INVESTIGATION OF SALT WATER INTRUSION BY GEOPHYSICAL MEASUREMENTS

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Abstract

This case study illustrates the advantages of geophysical investigation for mapping pollution. The groundwater reservoir is polluted by infiltration of dissolved salt of a former storage of de-icing salt. The survey was carried out using a network of individual lines. Along those lines electromagnetic prospecting (horizontal dipole mode) and geoelectrical measurements with the multi-electrode system (Wenner array) have been carried out. The pollution pattern is defined both horizontally and vertically. The results were confirmed by the measured groundwater conductivity at the water table.

Keywords: electromagnetic profiling, geoelectrical tomography, pollution, de-icing salt

Introduction

Soil and groundwater are polluted at a former storage site of salt used for road de-icing. The pollution is caused by infiltration of dissolved salt that reaches the groundwater table. For several years the activities have been stopped and the remaining storage and buildings have also been removed. Therefore, the source of pollution has been eliminated. Nowadays the plot is fallow, but the adjacent plots are in use for agriculture.

A geophysical investigation has been carried out along different lines to define the extension of the salt-water intrusion. In order to distinguish pollution from the natural background, the difference in conductivity should be significant. In the first place, the background resistivity and conductivity are determined in order to define the range of values of the resistivity and conductivity to indicate pollution.

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Background information

In the frame of the investigation of soil pollution, different drillings in the vicinity of the former storage site have been performed in order to install piezometers. The depth of those piezometers is, at the most, 10 m. The base of the groundwater reservoir has not been reached (see geology and hydrogeology). At several times, the electric conductivity of groundwater at the water table has been measured.

Since October 2003 the piezometric level has been followed monthly in the three remaining piezometers. The water table occurs at an average depth of 7 m. From those results, a north-western groundwater flow direction can be derived.

Geology and hydrogeology

Locally, anthropogenic materials can occur at the surface. The Quaternary sediments, consisting of silty sands, have a maximum thickness of 8 m and rest on the Formation of Brussels. The Formation of Brussels is formed by sand with cemented banks. At a depth of about 30 m, the top of the Formation of Kortrijk can be reached. The top of this grey sandy clay layer forms the base of the phreatic groundwater reservoir. Figure 1 shows a schematic cross-section of the site.

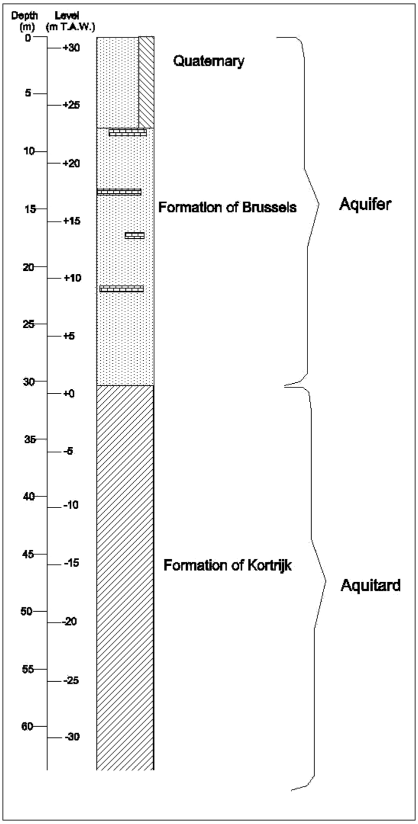

Figure 1. Geology and hydrogeology at the site.

Geophysical investigation

Introduction

In order to define the extension of the pollution caused by the dissolved salt, the investigation by electromagnetic prospecting and measurements with the multi-electrode system have been carried out along different profiles (Martens *et al.*, 2003). The position of the profiles has been chosen considering the location of the storage site of the de-icing salt and the storage of the fuel oil and is given in Figure 2.

The geophysical investigation can only be successful when pollution causes a significant difference compared with the background values. Salt-water intrusion lowers the resistivity and increases the electric conductivity.

