Terra et Aqua is a quarterly publication of the International Association of Dredging Companies, emphasizing "maritime solutions for a changing world." It covers the fields of (i) hydraulic and mechanical engineering including the technical, economic and environmental aspects of dredging. Developments in the state of the art and the industry from other disciplines 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 provide these 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.
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EDITORIAL

EROSION BEHAVIOUR OF A DRAGHEAD
ARNAUD VERSCHELDE, CEEES VAN RHEE AND MARC VAN DEN BROECK

The IADC Young Author’s Award-winning paper verifies the agreement between the theoretical calculations for a new toothless draghead and the real situation when the draghead is being used.

DREDGING AND DISPOSAL AT LOUGH FOYLE, NORTHERN IRELAND
DAVID CLOSE, ANTHONY BATES, ROBIN MORELISSEN AND CAROLINE ROCHE

Is it possible for an in-site disposal area to be environmentally and economically preferable to an offshore disposal site? Real-time monitoring says yes, there are numerous benefits to the disposal of dredged material in-site.

THE MONITORING PROGRAMME FOR THE MAASVLAKTE 2 CONSTRUCTION AT THE PORT OF ROTTERDAM – PART II
WIL BORST, TIEDO VELLINGA AND ONNO VAN TONGEREN

Given the inter-dependence of the underwater food chain from benthic fauna and algae to shells, worms, fish and birds, a new modelling strategy was instituted to evaluate the effects of enhanced silt concentrations during dredging.

BOOKS / PERIODICALS REVIEWED

Innovation is the keyword of two new publications, “175 Ideas on the Future of the Fehmarnbelt Region” and “Building with Nature”; and Facts About Subsea Rock Installation and Facts About Initiating Hydraulic Fill Projects as well.

SEMINARS / CONFERENCES / EVENTS

Plans for 2013 include two IADC Seminars on Dredging & Reclamation in Brazil and Delft; WODCON in Brussels; WEDA in Hawaii; the World Ocean Council Sustainable Ocean Summit in Washington and many other water-related events.
Education and the dissemination of information about state-of-the-art dredging and maritime construction stand high on the list of the priorities of the International Association of Dredging. With this in mind IADC publishes *Terra et Aqua*, the Facts About series, *Dredging for Development* and other books. IADC also supports the publication of third-party books such as *Hydraulic Fill Manual*, Clarksons’ *The Dredger Register* and FIDIC’s *Form of Contract for Dredging and Reclamation Works*.

Educational outreach is also achieved by organising seminars worldwide. The first of 2013 will be the International Seminar on Dredging and Land Reclamation, to be held in Búzios, Brazil in April. Brazil was chosen because of the enormous amount of activity going on in Latin America. That will be followed by the IHE-UNESCO seminar in Delft, an annual event that informs young professionals doing advanced water-related studies specifically about dredging. Ultimately this helps increase knowledge of sound dredging techniques in emerging nations. In both these seminars, the instructors are dredging experts with both academic and professional credentials.

Looking further forward, a reprisal of the “Early Contractor Involvement Forum” is planned for the autumn in Kuala Lumpur, Malaysia. This Forum, successfully held in London in 2011, is an interactive event which stimulated surprising, sometimes controversial, dialogues amongst participants. The Forum examines the full scope of maritime construction projects. It explores the possibilities for the exchange of knowledge and experiences between clients, consultants and contractors even before the launch of a project.

To execute successful dredging operations means finding the optimal working methods. To find these optimal methods demands extensive research and modelling and these are then tested by practical application and trials. The articles in this issue of *Terra et Aqua* clearly demonstrate the applied science of dredging: One is the IADC Young Author’s Award paper from CEDA Dredging Days in Abu Dhabi which reports the results of measuring the theoretical productions of “the pilferer” draghead with reality as it was used for a dredging project at the River Scheldt, Belgium. Two other articles focus on environmental monitoring under very different circumstances – one at disposal sites in Lough (lake) Foyle in Northern Ireland and the other at the land reclamation site of the Maasvlakte 2 in the Netherlands. Quite different projects, but both demanded scientific accuracy and verification of results.

The beauty of dredging – and the challenge – remains this intersection of engineering theory, research and modelling with practical application to site-specific circumstances. And that practical application is what makes dredging the backbone of the world’s economic engine – providing goods and energy and new land, and creating millions of jobs at ports, harbours and elsewhere.
ABSTRACT

A draghead known as “the pilferer”, based on the principle of erosion, was invented by DEME dredging company. Using the concept of van Rhee (2010) the erosion behaviour of this particular draghead was investigated. The erosion rates created by the flow velocity along the seabed are calculated using potential flow theory. Certain assumptions were made during the use of this theory. These assumptions were validated in a Computational Fluid Dynamics (CFD) model using OpenFOAM. The CFD model also gave a better understanding of the flow field of a draghead during the erosion process. With these theories the productions of the erosion head were calculated and compared to reality. Agreement between calculations and the real situation is promising. The theory explained in this research can also be used to describe the erosion behaviour of other types of dragheads.

The author wishes to thank C. van Rhee, Professor, Delft University of Technology, Section Dredging Engineering, Faculty Mechanical, Maritime and Materials Engineering, and M. van den Broeck, Head Research, Method, Production and Engineering department, DEME, Zwijndrecht, Belgium for their contributions to this research. This article originally was published in the Proceedings of the CEDA Dredging Days 2012 in Abu Dhabi and is reprinted here in an adapted version with permission.

INTRODUCTION

In 2010 DEME (Dredging, Environmental and Marine Engineering) wanted to tender for a dredging project at the River Scheldt in Belgium. At this project site two 50kV electricity cables were buried which could not be touched, yet dredging works needed to be done in their vicinity. As a result of years of erosion from river flow and other natural effects, the depth of these cables was not precisely known. Therefore careful dredging was recommended. DEME wanted to make use of one of their existing vessels without much extra equipment onboard and therefore they decided to develop a specialised type of draghead. The results was the so-called “pilferer” draghead (see Figures 1 and 2), which is based on the principle of erosion and can remove small layers of soil without really touching the river- or seabed. This would allow careful dredging without damaging the buried cables.

The draghead is the part of the dredging excavating system that is in touch with the seabed. Most dragheads excavate soil from the seabed with the help of jet water flow and a number of teeth. The pilferer draghead is designed without teeth and with jets that have a relatively low jet water velocity (up to 10 m/s). These jets are positioned in such a way that their only purpose is to create a higher water flow to the draghead for better transport of the eroded sand particles. The erosion is set up by a flow along the seabed which is created by the suction effect of the centrifugal pump. This topic was a research project as part of an MSc study in the Section Offshore and Dredging Engineering at Delft University of Technology, carried out under the guidance of Professor C. van Rhee and started in March 2011. For describing the erosion behaviour of the pilferer draghead actually three main ingredients are necessary:
1. erosion theory
2. flow velocities along the seabed
3. groundwater flow
These three subjects were each investigated separately and brought together at the end of the research for describing the erosion behaviour of the pilferer draghead. In this article, first a description is given of erosion theory, then how the flow velocities along the seabed evolve are explained, next the groundwater flow theory is clarified, and finally these three subjects are combined to explain the final erosion behaviour of the draghead.

Although in this research only the erosion behaviour of the pilferer draghead was investigated, using the theory explained here, the erosion behaviour of other types of dragheads can also be investigated.

**EROSION THEORY**

The research started by comparing several erosion theories in a literature study. Three erosion theories were found to be appropriate for this research. These were the theory of van Rijn (1984), the theory of Visser (1995) and the theory of van Rhee (2010). Visser (Bisschop, Visser, van Rhee and Verhagen, 2010) compared these theories with his theory and measurements and came to the conclusion that the van Rhee theory (2010) was the most consistent with the real situation. This is one of the reasons why the van Rhee theory was used for this research.

The theory of van Rhee (2010) is based on the theory of van Rijn (1984). The theory of van Rijn (1984) can only be used for erosion created by low velocities (< 10 m/s). With the adjustments of van Rhee, this theory can be used for erosion created by higher flow velocities (≥ 10 m/s). Because during dredging the flow velocities that are encountered are higher than 10 m/s, the van Rhee theory (2010) was preferred for this research.

Figure 1. A 3D drawing of the pilferer draghead. The draghead is designed without teeth but with jets with a relatively low jet water velocity, which are positioned so that they purposefully create a higher water flow to the draghead for transporting the eroded sand particles.

Figure 2. Two views of the pilferer with a close-up of the waterjets.
IADC YOUNG AUTHORS AWARD
PRESENTED AT CEDA DREDGING DAYS
ABU DHABI, UAE, DECEMBER 12-13 2012

The International Association of Dredging Companies (IADC) presented its Best Paper Award for a Young Author for the 28th time at the CEDA Dredging Days on December 13, 2012 in Abu Dhabi, to Mr. Arnaud Verschelde for his paper “Erosion Behaviour of a Draghead”. Mr. Verschelde started his studies at Delft University of Technology in 2006. In 2009 he obtained his bachelor degree of Marine Technology. He continued his studies with a Master’s degree in Offshore and Dredging Engineering. In 2011 he graduated from the Delft University of Technology Faculty of 3ME (Mechanical, Maritime and Materials Engineering). His graduation project was developed in cooperation with Dredging International, part of the DEME (Dredging, Environmental and Marine Engineering) group. In 2012 his graduation project was selected as best graduation project of 2011-2012 by the Dutch engineers society KIVI (Koninklijk Instituut van Ingenieurs) Nijm. He is presently a Project Engineer Automation at DEME.

The purpose of the IADC Young Authors Award is to stimulate the promotion of new ideas and to encourage young professionals under the age of 35 working in the dredging industry and related fields. It is presented each year at selected conferences at the recommendation of the Conference Paper Committee. The winner receives €1,000 and a certificate of recognition. The paper may then be published in Terra et Aqua, IADC’s quarterly journal.

Figure 3. Division of the dredging profile into several intervals.

Erosion Behaviour of a Draghead

The van Rhee theory (2010) is based on the following equation:

\[ v_e = \frac{E - S}{\rho_s (1 - n_0 - c_b)} \]  

(1)

where:
- \( v_e \) = erosion velocity
- \( S \) = settling flux
- \( E \) = pick-up flux
- \( \rho_s \) = density of particles
- \( \rho_w \) = density of water
- \( n_0 \) = porosity of the settled bed
- \( c_b \) = near-bed volumetric concentration
- \( w_s \) = settling velocity

With certain assumptions and sub-calculations (van Rhee, 2010) equation (1) can be rewritten to:

\[ v_e = \frac{1}{1 - n_0 - c_b} (\phi_P^1 \sqrt{g \Delta D} - c_b w_s) \]  

(2)

If this equation is solved one can calculate the erosion velocity. \( w_s \), the settling velocity, in equation (2) was set to 0 for this research because it was assumed that settling would not occur, only erosion. In equation (2) lies the difference with the van Rijn theory. The van Rijn pick-up function adapted for high-speed erosion using the new critical Shields parameter is used in this expression (2). The adapted function is defined as follows:

\[ \phi_P^1 = 0.00033 \cdot D_s^{0.3} \cdot \left( \frac{\theta - \theta_{cr}^1}{\theta_{cr}^1} \right)^{1.5} \]  

(3)

where:
- \( D_s \) = dimensionless particle diameter
- \( \theta_{cr}^1 \) = adapted critical Shields parameter

This adapted critical Shields parameter \( \theta_{cr}^1 \) is different from van Rijn in that it takes into account a hydraulic gradient and the slope angle. The adapted critical Shields parameter is:

\[ \theta_{cr}^1 = \theta_{cr} \left( \frac{\sin(\phi - \beta)}{\sin \phi} + \frac{v_e}{k_1} \frac{n_1 - n_0}{1 - n_1} \frac{A}{\Delta} \right) \]  

(4)

where:
- \( \theta \) = Shields parameter
- \( D_{50} \) = median particle size diameter
- \( \phi \) = angle of internal friction
- \( \beta \) = slope angle
- \( k_1 \) = permeability at moment of dilatation
- \( n_1 \) = porosity at moment of dilatation
- \( A \) = constant describing single particle or continuum mode stability
- \( \Delta \) = relative sediment density

\( \theta \) is the Shields parameter and is a non-dimensional number for describing the bed shear stress. If the critical Shields parameter \( \theta_{cr} \) is exceeded then the initiation of motion of the sand particles will start (Miedema, 2008). The critical value of \( \theta \) in equation (4) is multiplied by a term which includes the slope angle and an extra term which is important at high erosion velocities. This last term is a multiplication of the hydraulic gradient that is present during erosion with a constant.

