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Front cover:
A new system has been developed which provides worldwide satellite data on offshore wind and wave climates (see page 11).

IADC
P.J.A. Hamburger, Secretary General
Duinweg 21
2585 JV The Hague, The Netherlands
Tel. 31 (70) 352 3334, Fax 31 (70) 351 2654
E-mail: info@iadc-dredging.com
http://www.iadc-dredging.com

International Association of Dredging Companies
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EDITORIAL

In the last decade trailing suction hoppers have emerged as one of the most important tools of the dredging industry. With the introduction in 1994 of a TSHD with a capacity of 17,000 m³, a new era was launched. In retrospect today this seems rather small. The seemingly large dredgers of the 1990s are now being dwarfed by still larger “jumbos”. These vessels are part of the economy of scale which has made capital dredging projects feasible all over the world. Land reclamation and expansion of container harbours as well as the construction of artificial islands for new airports and other purposes are no longer hindered by sand scarcity in some areas because of the ability of these vessels to travel long distances and carry greater amounts of sand than their predecessors.

Clearly it follows that research into the capabilities of these TSHDs is necessary. In this first issue of Terra in 2002 we are therefore glad to be able to focus attention on two on-going research projects concerning trailers. One study creates a numerical model to evaluate the overflow phase of the dredging cycle; this was conducted at the Technical University Delft. The other is a comparison of environmental dredging techniques when a TSHD is equipped with two different types of specially designed devices; this study was done on site at the Port of Zeebrugge.

Such is the state of the art in dredging: a combination of hands-on and academic, seeking together to achieve the highest standards of environmentally sound and economically viable dredging solutions. As we see the dredging industry continue to consolidate – as witnessed by the most recent merger of Ballast Nedam and HAM to form Ballast Ham Dredging – we also see a growth in efficiency and dedication to the betterment of global infrastructure.

The combination of hands-on and academic training is also evident at the IADC Seminar on Dredging and Reclamation which will be held again in autumn 2002 in Singapore. The IADC Secretariat in The Hague will be glad to provide you with further information about this up-coming event.

Robert van Gelder
President, IADC Board of Directors
Chemical Monitoring of Maintenance Dredging Operations at Zeebrugge

Alain Pieters, Marcel Van Parys, Guido Dumon and Lode Speleers

Abstract

Under the auspices of the Waterways and Marine Affairs Administration of Flanders, Belgium, an intensive research project to evaluate the ecological impact of dredging and relocation operations in the Belgian Coastal Zone has been conducted over the last 5 years. The Port of Zeebrugge, which is the major harbour in this area, was chosen as the appropriate place for evaluation.

Two different dredging techniques were compared: the hopper dredger equipped with standard suction pipes and an environmental valve in the overflow funnel; and the hopper dredger, equipped with a specially designed re-circulation pipe.

Whilst during the MOBAG 2000 project all three major effects (physical, chemical and biological) caused by dredging operations have been studied, this article will primarily focus on the chemical impact on the environment.

Method

Studies have been carried out on the three main phases of dredging. They include:

1. the characterisation of the in situ sediments;
2. physico-chemical changes in the sediment during different phases of the dredging process on board the dredger; and
3. studies at the disposal areas.

In Situ Sediments

Pollutants

The sediments of the Outer Port of Zeebrugge are strongly reduced fine sediments with a density between 1.02 and 1.24 kg/litre. The heavy metal content in the sediment is fairly low and for all metals beneath the critical value of the Belgian criteria for disposal at sea. The metal concentrations in the pore water are very variable and are the highest for As and Zn. The concentration of organic pollutants (PAHs) is low (1-1.5 mg/kg DM for the sum of 16 PAHs).

The variability of the mobility of arsenic and zinc was the subject of a study in April 2000.
An extensive sampling campaign was organised in order to investigate the evolution of the mobility of arsenic and zinc as a function of the sediment density. For that purpose a newly designed multi-sampling device, capable of sampling sediments in a wide density range, was successfully used (Figure 3). A total of 70 sediment samples, spread over 10 locations in the CDNB, were collected.

The mobility of both heavy metals, chosen for their relative high pore-water concentrations measured during previous investigations, was evaluated by analysing different physico-chemical parameters, the evaluation of the distribution coefficients and the determination of the SEM/AVS ratio, which give an indication of the toxicity of the sediment for bentic organisms.

On the bulk sample acidity, redox potential, dry matter content, density, grain-size distribution, arsenic and zinc content were determined. On the pore waters the following parameters were determined: acidity, redox potential, arsenic content, and zinc content.

During the analysis of arsenic and zinc severe quality control was done, including the use of duplicate measurements, matrix spikes and recovery of certified material (CRM 320).

From the analysis it appears that most physico-chemical parameters of the loose sediment in the CDNB vary slightly, except in the top layer of the in situ sediments. This points to the fact that the thickness of the oxic-anoxic interface layer is very limited.

Evaluation of the distribution coefficients (Kd) of arsenic and zinc showed that both elements show a sharp decrease of mobility with increasing depth in the upper half metre of the sediment. Deeper in the sediment the mobility of arsenic increases again with depth. On the contrary, the mobility of zinc decreases further with depth.

The mobility of arsenic and zinc were significantly correlated to the density but not to the redox potential and the acidity of the sediment. The correlation between the arsenic concentration in the pore water and the acidity of the pore water was however significant.

In general the mobility of arsenic is much higher compared to zinc (average Kd resp. 0.6 and 18.2 l/g).

The results for the SEM to AVS ratios showed that no toxicity as a result of the bio-availability of heavy metals should be expected. As a matter of fact, these results were confirmed by ecotoxicity experiments which have been finalised recently at the laboratory of the University of Ghent in co-operation with EURAS (Figure 4).
The ecological impact of dredging activities was determined by means of evaluating the mobility of contaminants and nutrients during the dredging cycle of the hopper dredger *Cristoforo Colombo* (Figure 5).

Two different dredging techniques were compared:
- the hopper dredger equipped with standard suction pipes and an environmental valve in the overflow funnel; and
- the hopper dredger, equipped with a specially designed re-circulation pipe.

To obtain good insight into the different phases during dredging the following sampling campaign was set up: In situ samples were taken in the dredging area.

The samples taken whilst dredging with the hopper dredger can be subdivided in three groups:
- samples of the dredged material when leaving the hopper line and entering the hopper;
- samples of the overflow; and
- samples in the hopper well just before disposal.

**Nutrients**

The in situ sediments have about 3 gram Kjeldahl-Nitrogen/kg dry matter, 0.5 gram NH₄-N/kg DM and 1 gram P/kg DM. Analysis on the sediments pore water revealed that the Kjeldahl nitrogen occurs predominantly under the form of ammonium-N (70 to 90%) compared to only 15% in the total analysis on the sediment. Apparently ammonium is more mobile and is more easily released to the pore water. The Kd of phosphorus is much higher than the Kd of total N and is therefore less liberated in the pore water.

From this study it can be concluded that:
- The in situ sediments have a fairly low pollution degree.
- There exist natural temporal and spatial variations in the mobility of arsenic and zinc which have to be taken into account when evaluating the ecological impact of dredging.

The tests were conducted with organisms representing several trophic levels and produced no acute toxicity. An overview of the test organisms and methods are given in Table I.

**On Board The Dredger**

The ecological impact of dredging activities was determined by means of evaluating the mobility of contaminants and nutrients during the dredging cycle of the hopper dredger *Cristoforo Colombo* (Figure 5).

Figure 1. Aerial view of the Port of Zeebrugge, looking east toward the hinterlands.

From this study it can be concluded that:
- The in situ sediments have a fairly low pollution degree.
- There exist natural temporal and spatial variations in the mobility of arsenic and zinc which have to be taken into account when evaluating the ecological impact of dredging.
In order to evaluate the mobility of contaminants between different phases of the dredging cycle, the following parameters were determined on the samples:

- physico-chemical parameters (redox, pH, dry matter, density, carbonates, grain-size and organic matter);
- natural and heavy metals (Mn, Fe, Al, As, Hg, Cd, Pb, Zn, Cu and Ni); and
- organic contaminants (PAHs).

Pore water analysis focused on the 11 metals mentioned above. Also the following parameters were determined: redox, pH, conductivity, Kjeldahl and ammonium nitrogen, total phosphorus, chloride and sulphate.

In order to assess the mobility of contaminants, distribution coefficients were calculated and finally sequential extractions on 11 metals following the “BCR-3 step” procedure were performed.

**Heavy metals**

During dredging the concentration of As and Zn have a tendency to rise (with approximately 50 µg/litre) whilst dredging with the re-circulation head. With the environmental valve the evolution is less clear.