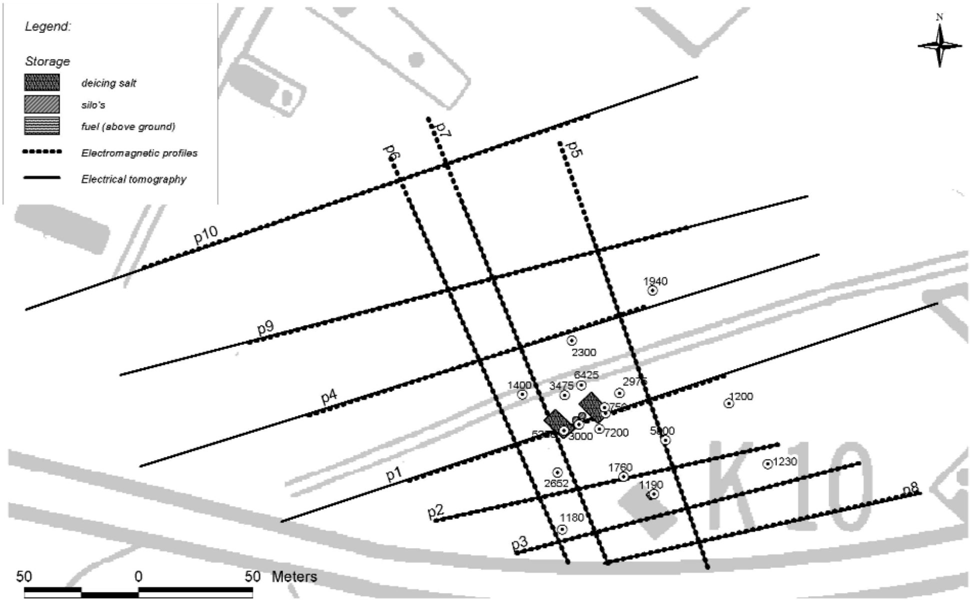

Figure 2. Location of the different profiles for the electromagnetic prospecting and the multi-electrode system.

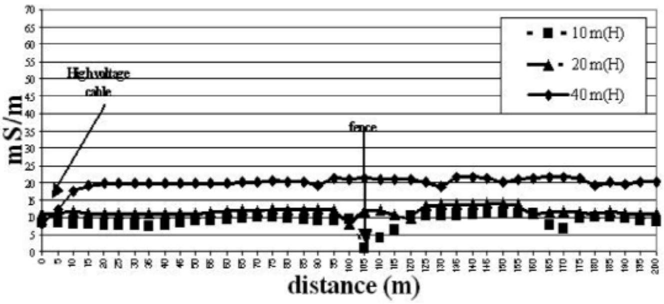

Figure 3. Electromagnetic measurements with intercoil spacing of 10 m, 20 m and 40 m along profile P10.

Electromagnetic prospecting

Electromagnetic prospecting (horizontal dipole mode) was performed along several lines by means of the EM34-3 instrument. With increasing the space (S) between the coils, the exploration depth increases. For homogeneous subsoils, the exploration depth for horizontal dipole mode is 0.75 times the intercoil spacing (McNeill, 1980). The space between the coils along each profile was 10 m, 20 m or 40 m. So, an exploration depth of ca. 7.5 m, 15 m and 30 m can be reached. For S = 10 m, the unsaturated zone is totally included together with the upper part of the groundwater reservoir. With a distance of S = 40 m, the entire groundwater reservoir can be investigated on the condition that the groundwater reservoir is homogeneous.

Because of the negligible variety of the measured values for each intercoil spacing along profile P10, the natural background conductivity for this study area can be deduced from this profile and is given in Table 1. A conductivity of more than 20 mS/m indicates the occurrence of pollution for S = 10 or S = 20 m. For S = 40 m, the natural background conductivity is below 25 mS/m. The deviating lower values found at the beginning of the profile for S = 40 m are due to the presence of high voltage cables. Some metal accessories for cultivating chicory and a fence lowered the measured conductivity in the middle of the profile for S = 10 m.

Table 1. Natural background conductivity and conductivity indicating pollution.

