ELECTROMAGNETIC INDUCTION METHOD TO CHARACTERIZE THE REFERENCE SITUATION OF FRESH-SALT WATER DISTRIBUTION AT THE AREA OF THE DEURGANCK DOCK, ANTWERP, BELGIUM

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Abstract

For the extension of the harbour of Antwerp (Belgium), excavation is needed for a new dock. Appropriate measures need to be taken for the monitoring of the possible disturbance of the salt/fresh water distribution in the phreatic aquifer. The disruption can be caused by the deposition of the dredging sludge. In several piezometers, measurements have been carried out before the dredging started. In this way, the salt/fresh water distribution at time t_0 (March 2003) has been qualified. In March 2004, the first measurements to investigate the possible changes in groundwater quality have been carried out. There are no significant changes expected in the groundwater quality after one year. This is confirmed by the electromagnetic induction loggings.

Keywords: monitoring; electromagnetic induction; salt/fresh water distribution; groundwater electrical conductivity

Introduction

During the past few years the volume of container traffic in the port of Antwerp, Belgium, has grown annually. The existing container terminals on the right bank of the Scheldt river have now reached their maximum capacity. In order to deal with this exponential growth, it was decided to build a new, tidal container dock, the Deurganck dock, on the left bank of the Scheldt, in the polders.

To build the new dock, the soil has to be excavated and stocked in the vicinity of the existing Doel dock. The polder area is affected by the presence of salt groundwater. Saline or brackish porewater leaking out of the stock piles may change the local fresh/salt water distribution. The reference situation (March 2003) has been defined by sampling the groundwater at different depths and performing electromagnetic (EM) induction logging in each piezometer.

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To evaluate the influence of the leakage of the soil on the groundwater quality, a monitoring programme has been set up. Each year, samples of the groundwater will be taken in each piezometer to follow up the groundwater quality. The EM induction loggings in the piezometers will also be repeated yearly to see the evolution of the conductivity with depth as a function of time.

Background information

History of the storage zone

To guarantee the accessibility of the harbour, different maintenance activities have been carried out in the past, such as dredging the docks. The sand-in-water slurry is stored in different phases in different zones surrounded with dikes. Figure 1 shows the study area with the different existing stocks and the zones that will be used for the sand-in-water slurry from the new Deurganck dock. All the zones have already been raised up for about 2 m with sludge from former maintenance activities. For the new Deurganck dock, the storage of the sand-in-water slurry started in April 2003 on top of the existing soil storages. The total

