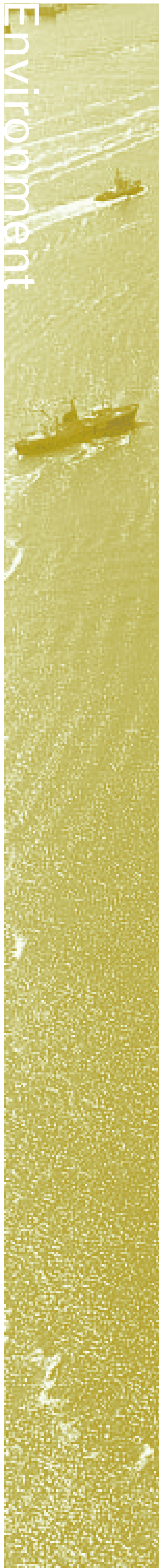

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High Accuracy Sanitation Dredging Trials

Abstract

Lake Ketelmeer is one of the major lakes in The Netherlands. Unfortunately the bottom of the lake is largely contaminated. Therefore plans for an environmental clean up are being developed. Although several remedial dredging projects have taken place in The Netherlands, there is not much experience in accurately dredging thin layers in large lakes. To gather more knowledge on the specific problems that can occur dredging trials have taken place in 1995 and more are scheduled for 1996. The extent of the pollution (28 km^2 out of a total surface of 38 km^2) and the expense of a clean up are reasons enough to investigate the possibilities of state-of-the-art dredging equipment and survey methods.
In order to achieve an optimal removal efficiency the accuracy of determination of the contaminated layer and dredging related environmental criteria like accuracy, spillage and turbidity are of great interest.
This article describes the preparation and execution of the first two dredging trials. Although the emphasis of this article is set on the testing of the dredging techniques (assessment and performance), the determination of the contaminated layer is also discussed (survey and field investigations), and the preliminary results are reported. The appendices present the descriptions of the two dredgers, the environmental impact, and the temporary disposal site. Further reports will be forthcoming.

Introduction

The settings for an environmental hazard at the IJssel Delta are as old as Holland: the rivers Rhine, Meuse and IJssel carried huge loads of fine silt towards their deltas. Protecting the reclaimed land against the sea, the Afsluit Dam with a length of 32 km was built in 1932. This dam changed a tidal area into the largest freshwater lake of The Netherlands: Lake IJsselmeer. In the 1950s new land was created at the southern part of that lake. Between the dikes of the new land a lake was created which is now known as the Ketelmeer (Figure 1).
From 1950 to 1980 the top layer of the Ketelmeer became heavily polluted, mainly with PCBs and heavy metals. Therefore it was necessary to develop a plan to clean up the polluted heritage of the previous decennia. Environmental impact assessments showed that the best way to deal with the problem was to remove the polluted layer of sediment and deposit it into a large depot. Reasons for this action are the site-specific circumstances of the Ketelmeer system:

– to call a halt to further dispersal of pollutants into the clean regions of the major IJsselmeer system;
– to stop emission of contaminants into the groundwater;
– to enable the multi-functional use of the Ketelmeer including recreational prospects; and
– to mitigate ecotoxicological impact on fauna and flora.

The disposal site is designed as an island, combining recreational developments whilst solving the environmental problems. The disposal site will be build from 1996 to 1998.

Characteristics of the Ketelmeer
The lake has a surface area of 38 km^2 of which about 28 km^2 is polluted. The polluted layer has an average thickness of 0.55 m, which leads to high quality demands for dredging techniques. As an illustration the consider following calculation:
Every centimetre of the polluted layer equals 280,000 m^3 of in situ sediment. A cubic metre disposal site costs about US$ 10, which implies that every centimetre in excess removed material costs US$ 2.8 million apart from the dredging costs.

These figures are reason enough to investigate the possibilities of state-of-the-art dredging equipment and survey methods. In order to achieve an optimal removal efficiency the accuracy of determination of the contaminated layer and dredging related environmental criteria like accuracy, spillage and turbidity are of great interest.

