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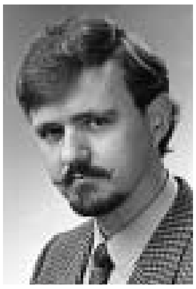
Turbidity Caused by Dredging; Viewed in Perspective

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Abstract

Over the past decade there has been increasing awareness of the environmental impact of dredging, and in particular, one of the side effects receiving attention was the extra turbidity of resuspended waterbed material occurring whilst dredging. With the help of environmental impact assessments a great deal of knowledge about "turbidity caused by dredging" has been acquired in The Netherlands. However many measurements must be considered in order to provide answers to whether or not turbidity has adverse impacts. How a dredging technique is applied is of utmost importance. The background turbidity, collapse times, and resuspension must be considered.
But analyses need to be localised and specific to a certain situation.

This paper is the result of the work of the project group, Environmental Effects of Dredging, a joint effort of several organisations in dredging-related industries and the Netherlands Government. At present some 35 standardised turbidity measurements have been executed around various dredging techniques. Photographs are used courtesy of Delft Hydraulics.

Introduction

Over the past decades there has been a considerable increase in awareness that the conduct of man has an impact on the environment. This applies in particular to the interventions of a civil engineering nature. Dredging is one of the major activities executed by man to alter or control the environment at will. In addition to the desired result, dredging activities have side effects on the environment. Recently these side effects have been receiving more attention from an environmental-hygienic point of view, which is particularly because of the pollution of the water bed. One of the side effects receiving attention was the extra turbidity of resuspended water bed material occurring whilst dredging. This article highlights the knowledge of "turbidity caused by dredging"; this is knowledge which over the past decade has been acquired in The Netherlands.

Environmental Impacts of Dredging

In many ways dredging can have an impact on the environment. One can think of spill, dredging precision and selectivity, noise, stench, and turbidity. It depends on the situation in and around the dredging site, the execution of the work and the aimed result whether these aspects have a greater or smaller impact on the environment.
One reason why turbidity caused by dredging has been investigated first, is that the consequences of turbidity do not necessarily confine themselves to the area where the dredging takes place; the impacts of other aspects remain more or less confined to the area itself. Turbidity can, as density current or carried by the main current, be moved away far from the dredging area. However, this does not necessarily mean that turbidity caused by dredging is at all times its most important environmental impact. It may be that the impact of turbidity is of a different order. Whether turbidity caused by dredging is important or not must be established by way of an environmental impact assessment. Such an environmental impact assessment must determine what, and to what extent, the eventual environmental impact is of the extra turbidity caused by dredging. This eventual environmental impact can, for instance, consist of:

- sedimentation inside or beyond the dredging area;
- the uncontrolled movement of attached pollutants;
- the pollution of clean areas;
- the release of nutrients;
- oxygen consumption in surface water;
- the blocking of sunlight, and so on.

Naturally, in such an assessment the situation in the surroundings (natural and artificial variables) have been taken into account.

History of On-site Turbidity Measurements

It was in 1985 that, for the first time systematically and according to a fixed routine, turbidity measurements were executed in the vicinity of dredging vessels.

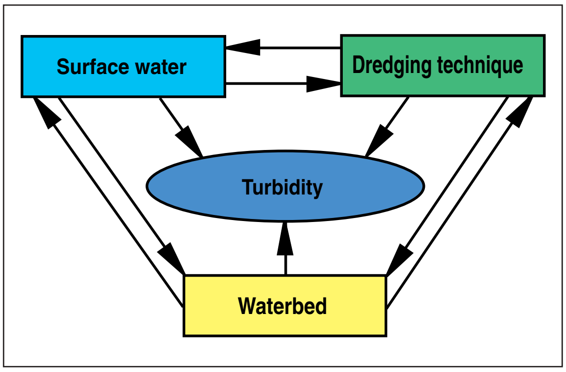

Figure 2. Factors that can affect turbidity.

Figure 1. Turbidity caused by clamshell dredging contained within a siltscreen enclosure in the Geul Harbour, Port of Rotterdam.