Ni, Cu, Cd and Hg show no significant variation during dredging except for Ni where a minor decrease can be noticed. Concentrations in the pore water are generally low (Ni, Cu) or very low (Cd and Hg).

Mn and Fe concentrations in the pore water are very high (respectively, 10 to 35 and 10 to 15 mg/litre). Although iron increases, the manganese content shows almost no variation during dredging. The aluminium content is much lower (max. 400 µg/l) and increases slightly with the re-circulation pipe.

By calculating the distribution coefficients (Kd values), the heavy metals can be grouped by their tendency to become mobile. The mobility decreases as follows: As>Zn>Cu=Nd>Pb=Cr.

For the natural metals manganese is the most mobile element, followed by iron and aluminium. When assessing the mobility by comparing the Kd values from the in situ samples and the samples during
When comparing the two dredging techniques the conclusion is that the shift to more immobile fractions differs for every metal considered (Table III). It should, however, also be noted that all the observed shifts were very small.

Other parameters
During dredging the ammonium-N decreases in comparison to the in situ sediment, except for the samples just before disposal when dredging with the re-circulation head. The same evolution is more or less observed for Kjeldahl-N.

Table I. Overview of the bioassays used.

<table>
<thead>
<tr>
<th>Species tested</th>
<th>Elutriate test</th>
<th>Sediment suspension test</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Duration</td>
<td>End point</td>
</tr>
<tr>
<td>Algae Phaeodactylum tricornutum</td>
<td>72 h</td>
<td>Growth</td>
</tr>
<tr>
<td>Crustaceans Americanis bahia</td>
<td>96 h</td>
<td>Mortality</td>
</tr>
<tr>
<td>Tisbe battagliai</td>
<td>48 h</td>
<td>Mortality</td>
</tr>
<tr>
<td>Fish Dicentrarchus labrax</td>
<td>96 h</td>
<td>Mortality</td>
</tr>
</tbody>
</table>

When comparing the two dredging techniques the conclusion is that the Kd value varies slightly and that this variation is different for every metal.

The sequential extractions on the in situ samples revealed that most metals were found in the third step (organic matter and sulphide bound) and in the residual fraction. Only nickel is partially mobile (first step is = 10%) and cadmium was found mainly in the third step, which could mean that it is mostly precipitated as a sulphide. Forty percent of the manganese is found in the most mobile fraction.

Figure 3. Detail of new multi-sampling device for sampling fluid mud.
The pH of the sediment increases slightly during dredging. Although the redox potential of the sediment is not influenced by dredging, the pore water redox shows an evolution to less negative values at the end of the dredging cycle. The redox potential is however still strongly anaerobic (-150 mV).

Discussion
On the basis of the analytical results it is difficult to quantify the impact on the environment induced by dredging operations. Nevertheless, the results of the distribution coefficients and the sequential extractions give a good indication of the impact. Pore water analyses indicate that there is a not-negligible amount of metals which are liberated during dredging operations, especially As and Zn (approx. 50 µg/l). The free pore water in the overflow and in the hopper well can be liberated in the water column, respectively during dredging and disposal.

Nevertheless one should note that the liberated contaminants and nutrients will come into equilibrium by sorption and desorption processes (sorption of contaminants on sediment particles is a common feature). This fixation is seldom irreversible and because of changing chemical and physical conditions, the contaminants can be liberated again. The free pore water can be seen as a potential “reservoir” of contaminants and keeping the pollutant and nutrient concentrations in the pore water as low as possible during dredging and disposal is important.

On the other hand, contaminants bound to the sediment particles themselves can be liberated into the

Table II. Variation of the distribution coefficient (Kd) in function of the dredging techniques.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Campaign 1 Re-circulation pipe</th>
<th>Campaign 2 Environmental valve</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Kd overflow / Kd in situ (%)</td>
<td>Kd hopper well / Kd in situ (%)</td>
</tr>
<tr>
<td>Al</td>
<td>+ 37</td>
<td>- 27</td>
</tr>
<tr>
<td>Fe</td>
<td>- 93</td>
<td>- 92</td>
</tr>
<tr>
<td>Mn</td>
<td>- 16</td>
<td>- 12</td>
</tr>
<tr>
<td>As total</td>
<td>- 49</td>
<td>- 42</td>
</tr>
<tr>
<td>Cr</td>
<td>+ 69</td>
<td>+ 5</td>
</tr>
<tr>
<td>Cu</td>
<td>- 53.3</td>
<td>- 21.1</td>
</tr>
<tr>
<td>Ni</td>
<td>+ 11</td>
<td>+ 58</td>
</tr>
<tr>
<td>Pb</td>
<td>- 73</td>
<td>- 43</td>
</tr>
<tr>
<td>Zn</td>
<td>- 45</td>
<td>- 73</td>
</tr>
<tr>
<td>Sum</td>
<td>- 212</td>
<td>- 247</td>
</tr>
<tr>
<td>Average</td>
<td>- 24</td>
<td>- 27</td>
</tr>
</tbody>
</table>
the vessel (Figure 6) and were sent to the lab for further analyses. On the samples the following parameters were determined:
- content of dissolved arsenic and zinc;
- redox potential;
- acidity; and
- conductivity.

During the analyses of arsenic and zinc, with an axial ICP-AES, the quality control was assured by the environment but the quantity and the velocity of these processes is difficult to estimate. Comparison between different studies conducted during the MOBAG 2000 project revealed that the mobility of heavy metals in the in situ sediments have a natural spatial and temporal variability. This has to be taken into account when evaluating the mobility caused by dredging operations.

**ECOLOGICAL IMPACT AT THE DISPOSAL SITE**

To estimate the impact of disposal activities at the disposal areas, a study was conducted to evaluate the release of arsenic and zinc, the most mobile heavy metals. Therefore an extensive sampling campaign was organised in April 2000 during the disposal of dredged material from the harbour of Zeebrugge. To avoid any contamination of the seawater samples during handling, the survey vessel DN 62 was equipped with a laminar flow workstation (microsafe CLASS II SE) and special care was taken by using acid-rinsed filters, recipients, syringes and so on.

A total of 153 seawater samples were taken spread over 9 disposal cycles, and 34 samples were taken for the determination of the background values. Simultaneously the turbidity, the temperature and the salinity were measured by using an OBS-5 turbidity sensor. The seawater samples were filtered on board the vessel (Figure 6) and were sent to the lab for further analyses. On the samples the following parameters were determined:
- content of dissolved arsenic and zinc;
- redox potential;
- acidity; and
- conductivity.

**Table III. Results sequential extractions: Evolution to more mobile fractions in function of the dredging technique.**

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Campaign 1 Shift of fractions</th>
<th>Campaign 2 Shift of fractions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Al, Fe, Ni</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td>Mn</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>As total, Cd</td>
<td>-</td>
<td>0</td>
</tr>
<tr>
<td>Cr</td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td>Cu</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Hg, Zn, Pb</td>
<td>0</td>
<td>-</td>
</tr>
</tbody>
</table>
Salinity and acidity did not seem to be affected by the disposal operations. However, the redox potential of the seawater was clearly lower during disposal operations. This means that disposing of strongly reduced sediments has an important influence on the redox potential of the seawater, without seriously threatening the oxygen availability in the water column. The variation of the redox could not be statistically correlated to the turbidity.

The concentration of arsenic during disposal operations was higher compared to the background values. An average increase of 1.03 µg/litre dissolved arsenic above the background value (= 1.25 µg/litre) was observed.

The average dissolved zinc concentration of the first 4 disposal cycles was much lower than those of the 5 following cycles. The background concentrations were even higher compared to the samples collected during the disposal cycles. Stormy weather conditions occurring after the second day of the sampling campaign are a possible cause for the elevated dissolved zinc concentrations.

The turbidity measurements carried out simultaneously with the seawater sampling showed that sediment plumes on the disposal ground vanished after approximately 25 minutes. The highest concentrations that were measured occurred near the seabed and are as high as 6 to 8 gram/litre.

Ecotoxicity tests in which different organisms (see Table I) were continuously exposed to turbidity concentrations, comparable to those found at the disposal area, showed no effect compared to the control group.

**Conclusions**

General conclusions are difficult to draw. The mobility of contaminants in dredged material changes during dredging. This change is different for every examined contaminant. For some contaminants the mobility decreases; for others it increases. However, it is important to note that the change in mobility is very low for all the considered contaminants and for both dredging techniques.

At the disposal area, there are indications that arsenic is liberated to the surrounding seawater. However, the concentrations remain very low and in the laboratory, no negative effects could be detected for the organisms tested.
Abstract

Worldwide satellite data on the offshore wind and wave climate are now available through the Internet. A few mouse-clicks at "www.waveclimate.com" can give easy and quick access to precise information on the height, period and direction of the waves that a dredging company must deal with in its daily activities. This information is available for all oceans and coastal seas all over the world.