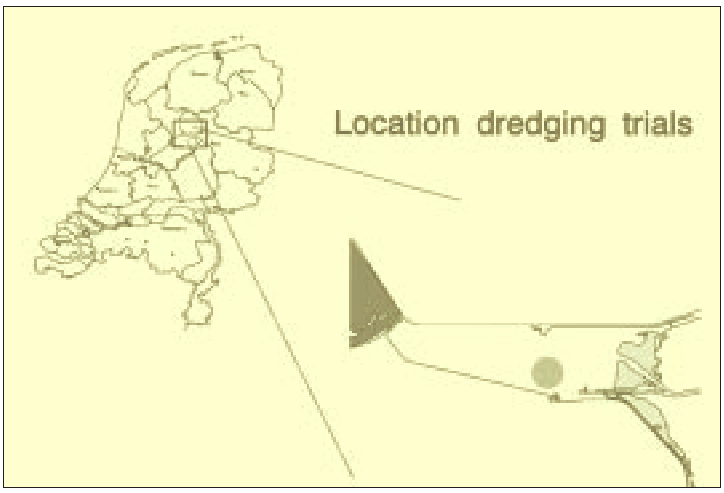
Initiators and Aim of the Trials
Two departments of the Netherlands Ministry of Transport, Public Works and Water Management initiated the dredging trials. The IJsselmeer Directorate, which is responsible for the IJsselmeer and the Ketelmeer,

From left to right: W. Borst, T. Mullié, B. Kappe, J. Pennekamp, K. Spelt, T. Arts, R. Elsman and W. Rosenbrand.

A number of people both in government and private industry have cooperated on this project and writing this report: From the Netherlands Ministry of Transport, Public Works and Water Management, Directorate General for Public Works and Water Management: Thomas Arts, North Sea Directorate; Rinus Elsman, Road and Hydraulic Engineering division; Bert Kappe, Directorate IJsselmeer; and from the dredging contractors: Ton Mullié, HAM-VOW; Wim Rosenbrand and Koos Spelt, Boskalis Oosterwijk; and supporting contractors: Wil Borst, Delft Dredging and Johan Pennekamp, Delft Hydraulics.

was the major initiator. The aim of this directorate is to gather information by means of a field trial on the method in which the future clean up could best be carried out.
The second initiator is the Development Programme Treatment Processes for polluted sediments (POSW).

Figure 1. Lake Ketelmeer in The Netherlands.



The aim of the POSW is mainly to collect data to compare different dredging techniques in a similar location, eliminating the variations in hydro-dynamic conditions and sediment characteristics.

Preparation of the Trials

Four promising techniques were selected by the Ministry. Each technique was either newly developed or a modification of a conventional technique to suit the demands of environmental clean-up operations. Contracts were negotiated with the companies that developed or modified these techniques. Two of the contractors decided to form a joint venture to perform the first two trials. The project plan was detailed, in close cooperation with these contractors, into a survey plan describing all the necessary measurements and a dredging plan containing all necessary dredger-related settings. These two documents formed the core of the work plan containing a day-by-day description and planning of all activities during the trials. A separate plan was put together to deal with the problem of accurate determination of the contaminated layer.

Preparation for Dredging Activities
The excavated sediments during the trials are deposited in a circular confined temporary disposal site situated next to the dredging areas. The site chosen for the first two trials was close to the disposal site in order to minimise the cost of transport. Because the design and filling of a disposal site is not straightforward, the behaviour of the deposited sediments in this depot is also closely monitored. Each trial was expected to be executed within a three week period, with an amount of excavated sediment that was not to exceed 15,000 situ m^3.

Field Investigations

Prior to the dredging trials an intensive field investigation was carried out to determine the contaminated layer. The described positioning system and echosounder measurements were also used as assessment tools during the dredging trials.

Positioning System
The essence of all measurements is high accuracy of the acquired data. To achieve this high accuracy the newly developed kinematic dGPS-Kart was chosen as main positioning system for both vertical as horizontal position. Although the expected accuracy of dGPS-Kart was within the specifications set for the trials (0.05 m, 2 x standard deviation), the vertical accuracy was almost equal to the specified accuracy.
To check the accuracy and reliability of the system a monitoring station was set up in the close vicinity of the dredging area. To establish the accuracy in several

Table I. Results Accuracy dGPS-Kart

	Horizontal - X		Horizontal - Y		Vertical - Z	
	Mean difference (m)	Standard deviation (m)	Mean difference (m)	Standard deviation (m)	Mean difference (m)	Standard deviation (m)
Monitoring station	0	0.015	0	0.015	0	0.025
Comparison Tachometer	0.016	0.022	0.039	0.023	0.004	0.024
Comparison Minilir	-	-	-	-	– 0.033	0.021

parts of the Ketelmeer a comparison between a tachometer (AGA 140H) and a Minilir and dGPS-Kart was made. The results which are shown in Table I clearly indicate the high achieved accuracy of dGPS-Kart. The differences found are obviously not absolute values but are related to the accuracy of the system used for comparison. Both the Tachometer and Minilir have specified accuracies only slightly better then the dGPS-Kart system.

