Innovative use of remote sensing in combination with chemical borehole data results in superior insights in the spread of contaminated sediments

Haan, W.F. de[1], Fontein, W.F.[2], Oosterbaan, H.E.[3]

[1]Waternet, Sector Watersysteem, PO box 94370, 1090 GJ Amsterdam, Nl. Phone: +3120-6083606
[2]Stema Survey Services B.V., PO box 69, 4190 CB Geldermalsen, NL E-mail: fred.de.haan@waternet.nl
[2]Oranjewoud Consulting Engineers, PO Box 10044, 1301 AA Almere-Stad, NL

Abstract

Present sediment investigation strategies in the Netherlands are based on sampling and chemical analyses in boreholes. In natural rivers, where the lateral variation of the contaminated silt layer is considerable, this strategy will lead to extensive investigations to asses the layer thickness and location adequately. Waternet carried out investigations in the former? river Vecht with an innovative process consisting of a combination of very high resolution seismics, echo sounding, sampling boreholes and chemical analyses of borehole samples. This combination is chosen due to the lateral variability in thickness, top- and base level of the sediment. The investigation started with bathymetric and seismic data acquisition in cross sections every 50 m. (direction of highest variability). In nearly every cross section a borehole was planned and sampled based on an initial seismic interpretation. Every visible layer in the core is chemically analyzed. The top of the first clean layer is the base of the contamination. This layer is converted into the seismic data, resulting in detailed information on the variability of the contaminated sediments. A digital terrain model (dtm) of the contaminated layer was made by interpolation top and base level of the contaminated sediments between the cross-sections.

Introduction

Waternet, a foundation of the Water board Amstel Gooi and Vecht and the city of Amsterdam, is the responsible authority concerning the River Vecht in the Netherlands (Utrecht and Noord-Holland province). In many cases the quality of the sediments of the Dutch aquatic area does not comply with the regulations for pollution levels of these sediments and the River Vecht is no exception. Over the last 150 years frequent discharges have polluted the river and the sediment with heavy metals and PAH. Recent actions on improving discharge sources has improved the water quality, but deposited sediments remain contaminated. Removal of the contaminated sediments is planned to start in 2009. In order to prepare the remediation dredging project Waternet initiated a sediment investigation traject in 2006. Part of this traject was an additional site investigation mainly focusing on the total amount of the contaminated sediments and its distribution. These investigations were carried out in cooperation with Oranjewoud Consulting Engineers and Stema Survey Services as specialized subcontractors on survey and high resolution seismics.

Situation and history

The project area is the river Vecht situated in the provinces Utrecht and Noord-Holland, in the Netherlands. The river Vecht starts in Utrecht and ends at the old sea sluices in Muiden. It has a length of 42 km and its width varies between 25 tot 100 m with an average of 55 m.

Approximately 2600 years ago the river Vecht was connected with the river Rhine. Prior to this it was only a small river in the Dutch marsh area's. In Roman times the river Vecht was an important sailing route. The river had a connection with the North sea via the former Lake Flevo and the oer-IJ. The Romans used the river Vecht as part of the trade route from South Europe and Germany to Scandinavia. In later periods the river Vecht remained an important trade route. In 1122 AC the river Vecht was dammed at Wijk bij Duurstede in the Netherlands and the flow was regulated and minimized. The function as transport route continued, being part of the "Keulse Vaart". Only, after completion of the Merwede Kanaal and a completely new canal from Amsterdam to the river Rhine (Amsterdam-Rijnkanaal), this function declined. The river Vecht is nowadays mainly used for water discharge and recreational purposes and scarcely for trade. Nowadays the embankments locate houseboats.

Human activities in the past like discharges of sewerage and handcraft/factories are likely to have influenced the quality of the sediments. It is assumed that over more than 150 years contaminated suspended sediment particles have settled in the Vecht. The sediments in most of the river are assumed to be undisturbed and are expected to have a maximal magnitude of 1.5 meter. Only in urban areas and along the embankments dredging works may have been executed. Besides these areas dredging was not necessary for maintenance, because the river was deep enough for the ships that used the trade route.

Fig. 1: River Vecht. Shown is the river Vecht between The city of Utrecht en Muiden. In de left top angle of the figure the city of Amsterdam can be seen.