Introduction

To plan dredging operations, companies regularly need reliable information concerning the wind and wave climate of the region where the operation will take place (Figure 1).

In regions where no reliable wave buoy records are available, wind and wave climate estimates are derived from a ship’s observations or from predictions by numerical wave models running at a meteorological office. Often the quality of the information from these sources does not match the requirements of the users. And, if available, it is very difficult to get access to the data and to integrate them into other software packages.

Several satellites operated over the past decade have carried microwave sensors that give information about the sea-state and about the wind above open water. The most widely used sensor for this purpose is the radar altimeter. This sensor is capable of measuring the wind speed and the significant wave height along its ground track. Since the mid 1980s several satellites have carried radar altimeters (such as GEOSAT, ERS-1, ERS-2, TOPEX/POSEIDON), each of which produced records several years long.
Data from satellites have been exploited in several global wave climate atlases. However, the value of these products is restricted by the lack information about wave directions and periods. Moreover, to produce these atlases, the data collected before a certain date have been condensed into a number of statistical parameters for pre-defined regions, which are generally rather large. Consequently new data are not used, and zooming in on a particular region of interest is not possible.

To provide better information, an online climate assessment system has been developed which allows greater flexibility in the selection of a region of interest, and is updated automatically with new data. Moreover, it exploits the spectral wave information provided by imaging radar (SAR) using new data analysis techniques.

### Data and Quality Control

To assess wind and wave climate three types of microwave sensors are of particular interest (see also Table I):

- the altimeter;
- the scatterometer; and
- the SAR.

### Table I. Overview of variables, sensors and satellites to measure waves and wind.

<table>
<thead>
<tr>
<th>Variables</th>
<th>Sensors</th>
<th>Satellites</th>
<th>Time period covered</th>
</tr>
</thead>
<tbody>
<tr>
<td>Significant wave height</td>
<td>radar altimeter</td>
<td>Geosat</td>
<td>from March 1985 to Dec 1989</td>
</tr>
<tr>
<td>Significant wave height and wind speed</td>
<td>radar altimeter</td>
<td>ERS1/ERS2</td>
<td>from Aug 1991</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Topex/Poseidon</td>
<td></td>
</tr>
<tr>
<td>Wind speed and direction</td>
<td>scatterometer</td>
<td>ERS1/ERS2</td>
<td>from Jan 1993</td>
</tr>
<tr>
<td>Wave spectral density and mean direction in 25 frequency bands, together with coincident wind speed and direction</td>
<td>synthetic aperture radar (SAR) and scatterometer</td>
<td>ERS1/ERS2</td>
<td>from April 1993</td>
</tr>
</tbody>
</table>

Figure 1. Wind and waves along the Dutch coastline. To plan dredging operations, companies regularly need reliable information concerning the wind and wave climate of the region where the operation will take place.
The primary use of the altimeter is its capability to measure the significant wave height along its ground track. In addition to the wave height, the altimeter also produces estimates of the wind speed.

The scatterometer yields estimates of the wind vector (speed and direction) above open water. The SAR is able to detect the energy and propagation direction of waves.

New retrieving algorithms have been developed to extract wave spectra out of multi sensor satellite observations (see J. Geophys. Res., 105, 3497-3516). This technique uses the SAR spectrum as well as the scatterometer wind vector acquired at the same place and time by the ERS satellites.

The quality of the data is assured by various automated procedures such as range checks, checks for error flags and detection of outliers along a track. For wave spectra obtained from SAR, spectra with very low signal-to-noise levels are rejected.

Currently the databases cover all of the world’s seas and oceans up to the year 2001 (see Figures 2 and 3).

**Generation of Information Products**

The service is for all companies that regularly need information about the offshore climate for their operations. Because companies’ needs differ from one another, the information in www.waveclimate.com can be tailored to suit the specific requirements of each company.
easily be tailored to the requirements of each individual user by the user (Figure 4).

The online system is regularly augmented with the most recent measurement data and is, as a result, always up-to-date. Whilst other sources lose their value as time passes, www.waveclimate.com continues to become more valuable because with each passing year the volume of data increases.

Amongst a mass of observations www.waveclimate.com offers the user a range of functions:
- probability distributions;
- joint probability tables;
- season selection (months); and
- short time series.

Tables II and III are examples of the service and are easily copied into Excel.
Table II. Example of joint probability distribution of significant wave height and mean wave period (in % of occurrence).

Relative occurrence of significant wave height (m) in rows versus mean wave period(s) in columns

<table>
<thead>
<tr>
<th>&lt;3</th>
<th>3-4</th>
<th>4-5</th>
<th>5-6</th>
<th>6-7</th>
<th>7-8</th>
<th>8-9</th>
<th>9-10</th>
<th>10-11</th>
<th>11-12</th>
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<th>13-14</th>
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<tr>
<td>&lt; 0.5</td>
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<tr>
<td>0.5-1.0</td>
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<td>0</td>
<td>0</td>
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<tr>
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<td>0.3</td>
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<td>0</td>
</tr>
<tr>
<td>1.5-2.0</td>
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<td>0</td>
<td>0</td>
<td>0.1</td>
<td>0.7</td>
<td>1.6</td>
<td>2.8</td>
<td>1.9</td>
<td>0.2</td>
<td>0</td>
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<td>0</td>
</tr>
<tr>
<td>2.0-2.5</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0.3</td>
<td>1.1</td>
<td>2.5</td>
<td>4.5</td>
<td>4.8</td>
<td>2.1</td>
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<td>0.1</td>
<td>1.4</td>
<td>2.9</td>
<td>3.5</td>
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<td>1.5</td>
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</table>

Table III. Example of probability distribution of significant wave height for every month (in % of occurrence)

Monthly distribution of significant wave height (m)

<table>
<thead>
<tr>
<th>Jan</th>
<th>Feb</th>
<th>Mar</th>
<th>Apr</th>
<th>May</th>
<th>Jun</th>
<th>Jul</th>
<th>Aug</th>
<th>Sept</th>
<th>Oct</th>
<th>Nov</th>
<th>Dec</th>
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<td>0</td>
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<td>0.3</td>
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<td>0.5</td>
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<tr>
<td>1.5-2.0</td>
<td>9.9</td>
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<td>25</td>
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<td>11.6</td>
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<td>0.2</td>
<td>0</td>
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</table>
The service offered has been validated against buoy data. At the site extensive validation reports can be downloaded freely from www.waveclimate.com.

The accuracy of significant wave height and wind speed data is summarised in Table IV. These are averages over all sensors and satellites. The figures are based on comparisons against wave buoy data at 28 locations in the Pacific and Atlantic (including the Gulf of Mexico) from the U.S. National Oceanic and Atmospheric Agency (NOAA) and Environment Canada. These buoys report hourly one-dimensional energy density spectra and wind.

The degree of mismatch between satellite and buoy data is expressed in terms of the root-mean-square error as well as a relative error measure.

The root-mean-square (RMS) error of say, significant wave height, is

\[
\text{RMS error} = \sqrt{\frac{1}{n} \sum_{i=1}^{n} (H_{i}^{\text{retrieved}} - H_{i}^{\text{buoy}})^2}
\]

with \(H_{i}^{\text{retrieved}}\) the wave height of sample no. \(i\) retrieved from satellite data, and \(H_{i}^{\text{buoy}}\) the coincident buoy measurement of the wave height. It is similar to the standard deviation, but also includes the bias error.