Bathymetry

All bathymetric measurements for preparation of the project as well as the continuous monitoring during the trials were executed following strict procedures.
The actual depth measurement is corrected to an absolute level using the dGPS-Kart vertical component. The dGPS antenna was mounted directly above the transducer to eliminate offsets and gyro corrections. Before and after each survey the complete systems was checked using a metallic frame situated on the bottom of the lake with dimensions of 10 by 4 metres. The results of this check showed that the mean difference between echosounder measurement and actual depth was 0.02 m with a related standard deviation also of 0.02 m. The line spacing of the survey lines was minimised to 5 m to enable an accurate translation to a digital terrain model (DTM).

Coring

Coring was used to establish the boundary between contaminated and clean sediments. Fortunately the contaminated layer could be distinguished by means of visual interpretation. The coring instrument used was the "Vrijwitboor". Figure 2 shows the Vrijwitboor and a typical core sample. The position of the Vrijwitboor is accurately known by placing a dGPS-Kart antenna directly above the coring device. The estimated standard deviation of the thickness of the contaminated layer is 0.03 m.

Digital Terrain Model (DTM)

Two digital terrain models with a grid size of 1 m are necessary for the trials. The first is the DTM of the top of the contaminated layer and the second of the bottom of the contaminated layer. The first DTM was is based on the detailed bathymetric survey, due to the large amount of data available a high accuracy could be achieved. The calculated standard deviation of this DTM is 0.05 m. The second DTM is based on the results of the coring programme and is defined as the boundary between contaminated and clean layer.
The calculated standard deviation is 0.08 m. In both cases the kriging method was used to interpolate the data and to calculate the standard deviation.
To optimise the coring distance the initial grid distance of 100 m was decreased in specific areas to 20 m.
In addition 4 "crosses" were made consisting of two perpendicular lines of approximately 10 cores with a separation of 1 m. The optimum coring distance based on expected accuracy, dredging accuracy and cost is still under investigation.

Figure 2. The coring instrument "Vrijwitboor" and a typical core sample of a contaminated layer.

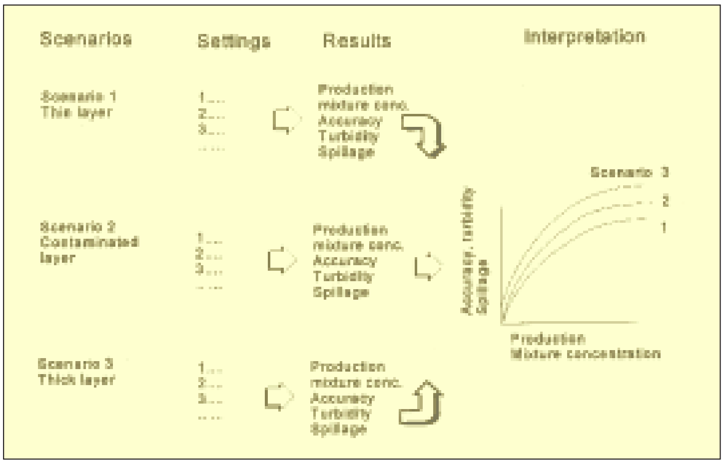
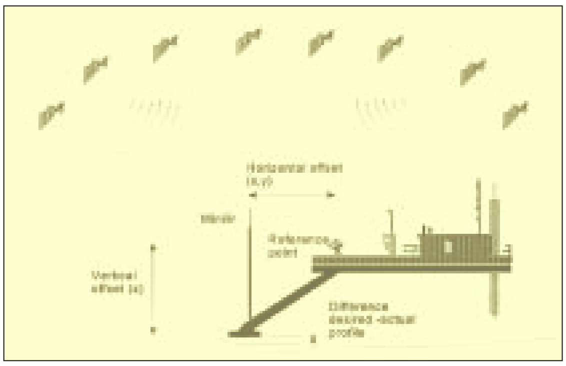


Figure 3. Summary of the method by which each dredging technique is assessed.