This took place in the harbours of Rotterdam under the auspices of the Municipality of Rotterdam and "Rijkswaterstaat" (a part of The Netherlands Ministry of Public Works and Water Management). Both partners joined up in the research venture "Minimalising Costs of Maintenance Dredging" (MKO). One assignment of MKO was the study of the environmental impact of dredging. By employing on-site measurements MKO intended to gain insight into the nature and extent of turbidity caused by dredging activities in the Rotterdam harbour area (Figure 1).
In the latter days of MKO the project group "Environmental Impacts of Dredging" founded by the "Dredging Research Association" (CSB) sought contact with MKO with the intention to also carry out on-site turbidity measurements. Even now CSB collaborates with its former MKO partners in the execution of turbidity measurements. Currently turbidity measurements are also carried out in collaboration with the "Development Programme Treatment Processes for Polluted Sediments" (POSW) of Rijkswaterstaat. Up to now about 35 standardised turbidity measurements have been executed around a wide variety of dredging techniques.

Turbidity Caused by Dredging Activities

Dredging nearly always causes some measure of resuspension of bed material. In practice measurements have demonstrated that the extent to which this happens not only depends upon the dredging technique used but also upon the interaction of three factors (see Figure 2), which are:

- The dredging technique itself, with considerations such as:
  the manner of mechanical or hydraulical excavation;
  the manner of vertical and horizontal transport of dredged material;

Figure 3. Turbidity measurements in progress with small vessels around the auger dredge during clean-up dredging in the Sea Harbour Channel, Delfzijl, The Netherlands.

Figure 4. Taking site water samples of the background and turbid water with a NISKIN water sampler for laboratory analysis to enable the calibration of the turbidity sensors.

the manner in which the dredging activities are actually being executed.

– The sensitivity to resuspension of the water bed, i.e. the ease with which the bed material will become resuspended.

– The condition of the surface water, with considerations such as: water depth; current velocity; wave action; but also salinity and density stratification can be of some importance.

The interaction of these various factors and their mutual effect will eventually determine the nature and extent of the turbidity. If sufficient insight into these interactions is available, the extent of the turbidity can be predicted.

Methodology of the Research into Turbidity

From an analysis of the turbidity development it appears impossible to develop a simple and universally applicable model of turbidity caused by dredging. Too many locally-determined factors play a decisive role in this phenomenon.
As has been remarked earlier it is important to appreciate that the measurements were conducted under the specific circumstances of the dredging project, that is, so to speak, highly local observations with three substantial variables:
– the nature of the local water bed,
– the used dredging technique, and
– the condition of the surface water in and around the dredging area.

One single measurement cannot provide an immediate and decisive insight into the variation of the turbidity, for example, if a different dredging technique had been used, or if there had been more or less water flow, or if the water bed had been more or less sensitive to resuspension. In order to achieve some prediction of the turbidity phenomenon the following strategy has been adopted.

The Dredging Technique

To get some idea of the extent of resuspension of bottom material when using specific dredging techniques, the turbidity measurements are executed under on-site circumstances. Naturally, the results of the measurements can be compared best with one another if the two other variables (condition surface water, and type of water bottom) have not been changed. For both this is only possible to some extent. One choice for a measurement dredging project is, for example, that the flow velocity of the surface water is practically zero. But even then the condition of the surface water is seldom exactly the same; one can think of water depth, salinity, density stratification, and so on. With measurements in on- site situations at various dredging projects it is virtually impossible to have everywhere an even sensitivity of the water bed to resuspension. Despite that, one should try to extract from the results of the on-site measurements the influence of the dredging method on the nature and extent of the turbidity. The insight into this will expand with an increase of the number of measurements.

The Sensitivity to Resuspension of the Water Bed

The impact of the second factor, i.e. the sensitivity to resuspension of the water bed material, will be accounted for in a different way. This sensitivity is the result of the geo-technical, rheological and micro-biological nature of the water bed material. The strategy is to classify this sensitivity to resuspension on a proportional scale using a standardised test. Currently a standard test device is worked out in detail. With this test the sensitivity to resuspension is established in proportion to other water beds. This device is called a TACT, which stands for Turbidity Ability Criterion Test device (in the Dutch language this device is known as a "VGS-apparaat", which is why the derived values are called VGS-values) (Figure 5).