The hydraulic gradient results from the dilatant behaviour from the upper part of the soil that is subjected to the flow. The slope angle of the soil is rapidly changing during the dredging process of erosion. This problem is encountered by dividing the erosion zone into several subparts and constantly calculating the erosion and slope angle subsequently (see Figure 3). This calculation was done numerically by solving
Sand particles will start (Miedema, 2008). The critical value of $\theta$ by a term which includes the slope angle and an extra term which is important at high erosion account a hydraulic gradient and the slope angle. The adapted critical Shields parameter is:

$$\theta = \phi \sqrt{\frac{g}{\Delta A}} - c_w w_c = 0$$  (5)

FLOW VELOCITIES ALONG THE SEABED

For erosion to occur a flow along the seabed, which picks up the sand particles and brings them to the suction mouth, must be present. This flow is created by the pressure difference between the inside and the outside of the draghead. This pressure difference is set up by the centrifugal pump of the trailing suction hopper dredger. The problem of determining the evolution of the flow velocities along the seabed was solved with the potential flow theory. The assumption of the pattern of the potential flow lines and the corresponding changing seabed profile are shown in Figure 4. In this figure the potential lines are drawn when the flow comes from the left-hand side only. This is done for clarity of the picture.

In reality, the flow comes from the left- and right-hand sides. The assumption was made that these flows will interfere and on the middle line of the suction mouth there will be no flow. This explains the horizontal path of the dredging profile in Figure 4. Also some turbulence will occur when the flow enters the suction mouth of the draghead.

In Figure 4, $V_p$ is the undisturbed flow going to the suction mouth and $V_m$ is the mixture velocity. $SO_p$ is the suction opening at the left hand side and $SO_m$ is the suction opening at the other side of the draghead. $\phi$ is an indication of the potential line with an increasing indices for the potential lines moving further away from the suction mouth. The potential lines combined with the erosion theory described in the first part of this article can determine the final seabed profile and the geometric production of the draghead.

To determine the potential lines, first a calculation was made of the flow created by the centrifugal pump. This flow was calculated with the help of the vacuum formula for a centrifugal pump. This formula consists of a pressure head, a velocity head and an elevation head. The velocity head includes extra losses of the flow going to the centrifugal pump. For the frictional losses the Wilson model for inclined flow was used (Matousek, 2004).

Other frictional losses are created by the contraction of the flow coming from outside the draghead and going to the suction mouth. When the flow enters the suction mouth and goes through the draghead, the flow expands again going to the suction pipe. A simple drawing of this process is shown in Figure 5. This is again for the clarity of the figure shown for the flow going from one direction to the suction mouth. In reality the flow comes from two directions. The losses created by the contraction and expansion of a flow are described by Carnot (Becker, 1977).

The vacuum formula calculates the flow velocity in the suction pipe. By the relationship between the diameter of the suction pipe and the suction opening, the flow velocity at the suction opening could be predicted. The evolution of the flow velocities along the seabed could then be found with the help of the potential lines shown in Figure 4. This was done by taking the calculated flow velocity under the suction mouth, calculating the length of the corresponding potential line and then frequently calculating the length of the potential lines (see Figure 4) and the corresponding flow velocity at that position. This made it possible to predict the flow velocities along the seabed necessary for creating erosion.

For the pilferer draghead three possible suction openings were made: 20 cm, 10 cm and 5 cm. For the 20-cm suction opening realistic results were found for the flow velocity under the suction mouth with the theory described here.

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**Figure 4.** Potential (green) lines and flow (blue) lines at the suction mouth of the draghead.

**Figure 5.** Illustration of contraction and expansion of the flow (here outer flow lines are shown).

**Figure 6.** Cross-section of the CFD results with the flow velocities of the pilferer draghead.
For smaller suction openings (10 and 5 cm), no realistic results were produced. This can be explained by the fact the flow velocities under the suction mouth can increase to high values (locally this can be higher than 30 m/s) and the Wilson model is not developed to work with such high accelerations of the flow. Therefore it was decided to use a Computational Fluid Dynamics (CFD) model. This model was also necessary to check whether the assumptions made in the beginning of this research were correct. For the CFD modelling the programme OpenFOAM was used. The Navier Stokes equations were solved using the RANS (Reynolds Average Navier Stokes) method. This solution was done with the help of the SIMPLE FOAM solver of the OpenFOAM CFD library (SIMPLE = Semi-Implicit Pressure-Linked Equations).

In Figure 6 some pictures of the CFD calculation results are given. Some results of the CFD calculation of the flow velocities in and around the draghead are shown when the draghead is perpendicular to the seabed. These are two cross-sections of the pilferer draghead; one cross-section from the side (see Figure 6a) and one cross-section from the front (see Figure 6b) of the draghead. These cross-sections are taken at the middle line of each side. Figure 7 gives a more detailed view of the suction mouth and its flow velocities calculated with the CFD programme OpenFOAM. In these calculations the flow velocities are calculated for a flow velocity set up by the pump. The scale next to each picture in Figure 6 indicates the values of the flow velocities. The closer to the color red, the higher the flow velocity. The flow velocity set up by the pump is here 10 m/s.

These values were taken from the real measured pump flow velocities onboard DEME’s trailing suction hopper dredger Jade River. The average suction opening used for the calculation shown here is 20 cm. The local accelerations of the flow going under the suction mouth into the draghead were also noticed in the CFD results (see red area in Figure 6). For smaller suction openings, this effect was even more noticeable, which agreed with the assumptions made in the beginning of the research (the contraction and expansion of the flow shown in Figure 5 and the local accelerations created by these effects). The inclination angle of the suction pipe according to the ship is for this calculation set to 45 degrees. This is done because then the draghead is perpendicular to the seabed. According to the calculations this situation gives the highest geometric productions. This is an effect that was also experienced in the field.

Note that the bottom line in Figure 6 is kept fixed. This line represents the seabed. Also one can see that in Figure 6a there is more flow coming from the left-hand side than from the right-hand side. This is because at the left the suction opening is bigger, allowing more flow to pass. In reality the seabed will deform and the flow will be coming more from the right-hand side than is shown in Figure 6a. Therefore, for this research, the flow velocity just under the suction mouth is taken and the other flow velocities in the erosion affected zone are calculated with the potential flow theory. Combining this theory with the theory explained under “Erosion Theory” above, it was now possible to determine the seabed profile.

**GROUNDWATER FLOW**

During the excavation process of sediment from the seabed, groundwater flow is present. This groundwater flow moves towards the suction opening of the draghead creating an area under the suction mouth at which the stability of the sand particles is reduced. If the stability of the sand particles is lower, the sand can be eroded more easily. Therefore the groundwater flow theory is examined here to see if this flow is great enough to increase the erosion process.

Figure 8 shows approximately what the groundwater flow in the width of a draghead looks like. The function describing the groundwater flow going from left to right was deduced as:

$$\phi = -\frac{\phi_1}{\pi} \cdot \tan^{-1} \frac{x}{y}$$

(6)

The function is the same for the flow going from right to left, except for a sign difference:

$$\phi = \frac{\phi_1}{\pi} \cdot \tan^{-1} \frac{x}{y}$$

(7)

It should be noted that the $\phi_1$ in the formulas (6) and (7) represents the same potential lines (the green lines) as defined in Figure 4. The groundwater flow can be found by super-position of formulas (6) and (7). The coordinate system for defining the groundwater flow of the pilferer draghead was chosen as shown in Figure 9.

In Figure 9, ‘b’ represents the width of the draghead. With the help of Figure 9 and formula (6), it was deduced that the flow
where:

\[ b = \text{width of the suction mouth of the draghead.} \]

The implementation of the groundwater flow theory in the final calculation of the erosion behaviour of the draghead only gave a slight improvement to the real situation. The calculated geometric productions matched the real productions a few m\(^3\) per hour more. Still this theory was an improvement of the calculations in comparison to the real production. The final calculation of the geometric productions is explained in the next paragraph.

### CALCULATION OF THE EROSION BEHAVIOUR OF THE DRAGHEAD

The theories described above were combined in a MATLAB calculation model. With this model the removed amount of sediment was calculated. The dredging profile was set up by calculating the slope and the erosion velocity at a certain distance between the boundaries of the erosion-affected zone. These boundaries were determined with the help of the corresponding potential lines and transport parameter \( T \).

\[
T = \frac{\phi - \phi_{cr}}{\phi_{cr}}
\]

(11)

The distance between the boundaries of the erosion-affected zone were divided into a certain amount of intervals. These intervals needed to be made small enough so as not to have an overestimation of the calculated geometric production. This phenomenon is explained by the fact that the flow velocity slowly increases going to the suction openings of the draghead. Closer to the suction openings the flow velocity will rapidly increase. If the amount of intervals chosen is too small, the acceleration of the flow going to the suction mouth is overestimated. This results in erosion rates that are too high. With the help of the MATLAB code the correct amount of intervals was found. This was done by searching for a number of intervals at which the dredging profile did not change anymore. If the amount of intervals exceeded this number and the calculated dredging profile remained unchanged, the correct amount of intervals was determined. Figure 10 shows a calculated MATLAB example of the dredging profile.

One should assume in Figure 10 that the draghead is located at position 0 of the x-axis. The calculated dredging profile shown in Figure 10 was done for a median particle size diameter \( D_{50} \) of 300 \( \mu \text{m} \) and an average suction opening of 10 cm. (This suction opening was taken at the middle line of the pilferer draghead.) The maximal flow velocity along the seabed was calculated to be 15.5 m/s. This was calculated with the help of the CFD model and the potential flow theory. For this example a soil layer of 11 cm is removed and the production was calculated to be 786 m\(^3\)/hour. In reality the production varied between 784 and 794 m\(^3\)/hour for this case.

**Figure 10.** Calculated dredging profile for a suction opening of 10 cm.
Another case that was investigated was for an average suction opening of 5 cm. The maximum flow velocity along the seabed was 30 m/s according to the CFD model. The median particle size diameter was 310 μm. The productions were in the range of 800 to 820 m³/hour. The calculated production was 816 m³/hour with a corresponding removed soil layer of 14 cm.

Several other cases were investigated and further agreement between the calculations and the real situations were found to be good. The maximum D₅₀ particle size diameter dredged with the pilferer draghead was 400 μm.

Later on it was decided to add a jet system to the pilferer draghead to create an extra water flow to the suction mouth of the draghead. It was assumed that this jet flow would not create erosion because of its low flow velocity (∼10 m/s), but this was not investigated and so it is not clear whether the jet flow actually does or does not create erosion. The jet flow was taken into account in the calculation of the dredging profile according to the jet flow concept of Pani and Dash (1983). This gave only a slight improvement in the calculated production values as compared to the real values.

CONCLUSIONS

During this research on the erosion behaviour of the pilferer draghead, several topics were investigated. The main topics of investigation were erosion, flow effects along the seabed during dredging and groundwater flow. These were analysed together to describe the final erosion behaviour of the pilferer draghead. Some elements such as the jet flow and the groundwater flow do not affect the results of this research significantly. Still they gave a small improvement of the calculated results compared to the real values.

It can, however, be concluded that the erosion theory and the theory describing the flow velocities along the seabed have a strong influence on the results of the calculations of the erosion behaviour of the draghead. The fact that the calculations and reality are matched quite accurately shows that the van Rhee erosion theory (van Rhee, 2010) is pointing in the right direction for describing erosion in dredging practice. This can be explained by the fact that the van Rhee theory takes into account the effect of dilatancy of sediment at high flow velocities during erosion. Van Rhee achieves this by taking the van Rijn pick-up function (van Rijn, 1984), valid for low-velocity erosion, and modifying it to deal with high-velocity regimes. This modification is done by changing the critical Shields parameter.