Dredging Techniques Assessment Method

The monitoring programme focussed on three criteria, namely, accuracy, spillage and turbidity, as these three items could to a large extent determine the impact of re-suspension, dispersion and re-sedimentation of (polluted) dredged material. The results of the criteria as measured during the trials are dependant on different dredging related process parameters (settings) all resulting in different productions and mixture concentrations. For every technique approximately 40 tests are scheduled each with different settings.
To reflect the situation of the Ketelmeer, where contaminated top layers are present within the range of 0.10 to 0.80 m, three scenarios were defined. The first scenario is the excavation of a thin top layer with a thickness of 0.20 m. The second scenario is the removal of the contaminated layer with an average thickness of approximately 0.40 m. The third scenario is defined as the removal of the thickest layer possible with that specific technique, which in the case of the first two tested techniques is approximately 0.70 m.
The aim of the tests is to establish a relation between the mentioned criteria and the actual production and mixture concentration. Figure 3 summarises the method by which every dredging technique is tested.

Figure 4. Positioning of the excavation head.



The criteria used for the assessment of the dredging techniques are detailed below.

Accuracy

The overall accuracy is calculated by means of comparison between the desired profile and the actual dredged profile. The actual dredged profile is determined by using a high precision echosounder system. However, not only this overall accuracy is measured but also the individual position components are determined. The individual measured components are shown in Figure 4, and are detailed as follows:

1. *Horizontal and vertical accuracy of the reference positioning system*
   All trials and related surveys will be carried out using the same reference system, namely the dGPS-Kart system. This system has a specified accuracy of less then 0.05 m in both horizontal and vertical direction.
2. *Horizontal and vertical accuracy of positioning the excavation head*
   The system used for converting the reference position on the dredger to the excavation head position is largely dependant on the dredger which is tested. Common systems used are pressure box and laserplane for the vertical correction and angle measurement in combination with offsets for both vertical and horizontal correction.
3. *Vertical accuracy of following the desired profile*
   Accuracy of excavation head to dynamically follow the desired profile according to the information from the digital terrain model.

To check the accuracies of the individual components an optical high accuracy system (Minilir) is used.
This system has a slightly higher specified accuracy than the dGPS-Kart system.

Spillage

Spillage is defined as all material that is loosened by the dredging technique without entering the transport system. In the case of the Ketelmeer trials this is translated to the soft material that is found on top of the dredged surface. Spillage is an important criterium because in this case spillage in general is often contaminated. To determine the spillage an intensive coring programme was set up after each trial. During each day an average of 25 cores were taken and interpreted. The Beeker sampler was used as a coring device due to its possibilities for highly accurate sampling with minimal disturbance of the top layer. Figure 5 shows the Beeker sampler with the result of a typical core. Selected samples of some cores were used to analyse the chemical quality of the top layer after dredging.

Turbidity

Turbidity is an important criterium in the Ketelmeer. Contaminants can be attached to the suspended solids which enables contamination to disperse to clean locations in the area.

Figure 5. The Beeker sampler (left) with several cut-open samples of a typical core (above).

The turbidity measuring campaign complies with the Dutch standard as developed by the Rotterdam Harbour Authority in combination with the major dredging contractors and the Ministry of Public Works.
This method allows an objective comparison between different dredging techniques. The turbidity is measured using optical sensors positioned in a "fixed" grid with a spacing of 30 x 30 metres around the tested dredger. In addition one measurement point is fixed on the dredger with continuous monitoring. To eliminate the influence of local disturbances and to enable a proper calibration, the background turbidity is continuously measured and water samples are taken regularly. Two major parameters which are extracted from the measurements are the characteristic increase of turbidity caused by the dredging activity and the amount of resuspended dredged material.
To quantify the turbidity a three-day measurement campaign is executed during the testing of each dredging technique. The turbidity measurement is not restricted to the actual dredging process but also other activities are monitored (eg replacing anchors). Included in the turbidity measurements are some "worst case" settings of the dredging technique.

PERFORMANCE DREDGING TRIALS

Operations During the Trials

During the trials different settings were used to analyse the effects of these settings on the environmental criteria. Examples of these settings are swing or hauling speed, cutter or auger speed, concentration and step length.
Approximately 5 to 6 tests could be carried out per day under favourable conditions. All individual tests were closely monitored. Before and after each test a bathymetric survey was carried out, whilst during the test all related parameters were recorded on digital format.
For quantification of the spillage, samples were taken after each test on several places in the dredged area. Results were available within 6 hours after dredging, allowing feedback on the interpretation of the applied settings. Although working with heavy contaminated sediments, no physical contact could occur due to the closed hydraulic system. Only the sampling activities required protective clothing.
Throughout the test period relevant environmental parameters like wind strength and direction, wave height and period were collected.