Intercoil spacing	Natural background conductivity	Conductivity indicating pollution
10 m	± 12 mS/m	> 20 mS/m
20 m	± 15 mS/m	> 20 mS/m
40 m	± 20 mS/m	> 25 mS/m

Along profile P1 (Figure 4), the highest conductivities are measured with spacing S = 10 m. The raise in conductivity is a measure for the presence of the pollution, in this case, a salt-water intrusion. The absence of a significant increase in conductivity with S = 40 is probably related to the absence of the salt-water intrusion at the base of the groundwater reservoir. The dissolved salt probably only occurs in the unsaturated soil and in the upper part of the groundwater reservoir.

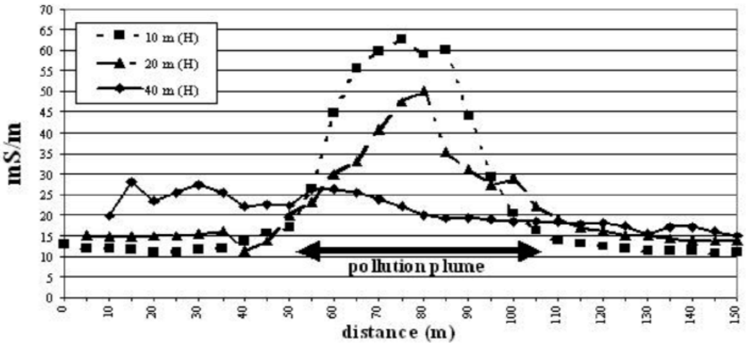

Figure 4. Electromagnetic measurements with intercoil spacing of 10 m, 20 m and 40 m along profile P1.

Maps with isolines of the apparent conductivity can be drawn based on the measured values along all profiles. Figures 5 and 6 are illustrations of these results and represent the maximum extension of the salt-water intrusion with intercoil spacing of S = 10 and S = 40 m. They illustrate that two sources of pollution can be derived for S = 10 m. One source is located at the former storage of salt. The second one is located in the southern part of the area, close to the street. There are no significant indications that this pollution plume is due to the storage of fuel oil, but rather due to the transport by trucks of the de-icing salt.

Comparing Figure 5 with Figure 6, a displacement to the northwest of the source can be observed. This is related to the direction of the groundwater flow. The highest conductivity can be observed northwest of the former storage and indicates that pollution has probably reached the base of the groundwater reservoir due to gravity (salt water is denser than fresh water).

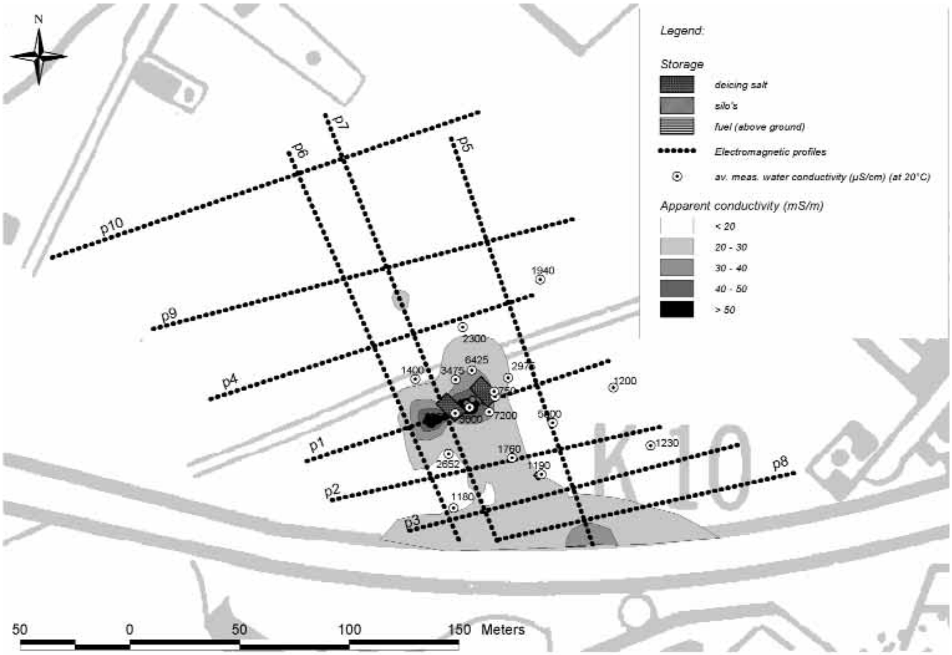

Figure 5. Isolines of the apparent conductivity with intercoil spacing of 10 m.