During this research the limitations of the Wilson model were encountered. For small suction openings where the flow locally accelerates strongly, the model could not be used anymore. Therefore a CFD model was chosen instead. In the beginning of this research certain assumptions were made regarding the contraction and expansion of the flow. These effects were found back in the CFD model. The CFD model thus gave a good understanding of the flow behaviour of the pilferer erosion draghead during dredging.

The pilferer draghead finished its job successfully at the River Scheldt in Belgium without damaging any buried cables. After this job the contractor, Dredging International, part of the DEME group, patented this erosion draghead.

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ABSTRACT

The Port of Londonderry is located at the point of discharge of the River Foyle into Lough Foyle, the lake on the western boundary of Northern Ireland, and is an important strategic business in the North of Ireland, which serves the entire region and promotes economic growth and stability. Historically the Port disposed of the entirety of its dredging requirement at the “traditional” disposal site within Lough Foyle. Because of changes in the dredging regime, new licensing was required. The local shellfisheries then objected to the increase in disposal at the currently used inshore disposal site at Redcastle and expressed a preference for alternative sites, principally McKinney’s Bank. The Port with the shellfishery industry undertook to apply for the alternative (McKinney’s Bank) site and an additional modelling exercise was then commissioned for this alternative site. The monitoring programme demonstrated that the changed regime of regular small-scale dredging and disposal of all dredged sediments at the new McKinney’s Bank disposal site has no significant detectable effect on water quality or seabed sediment characteristics within the Lough (lake), other than within the immediate environs of the licence area. It also demonstrated clearly the numerous benefits to the disposal of dredged material within the Lough.

Londonderry Port and Harbour Commissioners owns the copyright in reports by Anthony D Bates Partnership, Deltares and Aquafact that were commissioned for the purpose of relocating the silt disposal site. The authors wish to thank LPHC for consenting to the use of images and extracts from those reports for use in the technical paper presented here.

INTRODUCTION

The Port of Londonderry is located at the point of discharge of the River Foyle into Lough Foyle, the lake on the western boundary of Northern Ireland (opening photo) and is an important strategic business in the North of Ireland, which serves the entire region and promotes economic growth and stability. Historically the Port disposed of the entirety of its dredging requirement at the “traditional” disposal site within Lough Foyle. Historically the Port disposed of the entirety of its dredging requirement at the “traditional” disposal site within Lough Foyle. This site had been in use since the 19th century and was centred at approximately 55° 09.5’ North, 007° 04.5’ West; it is still shown on the current Admiralty navigation charts although it is annotated as disused (Figure 1).

Until 1977, when the Port’s bucket dredger and self-propelled hoppers were withdrawn from service, quantities in the range of 86,220 m$^3$ to 180,090 m$^3$ of mixed dredged materials were disposed of at the traditional site and in 1977/78 1.055 million m$^3$ were disposed of with no adverse effects within Lough Foyle. In 1982 a volume of 324,750 m$^3$ and in 1983 some 263,053 m$^3$ were removed from the channels and berths and were either disposed of at the traditional site or else dispersed during dredging. That is, this large volume of material remained within Lough Foyle.

Routine maintenance dredging from 1984 to 1994 was sporadic and was considered unlikely to have exceeded 100,000 m$^3$ per annum. In 1993/94 the Port moved its main base of operations from the constrained confines of the city to new berths and shore facilities at Lisahally. The new facility was supported by a deepened access channel through Lough Foyle (see Figure 2), which was dredged during the winter of 1993/94.

In support of the new access channel, 2D mathematical modelling was undertaken and
A variety of options for disposal were investigated including land reclamation and beach recharge. One of the favoured sites for disposal was near to the mouth of the Lough at McKinney’s Bank (Figure 2). Modelling proved that the proposed McKinney’s Bank site would have been suitable for disposal of whatever arose from the capital dredging without causing any adverse effects within the Lough. However, following objections from the Lough’s fishing industry, an agreement was reached that the capital dredged materials (a paid volume of some 728,060 m³) be disposed of at sea far outside of the Lough (Figure 2). This action removed material from circulation within the Lough Foyle sediment cell and the Natural Heritage Directorate (the predecessor of the Northern Ireland Environment Agency) objected strongly to the material being removed and lost to the sediment system, but the views of the fishermen prevailed.

Since the deepening of the access channel, the Port has had a regular maintenance dredging requirement for the channel amounting to about 95,000t annually which has been disposed of mainly (80,000t) offshore by contract dredgers with the balance (15,000t) being disposed of at the Redcastle disposal site (shown at the centre of Figure 1) by the Port’s own dredger.
The major part of the maintenance dredging has been undertaken by contract dredgers in single campaigns as required by conditions within the Port and Harbour, with a smaller amount removed by the Port’s own dredger – originally the Mary Angus and, now, the Lough Foyle – to keep the channel clear between the more substantial and more general contract maintenance dredging campaigns. No contract dredging has been carried out since the Port acquired the Lough Foyle in 2010. Until recently, sand dredged by the Port dredgers was not disposed of, but is landed ashore for beneficial use.

The current inshore site at Redcastle within Lough Foyle has been licensed since 1995 for the disposal of 15,000t annually by the Port’s own dredger – originally the Mary Angus and, now, the Lough Foyle – to keep the channel clear between the more substantial and more general contract maintenance dredging campaigns. No contract dredging has been carried out since the Port acquired the Lough Foyle in 2010. Until recently, sand dredged by the Port dredgers was not disposed of, but is landed ashore for beneficial use.

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The location of the current Redcastle site was established after extensive consultation with, amongst others, the Foyle Fisheries Cooperative after trial shellfish dredging in 1994. The trial shellfish dredge established that the nearest known shellfish beds were located 1000 m (oysters) and 3500 m (mussels) away and it was concluded (Anthony D Bates Partnership, 1994) that the site was the best practicable environmental option (BPEO). Despite establishing the disposal site in dialogue with the Lough Foyle fishing industry much commercial shellfishery development has subsequently taken place up to and, it is understood, even within the boundaries of the licensed disposal site.

Note that the existing Redcastle licensed sediment disposal site is not correctly shown on the current Admiralty Chart 2511 in respect of either location or size (see Figure 1). It is incorrectly charted as a 400-m diameter circle with its centre 100 m east of the licensed location but its licensed size is actually much bigger; it is a 0.25 nautical mile radius (926-m diameter) circle. The disposal of maintenance material at the two existing (Redcastle and offshore) sites was previously covered by the issue of two separate licences but, more recently and logically, has been amalgamated under a single licence.

### PROPOSALS TO EXPAND USAGE OF THE REDCASTLE DISPOSAL SITE

As mentioned above, the Port recently purchased the trailing suction hopper dredger renamed Lough Foyle (previously, Saeftinge) (Figure 3), which is outfitted with bottom doors. This vessel is capable of maintaining the channel depth of the Port’s recent annual requirement of 80,000t without the need for periodic contract dredging. The offshore disposal site (see Figure 2), which has taken the majority of the dredged sediment since the Lisahally berths were created, is a round trip of approximately 65 km from the Redcastle disposal site with consequentially substantial energy consumption and associated carbon emissions. Therefore, to keep sailing times, and hence costs, down the Port has sought (from 2008 to 2010) to re-establish the former practice of disposal within the Lough.

In practice, this would mean the disposal of up to 80,000t annually at the Redcastle site. However, dredging and disposal would be regular – no more than one trip per day, five days per week – such that no more than a couple of thousand tonnes a week would be relocated within the Lough. This is in sharp contrast to the contract dredging situation, when up to 15,000t was sometimes disposed of within the Lough in only a few days.

The proposal to keep the dredged sediment within Lough Foyle would be in line with the stated preference of the NIEA’s predecessor (Connor J, 1995) and various official bodies, “… to retain dredged sediment within the coastal cell or sediment transport system from which it is removed.” It is, however, a change from recent practice and would require going through the full FEPA (Food and Environmental Protection Act) licensing process.

### THREE-DIMENSIONAL MODELLING

An extensive data collection and modelling exercise (Deltares, 2009) was conducted from 2008 to 2009. A dedicated Delft 3D-FLOW model was developed for Lough Foyle with a high level of detail in the areas of interest (i.e., dredged sediment disposal sites). To demonstrate the predictive value of the hydrodynamic model, the model was calibrated and validated with field measurements of water levels and three-dimensional current measurements (see Figure 4, which shows a vector plot and comparison with the model current predictions and field measurements). These measurements were collected in transects around the area of interest in a survey campaign dedicated to this study.
Furthermore, other data sources, including water level data, salinity data (conductivity, temperature and density (CTD) profiles) and sediment concentration data, were used to further validate the model's predictive value. This calibration and validation has demonstrated that the developed model was very capable of replicating the present behaviour of the natural system and predicting expected future effects of proposed different dredging regimes.

The modelling exercise presented the existing situation (15,000t per annum) and showed the patterns of redistribution of sediment within Lough Foyle from the disposal ground at Redcastle as an “excess” quantity above background levels (see Figure 5). Other simulations were carried out for the situation of 60,000t and 80,000t disposed of annually at Redcastle.

The modelling showed that as a result of the infrequent sediment discharges at the disposal site location in the new regime, the dredging-induced suspended sediment concentrations can be increased in the direct vicinity of the disposal site, but only for short periods. Lower suspended sediment concentrations are expected compared to the existing dredging regime involving a contractor dumping high volumes in a short period of time. Because of the increased amount of annually discharged sediment, the sedimentation as a result of the new dredging regime inevitably shows an increase compared to the old regime.

The model showed that the impacts of increased sedimentation >10mm were mainly restricted to an area local to the disposal site (see Figure 6). The majority of the additional annual sedimentation is expected in the East channel, with a typical layer thickness of 5 mm.

Because the local shellfisheries objected to the increase in disposal at Redcastle (see below), additional modelling of disposal at a potential alternative site at McKinney’s Bank was required. The sedimentation pattern after one year (long-term simulation) of disposal of 80,000t at McKinney’s Bank is presented in Figure 7.

In this case, approximately 50% of the discharged sediments are predicted to be transported out of the Lough because of the close vicinity of the Lough’s entrance. The modelling shows that after one year, the excess sedimentation resulting from the full dredging operation is limited to a number of patches with sedimentation over 1 mm on shallow areas inland of the disposal site and on the north shore of the Lough and that the discharged sediment will be transported away from the disposal site. A few patches are expected to have a local sediment layer thickness up to a few tens of millimetres, but most patches will have a thickness of a few millimetres.

**THE REGULATORY CONTEXT**

**Sediment contamination**

The normal regulatory process for the disposal of dredged sediment requires a demonstration that the sediment is within acceptable limits set out by OSPAR (Convention for the Protection of the Marine Environment of the North East Atlantic). This is done by testing sediments for their physical and chemical properties. Samples were taken for testing from the access channel (see Figure 8), which is the source of the proposed maintenance dredging.

The samples were tested and tested against the widely accepted CEFAS “Action Levels”
shown in Table I (CEFAS is the UK Government’s Centre for Environment, Fisheries and Aquaculture Science). The CEFAS guideline action levels for the disposal of dredged material are not statutory contaminant concentrations for dredged material but are used as part of a weight of evidence approach to decision-making on the disposal of dredged material to sea. Table II shows the results of the testing.

ENVIRONMENT AND FISHERIES
After the modelling was complete, a presentation was made to principal consultees – NIEA (Northern Ireland Environment Agency), DARD (Department of Agriculture and Rural Development) and the Loughs Agency. The Loughs Agency recommended that the Port discuss the results with the commercial shellfisheries and open a dialogue. This was done, but despite the prediction of only minor impact, the shellfisheries expressed a preference for alternative sites, principally McKinney’s Bank. This is approximately the same location rejected by fishery industry for disposal of capital dredging in 1993. It is important to note that the new site now proposed was identified by the shellfishers themselves. The Port undertook with the shellfishers to apply in the future for the alternative (McKinney’s Bank) site and an additional modelling exercise was then commissioned for this alternative site.