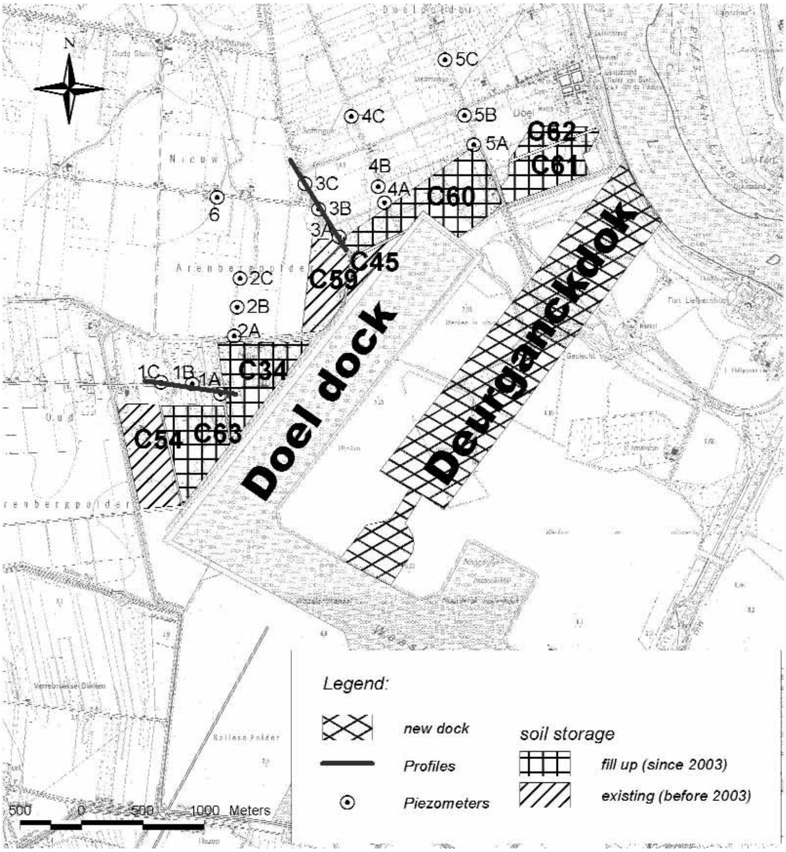

Figure 1. Study area with indication of the storage zones and piezometers.

height of the storage will be up to 8 m above the original surface level. The dredging operation will take place in different phases, for the water to allow to percolate, be evaporated are be pumped out. Also the existing ditches are responsible for the draining of the storage. When the zone is stabilised a new phase can start with new sand-in-water slurry.

Structure of the shallow groundwater reservoir

The groundwater reservoir consists of Quaternary sediments and sandy Tertiary sediments. At a depth of ca. 30 m in the south and up to 46 m in the north of the study area, a heavy Tertiary clay sediment occurs and forms the base of the groundwater reservoir.

At several places, anthropogenic sediments occur on top of the Quaternary sediments. The thickness of these sediments can be up to 2 m. They are derived from the former dredging activities in the harbour area. Quaternary sediments consist of polder clay, peat, and sometimes a sand layer. The thickness of the polder clay varies between a few dm to 2 m. The polder clay rests on a peat layer. The base of this peat, that can contain sand or clay, occurs at a maximum depth of 10 m below surface. In most cases, a Quaternary sand layer overlies the Tertiary sediments. The boundary between the bottom of the Quaternary sediments and the Tertiary sediments is difficult to define. The Tertiary sediments consist mainly of shelly sands with glauconite and a small amount of clay. The base of the groundwater reservoir is clearly defined by the interphase sand/clay.

The results of the measurements of natural gamma radiation (figures 2 and 3) allow to distinguish three layers. At the surface, high values of natural gamma radiation are measured, which correspond with the anthropogenic sediments and the polder clay. The second layer, with very low

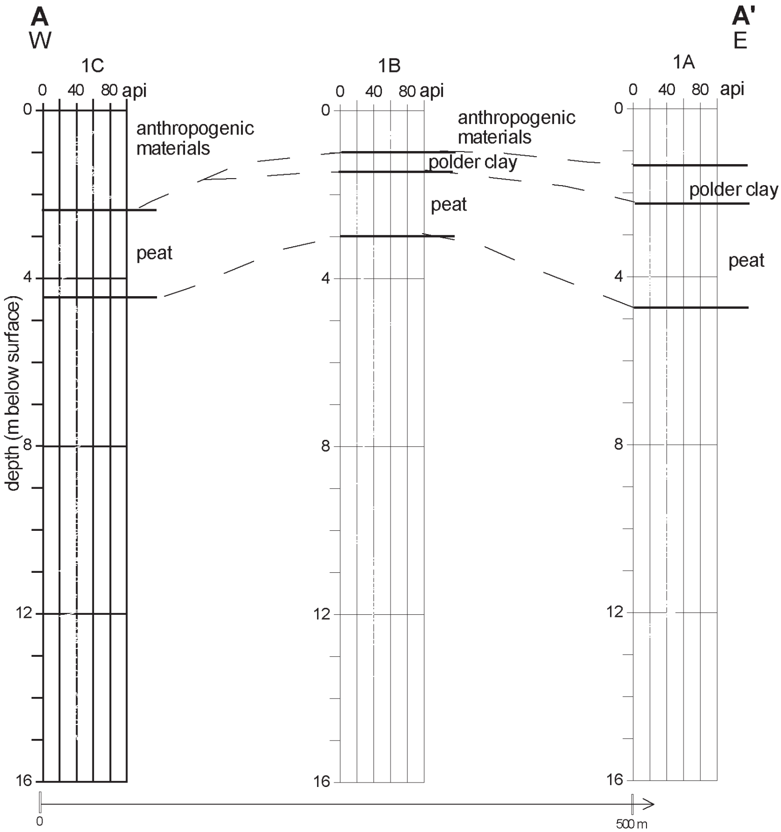

Figure 2. Interpreted layers based on natural gamma logging along profile AA' (see Figure 1).