General Results of Dredging Techniques

The first two trial were carried out in the period from June to the beginning of September 1995 (Figure 6). The interpretation of the gathered data will take at least the months October and November. The final report is expected in December 1995. Preliminary results of the first two trials are shown in Table II. The results are an average for all individual settings and related scenarios.

Figure 6. Dredging location with dredgers and the disposal site.

Table II. Preliminary Results of Dredging Trials

Accuracy	Mean	Standard deviation	Remarks
Accuracy positioning excavation head (m)	< 0.02	.01	dGPS - Kart, Minilir, Laserplane
Accuracy following desired profile (m)	< 0.02	.02	dGPS - Kart, Minilir, Laserplane
Accuracy profile after dredging (m)	< 0.04	.03	Echosounder
Turbidity			
Background turbidity (mg/l)	25 - 40		MEX -3, water samples
Characteristic increase (mg/l)	insignificant		MEX -3, water samples
Suspension parameter (kg/m^3.m^3)	insignificant		MEX -3, water samples
Spillage			
Thickness of layer (m)	0.00 - 0.05		Beeker sampler, influenced by weather conditions
Chemical quality	not yet analysed		Chemical analyses
Gross production (per cycle)			
Production (situ m^3/hour)	150 - 450		Scenario and settings dependant
Transport concentration (%)	up to 75%		Influence of occurrence of gas
Tonnes dry solids (situ tds/hour)	100 - 300		Based on situ density of 1.425 ton/m^3

Specific Results

The dGPS-Kart system worked in general well within the specifications. However, the installed systems on the dredgers occasionally experienced problems. Especially when the signal was lost for a short period of time it took sometimes more than half an hour before the system worked within the desired accuracy.
The specific problems could be caused by the relative new development of the system.
The gas content in the top layer was determined before the dredging trials. An average was measured of approximately 5-10%. This percentage influenced the results of tested dredging techniques, therefore adjustments in the hydraulic system were necessary.
De-gassing systems were installed during the trials which successfully limited the negative effects.

Conclusions

Although the final results are still buried in a pile of data, it is becoming clear that already a great deal has been learned during the first two trials. The survey departments have gained valuable information on procedures to achieve high accuracy on coring and bathymetric surveys. The results will be translated in clearer and concise demands which will be used in future dredging contracts for removal of contaminated sediments.
The measurements in the temporary disposal site with regard to design and operational management already proved to be very useful for the planned construction of the large disposal site for storage of the contaminated sediment of the Ketelmeer.

The four appendices which follow give more detailed descriptions of the two dredgers used, the environmental impact and the temporary disposal site.

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"The development of a special remedial dredging technique: 'the environmentally-friendly auger dredger". Proceedings CEDA Congress. Amsterdam, Netherlands. 1993.

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Appendix 1: Test 1, Modified Auger Dredger Willem Bever

During the past years HAM has developed the auger dredger into a useful environmentally friendly dredger. The first project was the Geulhaven where practical experience with the patented silt screen mounted around the auger was gathered. Results were very promising as during the testing hardly any spillage and turbidity occurred.
After this project model tests were executed in HAM's laboratory (see Figure 7) in order to further optimise the auger. In August 1992 the auger was used to clean up the Seaharbour Channel of Delfzijl in The Netherlands. To meet the requirements of this project a new auger was built and mounted on the *Willem Bever* pontoon. To dredge a hot spot, where pollution exceeds the accepted standards by 1000 times, strict requirements with respect to turbidity, spillage and accuracy were necessary. On this project further modifications were executed to the auger blades and the hauling winch. Moreover a so-called debris box was placed in front of the suction mouth in order to prevent damage to the auger blades caused by blocked debris and to quickly get rid of the debris by relieving the valve.
The *Willem Bever* as used in the Ketelmeer trials is equipped with an auger of 8 m width and a diameter of 1.25 m (Figure 8). Dredging is performed in 7 m wide tracks (1 m overlap) in one direction. For the accurate hauling of the pontoon along the track, the withdrawing and the positioning for the next track, 6 constant tension winches are used. With this system in combination with an automated hauling system a hauling accuracy of <0.25 m can be achieved.

Figure 7. Model test auger, above working without a silt screen and causing turbidity; below, with a silt screen, turbidity is completely absent.