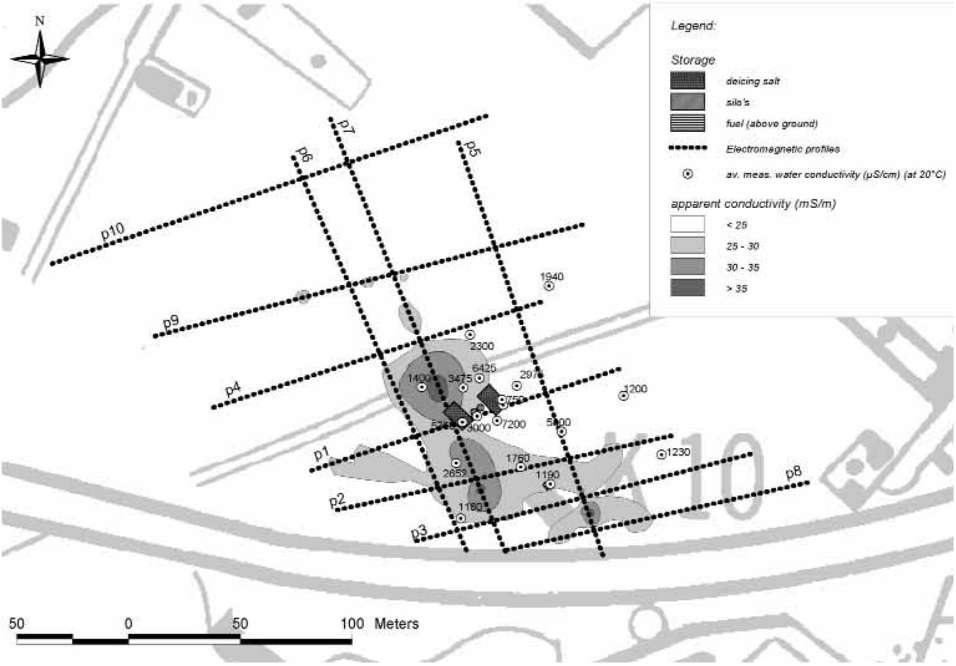

Figure 6. Isolines of the apparent conductivity with intercoil spacing of 40 m.

Multi-electrode system measurements

Along the profiles, the apparent resistivity of the groundwater reservoir has been measured by means of the multi-electrode system. The measurements were done with the Wenner array. The distance between the electrodes is 5 or 10 m, depending on the available length along the profile. By automatically addressing a combination of 4 electrodes out of the available 32 electrodes, the total length of the profiles is 155 m or 310 m. Profile 1 has been carried out with both distances with the same centre.

The results of the electrical tomography allow characterising the subsoil both in vertical and horizontal directions. The measurements by the geo-electrical tomography were interpreted by means of the program RES2DINV (Loke and Barker, 1996; Loke, 2002). Figures 7 to 8 are the results of the interpretation with the inverse model.

With the distance of 10 m between the electrodes, the interpreted penetration depth is at least 58 m, and includes the entire phreatic groundwater reservoir. It is also possible to define the base of the phreatic aquifer. A distance of 5 m between the electrodes gives more detail of the upper part of the groundwater reservoir.

Profile P10, presented in Figure 7, is representative for the reference situation. The natural background resistivity of the different entities can be defined and is also marked on the profiles. A value of at least