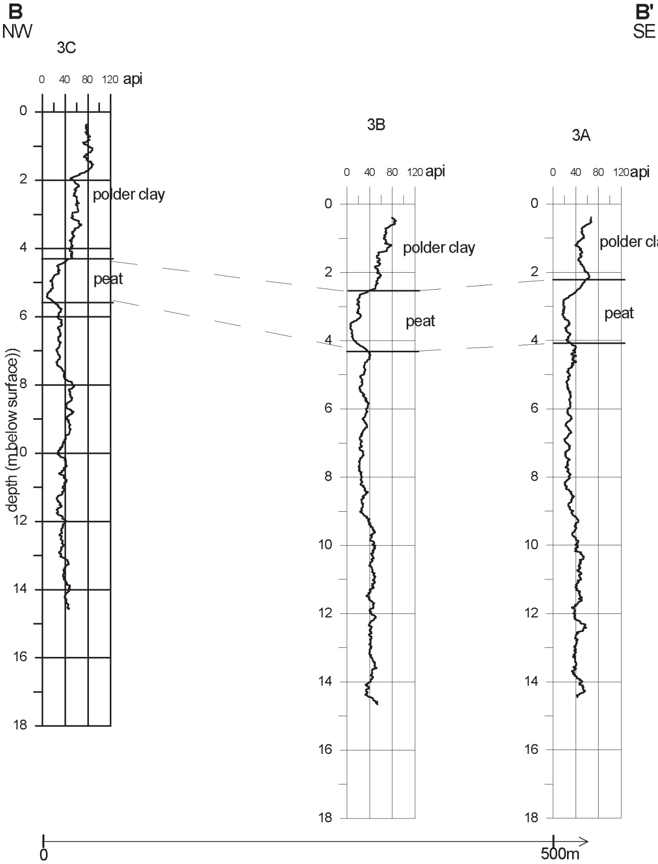

Figure 3. Interpreted layers based on natural gamma logging along profile BB' (see Figure 1).

values for the natural gamma radiation, can be attributed to the peat layer. Beneath the peat layer, the natural gamma values increase, but not as high as measured in the top layer. This corresponds with the sand layer. Since the well logging was carried out in the equipped piezometers, the base of the groundwater reservoir has not been reached.

Fresh-salt water interface

The Laboratory for Applied Geology and Hydrogeology has mapped the depth of the fresh-salt water interface in the phreatic aquifer by means of resistivity profiling (De Breuck, 1989). Figure 4 shows the fresh/salt water interface in the study area. From this figure it can be inferred that the salt water occurs at a depth of less than 5 m.

