico Program, Gulf of Mexico Coastal Ocean Observing

CALL FOR PAPERS

System Regional Association (GCOOS), Gulf Intracoastal Canal Association (GICA), National Oceanic Atmospheric Administration (NOAA), Northern Gulf Institute, Transportation Research Board/Marine Board, US Army Corps of Engineers, Mobile District.

Topics include: Long Term Economic and Environmental Recovery, Emergency Preparedness, Watershed wide flood hazard master planning, Self Sustaining Ports, Navigation, Regional Sediment Management, Ecosystem Resiliency, Community Resiliency, Beneficial Uses of Dredged Material, Flood and Storm Damage Reduction, Engineering and Environmental Challenges and Technological Advances.

For further information about exhibiting or sponsoring contact:
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www.pianc.us

CEDA-African Section Conference
NOUKCHOUT, MAURITANIA
DECEMBER 2-4 2008

The African Section of CEDA will be convening in Mauritania for its annual international conference. This year's conference is entitled "Maritime Infrastructure, Coastal Protection and Sustainable Development". The highlighted subjects will be:
- Design parameter for maritime facilities and coastal protection
- New constraints for port management
- Facilities maintenance and prevention measures

For further information visit the website:
http://www.cedaconferences.org/mauritania2008
Or Secretariat of the African Section of CEDA
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The Third International Congress for Dredging
TECHNOLOGY DEVELOPMENT IN CHINA
TIANJIN, CHINA
NOVEMBER 18-19 2008

The rapid and sustained development of China's economy has demanded expansion and upgrading of China's harbor facilities. This increased harbor and waterway construction activity has generated increased volumes of dredged materials. Clearly, such a volume of dredged material has the potential to provide a source of Beneficial Uses of Dredged Material. To support the research about the economic and social benefits of Beneficial Uses of Dredged Material, the China Dredging Association (CHIDA) has decided to hold The Third International for Dredging Technical Development Congress in Tianjin, China.
This Congress is jointly organised by CHIDA and EADA. EADA is responsible for calling, appraising and selecting papers from abroad, while CHIDA is responsible for calling, appraising and selecting papers from China as well as the detailed works of the Congress. Chinese and English are the official languages of the conference. Simultaneous interpretation will be provided.

Topics suggested for papers are:
- Actual projects involving Beneficial Uses of Dredged Material.;
- The physical, chemical and engineering properties of material associated with the Beneficial Use of Dredged Material;
- Technical feasible projects for harnessing the benefits from the use of dredged materials;
- Policies, regulations and international laws relating to the Beneficial Uses of Dredged Material.;
- Evaluation of the environmental impacts from the adoption of Beneficial Uses for Dredged Material;
- Investment and return analysis (both economic and social) in relation to the Beneficial Uses of Dredged Material;
- Monitoring of the results associated with the Beneficial Uses of Dredged Material.

Participation in this Congress and the contribution of papers by colleagues from the overseas dredging industry is warmly welcomed. Abstracts for papers from abroad and complete papers which have a text of 3000-5000 words should be submitted to John Dobson at EADA

The two-day Congress will feature the presentation of the papers on the first day and the dredging technical visits on the second day. The preliminary site visiting plan is either to Tianjin Binhai (New Coastal District), Tianjin Artificial Island or Tianjin Container Terminal.

For further information contact:
The Secretariat of the Preparatory Committee of this Congress is set at China Dredging Association.
Yang Zun Wei ,Secretary General CHIDA
522 Room No.9 Dong Zhi Men Wai Chun Xiu Road, Beijing, China, 100027
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Information on congress will be posted at www.chida.org

Please direct all overseas enquiries to:
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Eastern Dredging Association (EADA) Secretariat,
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Email: david@pka.gov.my

Coasts, Marine Structures and Breakwaters 2009 Conference
EDINBURGH INTERNATIONAL CONFERENCE CENTRE, EDINBURGH, SCOTLAND
SEPTEMBER 16-18 2009

The Coasts, Marine Structures and Breakwaters 2009 Conference will address the design, performance, installation and maintenance of the structures necessary to extract marine energy around nearshore seas and coasts. It will also offer new material on coasts, marine structures and breakwaters. This is the ninth conference in the international breakwaters series, which is recognised for its balanced presentations on research, design and construction with a strong emphasis on practical application. These conferences are a forum for forthright discussion, highlighting advances and identifying areas of debate.

The conference will comprise technical plenary sessions with each paper introduced by the authors. Papers will be issued to registrants beforehand, to allow informed discussion during the conference. As at previous conferences, both the papers and the discussions will be recorded in the formal proceedings. ICE welcomes technical papers on coastlines and coastal structures, particularly:
- Breakwaters, seawalls and jetties:
  - design and performance analysis
  - construction, refurbishment and rehabilitation
- Dredging and use of dredged materials
- Nearshore marine energy systems
- Coastal erosion, flooding and management
- Coastal data and measurement
- Developments in research, analysis and guidance

The conference will cover the following themes:
- Climate change and major storms
- Service re-assessment and adaptation
- New techniques and innovations
- Construction methods, equipment and experience
- Environmental and social awareness
- Procurement approaches, economics and finance
- Growing knowledge and understanding, and uncertainties
- Emerging markets and requirements
- Analysing, refurbishing or replacing ageing infrastructure

Abstracts can be up to two A4 pages, font must be size 11 Arial and submitted on the electronic template by 1 August 2008. To submit your abstract, please complete the submission template at the website and attach your abstract. All abstracts should be in English. Submitted abstracts will be reviewed by the Organising and International Scientific Advisory Committees and authors will be notified whether or not their abstract has been selected for the conference by October 2008. If selected, authors should produce a draft paper by January 2009 for peer review. Final papers are due in June 2009.

One author from each paper will be required to present the paper at the conference and will be offered a discounted fee.

For further information contact:
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Institution of Civil Engineers
One Great George Street
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Tel: +44 (0)20 7665 2293, Fax: +44 (0)20 7233 1743
Email: events@ice.org.uk, ice.org.uk

MEMBERSHIP LIST IADC 2008

Through their regional branches or through representatives, members of IADC operate directly at all locations worldwide

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Jan De Nul Singapore Pte. Ltd., Singapore
Van Oord Dredging and Marine Contractors b.v. Singapore Branch, Singapore

AUSTRALIA
Boskalis Australia Pty. Ltd., Sydney, Australia
Dredeco Pty. Ltd., Brisbane, QLD, Australia
Van Oord Australia Pty. Ltd., Brisbane, QLD, Australia
WA Shell Sands Pty. Ltd., Perth, Australia
NZ Dredging & General Works Ltd., Maunganui, New Zealand

EUROPE
DEME Building Materials N.V. (DBM), Zwijndrecht, Belgium
Dredging International N.V., Zwijndrecht, Belgium
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N.V. Baggerwerken Decloedt & Zoon, Oostende, Belgium
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Van Oord Middle East Ltd., Nicosia, Cyprus
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Terramare Oy, Helsinki, Finland
Atlantique Dragage S.A., Nanterre, France
Atlantique Dragage Sarl, Paris, France
Société de Dragage International 'SDI' S.A., Lambersart, France
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Societa Italiana Dragaggi SpA 'SIDRA', Rome, Italy
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TOA (LUX) S.A., Luxembourg, Luxembourg
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Boskalis Westminster (Oman) LLC, Muscat, Oman
Boskalis Westminster Middle East, Doha, Qatar
Boskalis Westminster Al Rushaid Co. Ltd., Al Khobar, Saudi Arabia
HAM Saudi Arabia Company Ltd., Damman, Saudi Arabia

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