### Table IV. Accuracy of wind speed and wave height.

<table>
<thead>
<tr>
<th>Statistics of all wave height and wind speed observations</th>
<th>Sensor</th>
<th>Buoy mean</th>
<th>RMS error</th>
<th>Relative error [%]</th>
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</thead>
<tbody>
<tr>
<td>Significant wave height</td>
<td>Altimeter</td>
<td>2.31 m</td>
<td>0.33 m</td>
<td>12</td>
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<tr>
<td>Significant wave height</td>
<td>SAR</td>
<td>2.39 m</td>
<td>0.42 m</td>
<td>16</td>
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<tr>
<td>Wind speed</td>
<td>Altimeter</td>
<td>7.67 m/s</td>
<td>1.61 m/s</td>
<td>19</td>
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<tr>
<td>Wind speed</td>
<td>Scatterometer</td>
<td>7.69 m/s</td>
<td>1.26 m/s</td>
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</table>

### Table V. Pacific: Statistics of data from SAR.

<table>
<thead>
<tr>
<th>Buoy mean</th>
<th>rms error</th>
<th>Relative error [%]</th>
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<tbody>
<tr>
<td>Significant wave height</td>
<td>2.64 m</td>
<td>0.40 m</td>
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<tr>
<td>Mean period</td>
<td>8.78 s</td>
<td>0.75 s</td>
</tr>
<tr>
<td>Zero-crossing period</td>
<td>6.87 s</td>
<td>0.60 s</td>
</tr>
<tr>
<td>Height of long waves (periods above 12 s)</td>
<td>1.13 m</td>
<td>0.40 m</td>
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</table>

### Table VI. Atlantic: Statistics of data from SAR.

<table>
<thead>
<tr>
<th>Buoy mean</th>
<th>rms error</th>
<th>Relative error [%]</th>
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</thead>
<tbody>
<tr>
<td>Significant wave height</td>
<td>2.03 m</td>
<td>0.45 m</td>
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<tr>
<td>Mean period</td>
<td>6.90 s</td>
<td>1.30 s</td>
</tr>
<tr>
<td>Zero-crossing period</td>
<td>5.77 s</td>
<td>0.97 s</td>
</tr>
<tr>
<td>Height of long waves (periods above 12 s)</td>
<td>0.36 m</td>
<td>0.36 m</td>
</tr>
</tbody>
</table>
Bias errors are in all cases small. The relative error is the RMS error normalised by the root-mean-square value of the buoy wave height:

$$\text{relative error} = \frac{\sum_{i=1}^{n} |H_i^{\text{retrieved}} - H_i^{\text{buoy}}|^2}{\sum_{i=1}^{n} |H_i^{\text{buoy}}|^2}$$

To validate the wave spectra obtained from SAR, the buoys are grouped into two geographical regions: Pacific (North American west coast and Hawaii) and Atlantic (North American east coast and Gulf of Mexico). The following wave parameters, derived from retrieved ocean wave spectra were validated: significant wave height; mean period $T_m$; zero-crossing period $T_z$; and significant height of only those waves with periods above 12 s. The mean period and zero-crossing period are defined as:

$$T_m = \frac{\int f^{-1} F(f) df}{\int F(f) df}$$

$$T_z = \frac{\int F(f) df}{\int f^2 F(f) df}$$

### Overview

Statistical information is provided about the overall sea-state (wave height, period, direction) but also about wind-sea only, or swell only. Wind-sea consists of the waves having crests moving no faster than 1.2 times the wind speed, so they are growing. Longer (and therefore faster moving) waves are called “swell”. Statistics of wind-sea and swell are derived from SAR data. Table VII indicates the various statistics of the overall sea-state which can be provided, and the source of the data (sensor) from which the statistics are derived.

### Conclusions: Outlook

To further serve the dredging industry a new Web-based service on tidal currents and sea level is currently under development. In this service, measurements of 10,000 tidal stations are integrated with 16 years of satellite data to provide accurate information on tidal sea level and tidal currents for every location in the world.

---

### Table VII. Statistics for total sea-state.

<table>
<thead>
<tr>
<th>Source of Data</th>
<th>Histogram</th>
<th>Scatter diagram</th>
<th>Extreme value analysis</th>
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<tbody>
<tr>
<td></td>
<td>Probability distribution</td>
<td>Joint probability distribution</td>
<td>Extreme value distribution</td>
</tr>
<tr>
<td></td>
<td>of wind speed</td>
<td>of significant wave height</td>
<td>of significant wave height</td>
</tr>
<tr>
<td></td>
<td>Probability distribution</td>
<td>and wind speed</td>
<td></td>
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<tr>
<td></td>
<td>of wind direction</td>
<td>of significant wave height</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Probability distribution</td>
<td>and mean period</td>
<td></td>
</tr>
<tr>
<td></td>
<td>of wave height</td>
<td>of significant wave height</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Probability distribution</td>
<td>and zero-crossing period</td>
<td></td>
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<tr>
<td></td>
<td>of mean period</td>
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<tr>
<td></td>
<td>Probability distribution</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>of zero-crossing period</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Probability distribution</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>of wave direction</td>
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</tr>
<tr>
<td></td>
<td>Monthly distribution</td>
<td></td>
<td></td>
</tr>
<tr>
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<td>Monthly probability</td>
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<td>Monthly probability</td>
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<td>distribution of wind speed</td>
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<td>Scatter diagram</td>
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<td>Joint probability distribution of wind speed and wind direction</td>
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<tr>
<td></td>
<td>Joint probability distribution of significant wave height and mean period</td>
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</tr>
<tr>
<td></td>
<td>Joint probability distribution of significant wave height and zero-crossing period</td>
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</tr>
<tr>
<td></td>
<td>Joint probability distribution of significant wave height and wave direction</td>
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</tbody>
</table>

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Abstract

In the last decades and in the near future, large areas of land, especially in the Far East, were and will be reclaimed using trailing suction hopper dredgers. During the overflow phase of the loading stage of the dredging cycle, a part of the dredged volume of sand will not settle in the hopper but will be transported with the overflow discharge overboard. For production, sand quality and environmental reasons it is important to predict the amount of these so-called overflow losses. The total volume of losses as the influence on the loaded (and lost) particle size distribution (PSD) is important.

Introduction

In 1997 a research programme was started to get more understanding of the sedimentation process onboard a hopper dredger. The goal of the programme was to develop a numerical model that can be used to predict the influence of the relevant parameters as hopper geometry, sand, discharge and concentration on the overflow losses (and which fractions of the PSD will be lost). The research programme consists of three parts: laboratory experiments, development of numerical models and full-scale validation of the models. In this article the developed 1DV numerical model will be presented. The 1DV-model is one-dimensional, but in contrast to most existing models in the vertical direction. The influence of the PSD distribution is modelled using a coupled system of transport equations (convection-diffusion) for the different grain sizes. The numerical results will be compared with experiments.

The financial support of the VBKO (Vereniging van Waterbouwers in Bagger-, Kust en Oeverwerken) for this research is gratefully acknowledged.

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The financial support of the VBKO (Vereniging van Waterbouwers in Bagger-, Kust en Oeverwerken) for this research is gratefully acknowledged.

Since 1985 Cees van Rhee has been engaged with research for the dredging industry, the first five years at WL/Delft Hydraulics and from 1990 to the present at Ballast HAM Dredging. At Ballast HAM he was employed at the Research Department, Estimating Department and worked for two years in Hong Kong where he was responsible for the Production and Planning of one of the large land reclamation projects that were executed at that time. From 1997–2001 he was posted for two days per week at Delft University of Technology where a PhD research programme, financed by major Dutch dredging contractors, was executed. This article is part of this research programme.

In the last decades, large areas of land were reclaimed using trailing suction hopper dredgers (TSHD), and in the near future more large reclamation projects will be executed, especially in the Far East. During the overflow phase of the loading stage of the dredging cycle, a part of the dredged volume of sand will not settle in the hopper but will be transported with the overflow discharge overboard. For production, sand quality and environmental reasons it is important to predict the amount of these so-called overflow losses.

A trailing suction hopper dredger (TSHD) is a sea-going vessel that is equipped with one or two suction pipes, which are lowered to the sea bottom during dredging (Figure 1). From the bottom a sand-water mixture is sucked up and discharged into the cargo hold, the so-
The hopper area can be divided into 5 different sections:
1. Inflow section
2. Settled sand or stationary sand bed
3. Density flow over settled bed
4. Horizontal flow at surface towards the overflow
5. Suspension in remaining area

In the inflow section the incoming mixture flows towards the bottom and forms an erosion crater and density current. From this current, sedimentation will take place which leads to a rising sand bed. The part of the incoming sediment which does not settle will move upward into suspension. At the water’s surface the vertical supply of water and sediment creates a strong horizontal flow towards the overflow section.

The loading process will be continued until the hopper is completely filled with sand or when the sand losses grow to an uneconomical level.

Apart from the inflow section the flow in the suspended part of the hopper is basically one-
dimensional. In the horizontal direction the (measured) concentration is very uniform (vertically layered). For more details of the experiments and results reference is made to Van Rhee (2001).

**Overflow losses**

A very important quantity during the loading process is the overflow loss. Two different definitions of this quantity are used. The loss can be defined as:

- the ratio of the outflow and inflow sand flux at a certain moment; or
- the ratio of the total outflow and inflow (sand) volume.

The overflow flux is defined as:

$$ OV_{flux}(t) = \frac{Q_o(t) C_o(t)}{Q_i(t) C_i(t)} $$  \tag{1} \hfill (1)

The (cumulative) overflow loss is defined as:

$$ OV_{cum}(t) = \frac{\int_{0}^{t} Q_o(t) C_o(t) dt}{\int_{0}^{t} Q_i(t) C_i(t) dt} $$  \tag{2} \hfill (2)

in which $Q$ is the discharge and $C$ the volume concentration. The indexes $i$ and $o$ relate to the inflow and outflow respectively.