Figure 8. The Willem Bever at work on Lake Ketelmeer.

In order to minimise turbidity caused by the anchor wires dragging through the sediment of the bottom of the lake, anchor-wire pontoons are used to keep the wires free from the bottom. The dredge level is automatically controlled by the PA (Production Automatisation) computer in combination with the survey computer. The survey computer at each auger position provides the exact desired depth, based on the DTM, to the PA computer. The PA computer measures the actual depth of the auger with an accurate pressure gauge, and controls the desired depth via the ladder-winch. The depth measure accuracy is 0.02 m and the depth steering accuracy is within 0.01 m. The speed of the underwater dredgepump is also controlled automatically in order to achieve a high concentration.
There are two operating modes. One mode using the in-situ density, as with a desired concentration the desired pumping mixture density can be calculated. The actual mixture density is measured with a density meter. With this system concentrations of up to 80% have been realised. The other mode is based on the measured actual dredged volume per second.
All relevant survey and process data are logged in the PA computer and available for processing and analysing after each test. All software is in-house designed by HAM's survey, PA and research departments.

Features of the *Willem Bever* are:
- width of 8 m, which means a calm and controlled process with relative low haulage speeds. Furthermore, little overlap between consecutive tracks, to allow for the haulage accuracy and to remove material breached off along the dredged track, is required;
- suitable to remove thin layers whilst retaining mixture density and capacity. Hauling speeds of up to 7 m/min and concentrations up to 75% have been realised;
- the maximum layer thickness which can be removed in one track amounts to 0.85 m;
- the flexible silt-screen curtain automatically follows the bottom profile, which means that no sophisticated and vulnerable control is needed to measure changes in layer thickness and to adjust the position of the baldachin construction;
- a debris box in front of the suction mouth makes the

system relatively invulnerable for debris;
- less problems with gas being released from the sediment when cut loose and whilst transported by the auger. The gas released during this process will accumulate under the baldachin and eventually escapes through the valves at the top;
- the baldachin construction with silt-screen curtain forms a closed box in which a slight under-pressure is maintained permanently, keeping the turbulated recirculated process water inside this box;
- spillage is prevented by keeping the lower side of the cutting blade of the auger at nearly the same level as the cutting edge of the augerblades. More safety is guaranteed by the rubber flap at the back of the cutting blade.
- and finally, when dredging polluted sediments, the working conditions and the safety of the dredge personnel are optimally guaranteed.

Appendix 2: Test 2, Environmental Disc Cutter Vecht

The environmental disc cutter as installed on the *Vecht,* is developed by Boskalis (Figure 9). The environmental disc cutter is derived from the disc bottom cutter and is based on model tests at the University of Delft. Prototype tests were carried out in the Berghaven, Hook of Holland.

Experiences in the past with a standard disc bottom cutter showed the suitability to realise a flat profile with a low spillage percentage. In addition to these positive properties the present developments are focussed on increasing the accuracy of the positioning of the cutter, increasing the mixture concentration and the reduction of turbidity around the cutter.

The pattern of movements of a disc bottom cutter is like an ordinary cutter: by means of two side wires arcs are described around a fixed spud pole, in each corner a step is made and when the spud carrier is at the end of its stroke a re-track is made in the centre line whilst the position is fixed by means of an auxiliary spud.

The soil is cut by means of a cylindrical cutter with a flat, closed bottom and vertical axis of rotation. A suction mouth, for the removal of cut material, is situated inside the cutter.

Accuracy of Positioning

The depth of the disc cutter is calculated from the height of a laser plane, the list and trim of the pontoon and the angles of the ladder and disc cutter. The horizontal position is determined by means of dGPS-Kart, gyro compass and the same angles as used for the depth calculation. Information about the disc cutter position and the DTM containing the actual soil surface and desired profile is used to control, fully automated, both the disc cutter position and orientation. The ability to adjust the orientation of the cutter in every direction is essential when slopes have to be followed accurately. The position of the disc cutter with respect to the actual and desired profile is displayed to the dredge master on a monitor (Figure 10).

Figure 9. The environmental disc cutter installed on the Vecht.

Control of Mixture Concentration

A high mixture concentration is advantageous with respect to required transportation capacity and to the required initial storage capacity. The geometry of the disk cutter allows a removal of dislodged soil from within the disc cutter without the supply of extra water. Dislodged soil is pushed into the suction mouth by the

Figure 10. Close up of the environmental disc cutter.