Former investigations (1992 and 2003) indicate that the sediments are heavily contaminated with heavy metals and PAH (class 4 sediment). The southern part of the Vecht shows the highest contamination levels. Also in the Northern part mainly class 4 is encountered. The top layers in the southern part seem to be less contaminated. The contamination sources that caused the bad water quality in the past (and responsible for the contaminated sediments) have disappeared or are connected to sewage-systems. Today only three sewage treatment plants discharge treated effluent in the river.

In this new situation water quality has improved and from observations it can be concluded that no further contaminated sediment will accumulate in the river system. The ecological health of the river however still suffers from historical burden as highly contaminated sediments are in contact or can renewed come in contact with the water column and biosphere. Because there ar no untreated discharges , the moment arises to start thinking of cleaning up these sediments.

Methods

At present sediment investigation strategies in the Netherlands are based on sampling and chemical analyses in boreholes. In natural rivers, where the lateral variation of the contaminated silt layer is considerable, such a strategy will lead to extensive investigations to asses the layer thickness and location adequately. According to Dutch regulations 600 boreholes are the minimal requirement along the 42 km long river. Though this is a considerable amount it will not allow the construction of an accurate sanitation? model by far. Only every 70 meter an axis borehole can be drilled. No insight will be gained in the variation perpendicular to the river axis. This is however the direction with the main variation. As the lower transition of the contaminated sediments is not expected to be a significant change in lithology or soil strength, a detailed sanitation model is necessary for the dredging works. Solid river base is no practical indication for this transition.

To tackle this problem an alternative investigation strategy, based on a combination of techniques is more appropriate. An innovative process consisting of two phases: A combination of indirect remote sensing (phase 1) and direct investigation (phase 2) methods is chosen due to the lateral variability in thickness, top- and basis level of the contamination.

Remote sensing data-acquisition is suitable to cover vast area's in relative short time, but do not provide direct information on contamination. The indirect data will however provide information on the most relevant positioning of sampling locations.

This investigation made use of a combination of very high resolution seismics, echo sounding, sampling boreholes and chemical analyses of borehole samples .

Geophysical seismic measuring techniques are widely in use in the oil and gas exploration industry, these systems are designed to achieve deep soil penetration by low frequency sound waves and associated low resolutions. For shallow bottom penetration much higher resolutions are required. This can be achieved with high frequency acoustic sources. In this study a narrow bandwidth acoustic source with a peak frequency of 24 kHz is chosen. This frequency has proven to provide a good compromise between penetration and resolution in similar conditions [1]. It can be used from very shallow draught vessel, able to measure on the shallow embankments of the project area. The acoustic waves are created in the same transducer array as used for the single beam. The seismic vertical profiles and echo sounder bathymetry are acquired simultaneously and provide layer resolutions and depth assessment in a 5 cm accuracy range.

In this first investigation phase the primary result is the actual bathymetry. The secondary result is a first sub bottom model for planning sampling locations. The quality of seismic data can be reduced by gas occurrences in the sediments reducing the interpretation accuracy. The data quality is therefore a parameter in the borehole planning process.

In the second phase borehole sampling and chemical analysis information are integrated in the seismic records. The combined dataset will results in better understanding of the spread of contaminated sediments and allows to eliminate erroneous measurements. The basal occurrence of contaminated material is mapped and profile data is modeled into a digital terrain model (dtm). This model is used for dredging quantity assessment. The base level of the contaminated sediments will form a basis for the development of the dtm and will be used by the dredge contractor.

Results

In the first phase of the site investigation, the bathymetric and seismic data acquisition, cross sections every 50 m perpendicular to the river axis (direction of highest variability) were measured.. The survey was executed in september 2006 and took about 2 weeks. Vertical accuracy was given proper attention by using RTK-dGPS systems with reference stations on permanent control points. To ty the seismic interpretation a seismic line along the central axis was recorded. The survey was performed from a small 4 meter open survey vessel, able to record data on the very shallow slopes of the river (minimal waterdepth 30 cm). Especially the sloped area’s of the Vecht show extensive water plant growth in this period. Standard echo sounding survey techniques do not perform accurately in these conditions. The sediment bathymetry was in post processing picked from the seismic recordings in this realm, eliminating the necessity of additional pole soundings.