**Overview of Existing 1DV Numerical Modelling**

In the past a number of models to describe the hopper sedimentation process have been published. These models were all based on the ideal settlement basin theory of Camp (1946) and Dobbins (1944). In this theory the hopper is divided in three areas: the inflow, outflow and settling section (Figure 3). From the inflow section the mixture flows over the total depth (like in river flow) in the settling section.

Both the flow fields as the diffusion coefficient are based on velocity distribution (uniform or logarithmic) over the total depth. Vlasblom and Miedema (1995) extended this theory with the influence of hindered settling and the influence of the rising sand bed. Owing to the rising sand bed, horizontal velocity increases during loading which leads to increased scour.

The effect on the overflow losses is, however, limited since it is assumed that velocity is uniform over depth and therefore apart from at the very last moment will remain at a low value.

More recently Ooijens (1999) extended this model by adding dynamics to the system. In the Vlasblom and Miedema model the concentration in the hopper is always equal to the inflow concentration and outflow concentration reacts instantaneously on the calculated settling efficiency.

Ooijens adds the time effect by regarding the hopper as an ideal mixing tank. The calculated concentration in the hopper is used for the settling efficiency calculation. The extension is an evident improvement, since it enables, for instance, the influence of overflow level variation on the calculation. The basis of the method is still, however, the Camp theory that is based on a flow
sedimentation velocity. Owing to scale effects this mechanism will not play an important role with the model hopper sedimentation. Instead of the horizontal one-dimensional approach of the Camp-like models with a horizontal supply of sand on one side and overflow on the other, this model supplies sand from the bottom (fed by the density current) and the overflow will be located at the top.

**The 1DV Model – Introduction**

It was mentioned in the “Process Description” that apart from the inflow section, near the bottom and near the water surface, the flow in the suspended part of the hopper is basically one-dimensional. In the horizontal direction the (measured) concentration is very uniform (vertically layered). Based on this observed flow field of Figure 2, the flow can be further schematised as indicated in Figure 4. Four different areas can be noticed in this figure. From bottom to top:

1. Settled sand
2. Area where sand is supplied to the model (simplification of the density current)
3. Suspension
4. Overflow section (the overflow section normally present at one or two locations is uniformly distributed over the total surface)

In area 2 the inflowing sand flux is prescribed. A part (depending on grain size and local concentration) will settle into zone 1. The remainder will be transported into zone 3. At the top (area 4) the sand can escape into the overflow. The concentration development in zone 3 is described with the advection-diffusion equations for all fractions. The theory will be outlined in the next paragraph.

Like all models this model simplifies reality:
- (possible) erosion or decreased sedimentation owing to the bottom shear stress from the density current is not taken into account.
- the suspension layer is supplied with a sand-water mixture with a concentration and discharge (point B in Figure 2). It is assumed that these quantities at this location are the same as at the inflow location in the hopper (point A in Figure 2). In reality this is not the case since owing to entrainment between points A and B (see Figure 2) mixing will take place between the inflow section and the suspended section.
- reduction of the effective hopper area owing to the presence of an erosion crater is not taken into account.
- the sand is uniformly distributed over the total surface of the hopper, so in fact an ideal inflow system is created (an infinite number of inflow points equally divided over the total hopper area). In reality the inflow is only located in a finite number of locations (in practice very often only at one location) and horizontal sediment transport must distribute the sand over the hopper surface. This horizontal transport is accompanied by a horizontal mixture velocity which, when above a certain threshold value, can reduce the sedimentation velocity. Owing to scale effects this mechanism will not play an important role with the model hopper sedimentation.

Instead of the horizontal one-dimensional approach of the Camp-like models with a horizontal supply of sand on one side and overflow on the other, this model supplies sand from the bottom (fed by the density current) and the overflow will be located at the top.
It will be shown that this will implement the influence of the hopper load parameter and the mutual interaction of the different grain sizes of the particle size distribution in a relatively simple way. The latter effect is totally absent in the Camp model; every fraction is calculated independently.

**Basic Equations of the 1DV Model**

The vertical transport of sediment in zone 3 is described with the one-dimensional advection-diffusion equation. Using the grain-size distribution the incoming sand flux can be distributed over the different fractions. The cumulative particle size distribution (PSD) is used in the model to take the different grain sizes into account. If the PSD is presented with $N+1$ points, $N$ fractions are used.

The advection-diffusion equation for a fraction $i$ can be written as:

$$\frac{\partial c_i}{\partial t} = - \frac{\partial}{\partial z} (c_i v_z) + \frac{\partial}{\partial z} \left[ \epsilon_z \frac{\partial c_i}{\partial z} \right] + q_{si} \tag{3}$$

In this equation $c_i$ is the concentration $v_z$ and the vertical velocity of a certain fraction. The vertical diffusion coefficient is represented with $\epsilon_z$. The equation includes a source term $q_{si}$ that is used to insert the sediment into the system.

If the equation is solved for a mono-sized suspension (only one grain diameter present), the fall velocity for that grain size can be substituted for $v_z$. The fall velocity of a grain is a function of the grain properties and the concentration. In general (Richardson and Zaki 1954), this relation is written as the product of a reduction function and the fall velocity of a single grain $w_0$ as in equation (4).

$$w_z = (1 - c_i^n) \cdot w_0 \tag{4}$$

The exponent $n_i$ is a function of the Particle Reynolds number defined as $Re_p = \frac{w_z D}{\nu}$. Richardson and Zaki (1954) provided different relations depending on the value of $Re_p$. A smooth presentation can be achieved using a logistic curve given with:

$$\frac{A - n_i}{n_i - B} = C Re_p^a \tag{5}$$

Or, more conveniently:

$$n_i = \frac{a + b Re_p^a}{1 + c Re_p^a} \tag{6}$$

For the coefficients, the values are reported as seen in Table I.

The different approaches are compared in Figure 5. It is clear that the expression according to Rowe (1987) is a smooth representation of the original Richardson and Zaki relations. The relation according to Garside and Al-Dibouni (1977) shows the same trend, but provides somewhat higher values for the exponent. Using the values according to Di Felice (1999) very high values for the exponent are found. This relation is however only valid for dilute mixtures.

When a multi-sized mixture is simulated, the situation becomes more complicated since the different fractions will have a mutual influence. The simplest approach, often used in numerical models used to compute suspended sediment transport, is to use the total concentration in the reduction function. The vertical velocity of a certain fraction is in that case calculated with equation (7). ($N$ is the number of fractions, and $n$ is the exponent valid for that fraction).

$$v_z = w_0 (1 - \bar{c}) \cdot n_i ; \quad \bar{c} = \sum_{i=1}^{N} c_i \tag{7}$$

This approach is however not correct because the effect of the return flow of large particles on the small particles is not included. With this simple relation all particles will move in the same direction, while in reality it is possible that small particles move in the opposite direction owing to the return flow of the large particles.

If the effect of the grain size is to be modelled correctly, a more sophisticated approach is needed. The

<table>
<thead>
<tr>
<th>Table I. Values of coefficients.</th>
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<tr>
<td>Author(s)</td>
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<tr>
<td>-----------</td>
</tr>
<tr>
<td>Garside et al. (1977)</td>
</tr>
<tr>
<td>Rowe (1987)</td>
</tr>
<tr>
<td>Di Felice (1999)</td>
</tr>
</tbody>
</table>
approach is to assume that every grain settles with a certain slip velocity relative to the fluid velocity (Mirza and Richardson 1979).

\[ v_{z,i} = v_w - w_{s,i} \]  

(8)

The slip velocity is calculated according to Mirza and Richardson (1979) with:

\[ w_{s,i} = w_{0,i} (1 - \xi) \gamma - 1 \]  

(9)

This results directly from the hindered settling equation, since the settling particles create a return flow that has to flow through an area \((1 - \xi)\). In this approach the influence between two or more different fractions is present with the total concentration and the return flow of all particles. The particle-particle interactions between different fractions are, however, not included and as a result this approach does not give good agreement with experimental data for particles with large differences in size (or density).

A relatively simple method to include the interparticle influences for different fractions was proposed by Selim et al (1983). On the fall velocity \(w_{0}\) of the larger grains, the influence of the smaller grains is taken into account by a correction of the specific density for the larger grains. It is assumed that a grain with a certain size settles in a suspension formed by the grains with a smaller size.