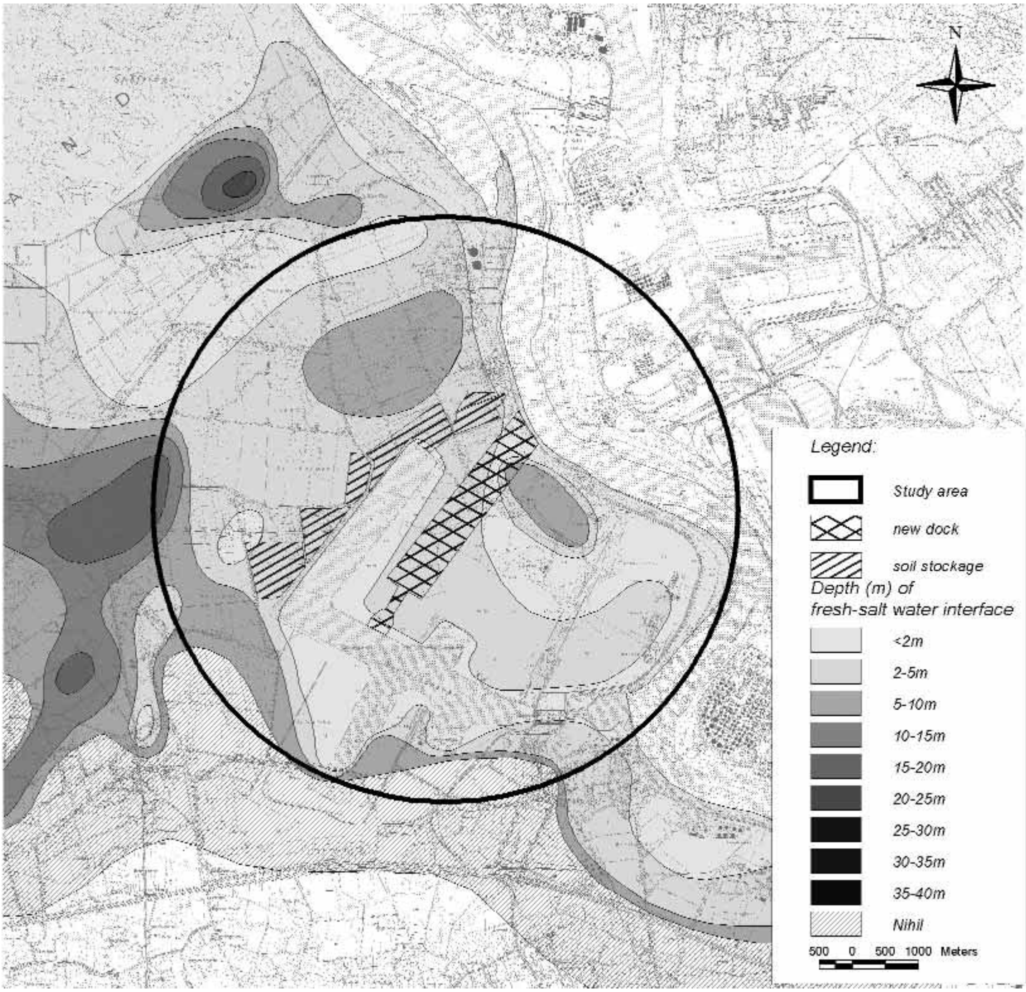

Figure 4. Depth of the fresh-salt water interface in the unconfined aquifer (De Breuck, 1989).

Installation of the piezometers

In order to install piezometers, 16 drillings have been carried out up to a maximum depth of 19 m. None of the drillings reached the base of the groundwater reservoir. The location of the piezometers has been chosen along 5 lines with increasing distance to the storage activities. Piezometer 6 is placed outside the zone where a change in hydraulic head is expected. In each borehole two filters are installed in order to sample the groundwater. The deep filter is placed at a depth of about 7 m; the shallow filter is installed at the depth of the water table.

Defining the reference situation (t_0, March 2003)

Groundwater quality

In March 2003 groundwater samples have been taken in each piezometer. In order to define the reference situation a wide range of parameters has been analysed (major ions, parameters that indicate pollution,…). The classification of Stuyfzand has been used (Stuyfzand, 1986) in order to determine the groundwater types. The results along the profiles AA' and BB' are represented in figures 5 and 6. Along profile AA', a brackish to salt NaCl-water type is the most important. Only in the shallow filter a fresh $CaHCO_3$-water occurs. Profile BB' (Figure 6) shows more variety in the groundwater types. The shallow groundwater types vary from brackish to fresh/brackish. In the deep filter, the main groundwater types are brackish to salt.