This availability of VGS-values of water beds in which tests have been or are to be executed, should make it possible to "calibrate away" the impact of the water bed on the results of on-site measurements. It goes without saying that the VGS-value of the water bed is indispensable if one has to make a prediction of the turbidity development during a future dredging activity.

The Condition of the Surface Water

The impact of the third (and last) factor, which is the condition of the surface water, is processed with the help of a numerical simulation of flow dynamics. It is expected that the dispersion and own dynamics of the turbidity plume can be predicted using mathematical models and certain computing methods.

Figure 5. Prototype of the TACT (Turbidity Ability Criterion Test) device showing the agitation propeller, the silt sample underneath and the turbidity sensor above the propeller. With this test the sensitivity to resuspension of the water bed material can be derived in proportion to other water beds.

Turbidity Measurements

When applying the standard turbidity measurements sensors are used which measure, on the basis of translucency for infrared light, the turbidity of the water. To obtain a correct conversion from translucency to dry solids concentration, afterwards the sensors are always (re)calibrated with water samples of the turbidity plume that have been collected during the measurements at the location where is being dredged.

An important requirement for the execution of the dredging process with every measurement, was that the dredging work had to be carried out in the usual way, that is, in accordance with the normal daily routine. The on-site measurements had to deal with the entire (gross) dredging process, that is:
replacing (swing and step); excavating the water bed; formation of the dredged material mixture; the vertical transport of the dredged material; the horizontal transport of the dredged material from the dredging area (possible rehandling in barges, barge manoeuvring and the like); in short, all work which is normal and necessary in the dredging area.

The measurement routine has been designed so that it is possible to compute four independent parameters for the development and extent of turbidity. These are:

1. The depth-averaged *background turbidity* (background concentration of dry material) (C). The background turbidity is certainly not always constant. In tidal areas the background turbidity is often varying with the phase of the tide.
2. The *characteristic increase* of the depth-averaged turbidity caused by the dredging activity (■C). By itself this is a just an arbitrarily chosen parameter. It has been defined as the average increase of the turbidity on the edge of an area of 50 by 50 metres around the centre of the dredging activity.
3. The *collapse time* of the increase of the turbidity (■T). This is the period after cessation of the dredging activity, after which the turbidity plume is no longer observed at the level of 50 cms above the water bed, meaning that after that period the turbidity in the dredging area has diminished to background values. From the measurement results the collapse time of the turbidity plume can be approximated. This measurement routine, however, does not allow the determination of the collapse time with a precision of minutes.
4. The *suspension parameter* (S). This S-parameter renders the volume of water bed material (in kilograms of dry material) that is resuspended in the surface water per cubic metre dredged (in situ) water bed. Thus, in this S-parameter the impact of production activity of the dredge has been accounted for. Although the S-parameter indicates how much water bed material is resuspended into the watercolumn no indication is given about the position of the turbidity plume over the water vertical. But this can of course be important for the final dispersion of turbidity.

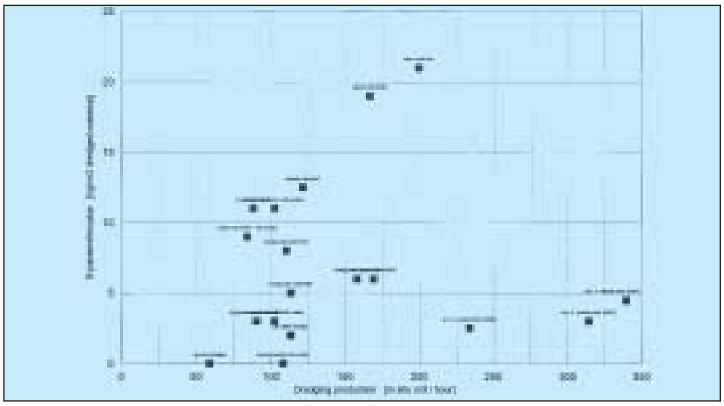

Figure 6. S-parameter values from various measurements.