Notwithstanding the preference expressed by the shellfishery industry for an alternative site, an application was made for disposal of all the Port’s 80,000t of maintenance dredging at the existing Redcastle disposal site because it was feared that unresolved national (Ireland/United Kingdom) jurisdiction concerns at the proposed new McKinney’s Bank site would delay licensing.
The fishery industry’s expected objections to this licence application were received and a meeting to discuss the situation was attended by NIEA, LPHC, the Loughs Agency and the Port’s consulting engineers, Anthony D Bates Partnership (ADBP). At the meeting, a compromise FEPA Licence for 30,000t annual disposal in Lough Foyle was agreed upon together with the agreement to proceed with an application for full disposal at McKinney’s Bank.

Ultimately, however, the monitoring requirements attached to the 2010 FEPA Licence for disposal of 30,000t annually at the current Redcastle site proved financially too onerous for the relatively small increase in disposal tonnage and the Port decided therefore to revert to the previous licensed tonnage, which did not require monitoring to be conducted. The 2010 FEPA Licence was accordingly varied back to 15,000t at Redcastle and 65,000t offshore.

**ENVIRONMENTAL CONSIDERATIONS AT REDCASTLE**

CEFAS had carried out a baseline survey of the shellfish resource in Lough Foyle on behalf of the Loughs Agency in 2007. Figure 9 shows a distribution map of oyster and mussel grounds resulting from the CEFAS study. Oyster ground was typified not only by the presence of oysters but also of suitable shell cultch.

Large areas of the Lough are in use for mussel relaying (i.e., farming) and there are also considerable stocks of wild mussels either naturally settled or remnants of previous relaying exercises. Mussels are relaid onto ground that has been cleaned by (mussel) dredging. A total of approximately 32% of the Lough’s entire surface area is occupied by relaid mussels, a quarter of which was considered unproductive (CEFAS, 2007). Approximately 42% of the Lough can be characterised as oyster grounds, more than half of which contained significant amounts of oysters during the 2007 CEFAS survey.

Additional species such as green crabs (*Carcinus maenas*), whelks (*Buccinum undatum*), cockles (*Cerastoderma edule*), palourde clam (*Tapes senegalensis*) and the trough shell (*Spisula solida*) were recorded during the CEFAS (2007) survey.

The existing disposal area is located on potential oyster ground, relaid mussel ground and undifferentiated ground. The disposal of sediment on any of these grounds will impact on the resident fauna within the area. While the proposed quantities of sediment (60,000t or 80,000t annually) are larger than is disposed of currently (15,000t), given the much larger timeframe over which the sediment is disposed of in the proposed new disposal regimes, tidal movements and variation in individual cargo disposal locations, the depth of sediment in the disposal site at any one time will not vary from what is present under the existing regime (approximately 1.0-1.5 m). The larger quantity of sediment disposed under the proposed new disposal regimes will result in a larger quantity of sediment being dispersed over the Lough over a one-year period. However, these levels are all less than 10 mm deep. The specific impacts of this sediment dispersal on the key shellfish species is discussed below.

### Table I. CEFAS Contaminant Action Levels.

<table>
<thead>
<tr>
<th>Contaminant</th>
<th>Action Level 1 (μg/g wet weight)</th>
<th>Action Level 2 (μg/g wet weight)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arsenic (As)</td>
<td>10</td>
<td>25-50</td>
</tr>
<tr>
<td>Mercury (Hg)</td>
<td>0.15</td>
<td>1.5</td>
</tr>
<tr>
<td>Cadmium (Cd)</td>
<td>0.20</td>
<td>2.5</td>
</tr>
<tr>
<td>Chromium (Cr)</td>
<td>20</td>
<td>200</td>
</tr>
<tr>
<td>Copper (Cu)</td>
<td>20</td>
<td>200</td>
</tr>
<tr>
<td>Nickel (Ni)</td>
<td>10</td>
<td>100</td>
</tr>
<tr>
<td>Lead (Pb)</td>
<td>25</td>
<td>250</td>
</tr>
<tr>
<td>Zinc (Zn)</td>
<td>65</td>
<td>400</td>
</tr>
<tr>
<td>Organotins (TBT, DBT, MBT)</td>
<td>0.10</td>
<td>1.0</td>
</tr>
<tr>
<td>PCBs Sum of ICES 7</td>
<td>0.010</td>
<td>–</td>
</tr>
<tr>
<td>PCBs Sum of ICES 25 congeners</td>
<td>0.020</td>
<td>0.20</td>
</tr>
<tr>
<td>Oil (petroleum hydrocarbons)</td>
<td>100</td>
<td>–</td>
</tr>
<tr>
<td>Sum of DDT</td>
<td>0.001</td>
<td>–</td>
</tr>
<tr>
<td>Dieldrin</td>
<td>0.005</td>
<td>–</td>
</tr>
</tbody>
</table>

**Notes:** Tick indicates below CEFAS Action 1 Levels. Cross indicates exceedance of CEFAS Action Level 1 but still substantially below CEFAS Action Level 2.

### Table II. Sediment Sampling Results.

<table>
<thead>
<tr>
<th>Contaminant / Compound</th>
<th>Sample 1</th>
<th>Sample 2</th>
<th>Sample 3</th>
<th>Sample 4</th>
<th>Sample 5</th>
<th>Sample 6</th>
<th>Sample 7</th>
<th>Sample 8</th>
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</thead>
<tbody>
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<td>✓</td>
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<tr>
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<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
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</tr>
<tr>
<td>Arsenic</td>
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<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Cadmium</td>
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<td>✓</td>
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<tr>
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<td>✓</td>
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<td>✓</td>
<td>✓</td>
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<tr>
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<td>✓</td>
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</tr>
<tr>
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<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
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<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Zinc</td>
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<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>PCBs</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Organotins</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
</tbody>
</table>
Table III. Summary of Critical Thresholds for Oyster (Ostrea edulis) Beds.

<table>
<thead>
<tr>
<th>Species</th>
<th>Parameter</th>
<th>Optimum Range</th>
<th>Maximum Tolerated</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ostrea edulis</td>
<td>Suspended sediment</td>
<td>&lt;100 mg/l</td>
<td>Tolerant of short periods of high turbidity.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>&lt;3 mm (larvae after attachment)</td>
<td>10-20 mm (adult)</td>
</tr>
<tr>
<td></td>
<td>Sedimentation</td>
<td>&lt;3 mm</td>
<td>1-2 mm (larval settlement)</td>
</tr>
</tbody>
</table>

Oysters

Oyster larvae appear to tolerate relatively high suspended sediment concentrations, as high as 400-800 mg/l (Germano and Cary, 2005). They require a clean, hard substratum (e.g., oyster shell or shell cultch) for attachment, but can tolerate thin layers of deposited sediments, perhaps up to 1 mm. After attachment, oyster larvae can tolerate deposition of 2-3 mm, but thicknesses >3-5 mm are likely to have some negative effects (Germano and Cary, 2005). Table III summarises the tolerance thresholds for oysters.

Larval settlement of oysters (which usually takes place during the summer months: June-September) is, however, sensitive to sedimentation levels greater than 1-2 mm (Table III). The model calculations show that in both proposed disposal regimes at Redcastle (i.e., 60,000t and 80,000t annually), this sedimentation threshold is exceeded over an area of approximately 10-15 km² within the Lough (Figure 6), partly overlapping with some of the current and potential oyster grounds (Figure 9). However, note that the threshold is also exceeded in the current disposal regime, although in a smaller area, but this has not impeded recruitment of oysters to date (CEFAS, 2007).

Furthermore, modelling results should be considered against the prevailing natural background sedimentation in the area, which could be in the same order of magnitude or more. In addition, storm events in the Lough, which is mostly rather shallow, are expected to wipe the oyster shells clean of built-up sedimentation.

Mussels

Previous studies on the effects of suspended sediments on adult mussels (Mytilus edulis) have shown that they are capable of coping with extreme high concentrations of suspended material (Kiørboe et al., 1980). The ability for mussels to effectively utilise suspended food particles for growth is optimal at concentrations below 50 mg/l and concentrations above 100 mg/l result in weight loss (Prins and Smaal, 1989).

Mussels can protect themselves from overloading by temporarily closing their valves and when given sufficient time (months), which may be expected to be the case in Lough Foyle, they can adapt their gills and palps to higher concentrations of suspended matter. The tolerance thresholds of mussels are summarised in Table IV.

Mussels are very tolerant of extremely high turbidities (see Table IV). Although incidental excess turbidities higher than 100 mg/l do occur near the disposal site (see Figures 6 and 9), excess turbidity never exceeds 10 mg/l for more than 5% of the time (over a 14-day spring-neap tidal cycle) except in a very small area near the disposal location. This will not have any impact on mussels (adults, larvae or spat).

Increased Disposal at Redcastle Site

The model demonstrated, in the main, the viability of disposal at Redcastle. Some concerns about the spat of native oysters were raised but these could potentially have been overcome by the implementation of a closed season. Sedimentation nowhere reaches lethal levels for mussels, except at the sediment disposal site and its immediate vicinity. Impacts of the dredging plume on mussel beds in Lough Foyle are therefore considered negligible.

ENVIRONMENTAL CONSIDERATIONS AT ALTERNATIVE MCKINNEY’S BANK DISPOSAL SITE

Figure 7 shows the sedimentation in metres after one year following the disposal of 80,000 tonnes of sandy silt at McKinney’s Bank. (For ease of reference, the locations of sediment monitoring sites imposed by the licence are also shown on this image to show their correlation with predicted sediment areas.)

Oysters

Adult oysters will not be affected by the sediment plume, as excess turbidities >10 mg/l are not sustained for more than 5% of the time (over a 14-day spring-neap tidal cycle) almost anywhere in the Lough, and sedimentation nowhere reaches lethal levels for adult oysters. Larval settlement of oysters (which usually takes place during the summer months, June-September) is, however, sensitive to sedimentation levels >2 mm. The model calculations show that this threshold is exceeded over an area up to approximately 5 km² within the Lough, overlapping only for a small part with potential oyster grounds. Therefore, relocating the disposal site to McKinney’s Bank causes no significant impact on oysters. In fact, the relocation of the disposal site would result in significant
improvements with respect to potential adverse effects on the settlement of oyster larvae compared to the use of the Redcastle site.

Mussels
Impacts of the dredging plume from the McKinney’s Bank disposal site on mussel beds in Lough Foyle are considered negligible. Mussels are known to be very tolerant of extremely high turbidities. Although incidental excess turbidities over 100 mg/l do occur in the vicinity of the McKinney’s Bank disposal site, excess turbidity never exceeds 10 mg/l for more than 5% of the time (over a 14 day spring-neap tidal cycle) except in an area limited to the McKinney’s Bank disposal site. This will not have any impact on mussels (adults, larvae or spat). Sedimentation nowhere reaches lethal levels for mussels.

Disposal at McKinney’s Bank
Clearly sedimentation and, therefore, impacts throughout the Lough are significantly lower if the alternative McKinney’s Bank disposal site is used rather than the existing Redcastle disposal site.

licensing
Following the encouraging predictions of the modelling in relation to the published knowledge concerning shellfish response, application was made for a licence to dispose of 60,000t annually at the McKinney’s Bank disposal site.

As is standard procedure, the application was subject to widespread consultation. No objections were received that were judged by NIEA to be of sufficient concern to justify refusal. However, as a precautionary measure, it was agreed that prior to the issue of a licence a programme of monitoring should be agreed between the Port, NEIA and the Loughs Agency. The agreed monitoring programme specified that turbidity levels be continuously monitored at a fixed station for a period commencing one month prior to the commencement of dredging and for three months thereafter. The location finally agreed for monitoring was: Glenburnie Light at 55° 10.41’N, 007° 1.56’W.

It was further agreed that 20 bed samples be collected on a grid basis from three locations (approximately seven per site). The sampling sites selected were those identified by the modelling process as the potential areas of highest deposition. The analysis of these samples was to determine if the particle distribution in the selected areas had been changed significantly during the initial six months of dredging and disposal.