To solve the advection-diffusion equation for all grain sizes the combined action of all grain sizes must be quantified. This can be done using the volume balance in vertical direction for both sand and water:

\[
\sum_{i=1}^{N} v_{z,i} c_i + \left[ 1 - \sum_{i=1}^{N} c_i \right] v_w \frac{Q_s}{A} = w
\]  

(10)

Note that the vertical bulk or mixture velocity \(w\) is based on the discharge into the hopper and the total hopper area as a result of the simplifications mentioned earlier in “1DV Model – Introduction”. Together with equations (8) and (9) this last relation forms a system of \(N+1\) equations with \(N+1\) unknowns \((v_w, v_{z,i})\). With some mathematics the following simple relation can be derived from this system:

\[
v_w = w + \sum_{i=1}^{N} c_i w_{s,i}
\]  

(11)

Substitution in (8) leads to the following result:

\[
v_{z,i} = w + \sum_{i=1}^{N} c_i w_{s,i} - w_{s,i}
\]  

(12)

Apart from the vertical bulk velocity \(w\), this result was already published by Smith (1966).
NUMERICAL PROCEDURE

When at a certain time the concentration of all fractions is known, the right-hand side of equation (12) is known and the grain velocity can be calculated. Using the grain velocities on time $t$ the advection-diffusion equation can be solved for the next time step.

The partial differential equation (3) is solved for every fraction using a finite difference scheme. A semi-implicit approach is used. The first term in of the right-hand side (advection) is treated explicitly with a first order upwind scheme or with central differences; the second term (diffusion) is treated implicitly with central differences. This leads to a tri-diagonal system of equations.

The numerical procedure is as follows:

– Step 1. At the beginning of loading the concentration distribution is known for all fractions. In most cases $c_i = 0$ over total height (but can be arbitrarily chosen).
– Step 2. Using (12) the vertical velocities of the grains can be calculated.
– Step 3. Subsequently using the finite difference method all fractions are solved independently for one time-step. This leads to a new concentration distribution on time $t + \Delta t$.
– Step 4. Steps 2 and 3 are repeated until the hopper is filled to certain level or for a certain total simulation time.

The system can be solved when the following parameters and conditions are known:

– the initial condition (values of all quantities at $t = 0$);
– the boundary conditions;
– the value of the diffusion coefficient $\varepsilon_z$ as a function of height $z$ and time $t$;
– the value of the vertical bulk velocity $\nu$;
– the grain size distribution; and
– the value of $q_{s,i}$, the incoming sand flux per fraction.

A detailed description of the numerical procedure (Finite Difference Method) is beyond the scope of this article. Reference is made to Ferziger and Perić (1999). The boundary conditions and diffusion coefficient, however, deserve some extra attention.

BOUNDARY CONDITIONS

At the bottom the net sedimentation flux (depending on the concentration at the bottom) will be calculated, and this amount will be stored in the bed. At the water surface normally the sand flux will be put to zero. In this case at the surface the sand flux $s$ will be prescribed to simulate the overflow:

$$ s = v_{z,i}c_i \left( v_{z,i} > 0 \land Q_{i} > 0 \right) $$

(13)

The two conditions must be included, since overflow will only take place when the mixture is discharged in the hopper, and to prevent the surface point from acting as a source term in case the vertical sand velocity is directed downwards.

TURBULENT DIFFUSION COEFFICIENT

It is common to relate the diffusion coefficient to the turbulent eddy viscosity using the Schmidt number $\sigma_t$:

$$ \varepsilon_z = \frac{\nu}{\sigma_t} $$

(14)

Unlike the eddy viscosity, which is not a fluid property since it depends strongly on the flow field, the Schmidt number varies only slightly across any flow and also slightly from flow to flow (Rodi, 1993). Using the above relation, the problem has shifted towards the determination of the eddy viscosity. When focusing on the situation near the bottom in the density current, the order of magnitude of this parameter during the tests can be estimated using the mixing length theory of Prandtl:

$$ \nu = \frac{l^3}{2} \left| \frac{\partial u}{\partial z} \right| $$

(15)

The mixing length increases with distance from the bottom. When $\delta$ is the thickness of the density current, the mixing length can be estimated as $0.09 \delta$ (Rodi 1993). Typical values measured from the experiments are $\delta = 0.25 \text{ m}$ and $\partial u / \partial z = 2.5 \text{ s}^{-1}$. This leads to an eddy viscosity of $0.0013 \text{ m}^2/\text{s}$.

COMPARISON BETWEEN THE 1DV MODEL AND EXPERIMENTS

The numerical model is compared with one-dimensional tests in a sedimentation column and the model hopper sedimentation tests.

Sedimentation column

The one-dimensional sedimentation tests were carried out in a tube with an inner diameter of 0.3 m and height of 1.5 m at the Laboratory of Fluid Mechanics at the Delft University of Technology (Runge et al. 1998 and Klerk and Meulepas 1998). Inside the tube a grid was placed, which was fixed to the walls of the column. By rotating the column (with grid), turbulence inside the column could be generated and the sedimentation of sand in turbulent conditions could be studied as well.

It is more common to generate turbulence by oscillating the grid into vertical direction inside a stationary column. In this case this approach could not
settlement function is according to the standard values of Richardson and Zaki (1954). The density correction according to Selim et al. (1983) was not used. The agreement between the measured and computed concentrations is good. During the test, samples were taken from the column at four different levels (0.3, 0.6, 0.9 and 1.2 m above the bottom of the column) at different times. The particle size distribution was determined from these samples.

During the calculation the concentration of all fractions is known as function of time and height. This enables calculation of the value of $d_{50}$ in the model as function of time and space. The computed values can be compared with the measured values at the sampling locations in Figure 7.

The agreement is reasonable. The grain size in the settled bed is predicted quite well but the measured grain size in the suspension decreases faster than calculated from which can be concluded that the actual segregation develops more quickly than calculated.

In the column, sand concentration was measured at twelve locations, so a good impression of the concentration vertical could be formed. Tests were carried out on uniform sands with grain diameter $d_{50}$ of 80, 160 and 270 µm and graded sand with a $d_{50}$ of 160 µm ($d_{10}$ is 85 µm, $d_{90}$ is 500 µm). Because the 1DV model includes the mutual interaction of the different fractions, results are shown here of the graded 160 micron tests. In Figure 6 results from a test are shown. The tube was filled to a level of 1.4 m with a sand concentration of approx. 30% by volume.

The measured and computed concentration profiles at different moments during the settling process are shown in Figure 6. The exponent in the hindered

be used owing to the projected high initial sand concentration and the resulting high level of settled sediment inside the column after a test. The grid would in that case be forced to move through the sand bed that would lead to large forces on the grid and most probably destruction of the grid.
**Hopper sedimentation tests**

Model hopper sedimentation tests were performed at WL/Delft Hydraulics (see Van Rhee 2001). The numerical model will be compared with two experiments Test 5 and Test 6. For both tests, sand with a d50 of 105 (m was used. The PSD is schematised to 7 fractions.

Table II shows the values used in the calculation.

<table>
<thead>
<tr>
<th>Diameter (µm)</th>
<th>Cumulative (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>0</td>
</tr>
<tr>
<td>42</td>
<td>14.0</td>
</tr>
<tr>
<td>57</td>
<td>17.0</td>
</tr>
<tr>
<td>75</td>
<td>34.0</td>
</tr>
<tr>
<td>100</td>
<td>43.0</td>
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<tr>
<td>134</td>
<td>73.0</td>
</tr>
<tr>
<td>178</td>
<td>97.0</td>
</tr>
<tr>
<td>318</td>
<td>100.0</td>
</tr>
</tbody>
</table>

Operational parameters:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Test 5</th>
<th>Test 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Discharge</td>
<td>0.099 m³/s</td>
<td>0.137 m³/s</td>
</tr>
<tr>
<td>Density</td>
<td>1310 kg/m³</td>
<td>1420 kg/m³</td>
</tr>
<tr>
<td>Overflow level</td>
<td>2.25 m</td>
<td>2.25 m</td>
</tr>
<tr>
<td>Water level at start</td>
<td>1.25 m</td>
<td>1.25 m</td>
</tr>
</tbody>
</table>

During the calculations the turbulent diffusion coefficient was constant over the height and equal to 0.0013 m²/s. In Figures 8 and 9 the results of the comparison are shown. In these figures four lines are shown:

- the concentration of the mixture entering the hopper;
- the measured concentration in the overflow; and
- two computed concentrations in the overflow.

Table II. Values used in the calculation.

One overflow computation is based on a multi-sized mixture of the 7 fractions shown above and one calculation is based on a mono-sized mixture with a particle size equal to the d50 of the PSD. The results from the mono-sized mixture underestimate the overflow concentration during the largest part of the loading time (which leads to a lower cumulative overflow loss).