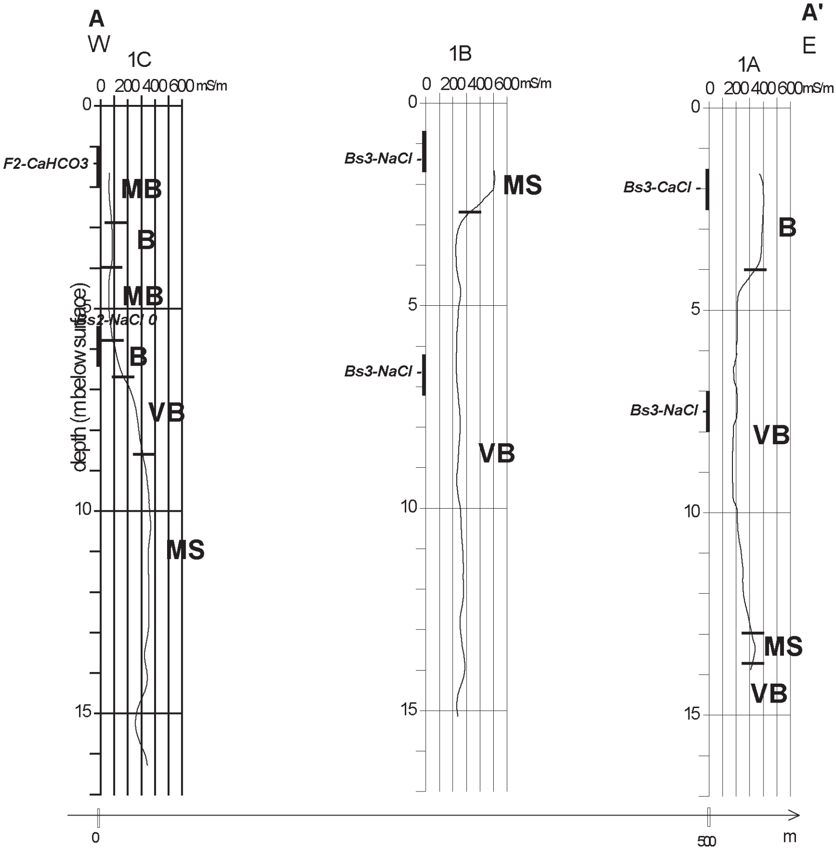

Figure 5. Groundwater quality along profile AA' (situation in 2003).

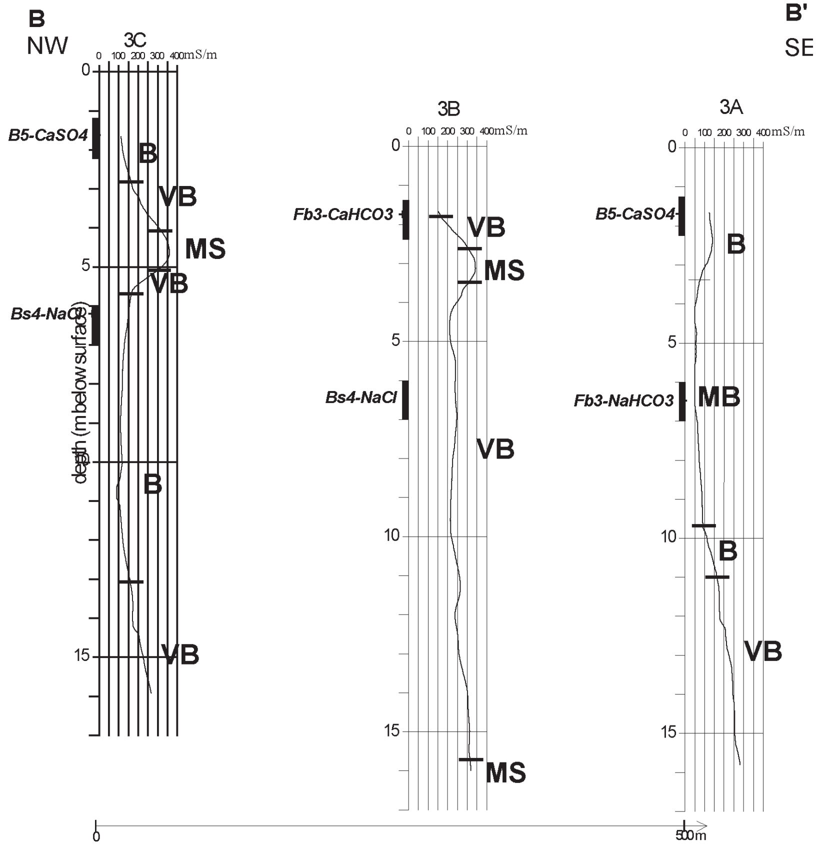

Figure 6. Groundwater quality along profile BB' (situation in 2003).