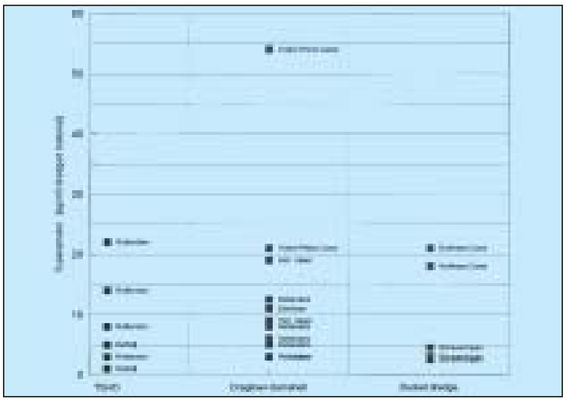

Figure 7. S-parameter values with "equal" techniques.

Results of Turbidity Measurements

In the past decade, 35 measurements dealing with several different dredging methods were carried out. At every measurement it was tried to record in the measurement reports as many as possible of the earlier mentioned three influencing factors. This was done to enable recalibration at a later stage. Some results of these measurements are given in Tables I, II and III. In Figure 6 the values of the S-parameter have been converted into a diagram. One can easily observe that the results have not only been determined by the various dredging methods but also by the specific situation of the dredging activity.

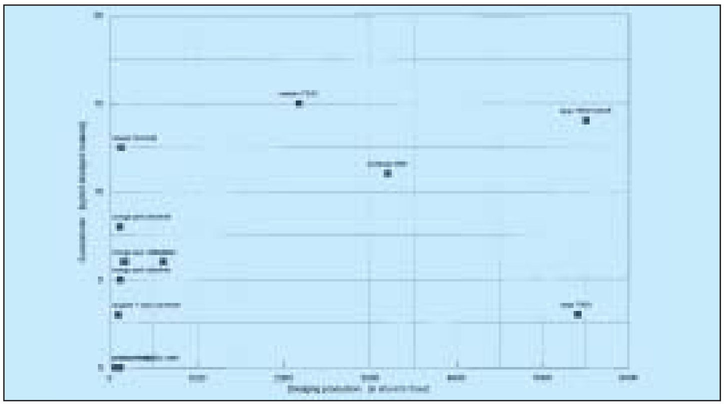

Figure 8. S-parameter values of various measurements in the Rotterdam harbour area.

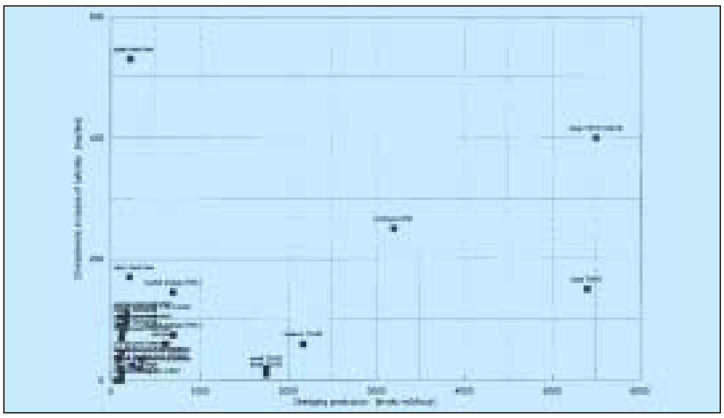

Figure 9. Characteristic increase of turbidity (50 x 50 m^2 around the centre of dredging activity) of various measurements.

In Figure 7 the S-parameters of "equal" dredging techniques at various locations have been converted into a diagram. For example, compare the results obtained from the Amsterdam-Rhine Canal, with those from the harbours of Rotterdam or Delfzijl.

Right now it has not yet been possible to remove the influence of the water bed from the results. Currently an investigation is in progress to find a method with which to establish the sensitivity of water beds to resuspension. In Figure 8 are shown graphically the results of the measurements in the harbour area of Rotterdam. If we may assume an equal sensitivity for resuspension for the Rotterdam harbour area, then it appears from this figure that for example big trailing suction hopper dredges can resuspend just as much bed material as grab cranes can.