In October 2010 a formal application was therefore made for the disposal of 60,000t annually at the McKinney’s site. Following a tendering procedure, a contract for monitoring was awarded to the Fisheries & Aquatic Ecosystems Branch of the Northern Ireland Agri-Food & Bioscience Institute (AFBI) for the provision, installation and operation of a fixed instrument. This was a fixed continuous turbidity monitor of the type “Hydrolab MiniSonde MS5”. The instrument was installed on 02 December 2010 to measure the following parameters: temperature; luminescent conductivity; and luminescent dissolved oxygen.
Upon installation of this instrument and the initial bed sampling NIEA granted a licence for the period 01 January to 31 December 2011 for 60,000 tonnes. Dredging and disposal operations by the Port dredger commenced on 11 January 2011. On 07 January 2011 the instrument was attended to download the collected data, but unfortunately it was found that the instrument attached to the Glenburnie Light had malfunctioned – a failure of the wiping mechanism caused an interference with the optical turbidity measurement. As a result, the data collected was not deemed reliable.

Fortunately, as a result of the extensive monitoring stations in the Lough, it was possible to interpolate between data sets routinely collected by AFBI at other locations within the Lough and mathematically deduce a substitute data set sufficient for the purpose of monitoring the effect of dredging and disposal.

Data from 07 January to 17 February 2011 was downloaded twice to minimise the risk of further failures – once on 11 January 2011 and again on 17 February 2011. No further malfunction of the instrument was noted.

Figure 11 presents the results recorded at that time (AFBI, 2011). The data indicates that tidal flow, as well as spring and neap cycles, are the dominant influence on the patterns of turbidity. Disposal activities at McKinney’s Bank disposal site have occurred on neap tides but have not caused any notable increase in turbidity levels.

To understand the effect of the dredging and disposal activity on turbidity levels the records obtained from the Glenburnie Light site (see Figure 10) were compared with contemporary records from two regular monitoring sites elsewhere within the Lough known as Lough Foyle North and South (see Figure 11). The results for all three sites are provided in Figure 13. The results of the second testing of seabed sediments at three sites were also favourable. The location of the three sites from which samples were taken is shown approximately in Figure 7.

The AFBI report (2012) provides the results of the sediment analysis and those results for Area 1 are provided in Figure 13. The results of testing at the other two sites also record no significant change in the characteristics of the seabed sediments. In fact, the AFBI report states that, “The three monitoring areas displayed statistically different sediment characteristics with subtle differences in the amount of fine material entrained within the samples. The differences were however consistent and stable; no statistical difference in the sediment composition or structure was detected over time”.

Figure 11. Turbidity (measured by optical backscatter) and Local Tide Height (above instrument) at Monitoring Stations within Lough Foyle. (All turbidity data have been normalised to a certified reference instrument for optimum comparability, and smoothed using a 3-hour rolling average.)
CONCLUSIONS

These conclusions regarding the effect of dredging and disposal are based on reports by AFBI on the results of monitoring of turbidity levels and other effects at Glenburnie Light in Lough Foyle. Glenburnie Light was chosen as a monitoring point as it is considered to be a convenient location at which the effect of dredging and disposal, if any, could be observed. The objective of the monitoring of turbidity levels at the Glenburnie Light was to determine whether or not the disposal of sediments during routine maintenance dredging activity causes any significant increase in turbidity relative to the ambient conditions in areas of the Lough that are remote from the dredging. The conclusion was that it does not, as is clear from examination of the recorded results that are illustrated in Figure 12.

The AFBI report states, “The combination of instrumental water quality monitoring and sediment analysis did not identify any significant transport (in the water column) or deposition of sediment in the monitored areas during or for the three months after the dredge disposal activity.”

It is apparent that the state of the tide is the predominant influence on sediment suspension and, furthermore, it is also clear that the level of suspension caused by tidal flow, particularly mid-flood and mid-ebb flow, is much greater than the effect of the disposal of dredged material. Occasional high terrestrial fluvial flows were also shown to result in raised levels of suspended sediments.

No correlation between dredging, disposal and turbidity levels has been identified. However, whereas the records of disposal available to AFBI are comprehensive, the records of dredging are not and hence it has not been possible to attempt any meaningful correlation between the act of dredging and turbidity levels. On the basis of the limited dredging activity data that has been examined, AFBI opine that there may be a weak but detectable affect. However, it is apparent that any affect is small in relation to the much stronger effects coming from the natural forces of tidal flow and wind generated waves over the many shallow areas of the Lough.

Other causes of sediment suspension, such as high fluvial flows, the navigation of deep draught vessels and the action of trawling when harvesting shellfish, can also be expected to have significant localised effects. Of these, from unrecorded observations, it will not be surprising if trawling has the greatest effect, but as this has not been measured, it is not certain.

The results of monitoring seabed sediments at three potential sediment receptor sites do not record any significant effect caused by the dredging and disposal activities. The AFBI report states that, “There has been no statistically detectable change in the sediment composition or structure at the three monitoring areas over time. The sediments from all three areas were characterised the same at the beginning, middle and end of the monitoring period. No significant changes in any of the sediment fractions were detected indicating that there had been no deposition of fresh material resulting from the dredge disposal.”

In summary, the monitoring programme has demonstrated that the changed regime of regular small-scale dredging and disposal of all dredged sediments at the new McKinney’s Bank disposal site has no significant detectable effect on water quality or seabed sediment characteristics within the Lough, other than within the immediate environs of the licence area.

The clear benefits of disposal of dredged material within the Lough include:
- the retention of sediment within the Lough;
- a large reduction in the carbon footprint of the disposal activity;
- reduced dredging cost, and
- the opportunity for maintenance dredging to be carried out by the port using local labour with consequent benefit to the local economy.

In all probability there is also a benefit to fisheries as a result of the modest, but regular reworking of the seabed sediments in areas of dredging and disposal with consequent increase in the availability of nutrients for shellfish and mobile species. This begs the question, why in the past have local fishing interests been so intransigent in resisting change when science has predicted no significant adverse effect?

The result of this unfounded attitude has been excessive cost and energy consumption, particularly associated with the channel deepening in 1993, when objections from fisheries interests resulted in all dredged material being disposed of outside of the Lough at a site so distant from the area of dredging as to be closer to Scotland than to Ireland. This situation persisted for maintenance dredging until the issue of the new licence in January 2011. Hopefully, henceforth, a more balanced approach that recognises the wider interests, not only of fisheries, but also of the environment, the local community and commerce will prevail.

REFERENCES


ABSTRACT

This is the second article in a series on the monitoring programme at Maasvlakte 2 in the Netherlands. The first article appeared in Terra et Aqua, number 129, December 2012 and described the framework of the monitoring of Maasvlakte 2 following the Environmental Impact Assessment and discussed the juvenile fish survey and the possible mismatch between cockles and algal bloom. This second article focuses on the monitoring aspects of silt (fines or SPM in the water column) resulting from the construction of Maasvlakte 2 and the possible effects on the benthic communities (mid and far field).

INTRODUCTION

The aspects that will be described are: the silt in the water column along the Dutch coast; the monitoring strategy for silt; and the effects on the food chain.

Silt in the water column is extremely variable in space and time. High concentrations of suspended silt as well as high concentrations in the seabed are found along the coast. The highest concentrations are in the region south of Scheveningen, especially in the “Voordelta”, whereas low concentrations are found further offshore. Owing to the residual current along the Dutch coast, silt is mainly transported in north-north-eastern direction. Because of the Coriolis force (the deflection of moving objects caused by the rotation of the Earth), the silt remains close to the shore.

A heavy storm has a large effect on the concentration of silt in the water column; the higher waves cause silt to be released from the seabed. Only after some time will such silt return into the seabed, for example as a result of the activity of benthic fauna, which is more active in summer than in winter. An increased flow velocity (during ebb and flood) also brings silt in suspension from the thin fluffy layer on the seabed that is present during slack tide.

Because of the expected effects of enhanced silt concentrations on the food chain, a condition was included in the permit for the construction of Maasvlakte 2 that silt should be monitored.

Regarding monitoring strategy for silt: Because statistical analysis of silt measurements, owing to the high variability and spatial autocorrelation, is complicated, a decision was made to develop a new modelling strategy, model supported monitoring, which is explained and discussed further in this article: All of the measurements gathered are input for the validation of a numerical model (MoS²).

Concerning the effects on the food chain: The dredging operations at sea for the construction of MV2 lead to extra fine particles from the trailing suction hopper dredger (TSHD) overflow. Silt, being part of the suspended particulate matter (SPM) in the water makes it turbid, with the result that the algae in the water (phytoplankton) receive less light. This allegedly slows down the growth of the algae and their spring bloom (peak) shifts to a later time.

Were this to happen, less food would be available for small creatures (zooplankton) in the water and those living on or in the seabed, such as shells and worms. This zooplankton and the benthic fauna are, in turn, eaten by fish. Birds, diving ducks in particular, also feed on benthic fauna. Other birds, such as gulls, enjoy fish. Reduced growth in algae may thus have possible consequences for the whole food chain. Therefore understanding how the
SPM is distributed before, during and after construction is important. By comparing these SPM patterns, any (negative) effects of sand extraction will become apparent (Figure 1).

Since benthic species are less variable within the year (between seasons) than algae (phytoplankton) and zooplankton (small animals floating in the water column and moving particularly with currents), the effects of large-scale interventions by human activities (for example sand mining) on benthic species are better indicators for changes in the environment. Also the effect of silt in the sediment on the benthic organisms is more direct. These organisms would perhaps have to work harder to filter the extra silt out of the water, thereby ingesting less food and, as a result, show less growth. Most species have a clear preference for certain grain sizes and mud contents in the sediment.

SILT MONITORING

In-situ silt measurements

For silt concentrations, the question is not of coincidental (high) values at a certain time in a

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**Figure 1.** Possible cause and effect chain initiated by extra fines (silt) in the water column.
certain place, but long-term deviations which could possibly be caused by the construction of Maasvlakte 2 (MV2). Only when these long-term deviations could not be explained by, for example, fluctuations in the climate or incidental peaks, such as heavy storms or high fluctuations in the volumes of silt brought from the rivers and from the coastal waters of Zeeland, Flanders and France, might they come from the MV2 construction.

Silt measurements at sea are not so easy to carry out and to interpret. Simply using the usual statistical methods without knowing the preceding history would make the interpretation of the measurements difficult or impossible. Hence, using only the measurements as prescribed in the permit might make it impossible to measure and distinguish any effect or consequences of the sand extraction for MV2.

The permit under the Earth Removal Act states that measurements must be taken every 14 days in three representative transects (imaginary lines) perpendicular to the coast. Along those three lines vertical silt profiles should be taken. The Port of Rotterdam (POR) and their experts doubted if the effect of the sand extraction on the Dutch coast could be measured reliably in this way. More emphasis on the changes in the spatial distribution of silt was considered to be necessary. In concert with the relevant authorities, the permit series (every fortnight) were substituted by a more extensive survey over a larger area along the coast, but limited to three campaigns per year in which 100 points would be investigated. The extent of the area was, amongst other considerations, determined by the initial mathematical modelling of the Environmental Impact Assessment (EIA).
The locations were divided over approximately 20 transects with at least four points per transect, divided over four depth classes. In the area around the sand extraction pit, the transects are longer and thus contain more sampling stations (Figures 2 and 3).

In 2007 three baseline silt survey campaigns were carried out by POR, i.e., in the same timeframe and on the same locations as the juvenile fish survey (April, June and October) (see *Terra et Aqua*, nr. 129, December 2012). The sampling route and the 100 locations were randomised as much as possible taking into account the available contract time of the vessel, the sailing distances, the tidal conditions (not all shallow samples at low tide) and so on. The frequency of sampling was changed in 2009 to six times 50 locations (for each campaign a different subset of the 100 locations) as the coupling with the juvenile fish monitoring was no longer necessary. In this way a better spread in time was obtained and possible problems with spatial autocorrelation were reduced.

In order to obtain more information about the physical processes in the coastal zone additional measurements were taken in certain areas of interest, starting with a 13-hour measurement (one tidal cycle) along a transect in Noordwijk in November 2007. In 2009 the changes during the tidal cycle at the Noordwijk transect were studied twice (spring tide and slack tide cycle) during two full tidal cycle (26 hrs). More 13-hour measurement campaigns at different locations followed in later years.