Figure 11. Echosounder position and silt screens.

rotating cutter. The mixture is pumped by a centrifugal pump which makes a dilution of the mixture necessary to limit the required pressures for pumping and to limit the decrease in performance of the pump. In order to prevent suction problems the pump is placed directly onto the disc cutter. A control system is required to achieve a high as possible mixture concentration.
The suction flow is controlled as a function of the actual amount of material being cut. The face height of the cutter is determined either by means of the difference in depth between the soil surface and the bottom of the cutter or by direct measurement of echosounders mounted on the cutter. To make the transducers less vulnerable to damage they are placed in a protected position and use acoustic mirrors to reflect their beams to the bottom next to the cutter (Figure 11).
The actual suction flow is measured, and based on this information and the required mixture concentration, the flow is controlled automatically. A quick adjustment of the suction flow is realised by means of a sliding valve (with hydraulic actuator); in addition the pump speed is made a function of the position of the valve.

Reduction of Turbidity

A screen around the cutter is used to prevent spillage and turbidity. The screen consists of a fixed screen at the back of the cutter over the full cutter height and an adjustable screen above the soil to be cut. Depending on the swing direction the position of the screen is adjusted by means of a rotation around the cutter axis. The height of the adjustable screen can be corrected automatically to the height of the soil to be cut.

Appendix 3: Dredging Activities and their Impact on the Environment

To assess what the effects on the environment of dredging will be (adverse and beneficial), it is essential not only to know the environmental aspects of the dredging technique but also the local, site-specific circumstances in and around the dredging area. The latter encompass the physical, chemical and biological situation and processes that occur in the water column and in or on top of the bed material.
Prominent aspects for the Ketelmeer system are:
- the typical thin layer in which the pollution is present;
- the small water depth;
- the open connection with clean water regions;
- the potential sink towards the groundwater.

It stands to reason that this calls for a thorough and accurate pre-project investigation.
When dealing with sensitive aqua-systems the following site-specific aspects need to be addressed and the relevancy of each of the items for the envisaged (dredging) activities shall be established before in-depth studies are initiated:
- the resuspension, dispersal and resedimentation of polluted sediment;
- the change in biological and chemical (e.g. mobility) activity of the pollutants;
- the effect on flora and fauna in the area under consideration;
- changes in surface and ground water flow patterns and consequently the chemical and biological conditions in the bed;
- exposure of underlying "other" sediment types;
- the particular type of sediment and its physical/-chemical composition;
- the flow patterns of the water including the vertical exchange of particles (pollutants);
- impact on adjacent clean or otherwise sensitive areas;
- use of the area (e.g. fishery) and accessibility of the dredging area to the public (e.g. recreational) and the dangers associated with the type of dredging operation.

Nowadays advanced mathematical simulation models can be used to assess the impacts. These models have been used successfully in the past to predict the behaviour of fine sediment in estuarine waters and their impact on the environment.
In order to reduce any negative impact on the environment the technical, dredging process related, aspects have to be considered in advance, e.g.:
- accuracy/selectivity of dredging (contaminated) sediments;
- spillage;
- turbidity;
- density of mixture with respect to the in-situ density;
- presence of gas in the layers to be dredged;
- handling of coarse debris;
- storage capacity, based on (assumed) attainable mixture density;
- changes of the physical and chemical properties of the sediment whereby the substances present in the sediment may become mobile or volatile;
- noise and smell nuisance;
- means of transport of the dredged material;
- spillage and other risks associated with the means of transport;
- discharge of the sludge at the storage area;
- settlement and consolidation behaviour of material in storage area.

The relevancy of each of the above items depends on the local prevailing conditions and a broad brush approach could filter out those that are indifferent for the environment. The proper assessment and evaluation of the remaining location parameters combined with the dredging process aspects, of which some are inter-related as well, must be based on a thorough knowledge and understanding of the basic dredging physics and backed up by applied scientific research.