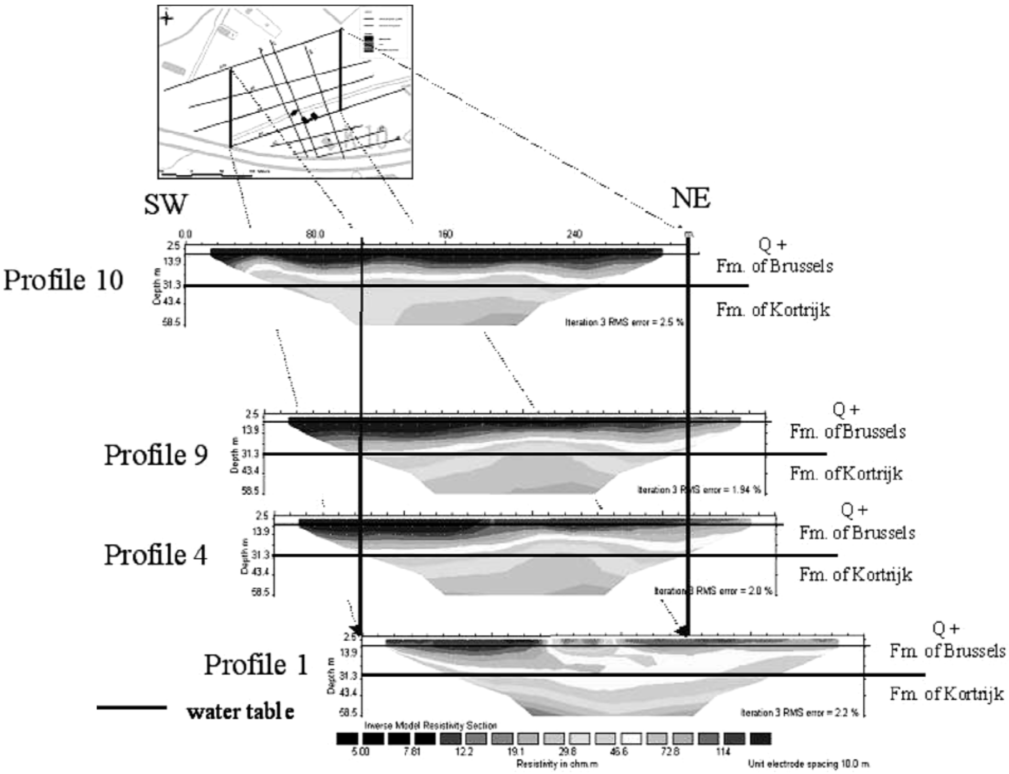

Figure 7. Correlation between 4 parallel profiles (distance of the electrodes = 10 m) from profile P1 to profile P10.

90 ohm.m indicates the unsaturated zone. The saturated zone, consisting of fine to coarse sand with cemented banks (Formation of Brussels), has an average resistivity of 70 ohm.m. A horizontal stratification in the phreatic groundwater reservoir can be observed. With increasing depth, the resistivity decreases. The base of the groundwater reservoir can be determined at a depth of ca. 31 m with a resistivity less than 30 ohm.m. At this depth, the top of a sandy clay layer (Formation of Kortrijk) occurs.

The salt-water intrusion clearly decreases the measured apparent resistivity (see profile P1). A resistivity of less than 30 ohm.m in the unsaturated zone and in the phreatic aquifer can be related to the salt-water intrusion. When the salt-water reaches the base of the groundwater reservoir, it will be indistinguishable from the top of the silty clay layer because of the same resistivity.

From profile P1 to profile P10, along with the groundwater flow, it is clear that pollution has moved from the unsaturated zone towards the base of the groundwater reservoir (profiles P4 and P9).

Along the direction of the groundwater flow, profile P8 to profile P1 are presented in Figure 8. The distance between the electrodes is 5 m. The difference in results of profile P1 shown in figures 7 and 8 is due to the distance of the electrodes.