Furthermore, measurements were taken during a storm (ad hoc decision in December 2010 to sail again), as well as following behind trailing suction hopper dredgers dredging at the sand borrow area in order to measure the extent and fate of the plume generated by the overflow (Figure 4). Also in 2013 silt measurements will be carried out.

**EQUIPMENT**

In the 2007 survey the measurements were taken by the silt profiler owned by the Port of Rotterdam (POR). The observations over the vertical profile were performed with the following devices:

- Two optical backscatter sensors with different ranges of SPM (suspended particulate matter) concentrations

**Figure 5.** The new silt profiler (designed and constructed in 2009 and owned by POR) is being placed overboard.

**Figure 6.** New silt profiler with all its sensors.
Transmission probe for the highest SPM concentrations
- Conductivity sensor, from which the salinity is computed after correction for temperature and pressure
- Chlorophyll sensor (fluorescence)
- Pressure sensor
- Temperature sensor
- Three Niskin water samplers, volume 1.8 litre each

After the silt measurement baseline study of 2007 it was decided to improve the measurements by building a new profiler. Mid-July 2009 the new profiler was tested and put in operation in the survey of July and thereafter up until the present (Figure 5). This new profiler measures, depending on the lowering speed, at least once in each 10 cm of the vertical profile.

The new profiler (Figure 6) has the following extra equipment:
- A Wetlab ACS spectrophotometer, measuring a continuous spectrum in the range of visible light to estimate the concentrations of dissolved substances and SPM.
- A LISST - 1000 probe, measuring particle size distributions and SPM concentrations in the vertical profile including the concentration of the SPM.
- An altimeter (echo sounder) to measure the height of the profiler above the seabed and to be able to close the bottom Niskin water sampler.

Figure 7. The crew of the Euro cutter Jade/BRA-7, the survey vessel used by the POR from 2007 to the present, were able to go to sea at wind forces of 8 or 9 on the Beaufort scale (BF). Most ships can only conduct their research at a maximum of 5 BF.

Figure 8. High SPM values measured during stormy conditions. The various simultaneously measured values are presented, i.e. alongshore and cross-shore velocity by ADV, temperature and salinity, Chlorophyll, SBS (sound backscatter) of the ADV (counts) and OBS (optical backscatter, FTU), LISST Extinction and particle sizes during up- and downcast. Please note that, when the OBS is going in overload (too much TSM, red and blue line in the lower left graph), the ADV (same graph) still records and so does the LISST, hence high values of TSM can still be evaluated correctly.
sampler precisely on a pre-determined height close to the seabed.
- An ADV probe to measure current speed and direction.

Part of the equipment is also a dedicated dGPS system, a detachable Acoustic Doppler Current Profiler (ADCP) and, in 2007 only, a portable TRIOS sensor (watercolour, incoming and reflected spectra of sunlight). The validation, elaboration and further analysis of the gathered data are done by POR staff in concert with external specialists.

**Bad weather and silt**
The crew of the *Jade/BRA7* (the fishing vessel used as a survey vessel for the silt measurements) (Figure 7) and the POR’s staff who carry out the silt measurements even go to sea at wind forces of 8 or 9 on the Beaufort scale (BF) and conduct their research under these difficult conditions. Most survey ships in the past, as far as available data is concerned, return to port at wind force in excess of 5 BF. Because of the *BRA7*’s ability to endure wind forces of 8 or 9 BF, researchers were able to get a much better understanding of the effects of storms at sea and the sediment that is brought up from the seabed as a result of wind and wave action.

The data appears to indicate that the silt concentrations during a storm can increase by a factor of between 10 and 100, because the fine particles from the bottom are turned up and over by the energy exerted by the waves and end up in the water column as a result (Figures 8 and 9). As a contrast, the variation of the average amount of fines over the vertical caused by the tide is a factor 2 (for this location the range is between 10 and 20 mg/l).

**New insights in the Rhine ROFI**
One of the striking things noted during the silt monitoring along the Dutch coast is the great influence exerted by the hugely variable volume of fresh water that flows into the sea. Fresh water continuously enters the North Sea coming from the River Rhine through de Nieuwe Waterweg and the Haringvliet, creating a Region of Freshwater Influence (ROFI). The Dutch call this phenomenon the “Coastal River” which in the USA is a called a “River Plume”. The ROFI interacts directly with the transport of SPM along the coast (Figure 10).

In his PhD thesis Gerben de Boer described the importance of changes in stratification of
the ROFI on a theoretical basis. During slack tide, there are currents perpendicular to the coast, which cause downwelling or upwelling. His only proof of the existence of upwelling was one remote sensing image in which cooler water was visible in a zone along the coast. The measurements made by the POR, particularly the 13- and 26-hour measurements were used to study the ROFI and the movement of SPM in the ROFI. The behaviour of the ROFI is extremely variable in terms of time and space (both location and size).

In one of the POR’s 26-hr measurements the upwelling was clearly visible in the measurements. The measurements and the analysis of the results have provided a better understanding of this phenomenon. Also turbulence in the water, particular in the ROFI dominated areas, is a source of uncertainty in the numerical models. A number of TU Delft students cooperated with the POR and Deltares, in their master thesis research, to see if they could explain, analyse and measure the upwelling and the water turbulence.

**MODEL SUPPORTED MONITORING OF SPM, A NEW METHOD**

In consultation with and following approval from the authorities, the decision was made (in 2008, before the start of the sand extraction) to set up a new monitoring method to provide much greater insight into the distribution of (the) silt off the Dutch coast. The basis for determining the amounts of SPM is an innovative method based on a combination of numerical models and measurements: MoS² (which stands for Model-Supported Monitoring) of SPM in the North Sea. The decision was based on an earlier pilot project, TnulTSM (Baseline Total Suspended Matter) in which the POR participated in the review of the results and the funding.

Using the Deltares numerical models (DELFT-3D) at ten-minute intervals, the water movement is calculated with input of real weather data and information on river outflows. Next the sediment transport model (DELWAQ) calculates how much silt is released from the seabed and how the silt rises and falls in the water column. Both models are huge: The amounts of grid cells in the model are approximately 300,000 and 160,000 for the hydrodynamic and silt model, respectively. All computations for one year, after investing in new Linux clusters, take a week computing time.

However good the numerical models might be, they always deviate from reality. The models can be adjusted on the basis of observations (data assimilation). Data from remote sensing (but not necessarily limited to observations using satellites) is used for these adjustments. The surface of the sea is observed regularly from satellites, amongst which MERIS, the satellite that passes over once a day and that supplied the images that are used in the MV2 model. The MERIS satellite stopped working in April 2012, many years after its predicted life time. The MODIS satellite images are a proper replacement. The pictures encompass the whole of the North Sea in the (visible) light spectrum. Hence data is only available when there is no cloud coverage, although partly clouded pictures are still useful (Figure 11).

Based on the colour of the water, an estimate can be made of the quantity of SPM (silt and algae) present in the topmost metres of the water column.

The combination of data with model results is referred to as data assimilation. The technique used by Deltares is ensemble Kalman filtering. This Kalman ensemble filtering is also used for weather forecasts. In addition to or instead of data-assimilation, the team at Deltares also applies parameter assimilation: Using the same principles, parameters of the model are adjusted in the ensemble Kalman filtering, leading to different parameter values in space (differences between regions) and in time (seasonal differences).

This ultimately leads to increasingly better models, which produce the most reliable results. This method must lead to a smaller margin of error and provide more insight into the different SPM flows. The procedure has been tested and it proved that the new monitoring model, the satellite observations and the measurements at sea provide a reliable picture and that it is possible to produce SPM maps and silt atlases. Finally, the uncertainty is still present regarding what happens deeper in the water column. For this reason, the model results are validated using the POR’s in-situ measurements at sea (2007-2013).

Furthermore, all other relevant available data from the Dutch Ministry of Infrastructure and the Environment, Rijkswaterstaat (RWS) and other parties, e.g., temperature, salinity (CTD series, Ferry box measurements, Tow fish and so on) are used to validate the model (Figure 12).

![Figure 11](image-url)
After combining and assimilating a year’s data, the SPM distribution maps can be made, for example as weekly or monthly averages of the silt concentrations. These maps are put into a silt atlas and can be used when deducing possible ecological effects of the sand extraction. Apart from that the POR receives all generated data on each grid point of the models on a hard disk in which a whole year’s output (at one hour intervals) is available. These can be looked at as time series in either 2 or 3-dimensional space. The silt atlases can subsequently be used to check the predictions of the EIA (Figure 13).

The first concept silt atlas for 2007 has been published in early 2012. The experience gained when creating this atlas will be incorporated into an updated version of the MoS² method. In the new setup atlases for the years 2003 through 2008, becoming available in the second quarter of 2013, will be prepared.

Results so far
At the end of 2012 a new model setup of MoS² was ordered from Deltares in which all the previous lessons learnt were incorporated. The new results of the improved MoS²-II model will start with all available data from 2003 continuing until 2008.
The second group are the creatures that live on or just above the seabed: the epifauna. Well-known examples include shrimp, hermit crabs, crabs and starfish. The spatial variation and the variation between years are large. Within just a few metres, the composition of the marine benthos can be completely different. A species can decrease in an area of several km² and at the same time increase in a nearby area. This variation in space and time, especially the spatial autocorrelation in changes, is a complicating factor in the analysis of the effects of the sand mining.

In order to determine the effects of the extra silt released as a result of the sand extraction, baseline measurements were made in the spring of 2006 and 2008 for the whole area, including the reference areas. During and after the peak of sand mining the benthic fauna was sampled again in 2010, 2011 and 2012. In 2009 a baseline survey in the borrow area, with a finer mesh, was carried out. This only concerned the area that will be investigated after the sand extraction is finished (2013) in order to find out if the benthos is recovering well, how recolonisation is taking place and on what time scale.

**Study design**

The study of the effects of extra silt on the benthic fauna was designed like a so-called Before After Control Impact (BACI) design. The basic principle of such a BACI design is shown in Figure 15.

A provisional analysis shows that there appears to be no evidence of significant increases in the SPM concentrations outside the borrow area on the basis of the in-situ filed measurements of 2009, 2010, 2011 and 2012. This means that, in accordance with the EIA and the Appropriate Evaluation, only minor effects, if any, can be expected on the Natura 2000 areas of the North Sea coastal zone and the Wadden Sea. The expected proof of this will be available in 2013 when the new MoS²-II model results will be available and can be compared with the in-situ measurements.

**BENTHOS AND SEABED COMPOSITION**

**Monitoring benthos**

More than 300 species of benthic organisms live in and on the bottom of the North Sea. Most of these are invertebrate organisms. Within the benthos, a distinction is made between two groups. First of all the creatures living in the seabed: the infauna. The infauna includes many species of worms, such as clam worms, tube worms and bristle worms. The worms vary in size from 1 millimetre to 10 centimetres (Figure 14). Many shellfish also live in the seabed, such as cockles, otter shells and razor shells.

The second group are the creatures that live on or just above the seabed: the epifauna. Well-known examples include shrimp, hermit crabs, crabs and starfish. The spatial variation and the variation between years are large. Within just a few metres, the composition of the marine benthos can be completely different. A species can decrease in an area of several km² and at the same time increase in a nearby area. This variation in space and time, especially the spatial autocorrelation in changes, is a complicating factor in the analysis of the effects of the sand mining.

![BACI (Before After Control Impact) study](image)

*Figure 14. Examples of some worms found in the box core samples.*

*Figure 15. The basic principle of a BACI (Before After Control Impact) design. The control area is used to estimate the autonomous development. The impact area is assumed to follow the same development. The difference between the expected end situation in the impact area and the real situation is the effect.*
The autonomous development in a so-called control area is estimated as the difference between the situation before sand mining and the situation during and after the sand mining (brown). In the impact area the same amount of autonomous change is expected.

Apart from the autonomous development there is also an effect of the sand mining in the impact area. This effect can be estimated from the change in the impact area and the change in the control area. The extent and the shape of the impact area were not known very well before, so a more complicated analysis of the changes in spatial pattern of the species was also planned and carried out by POR in 2012.