The results along profile AA' and BB' show that the distribution of groundwater types is very complex.

This complexity can be explained by the long history of the study area. In the Middle Ages, people tried to gain land from the sea and constructed dikes. Inundations lie at the basis of infiltration of salt water. In the 20th century, the expansion of the harbour of Antwerp is responsible for new changes. New docks are constructed, storage areas with dredged soil are exploited, and so artificial infiltration areas are created. Influences by the tides of the Scheldt have also to be considered. The direction of groundwater flow changes continuously in time. Nowadays, the influence of all the activities to build the Deurganck dock will contribute to new changes in the direction of the groundwater flow with changes in the distribution of groundwater quality as a result.

Concerning those aspects, it is very difficult to reconstruct the history of the evolution of groundwater quality with the available information.

Well logging

Well logs were performed in the deepest piezometers. These included natural gamma logging and electrical conductivity loggings. The natural gamma loggings were used to define the groundwater reservoir (see also 2.1). No changes in time are expected.

The conductivity loggings were carried out by means of electromagnetic induction in all piezometers. The distribution of formation conductivity along the profiles with the corresponding types of groundwater are presented in figures 5 and 6. Table 1 gives the corresponding groundwater quality group with the corresponding ground conductivity. We assume TDS (mg/L) to be approximately equal to groundwater conductivity (µS/cm) at formation temperature (11°C). Ground conductivity is then obtained dividing by the formation factor F (F ≅ 4) (Walraevens *et al.*, this volume). The measurements of the conductivity in the piezometers show that the groundwater reservoir is moderately brackish to moderately salt (Martens and Walraevens, 2003). The quick succession of the different groups can be ascribed to the historical development of the area. Nevertheless, the results from the conductivity survey show that the peat layer contributes to a more saline water type than the layer above or below (see Figure 6).

Table 1. Groundwater quality group versus groundwater conductivity and ground electrical conductivity.

Groundwater quality group	TDS (mg/L)	Groundwater conductivity EC_w (µS/cm, 11°C)	Ground conductivity EC_{gr} (mS/m, 11°C)
Very fresh (VF)	< 200	< 200	< 5
Fresh (F)	200 – 400	200 – 400	5 – 10
Moderately fresh (MF)	400 – 800	400 – 800	10 – 20
Weakly fresh (WF)	800 – 1600	800 – 1600	20 – 40
Moderately brackish (MB)	1600 – 3200	1600 – 3200	40 – 80
Brackish (B)	3200 – 6400	3200 – 6400	80 – 160
Very brackish (VB)	6400 – 12800	6400 – 12800	160 – 320
Moderately salt (MS)	12800 – 25600	12800 – 25600	320 – 640
Salt (S)	> 25600	> 25600	> 640

Situation in t = 1 year (April 2004)

Storage activities

The construction of the Deurganck dock is resulting in the excavation of soil; the sand-in-water slurry is being stored on top of the former storage zones. Since April 2003 a new phase has started in zone C63. Up to April 2004, five zones have been in use for the new excavation (C34, C60, C61, C62 and C63). In a further stage, the other available zones will be used (see Figure 1).

Electrical conductivity

In March 2004 the measurements of conductivity have been carried out. As storage activities were performed only recently, the conductivity measurements were only performed in the piezometers closest to the storage zones, and also in piezometer 6 as a reference.

The conductivity measured in March 2003 is plotted together with the measured conductivity in March 2004 (Figure 7). The conductivities measured in 2004 in piezometer 1A are lower than those measured in 2003. At first sight, it seems that the groundwater reservoir is freshening; this is not what is to be expected. The results in the other piezometers show that there are no significant differences between both conductivity profiles. The observed differences in all piezometers are within 5% of the accuracy of the measuring instrument, also for piezometer 1A.