The final outflow concentration agrees, however, with the measurements. Test 6 was performed at
maximum (for the installation) incoming sand flux. Owing to the high sand flux, the measured concentration in the overflow remains almost constant during some time. The model very well reproduces this phenomenon (which only occurs at very high or low sand flux). At the end of the test, the incoming sand flux decreases owing to a lack of sand in the storage tank (the overflow losses during the test were high, so a lot of sand was needed). The overflow concentration drops sharply in response. This phenomenon is reproduced nicely by the model.

It must be stressed, however, that it is not yet certain whether the model will reproduce the prototype situation as closely. On a larger scale, it is not known yet if the influence of the horizontal transport on the sedimentation velocity can be neglected (as is done in the 1DV model).

**Conclusion**

The flow field observed during the model hopper sedimentation tests formed a basis for the development of a relatively simple one-dimensional sedimentation model. This model is based on the advection-diffusion equation for a multi-sized mixture and includes the influence of the hopper load parameter and the particle size distribution.

The agreement between the numerical model and the experiments (one-dimensional sedimentation process in a sedimentation column and the model hopper sedimentation tests) is good. The model will now be extended to two dimensions to include the effect of the horizontal transport. Results of these efforts will be published in the future.

**References**

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Books/Periodicals Reviewed

Dredging Seen, Perspectives — From the Outside Looking In
Proceedings of the CEDA Dredging Day 2001,
The Netherlands. Looseleaf bound, 21 cm x 30 cm,
177 pages, illustrated. € 45 plus postage.

A. Csiti, Editor

The international professional society Central Dredging Association (CEDA) is a member of the World Organization of Dredging Associations, which also incorporates the Western Dredging Association (WEDA) and Eastern Dredging Association (EADA). CEDA is the member which serves Europe, Africa and the Middle East on all aspects of dredging and which hosts the “CEDA Dredging Day” in conjunction with Europort, the biennial maritime exhibition held in Amsterdam, The Netherlands. The one-day conference has a history of presenting a wide variety of relevant technical papers on dredging and related subjects. Over the years this biennial event has been an important source of new, relevant technical literature.

The objectives of CEDA are worthy of mention:
– to promote the development and dissemination of professional knowledge;
– to participate in developing international and national policies and guidelines;
– to facilitates contacts within and outside the dredging community; and
– to enhances the public image of dredging.

The Proceedings, which are published in loose-leaf form, are composed of two major sections:
– the Technical Programme papers, of which there are nine; and
– an Academic Session of which there are five papers.

The Academic Session is a special session to provide a forum for university and college students and young faculty to present research results on any subject matter related to dredging.

For this year’s technical programme the CEDA organization chose a unique format: it invited guest speakers who work with the industry but stand clearly outside of it to express their perceptions of the industry. This thematic portion of the Proceedings pertaining to the perceptions of dredging is divided into three separate sessions:

– Session A: Clients
– Session B: Quality Control and Environment
– Session C: Finance and Public Perception

Both the subject matter and substance of the papers from these three sessions varies considerably. Several papers were outline-type presentations that do not carry their messages on their own as they appear in the Proceedings. In other words, you must have been in the audience at the presentation to be able to garner the true value of the message.

It is important and significant that Greenpeace gave a presentation on tri-butyl tin anti-fouling agents and the resultant problems with contaminated sediments and their subsequent disposal. If the presentation had been in a more rigorous technical paper format, it would have been far more useful to readers who did not attend the conference. The same is true for the initial paper on the very interesting North Sea submersed pipeline projects. The paper is only an outline of these complex and milestone dredging and marine construction projects. The outline does give a sense of the key elements, but a more conventional paper would have been far more useful for inclusion in the written proceedings.

Regulators, the media, ship classification experts and financiers also presented papers as was consistent
with the theme, “from the outside looking in”. The paper on regulatory issues in the UK and the financial aspects both provide valuable insight.

The media presentation in the proceedings was limited to an abstract. The port authority paper, “How to Get Consensus between all Parties Involved in Dredging in the Port of Dunkerque”, offered by the UK regulatory Centre for Fisheries, Environment and Agricultural Science get high marks on presentation and content.

The Academic Session contains some very technical presentations that are consistent with the objectives of the session. All these papers have their genesis in the halls of academia and are mostly very theoretical analysis of distinct elements of the dredging process. They remain a mainstay for the inclusion of basic research into the literature of dredging and for that reason, the CEDA Dredging Days continue to play an important role in reaching its goal of promoting the development and dissemination of professional knowledge.

Certainly, these proceedings are an essential addition the technical libraries of universities, colleges, consultancies and dredging contractors. They build on the body of literature created over the years by the biennial CEDA Dredging Day.

Copies of the Proceedings may be obtained from:
CEDA Secretariat
P.O. Box 488
2600 AL Delft, The Netherlands
Email: ceda@dredging.org

www.dredgeline.net

CEDA, IADC, VBKO and OPL

Each year a vast amount of literature is produced about dredging and dredging-related subjects. While some of this appears in book or magazine form, much of this information is contained in so-called “grey” literature – research reports and papers presented at various conferences.

For a number of years, several professional organisations have been seeking a way to make this knowledge available to a wider audience. This effort has finally resulted in www.dredgeline.net, a website which recently – at the end of January – became fully operational.

“Dredgeline” is a bibliographical database, a so-called e-library, with over 4,000 documents. It is a joint initiative of CEDA (Central Dredging Association), IADC (International Association of Dredging Companies) and VBKO (Dutch Association of Dredging, Shore and Bank Protection Contractors), and is published by Oilfield Publications Ltd. The records have been produced by the Library of Delft University of Technology in the Netherlands which will keep it updated regularly.

The system is user-friendly and searching can be done by title, author, name of periodical or conference, abstract, classification number and by keywords (in English). The menu consists of the following:
- the “Browse” option allows the user to scroll through alphabetical indexes of authors, titles, terms and so on;
- the “Search” option finds records by keywords or phrases;
- “Previous Search” lists sets of records from the user’s past searches; and
- the “Basket” saves records in a basket for photocopy requests.

Alphabetical indexes include: document number, title, author, source, publication date, ISSN or ISBN Code, document type, controlled and uncontrolled terms and classification. Once the user has selected documents and put them in the “basket”, photocopies can be ordered directly from the Library of TU Delft or from the organisation mentioned in the “Note” field. Hot links are provided to the downloadable documents or to the source organisation.

Finally, if you have books or reports which you think might be appropriate for inclusion in this database you can send them to OPL or CEDA and they will determine if they should be included. In addition, as the system is newly operational the group is interested in comments and suggestions through the “Feedback” option.

Dredgeline.net is an excellent tool for anyone doing research on dredging and related subjects. It offers users the possibility to take advantage of the extensive experience of others in the field.

For more information go to www.dredgeline.net or contact CEDA at ceda@dredging.org or Oilfield Publications Ltd. at jasoncharlton@oilpubs.com.
Seminars/Conferences/Events

38th International Seminar on Port Management
UNESCO-IHE Institute for Water Education
Delft, The Netherlands
April 6-May 4 2002

This three-week seminar plus one-week study tour known as the “International Port Seminar” has been presented annually since 1964. Organised with the co-operation of the Municipal Port Managements of Rotterdam and Amsterdam, it provides a comprehensive overview of the organisational and managerial aspects of modern ports.

The programme includes (amongst others) lectures on Port Management, Port Reform and Strategy, Port Logistics and Economics, Port Marketing, Port Planning and Design, Tariffs, Hinterland Connections, Bulk-handling, Maintenance Dredging and so on.

Highlights include a hands-on workshop on Resource Control Management; a one-day seminar on Port Privatisation; day trips to the ports of Antwerp, Amsterdam and Rotterdam; and a week study tour to ports in the north of The Netherlands, Germany and Denmark.

A limited number of scholarships of the Netherlands Fellowship Programme (NFP) are available for nationals of developing countries (maximum age 45 years).

For further information and application forms:
IHE Delft/UNESCO Institute for Water Education
PO Box 3015
2601 DA Delft, The Netherlands
tel. +31 15 215 1715
fax +31 15 212 2921
email ihe@ihe.nl
http://www.ihe.nl

Sea Japan
Tokyo Big Sight Exhibition Centre
April 10-12 2002

This is the major biennial meeting place for Japan’s shipbuilding, marine equipment and ship-owning industries. Exhibitors include companies involved with software, communications, ship classification as well as government and regulatory bodies, and management. A New Technology Seminar programme will allow exhibitors to present details of their latest products.