In order to be able to demonstrate relatively small changes, given the great natural variation in the benthos, the number of samples has to be large.

The first baseline measurement of the benthos was carried out in 2006 (Figure 16, left). The area sampled was between IJmuiden and Schouwen-Duiveland (~100 km) and was about 50 kilometres wide, at right angles to the coast (Figure 16, left).

The second baseline measurement of the benthos took place in 2008 and had a more elongated shape (Figure 16, right). This modification was based on new additional impact scenario study result that indicated that the fines from the sand extraction would be transported more towards the coast over a longer stretch.

The boundaries were at Petten and Westkapelle (Walcheren) approximately a length of 200 km and the width of the survey area was reduced to a maximum 35 km. Thus the area under consideration is now similar to the area of the silt survey, which started in 2007 and was based on the new impact scenario study. The T1, T2 and other surveys were repeated during the sand extraction in 2010, 2011 and 2012 in the same area as the 2008 survey.

**Field and laboratory methods**

The samples from the seabed are taken using a box corer (infauna) and a benthic sledge (infauna, and epifauna in particular larger species). These two surveys are carried out independently from each other with different survey vessels; the MS Arca (2006), MS Luctor (2008, 2009 and 2010) and the BRA7 (2011 and 2012) for the box core sampling by NIOO and the MS Isis for the benthic sledge by IMARES. A Reinecke box corer of 32 cm diameter and added weight of 200 kg was used (Figure 17).

After taking small sediment samples, the benthos samples are sieved over a one-millimetre mesh. The residue is collected in a bottle and fixated by adding pH-neutralised formaldehyde (formalin).

In the laboratory, the organisms are sorted under a stereomicroscope and counted and weighed per species. Species composition per sample, spatial distribution of species and groups of species, density (numbers per m²) and biomass (ash-free dry weight per m²) are derived from the collected data.

Figure 17. Reinecke box corer on the left and the first version of the benthic sledge on the right. Both photographed onboard the survey vessel MS Arca (2006 baseline study).
The box corer surveys and laboratory work were carried out by the Netherlands Institute for Ecological Research (NIOO-KNAW). The 2011 samples have been processed by two other laboratories (IECS from the UK and Koeman & Bijkerk, the Netherlands) (Figure 18).

Sampling with the aid of the benthic sledge focuses mainly on the epifauna and the larger and rarer infaunal species which have a lower density. In this way, information is obtained to supplement that from the box corer samples. A benthic sledge is less standard than a box core. The benthic sledge used consists of a metal mesh cage fixed to a sledge. The base plate of the sledge is fitted with two vertical blades and a horizontal, sloping blade forming the knife (Figure 19).

The benthic sledge is dragged over the seabed and, in this way, cuts a strip about 10 centi-metres wide, 7-10 centimetres deep over a "controlled" length of approximately 150 metres, thus sampling ~15 m² of seabed. The material ends up in the cage and the water that flows through it ensures that sand and other small particles, including the tiniest worms and juvenile molluscs, are rinsed out of
the sample. The result is a sample that contains the larger species of infauna and epifauna. From this sample, that contains a large amount of dead shells and other by-catches, the live organisms are taken and processed.

Onboard the survey ship Isis, density, biomass, distribution and size category are determined. Afterwards, in the laboratory, the ash-free dry weight is determined. The benthic sledge provides information on, for example, the numbers of cockles, nuns, beach shells, mussels, lesser sand eels and gobies. This research was contracted out to IMARES (Yerseke, the Netherlands). During the first survey (2006) with the benthic sledge concern arose about its efficiency to cut sufficiently deep (10 cm) over the full length accounted for by the mechanic counting wheel. Consequently, an extensive research programme was initiated by the POR and resulted in adaptations to the regular benthic sledge of IMARES as well as mounting sensors to register the underwater movements of the sledge while being towed. This has increased the accuracy of the actual calculated (cutting) length of the knife through the seabed (Figure 20).

However, one of the lessons learnt so far is that the spatio-temporal variation appeared to be so large, that the sampling error is of minor importance.

Results so far
After statistical analysis of the box core data with CANOCO (ter Braak) the interpretation was rather straightforward, although the patterns looked complicated at first sight. Canonical Correspondence Analysis (CCA) revealed that most of the changes in the control and impact area were not related to silt. Only a rather low percentage (ca. 10%) of the spatial and temporal variation could be attributed to explanatory variables.

Time accounted for ca. 3.5% of the variation in the species data (not related to silt) and the percentage of the variation in space and time that could be attributed to silt was only 1.1%. However, a clear and significant, although small, effect of the increase of the silt contents in the impact area is present: Mussels, Baltic clam, dog whelks, some bristle worms and polychaetes increased in the high impact area. Many other changes, as well in the control area as in the impact area, could not be related to silt. These relatively small changes can be explained by considering the conceptual model explained in Figure 21.

The silt concentration in the bed and the SPM in the water column increase towards the shore (black line). The underlying assumption is that during and after the sand mining the silt increases (dashed line). Each species is

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Figure 20. Benthic sledge with extra equipment. The changes include extra weight at the bottom, removal of the spoiler, restriction on the free movement of the arm of the counting wheel, echo sounders (altimeters) on both sides plus the attachment of a motion sensor on top of the sledge (heave, pitch and roll recording). The drawback of this operation is that the sledge now has to be employed using an umbilical cord for powering the equipment and storage of the recorded data on a PC onboard the survey vessel.

Figure 21. Conceptual model of a few of the species abundant along the silt gradient perpendicular to the Dutch coast. Offshore, on the left-hand side, the coast is on the right. In reality over 300 species are present along this gradient.
CONCLUSIONS

The aspects that were described here focus on the silt in the water column along the Dutch coast; the monitoring strategy for silt; and the effects of silt on the food chain. Owing to the high variability and spatial autocorrelation, statistical analyses of silt measurements are complicated. Consequently, a decision was made to develop a new modelling strategy – model-supported monitoring. All of the measurements that are gathered are input for the validation of a numerical model (MoS²).

A new model set-up of MoS² was ordered from Deltares at the end of 2012 and all the previous lessons learnt were incorporated. The new model MoS²-II will start with all available data from 2003 and continues through 2008. After 2008 the differences between the deterministic model run results and the remote sensing and in-situ data will be used to evaluate the effect of the sand mining.

A provisional analysis shows that, on the basis of the in-situ field measurements of 2009, 2010, 2011 and 2012, there appears to be no evidence of significant increases in the SPM concentrations outside the borrow area. This means that, in accordance with the EIA and the Appropriate Evaluation, the effects can be expected to fall within the predicted ranges for the Natura 2000 areas designated as the North Sea coastal zone and Wadden Sea. The expected proof of this will be available in 2013 when the new MoS²-II model results will be available and can be compared with the in-situ measurements.

Other changes in the course of monitoring involved adaptations to the regular benthic sledge owned by IMARES. These included equipping the sledge with additional sensors to register the underwater movements of the sledge while being towed. This has increased the accuracy of the actual calculated (cutting) length of the knife through the seabed.

Regarding the statistical analysis of the box core data with CANOCO, the patterns looked complicated at first sight, but the interpretation was actually rather straightforward. The Canonical Correspondence Analysis (CCA) revealed that most of the changes in the control and impact area were not related to silt. Only a rather low percentage (ca. 10%) of the spatial and temporal variation could be attributed to explanatory variables.

Although small, the effect of the increase of the silt contents in the impact area is significant: Mussels, Baltic clam, dog whelks, some bristle worms and polychaetes increased in the high impact area. However, many other changes, in the control area as well as in the impact area could not be related to silt.

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Baseline reports: Benthos (2006 and 2008), Silt survey (2007). Reports delivered to Dutch Authorities, as data delivery according to the relevant permits. Data bases not yet available for public distribution.


In these two Facts About published in 2012, two very different types of dredging operations and dredged materials have been addressed: The subsea installation of rock and the use of hydraulic fill for land reclamation. Rock and hydraulic fill each have unique characteristics which demand extensive knowledge of the substance, the water depths and the type of equipment which are appropriate for these materials. The technical engineering details of each of these types of material are quite specific and each subject needs to be understood and appreciated on its own merits. Each of these Facts About defines the technical expertise that is necessary to execute these very different operations successfully, the environmental concerns and the financial consequences.

Facts About is an initiative of the International Association of Dredging Companies (IADC) to distribute up-to-date information on various maritime construction and dredging subjects. All are downloadable as PDFs at www.iadc-dredging.com, under publications, or by emailing the IADC Secretariat at info@iadc-dredging.com.

Building with Nature
EDITED BY VALERIE JONES

Beginning with an Introduction by Wim Kuiken, The Netherlands Commissioner for the Delta Programme, this compact book gives a clear explanation about why the Dutch Delta plan was enacted into law and why the EcoShape project, “Building with Nature”, is important.

EcoShape is a consortium of private sector partners, government agencies and knowledge institutes who have joined together to use their expertise to tackle the challenges of urbanisation, economic development, sea-level rise and climate change with innovative approaches. The idea is to think, act and interact differently. The book brings together the EcoShape team’s work during the last few years: The shift from building in nature to building with nature from mind from the very start. Projects that seek to nourish the coastline with ‘soft’ rather than ‘hard’ solutions. The use of oyster reefs to protect tidal flats from erosion in estuaries. Coastal protection in the tropics in order to strengthen coral reefs, seagrass meadows and mangrove forests. Seabed landscaping as a tool for restoring habitats that encourage biodiversity. Revitalising wetlands in freshwater lakes, especially in low-lying areas such as deltas.

Though this book provides an exciting overview, with wonderful illustrations, and a summary of what has been achieved, it is not the end. The partners in the programme are looking forward and outward offering guidelines, lessons learnt and practical tools. More about this innovative programme and the book are available at the website, www.ecoshape.nl.

175 Ideas on the Future of the Fehmarnbelt Region
Creative ideas from the workshops at Fehmarnbelt Days 2012
COMPiled By THE STRING SECRETARIAT On Behalf Of THE FEHMARNBELT DAYS ORGANISERS
December 2012. 62 pages. Downloadable as PDF.

The very essence of Fehmarnbelt Days 2012 held in Hamburg and Lübeck, Germany in September 2012 is now available as a book, which consolidates 175 unique ideas from this meeting with the aim to inspire decision-makers, developers and innovators in the corridor from the Øresund Region to Hamburg, from Scandinavia to Germany.

More than 300 people participated in 19 different events over the three days of the forum. Their common objective was to help create the new Fehmarnbelt Region within the context of the future tunnel between Denmark and Germany. Workshops, conferences and podium debates generated countless, many innovative ideas that are meant to point the way towards a dynamic and integrated Fehmarnbelt Region bound together by the Fehmarnbelt Fixed Link, which is scheduled to open in 2021. This so-called “Book of Ideas” was designed to serve as a guideline for the work of the various regional and national governments as well as for the many cross-border stakeholders and organisations in the region based on the many activities of the event. It attempts to point the way toward a common future, integrated perspectives on regional development sustainable growth, labour markets, infrastructure and scientific cooperation. It will, however, also encourage all stakeholders in public or private administration, politics and business to think and act creatively when looking at the future.

This publication was compiled by the STRING Secretariat on behalf of all the Fehmarnbelt Days organisers. Queries concerning this publication should be directed to STRING Secretariat, Region Sjælland, Alléen 15, 4180 Sore, Denmark, Tel: +45 5787 5851.

A copy of this publication can be downloaded free of charge at: http://www.femern.com/material-folder/documents/2013-publications/175-ideas.pdf
IADC SEMINAR ON DREDGING & RECLAMATION
APRIL 15-19, 2013
ATLÂNTICO BÚZIOS CONVENTION & RESORT
BÚZIOS, BRAZIL

The International Seminar on Dredging and Reclamation is being organised by the International Association of Dredging Companies (IADC), the premier organisation representing the private dredging industry, in Búzios, Brazil from April 15 to 19, 2013. The seminar includes a tour of the immense dredging project at Superporto do Açú, the biggest port complex of its type in the world, the largest investment in port infrastructure in Latin America, in the country with the greatest GDP growth for a region.