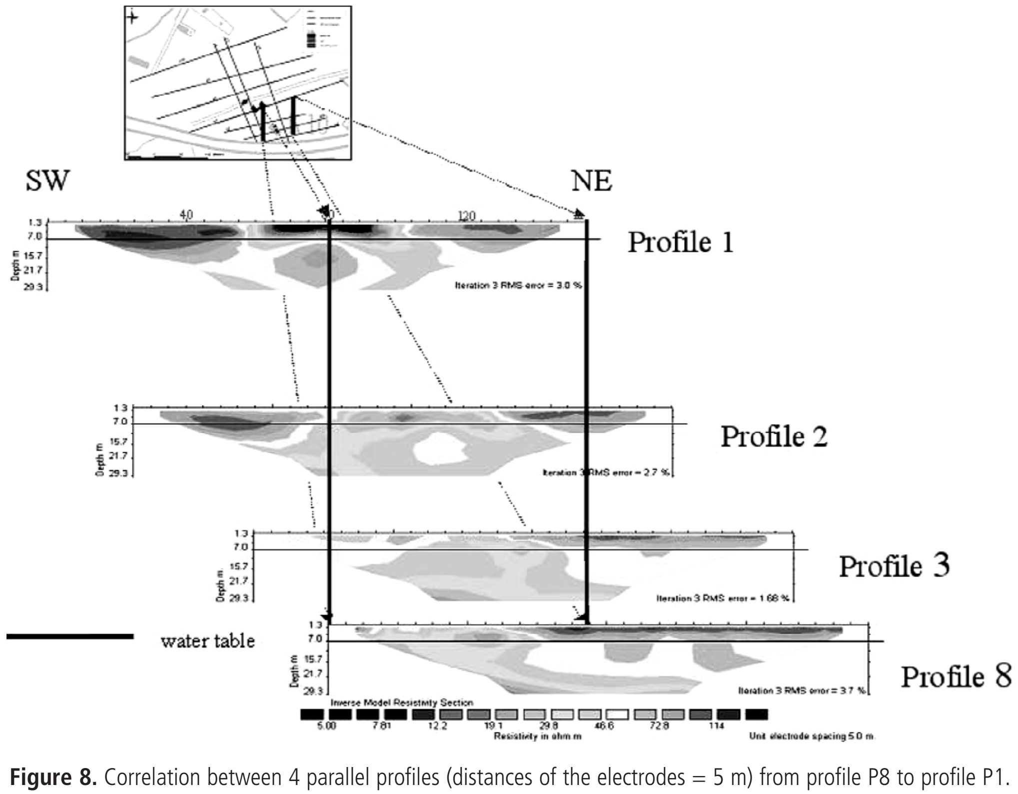

Figure 8. Correlation between 4 parallel profiles (distances of the electrodes = 5 m) from profile P8 to profile P1.

At the beginning of profile P8, a low resistivity is calculated and can be related to salt transport. That the salt-water intrusion migrates to the base of the groundwater reservoir is clearly visible in the central part of profile P3. A lens of low resistivity (< 30 ohm.m) is stretched in depth.

There are no significant indications that the former storage of fuel oil caused pollution that can be observed by means of geoelectrical measurements.

Validating the results

During previous studies, the conductivity of groundwater at the water table has been measured several times. The average measured conductivity is plotted on figures 5 and 6 together with the results of the electromagnetic investigations. The horizontal extension of the salt-water intrusion derived with the electromagnetic investigation with intercoil distance of 10 m corresponds very well with the observed conductivity in the piezometers. The highest values are located at the former storage site of salt. In the southern part, there are no values available for the measured conductivity at the water table. Because of the absence of a piezometer at the second plume, the pollution observed by electromagnetic investigation and by geoelectrical measurements by means of multi-electrode system can not be compared with the measured conductivity at the water table.

Conclusion

By a combination of an electromagnetic investigation and a multi-electrode system, the extension of the salt-water intrusion is defined horizontally and vertically. Two sources of pollution are the main reasons for the observed pollution in the groundwater reservoir. The former storage of salt for de-icing roads is one source. The second source is located close to the street and is due to the transport of the de-icing salt. In order to distinguish the pollution from the natural environment, it is important to have a significant difference in resistivity between the pollutant and the background resistivity. There are no significant indications in the measured resistivity and conductivity values that the former storage of fuel oil caused pollution of the groundwater reservoir.

The estimated thickness of the groundwater reservoir has to be taken into account when the distance between the electrodes is chosen. It is preferable that the base of the groundwater reservoir can be reached in order to follow the migration of the pollution in depth. In this case, the pollution forms a toe at the base of the groundwater reservoir.

Electromagnetic investigations in combination with geoelectrical tomography are fast and constitute an accurate tool to locate the extension of pollution under conditions when there is a significant resistivity contrast between the pollutant and the background. The results are confirmed by the measured conductivity at the water table in different piezometers.

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