In nearly every cross section a borehole was planned and sampled based on an initial seismic interpretation. Piston sampling cores were taken at the predefined locations and positioned as close to the seismic line as achievable to optimize the correlation. Every visible layer in the core is chemically analyzed. The top of the first layer with a contamination class of less than three is the base of the contamination. The absolute depth of the top of the sediment in the borehole and the base of the contaminated layer are integrated into the seismic data processing program. Based on the combined dataset and the borehole descriptions the final interpretation of the variability of the contaminated sediments is made. Figure 2 presents the results of one of the 900 cross sections in the river Vecht.

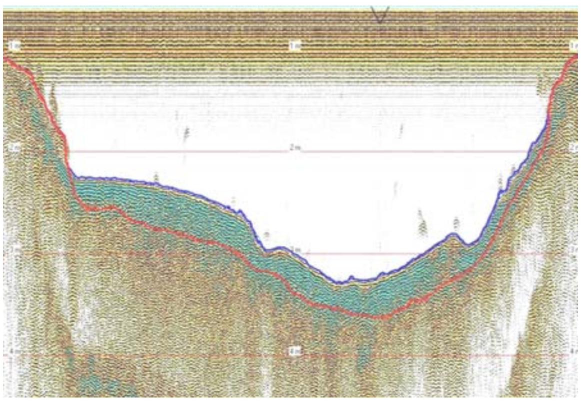

Fig. 2: *Results of cross section in the Vecht. The red line in the record represents the border between clean and contaminated sediments. Vertical scale ca. 5 m, horizontal scale ca. 60 m.*

A digital terrain model (dtm) of the contaminated layer is made by interpolation top and base level of the contaminated sediments between the cross-sections. A grid algorithm is used, where the preferring search direction is the same as the axis of the river Vecht. In this way the bends in the river Vecht are incorporated in the final model.

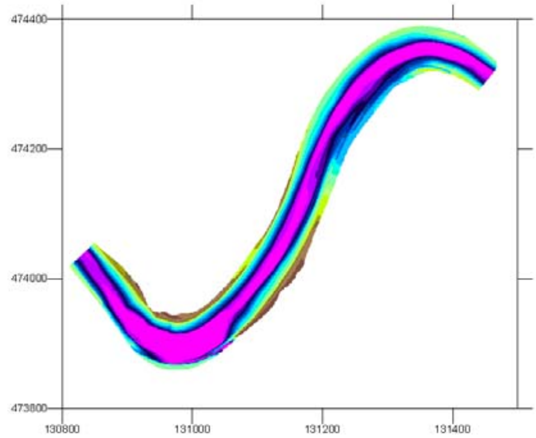

Fig. 3: *Contour map of digital terrain model of base contaminated layer*

Discussion:

During the investigation process new insights on the water system and investigation method are acquired. Today it is however to early to draw fixed conclusions on the results. In this section the main items that were relevant during the process are discussed.

- In this investigation single beam bathymetry and high resolution seismics were chosen as remote sensing survey technique. Other techniques have been considered. The top of the sediments, the upper level of the contaminated layer, can also be detected with handcraft techniques (sounding pole) or multibeam echo sounding. Handcraft techniques are not considered in this case due to the water depth and positioning accuracy (the use of a guiding line over the river is not acceptable due to the boat traffic on the river) and the inline data density. Multibeam echo sounding provides very high lateral data density and directly an area covering dataset. However the method does only provide information on the top of the sediment, and cannot be used on the very shallow slopes and cannot be used in area’s with water plants. Multibeam echo sounding may be considered in a later stage of the project when final dredging quantities have to be determined for contractual purposes.

- The stratification of the sediment layering can be visualised by remote sensing techniques as high resolution seismics and ground penetrating radar. The base of the contaminated sediment is however not necessarily uniquely related to a fixed stratigraphic unit. Combination with chemical borehole data is required to define the base level of the contamination for any type of remote sensing technique as ppm concentrations can not be detected directly. In this case high resolution seismics have been chosen as ground penetrating radar uses electromagnetic waves and is assumedly less suitable for purposes in sediments because of the sensitivity for salinity. Furthermore the practice of ground radar is complex in situations of high variation in depth, because the antenna needs to be kept close to the bottom to get sufficient penetration.