Why Brazil? Why now?
Latin America – and especially Brazil – is booming. And port development and dredging is an essential element. Dredging in Latin America has been steadily growing over the last few years including such mega-projects as the Superporto do Açú. And many more projects and works are going on or being planned for the near future. No wonder that ABD, Associação Brasileira de Dragagem – together with other interested parties – has asked IADC to organise its informative and educational Seminar in Latin America for a second time.

Seeing is Believing: Site visit to Boskalis’ Superporto do Açú project
Part of the beauty of the IADC Seminar is getting out of the classroom and into the field. In that context, seminar participants will be delighted that Boskalis, one of the world’s largest dredging companies, is allowing us a close up view of their dredging site at the Superporto do Açú. Most likely one of their state-of-the-art dredging vessels will be available for a visit.

The Superporto do Açú, a US$1.6 billion project developed by LLX, a logistics company, is an impressive effort to improve the freight transport infrastructure and support the country’s growing trade links with China, the U.S. and others. Deemed a one-stop-shop, the 90-kilometer square area (about 1.5 the size of Manhattan) will provide everything necessary for the production, processing, storage and transport of materials such as steel, iron ore, oil, slag, granite amongst others, as well as specialised companies to assist with regulations and customs clearance.

The port area of Açú will have a 2.9 kilometre-long bridge with 10 docking berths, which will be able to accommodate the latest generation of super-ships, including 380-metre-long Chinamax vessels with a reported capacity of 400,000 tonnes of cargo.

To appreciate the enormity of this project view this movie about the project(s): http://www.youtube.com/watch?v=G8e2lsclXCG

By Professionals for Professionals
Dredging plays an essential role in world trade and economic and social progress. To optimise the chances of the successful completion of a project, contracting parties should, from the start, fully understand the requirements of a dredging project.

That’s why IADC developed this comprehensive Seminar for professionals in dredging-related industries – presented by professionals from the major dredging companies. Since 1993 IADC, often in co-operation with local universities and/or other associations, has provided this Seminar combining classroom lectures and workshops with a site visit to a dredging project. Hundreds of past participants agree: this is a unique chance to receive invaluable hands-on experience.

Costs and early registration discount
The fee for the week-long seminar is €2,950. (VAT inclusive). This includes all tuition, seminar proceedings, workshops and special participants’ dinner, but excludes travel costs and accommodations. Seminar participants can get a preferential rate at the hotel where the Seminar will be held (Atlântico Búzios Convention & Resort). Participants registering before 1 March 2013 will receive a €200.- discount.

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WIND FARM DEVELOPMENT:
EUROPEAN OFFSHORE 2013
APRIL 10-11, 2013
EDINBURGH, UK

Wind Farm Development: European Offshore 2013 will provide presentations and interactive discussions lead by senior representatives from the leading companies operating in the offshore wind sector. Key industry players and decision makers will be present to discuss the development and future of this significant renewable energy source. This is an opportunity to enhance your network and gain contacts from within the leading organisations making a difference in the offshore wind industry with two days of networking and open interactive discussions.

Attendees will be senior management from within the industry including: wind farm developers, wind farm operators, turbine manufacturers, engineers, consultants, ports and harbours, offshore shipping companies, energy analysts and lawyers. Fees for the conference will be £1,495 (ex VAT).

For further information contact:
Justyna Korfanty
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Email: jkorfanty@acieu.net
THE HYDRAULIC FILL MANUAL INTERNATIONAL COURSE
APRIL 11-12, 2013
PAO POST-ACADEMIC ONDERWIJS, DELFT, THE NETHERLANDS

This course covers the initiation, design and construction of hydraulic fill projects as described in the recently published Hydraulic Fill Manual. Without proper hydraulic fill and suitable specialised equipment, major infrastructure projects such as ports, airports, roads, industrial or housing projects cannot be realised. To date comprehensive information about hydraulic fill is difficult to find.

The Hydraulic Fill Manual is a thoroughly researched book, written by noted experts, which takes the reader step-by-step through the complex development of a hydraulic fill project. This in-depth Manual will enable the client and his consultant to understand and properly plan a reclamation project. It provides guidelines for design and quality control and allows the contractor to work to known and generally accepted procedures and reasonable specifications. The ultimate goal is to realise better-designed, better-specified and less costly hydraulic fill projects.

The course is of particular interest to clients, consultants, planning and consenting authorities, environmental advisors, contractors and civil, geotechnical, hydraulic and coastal engineers involved in dredging and land reclamation projects. For following this course some background knowledge in geotechnical engineering is required. CEDA, CUR and IADC are happy to support The Hydraulic Fill Manual International. The course leader will be Engineer Jan van 't Hoff (Van 't Hoff & Partners), one of the editors of the Manual. The course fee is € 990,00 excl. VAT and includes a copy of the Manual. Participants will receive 10 PDH's Bouw- en Waterbouwkunde (Construction and Maritime construction) study points.

For further information contact:

WORLD OCEAN COUNCIL SUSTAINABLE OCEAN SUMMIT (SOS) 2013
APRIL 22-24, 2013
WASHINGTON, DC

In 2050, what will the state of the ocean and the ocean business community be – and what must be done between now and then to ensure that both are healthy and productive? The Sustainable Ocean Summit (SOS) 2013 is the only international, cross-sectoral ocean sustainability conference designed by and for the private sector, focused on Corporate Ocean Responsibility. This is the World Ocean Council’s second SOS and builds on the highly successful SOS 2010, held in Belfast, Northern Ireland, which drew together more than 150 representatives from a wide range of ocean industries. The aim is to further advance leadership and collaboration amongst the diverse ocean business community in addressing marine environment and sustainability challenges.

A wide range of industries are involved in the use of marine space and resources, including shipping, oil and gas, fisheries, aquaculture, ports, mining, renewable energy, tourism, dredging, marine science/technology, maritime law, insurance, finance, and others. The conference will address priorities for cross-sectoral industry leadership and collaboration in ocean sustainability, including: ocean policy, regulations and governance; marine spatial planning; the role of industries in ocean and climate observations; biofouling and invasive species; fisheries and aquaculture interaction with other industries; cross-sectoral collaboration in responsible use of the Arctic; sound and marine life; cargo issues, port waste reception facilities and marine debris; marine mammal interactions; the role of finance, insurance and legal sectors in ocean sustainability. Other cross-cutting topics critical to responsible industry operations in the marine environment will be developed as the programme evolves.

SOS sessions will be designed to provide the state of the knowledge on these issues, including topic overviews, case studies and examples of best practices. Limited opportunities are available for speakers to address the themes above. Experts and thought leaders interested in being considered as speakers are encouraged to contact the WOC.

SOS participants are primarily the senior management responsible for environment and sustainability in companies and industry associations from a wide range of ocean industries. Other ocean stakeholders are welcome to participate, e.g., senior representatives of international organisations, government agencies, academic/research institutions and non-government organisations.

For further information contact:
• Email: SOS2013@OceanCouncil.org
http://www.oceancouncil.org/site/summit_2013/

WODCON XX
JUNE 3-7, 2013
SQUARE-BRUSSELS MEETING CENTRE, BRUSSELS, BELGIUM

Organised by CEDA on behalf of WODA (World Organisation of Dredging Associations) which incorporates WEDA, CEDA and EADA, WODCON XX, with the theme, “The Art of Dredging” will showcase some 120 technical papers over three days covering all aspects of dredging and maritime construction. All WODCON XX papers will be peer reviewed and provide up to date, relevant and high quality information.

The Congress will also feature a technical exhibition and technical visits. These technical programme elements will ensure a complete learning process, while various social events will allow participants to meet fellow professionals from all over the world in a friendly and inspiring atmosphere. The 2013 conference marks the XXth edition of WODCON and coincides with the 35th anniversary of the current WODA and its three component associations.

Topics of interest include but are not limited to the following broad areas: Method, Equipment & Techniques; Management of Sediments
For further information contact:
Congrex Belgium - WODCON XX Organisation Office
Tel.: +32 (0)2 627 0166, Fax: +32 (0)2 645 26 71
• Email: wodcon@congrex.com
www.cedaconferences.org/wodcon

IADC SEMINAR ON DREDGING & RECLAMATION
JUNE 24-28, 2013
UNESCO-IHE DELFT, THE NETHERLANDS

For (future) decision makers and their advisors in governments, port and harbour authorities, off-shore companies and other organisations that have to execute dredging projects, the International Association of Dredging Companies will again organise the International Seminar on Dredging and Reclamation at UNESCO-IHE, Delft, The Netherlands. To optimise the chances of the successful completion of a project, contracting parties should, from the start, fully understand the requirements of a dredging project. This five-day course strives to provide an understanding through lectures by experts in the field and workshops, partly conducted on-site in order to give the “students” hands-on experience. An important feature of the Seminars is a trip to visit a dredging project being executed in the given geographical area. Each participant receives a set of comprehensive proceedings with an extensive reference list of relevant literature and, at the end of the week, a Certificate of Achievement in recognition of the completion of the coursework. Please note that full attendance is required for obtaining the Certificate of Achievement. The fee for the week-long seminar is €2,250.- (VAT inclusive). This includes all tuition, seminar proceedings, workshops and a special participants’ dinner, but excludes travel costs and accommodations.

For further information contact:
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WEDA 33 / TAMU 44
AUGUST 25-28, 2013
HILTON HAWAIIAN VILLAGE, HONOLULU, HAWAII

The theme of the Western Dredging Association’s 33rd Annual Western Hemisphere Dredging Conference and Texas A&M’s 44th Annual Dredging Seminar (WEDA 33/TAMU 44) is “So That Ships May Pass”. It will focus on the Historical, Structural and Operational Development of Navigation throughout the Western Hemisphere. Included in the dredging conversations will be the critical global economic need for dredging, the importance of enhancing the marine environment as well as historical dredging developments, trends and the dredging progress that has created today’s market trends and also emerging environmental issues. The conference will provide a forum for discussions between North, Central, South American and Pacific regions.

For further information contact:
Tel.: +1 360 750 0209
• Email: weda@comcast.net
www.westerndredging.org

PORTS 2013
AUGUST 25-29 2013
SEATTLE, WASHINGTON, USA

PORTS ‘13 – “Ports: Success through Diversification” – is the 13th in a series of international port and harbour specialty conferences held on a tri-annual basis since 1977. This year’s conference theme recognises the broad spectrum of factors that make ports so important to their local, regional and national communities, including the broad missions they support, such as moving cargo, providing recreational opportunities, serving as engines of economic development, and providing for stewardship of environmental resources. The PORTS Conference series is internationally recognised as an outstanding opportunity to network with hundreds of leading practitioners, researchers and specialists in the port engineering profession. This year PORTS ‘13 has expanded to 3 full days, resulting in a 50 percent increase in opportunities to present ideas and experiences.

For further information see:
http://content.asce.org/conferences/ports2013/index.html

COASTS, MARINE STRUCTURES AND BREAKWATERS
SEPTEMBER 17-20, 2013
EICC EDINBURGH, SCOTLAND, UK

The Institution of Civil Engineers is pleased to announce the tenth in this highly-regarded series of specialist conferences. This is an international forum addressing the developments in offshore and nearshore energy production, procurement, issues with coastal defence, and the construction, management and refurbishment of all coastal assets. Whilst retaining the historical coverage on shoreline structures, coastal processes, and design and construction of breakwaters and related structures, the conference will also emphasise aspects at the civil and coastal engineering interface, such as fluid loadings, resource modelling, interactions with the environment, construction, installation, cabling, servicing and maintenance.

For further information contact:
ICE Events Team, Institution of Civil Engineers
One Great George Street
Westminster, London SW1P 3AA, UK
Tel.: +44 (0)20 7665 222, Fax: +44 (0)20 7233 1743
• Email: events@ice.org.uk
www.ice-conferences.com/Upcoming-events/ICE-Breakwaters
MEMBERSHIP LIST IADC 2013

Through their regional branches or through representatives, members of IADC operate directly at all locations worldwide.
THEORY VS REALITY
testing the ‘pilferer’ draghead

SCIENCE VS PRECONCEPTIONS
Lough Foyle’s two disposal sites

EXPECTATIONS VS FACTS
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