The *background turbidity* differs very much per location. The lowest mean value was around 15 milligrams per litre; the highest mean was around 75 mg/litre. However, the greater part of the measured values was around 50 mg/litre. In tidal areas there was also a great variation in time; this variation measured now and then tens of milligrams per hour.
The *characteristic increase* of the turbidity was rarely higher that 500 mg/litre (see Figure 9). Here again virtually all measurements were conducted with very low flow velocities thanks to which virtually no additional resuspension occurred due to turbulence of the main flow. With some dredging techniques the resuspension was so trivial that a characteristic increase hardly exceeded the variation of the measured values.
The *collapse times* which, on the basis of the measurements, have been established, are no longer than 1.5 hours. This implies that the turbidity sinks quickly to the bed and is exposed to the highest flow velocities for a

Table I. Turbidity parameters of the measurements dealing with hydraulic dredging techniques.

Hydraulic dredging techniques

Location	Production (m^3/hr)	C (mg/litre)	■C (mg/litre)	■T (hours)	S (kg/m^3)
Large Trailing Suction Hopper Dredge *"Cornelia"* with LMOB (Lean Mixture Over Board)					
Third Petroleum Harbour Rotterdam	5500	75	400	1	14
Large Trailing Suction Hopper Dredge *"Cornelia"* without LMOB (Lean Mixture Over Board)					
Third Petroleum Harbour Rotterdam	5400	40	150	1	3
Small Trailing Suction Hopper Dredge *"Kinhem"*, limited LMOB					
Sea Harbour Channel Delfzijl	1750	65	15	0.5	1-5
Small Trailing Suction Hopper Dredge *"Hein"*					
Laurens Harbour Rotterdam	2170	23	60	1	8-22
Pneuma-dredge system					
Berghaven Harbour Hook of Holland	59	25	0	0	0

limited period only. However, it should be noted that due to turbulence coming with strong flows, resuspension can occur again. The turbidity does not appear to collapse with fall velocity of the individual dry-solid particles (something which is generally assumed), but with the often much higher velocities being developed by turbid water in comparison to the surrounding water. This also implies that with a density stratification of the surface water a turbidity plume can remain "floating" upon a layer of higher density. For example, at measurements in the North Sea Canal and Haringvliet basin it was found that in this way turbidity remained suspended at a certain water depth and then moved off with the local flow velocity.

The S-parameter values show a large dispersion. The various types of dredging techniques overlap to a great extent. It also appears (see the Tables) that the turbidity does not necessarily increase with the production capacity of the dredging technique.
The lowest values of the S-parameter are of the order of 0 kg/m^3; the highest calculated value is of the order of 54 kg/m^3. Most values however, can be found in a band between 0 and 20 kg/m^3. If the dredged water bed density equals 1300 kg/m^3 (that is a dry solid content of about 480 kg/m^3) an S-value of 20 means that 4% of the dredged volume enters surface water in the form of turbidity.

A few measurements have been extended with a test of the mobility of contaminants: the release of pollution from the water bed material that had been resuspended. As such an experiment is too expensive to establish whether there is mobility for all pollution, it is has been conducted in the form of a test. It was tested whether the hypothesis would be valid that during turbidity the pollution would remain attached to the solid particles. This test was conducted in such a way that verified whether or not the surface water in and around the dredged area at the time of, as well as after dredging retained an increased concentration of the pollution which at first could have been expected to be mobile. The results of these tests was negative: the hypothesis that the pollution remains attached to the solid particles during the "life time" of the turbidity was not refuted but neither confirmed for all contaminants.

Conclusions

The measurements by themselves do not provide an answer to the question whether or not turbidity has an important (adverse) impact on the environment. This question must be answered via an assessment of pollution and dissipation when designing a clean-up dredging project. However, the measurements of turbidity do contribute to the shaping of fundamental insights and information for such an assessment.

From the results of the measurements one can infer that not only the dredging technique determines the extent and development of the turbidity. The sensitivity

Table II. Turbidity parameters of measurements dealing with mechanical dredging techniques.