- In situations where the lateral variation in thickness and levelling of the contaminated layer is low, a reliable sanitation-model can be reached by interpolation of the results of bore-hole information and chemical analyses. The present sediment investigation strategies are primarily based on these situations which can be found in small creeks, canals and shallow lakes, or where the profile is known because of regular maintenance works in the water. As expected the variability of the elevation and magnitude of the contaminated sediment layer is beyond what can be detected based on borehole information alone (see example in figure 4). The minimal criteria for data-density and investigation approach in The Netherlands do not prove valid for these types of water systems.

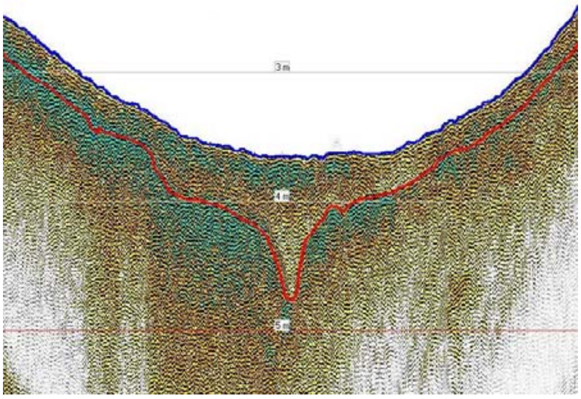

Fig. 4: *vertical seismic cross section in the Vecht. showing the lateral variation in the base of the contaminated layer. The red line in the record represents the border between clean and contaminated sediments. Vertical scale ca 5 m (m intervals), horizontal scale ca. 30 m.*

- The initial information on variability of the sediment and subbottom layering proved valid for borehole planning. Three area's in the river showed local depressions associated with increased magnitude of sediments. Boreholes have been planned in these area's based on seismic data. After sample analysis it appeared however that the magnitude of the contaminated layer exceeded the maximal reach of the piston sampling device. This coincided with the seismic data, but the drilling method did not allow for deeper measurements in this phase.

- The integration of the datasets showed at several locations a mismatch between the absolute elevation of the sediment in the boreholes and the seismic records. Especially in sloped area's this mismatch is observed. It appears that very accurate positioning of the boreholes is practically possible. RTK-dGPS antenna can not be attached to the bore string and also verticality of the bore string with non stationary positioning is problematic. The lateral accuracy of borehole locations is far less than the accuracy of the positioning system itself. On sloping sediments this also results in a vertical error. Another cause of the vertical mismatch is the depiction of the top of the sediment with the piston sampler. The very soft consistency of bottom material is difficult to detect. It will be better to relate the elevation of the sediment layering to the absolute depth at maximum penetration. Complicating factor is also the deformation of the sample during extraction from the tube. Correlation with hydrographic and remote sensing data will provide insight in the deviations and the causes. As the indirect remote sensing methods have a better performance in relating depth to an absolute reference, this is chosen as the primary base for modelling.

- In very shallow locations interpretation of the base of the contaminated layer was not possible due to the multiple reflection. This is the acoustic signal that is reflected at the water surface and overprints the seismic data of the deeper layers. These sections have been isolated and additional boreholes had to be planned to complete the model of the sanitation base.

- As described in this article a sanitation model of the river Vecht has been constructed on a combined dataset of more than 900 cross sections and more than 600 boreholes. The model will be the basis for the dredging contract for the actual sanitation of the Vecht. A point of discussion at present is the way to define the accuracy of the model. Several causes of uncertainty can be defined, but quantifying is less straightforward. Using only sampling information standard geostatistical methods and processes are in use to determine the required over dredging to achieve the sanitation objectives. In this integrated approach the process to define these attributes is not yet clear. At present additional verification boreholes are planned to test the present model.

References:-

[1] High resolution geophysical information to reduce contaminated sediment quantities and promote re-use; W.F.Fontein, J.van der Wal; proceedings Re-used conference 2006, Budapest.