Besides the geological structure, also the hydrodynamics are very important to explain the negligible changes. The polder clay, together with the peat layer, act as an aquitard. The aquitard slows down the vertical groundwater flow to the deep aquifer. The local ditches are responsible for the drainage of the water

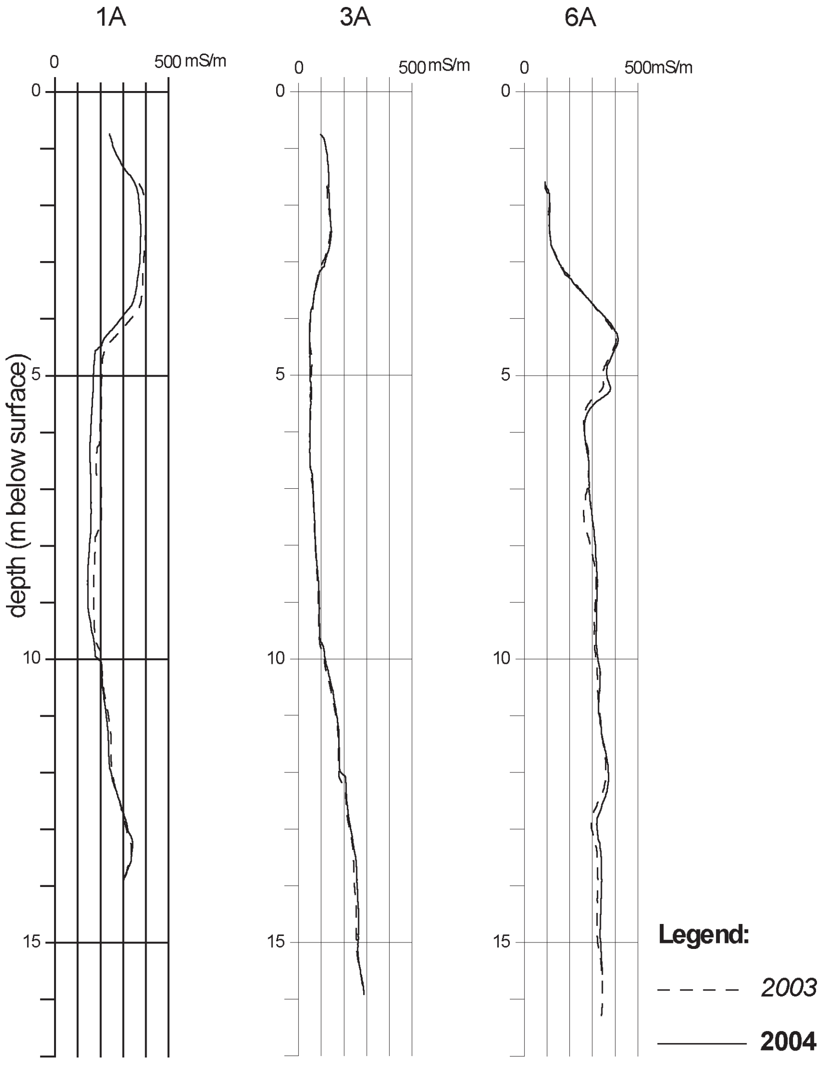

Figure 7. Measured electrical conductivity in 2004 compared with measured conductivity in 2003.

from the sand-in-water slurry. And last but not least, several pumps are installed to drain the water from the storage zones. For the construction of the Deurganck dock it is important that water disappears fast, so that new sand-in-water slurry can be stored on top of it. The amount of water infiltrating into the groundwater reservoir is consequently reduced.

Conclusion

The expansion of the harbour of Antwerp is needed. For this, a new dock has to be constructed and dredging activities are performed. The storage of the sand-in-water slurry will be on top of the already existing storage from former maintenance activities in the harbour area. In the first phase of the study, the reference situation (March 2003) has been determined. After one year of dredging activities and storage, new measurements have been performed. The results of these measurements show that there are no significant changes between the reference situation and after 1 year. This is due to the short period of deposit, the geological structure, the local drainage system and the pumps that drain water from the basins. Because the construction of the new dock is not finished yet and the dredging is still going on, the storage of the sand-in-water slurry is still continuing. To follow up the possible changes in groundwater quality, further measurements are needed.

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