For further information in Europe contact:
The Seatrade Organisation
Seatrade House, 42-48 North Station Road,
Colchester CO1 1 RB, UK
tel. +44 1206 545121, fax +44 1206 545190
email: Rjohnson@seatrade-global.com

In Asia:
 Miller Freeman Asia Limited
  17/F China Resources Bldg.,
  26 Harbour Road, Wan Chai, Hong Kong
tel. +852 2827 6211, fax +852 2827 7831

and other Miller Freeman offices in Asia through email: sales@cmpjapan.com
www.seajapan.ne.jp

ITMMA Maritime and Port Symposium
Antwerp, Belgium
April 18-20 2002

The Institute of Transport and Maritime Management Antwerp, an autonomous university institution within the University of Antwerp, in collaboration with McKinsey & Company has organised a symposium, entitled “The Maritime and Port Industry in Transition: Solutions Beyond Economies of Scale and Scope”.

The purpose of the symposium is to understand the challenges facing the maritime industry in this new century and is intended for top-level executives, policymakers and academics. A number of high-level international speakers from academia and McKinsey will address strategic issues, after which break-out workshops on inter-modality, logistics; port competition and co-operation and port networking are planned.

For further information contact:
ITMMAPS, Middelheimlaan 1, B-2020 Antwerp, Belgium
tel. +32 3 218 0678, fax +32 3 218 0743
email: itmma@ua.ac.be
www.itmmaps.com

COPRI Dredging ’02
Rosen Plaza Hotel,
Orlando, Florida USA
May 5-8 2002

Dredging ’02 organised by Coastal, Oceans, Ports, and Rivers Institute (COPRI) of the American Society of Civil Engineers, will focus on “Key Technologies for Global Prosperity”. The economic impacts of dredging will be emphasised, in subjects such as:
– increasing costs of dredged material disposal;
– the necessity for deepening projects to maintain port viability; and
– benefit and cost considerations of dredging as a large-scale environmental remediation tool.

A wide range of other general topics, such as, beneficial uses of dredged materials, treatment of contaminated sediments, specialty dredging equipment, case studies of special dredging projects and so on are also of interest. In addition, the conference will feature an Exposition of the newest technologies and services for dredging professionals.

For further information about technical programme contact:
Stephen Garbaciak, Jr., P.E.
Technical Programme Chair
BBL, Inc., 200 S. Wacker Dr, Suite 3100
Chicago, IL 60606-5802
tel. +1 312 674 4937
email: sdg@bbl-inc.com

For general information contact:
COPRI/ASCE Headquarters
Conference Department
1801 Alexander Bell Drive
Reston, VA 20191-4400
tel. +1 800 548 2723, fax +1 703 295 6144
email: conf@asce.org

WEDA XXII & TAMU 34
Omni Interlocken Resort,
Denver (Broomfield), Colorado USA
June 12-15 2002

The 22nd Western Dredging Association Annual Meeting and Conference and the 34th Texas A&M Dredging Seminar will be held in June 2002 at the Omni Interlocken Resort. The theme of the conference is “Dredging for Prosperity” and will provide a unique forum for all interested parties. Topics for the three-day technical programme and exhibition will include:
– dredging for development;
– beneficial uses of dredged material;
– wetland creation and restoration;
– beach nourishment;
– automation in dredging;
– contaminated sediments;
– project case studies and more.

For further information please contact:
Dr. Ram K. Mohan
Blasland, Bouck & Lee, Inc.
tel. +1 410 295 1205, fax +1 410 295 1209
email: rkm@bbl-inc.com

Dr. Robert E. Randall
Dept. of Civil Engineering, Texas A&M University
tel. +1 979 845 4568, fax +1 979 862 8162
email: r-randall@tamu.edu

Mr. Stephen Garbaciak, Jr.
Blasland, Bouck & Lee, Inc.
tel. +1 312 674 4937, fax +1 312 674 4938
email: sdg@bbl-inc.com

Shiport China 2002
Dalian Xinghai Convention & Exhibition Centre, China
June 26-29 2002

Dalian, the hub of the maritime industry in Northern China, is hosting this 3rd International Ship Building, Port and Marine Technology and Transportation Equipment Exhibition. It is the premier exhibition for the industry in China offering information on shipbuilding equipment, port facilities, marine technology, transportation equipment, as well as related services and equipment. Concurrently the International Marine-Tec Conference will be held at which experts address key technology trends.

For further information contact:
Business & Industrial Trade Fairs Ltd.
Unit 1223, HITEC, 1 Trademart Drive,
Kowloon Bay, Hong Kong
tel. +852 2865 2633
fax +852 2866 2076/ +852 2865 7729/+852 2866 1770
email: shiport@bitf.com.hk
30th PIANC Navigation Congress
Sydney, Australia
September 22-26 2002

The Organising Committee, under the auspices of PIANC and the Institution of Engineers, Australia, and with support from government, industry and academia, is presenting a conference which will focus on the following topics:
- How to guarantee sustainable navigation;
- Environmental issues;
- Policy issues, such as the role of public and private sectors in port development;
- Inland waterways transport;
- Port issues, such as revitalisation and port planning and operations; and
- Issues related to ships and fairways.

An IADC Award for the best paper by a younger author will be presented.

For further information please visit the Australian Organising Committee homepage: www.tourhosts.com.au/pianc or contact:
PIANC, General Secretariat
Graaf de Ferrairis - 11th Flr.
20, Boulevard du Roi Albert II,
1000 Brussels, Belgium
tel. +32 2 553 7160, +32 2 553 7155
e-mail: info@pianc-aipcn.org
Web: www.pianc-aipcn.org

European Conference on Dredged Sludge Remediation
Hilton Hotel,
Rotterdam, The Netherlands
October 30-November 1 2002

The conference is being organised by “Stichting Klasse 4” – Class 4 Foundation – which presents a platform for discussions about the possibilities of turning contaminated harbour and river sludge into useful building materials. The foundation has organised two national conferences in 2000 and 2001 where national developments and policies of environmentally sound remediation of contaminated dredged sediments were discussed. Following up on these conferences, the 2002 European Conference will look at international developments in relation to current policies, political ambitions and technological advancements.

For further information contact:
Stichting Klasse 4, PO Box 18
3830 AA Leusden, The Netherlands
tel. +31 33 434 3500, fax +31 33 434 3501
e-mail: info@klasse4.nl
www.klasse4.nl

Call for Papers
CEDA Dredging Days
Casablanca, Morocco
October 22-24 2002

For the first time in its history, the CEDA Dredging Days will be held outside Europe in Casablanca, Morocco. The event is being organised to celebrate the creation of the North African Section. The theme will be “Dredging Without Boundaries”. Suggested topics include but are not limited to: dredging philosophy; legislation; environmental and economic aspects of dredging; tendering procedures, pre-dredging survey; dredging equipment; capital and maintenance dredging operations; mining and beach nourishment; case studies; beneficial use of dredged material; and education and training.

Abstracts of 300 words should be submitted electronically by March 15th 2002. Adobe Portable Document Format (PDF) files are preferred. Rich Text Format (RTF) or plain text (ASCII) are also acceptable. Submissions must include the name, affiliation, complete return address, telephone and fax numbers and e-mail addresses of each author. The corresponding author’s name must be identified. Papers must be original and should not have been published or offered for publication elsewhere. The Technical Paper Committee will review abstracts. Authors will be informed by April 15th 2002 of the acceptance of the paper and will receive the Author’s Kit, which includes instructions for manuscript preparation, the conference registration form and a copyright transfer form.

Draft manuscripts of 3000-5000 words are due by June 1st 2002. Reviewer comments will be sent to the authors by July 15th 2002 for revisions. Final camera-ready papers must be received by August 15th 2002. An Academic Hour will be held as a special session to support young professionals, faculty and students. Especially those from the region are encouraged to submit papers. The International Association of Dredging Companies will present an IADC Award for the best paper by a younger author.

For further information or to submit abstracts electronically in English contact:
CEDA Secretariat, Anna Csiti
P.O. Box 488, 2600 AL Delft, The Netherlands
tel. +31 (0)15 278 3145, fax +31 (0)15 278 7104
e-mail: ceda@dredging.org

To submit abstracts electronically in French contact:
CEDA North Africa Secretariat, Dounia Gharbi
C/o: Dragage des Ports S.A.
5 Rue Charajat Addor, Quartier Palmier, Casablanca 20100, Morocco
tel. +212 22 95 91 00, Fax +212 22 23 26 00
e-mail: gharbi@drapor.com
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Jan De Nul Dredging, Abu Dhabi, UAE
Van Oord ACZ Overseas B.V., Abu Dhabi, UAE

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New Zealand Dredging & General Works Ltd., Wellington
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