Mechanical dredging techniques	Location	Production (m^3/hr)	C (mg/litre)	■C (mg/litre)	■T (hours)	S (kg/m^3)
Dragline with open clamshell	Merwe Harbour Rotterdam	90	20	35	1	3
Dragline with open clamshell and silt curtain	Hollandse IJssel river Nieuwerkerk a/d IJssel	84	35	35	1	9
Dragline with watertight clamshell	Hollandse IJssel river Nieuwerkerk a/d IJssel	166	35	100	1	19
	Oude Haven 't Sas Zierikzee	220	50	90	1	11
	First Petroleum Harbour Rotterdam	121	20	80	1	13
Dragline with watertight clamshell and silt curtain	Hollandse IJssel river Nieuwerkerk a/d IJssel	102	35	20	1	3
	Oude Haven 't Sas Zierikzee	204	50	105	1	11
Hydraulic crane with orange peel excavator and silt curtain	Geul Harbour Rotterdam	130	50	100	1	6
Hydraulic crane with open backhoe	Amsterdam-Rhine Canal, Wijk bij Duurstede	208	40	530	0.5	54
Hydraulic crane with closed visor backhoe	Amsterdam-Rhine Canal, Wijk bij Duurstede	199	45	170	0.5	21
Bucket dredge *"Saturn"*	North Sea Canal Amsterdam	714	15	110	1	18-21
Bucket dredge *"Aalscholver"*, adapted for environmental efficiency	2nd Inner Harbour Scheveningen	296	48	20-35	0.5	3-5

to resuspension of the water bed and the condition of the surface water are important.
An important conclusion is also that not so much the dredging technique but rather the way in which this technique is used determines the extent and development of the turbidity. For future dredging works it is

Table III. Turbidity parameters of the measurements dealing with hydraulical/mechanical and agitation dredging techniques.

Hydraulical/mechanical and agitation dredging techniques

	Location	Production (m^3/hour)	C (mg/litre)	■C (mg/litre)	■T (hours)	S (kg/m^3)
Environmental disc cutter	Berg Harbour Hook of Holland	113	25	0	0	0
Auger "Willem Bever"	Sea Harbour Canal Delfzijl	300	20-50	0	0.5	0
Siltcutter dredge *"Zsuzsa"*	Industrial Harbour Heusden	115	45	10	0.5	2
Water injection dredge *"Jetsed"*	Haringvliet Hellevoetsluis	*	20	30	0.5	*
Prototype water injection dredge *"Woelnix"*	Merwe Harbour Rotterdam	3200	45	250	1.5	11
Bed leveller *"Pesante"*	Waal Harbour Rotterdam	610	35	60	1	6

therefore not so simple to make predictions about turbidity. The background turbidity can differ several tens of milligrams per location; in tidal areas variations can occur in time of sometimes several tens of milligrams per hour.

The resuspension of water bed material caused by dredging activity varied from very trivial (meaning that it cannot be separated from background noise) to about 50 kilograms solid material per cubic metre of on-site dredged material. Most S-parameter values can be found in a range of 0 to 20 kg/m^3.

The collapse times of the turbidity plume rarely took more than 1.5 hours. The turbidity does not appear to collapse whilst matching the fall velocity of the individual dry-solid particles (something which is assumed by many), but with the often much higher velocities being developed by turbid water in comparison to the surrounding water. A greater density difference between the turbidity plume and the surrounding water results in a greater sinking velocity. In addition, the mixing with the surface water caused by turbulence becomes much more difficult when there is a greater density difference.

When analysing and designing dredging activities where turbidity has some importance, it is at all times advisable to localize and make an inventory of the turbidity sources. It is important to know whether turbidity is caused upward or downward in the water vertical.

To gain insight into the effects of a dredging technique in a certain situation, by way of testing, a goal-oriented measurement of the turbidity development can be done prior to commencing the real work.

It is expected that in the future it will be possible to determine unambiguously the sensitivity to resuspension of water beds. The development of such a measurement method is currently in progress. With this method parameters derived from the measurements would be freed of the impact of the water bed whereas the impact of the dredging technique can be isolated. It is expected that the impact of the surface water can be simulated with mathematical models. The measurements then provide a sound basis for predicting the impact of a dredging technique on turbidity caused by dredging activities.