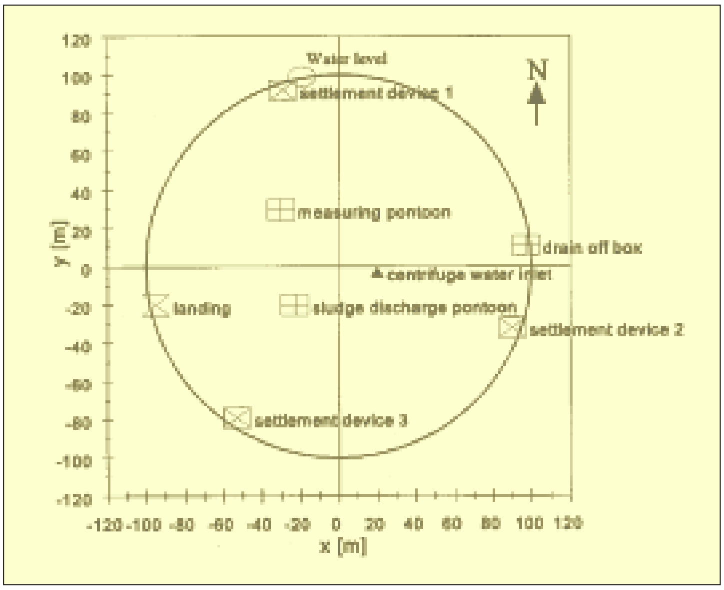
Appendix 4: The Temporary Disposal Site

The management and monitoring of the temporary disposal site is not only restricted to the periods of the dredging tests but extends to the cleaning up of the depot in 1999. There are several reasons for this intensive monitoring:

- To fulfil the conditions of the licences stated by the authorities. For instance the suspended material in the drained off water may not exceed 100 p.p.m. and the maximum sludge level may not exceed NAP –0.5 m.
- To develop a strategy concerning the discharge of sludge into the depot and the disposal of water out of the depot. Because of the limited depot capacity and the large horizontal dimension with respect to the vertical, it is of importance to control the way of discharging sludge into the depot and the amounts discharged. The discharge point is to be moved regularly to prevent mounting up the discharged sludge to an undesirable level. Depending on the rise of the water level due to the discharge depot water has to be drained off into the Ketelmeer.
- To gain knowledge about the behaviour of sludge in depots, in particular to use the experiences with the temporary depot for better management of future projects.
- To validate two design programmes, in this case the model "FSCONBAG" and the so-called "WRO water quality model".

The programme FSCONBAG is a sludge consolidation model based on the Finite-Strain-Theory which uses an one-dimensional approach to calculate the sludge settlement in time and the involved consolidation discharges at the top and bottom of the sludge layer. Creep is incorporated in the consolidation process and sedimentation is taken as being instantaneous.

Figure 12. Layout of the disposal site.



The WRO water quality model predicts on basis of a water-sludge-balance in time the suspended solids in the depot water, the quality of suspended particles and quality of the depot water.

The Area Setup

The disposal site consists of a circular confined depot with a diameter of about 200 m (Figure 12). The boundaries of the depot are formed by a cofferdam with a crown width of about 5 m and with sheet pile walls on either side. The sheet pile wall on the inside of the depot reaches up to NAP +1 m. The initial bottom level of the depot is approximately NAP –3.2 m. Filling up to a sludge level of NAP –0.5 m is allowed, which implicates a total storage capacity for contaminated sludge of 85,000 m^3. The mean water level in the Ketelmeer is about NAP –0.2 m and this is more or less the desired level at the end of the periods of sludge discharging into the depot.

On the east side a drain-off box is installed with two pumps and a turbidity meter. In the adjacent pipeline a discharge meter is installed.

Three settlement devices each made out of a base plate and a standard are installed. On every base plate two soil pressure transducers, two water pressure transducers and one thermo-couple are installed.

A second thermo-couple is installed near the standard on the supporting beams. On the north side the water level in the depot is recorded continuously. In the depot area a discharge pontoon and a measuring pontoon are installed. The discharge pontoon is by means of a floating pipeline connected with the landing point. Outside the depot the connection between the dredging equipment and the landing point is formed by another floating pipeline. Through the pipelines the dredged sediment is hydraulically transported. On the pontoon a diffusor is installed to prevent the initial subsoil and the already sedimented sludge from going into suspension by dispersing the outflow. The measuring pontoon is used for special investigations like density measurements with a back-scatter, sludge sampling and turbidity measurements. To prevent turbidity caused by anchor wires when moving the pontoons, plastic ropes are used which float on the water surface.

Measurement Points

Going from the settlement devices to the middle of the depot there are three section lines, each consisting of ten measuring points. At each measuring point the sludge level is frequently determined in combination with occasionally back-scatter measurements and sludge sampling to determine a vertical density profile and to detect any gas production in the sludge. The sludge level, back-scatter measurements and laboratory results together with the other measurements give insight in the settlement and consolidation behaviour of the sludge.