The implementation of geophysical investigation in the frame of soil and groundwater pollution

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Introduction
It is well known that geophysical investigation is used to differentiate lithological units. Experiences at different test sites prove that geophysical prospection, such as electrical and electromagnetic investigations, is able to detect and define contamination on the surface or in the groundwater, due to spills, leakage or filtration discharges, causing a significant difference in conductivity/resistivity. To examine the effectiveness of remediation of pollution, electrical and electromagnetic investigations can be used successfully because the conductivity will change throughout the remediation process.

1 Methodology
1.1 Electromagnetical profiling method
Electromagnetical profiling method measures the later variation in ground conductivity. The measurements are carried out with a transmitter and a receiver coil which record the conductivity (in mS/m).

The exploration depth depends on the distance between the transmitter and the receiver (see table). The minimum investigation depth (homogeneous soil) is determined by the receiver depth.

Table: Minimum investigation depth (homogeneous soil)

<table>
<thead>
<tr>
<th>Distance (m)</th>
<th>Minimum investigation depth (homogeneous soil)</th>
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<tbody>
<tr>
<td>5</td>
<td>1 m</td>
</tr>
<tr>
<td>10</td>
<td>2 m</td>
</tr>
<tr>
<td>20</td>
<td>4 m</td>
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</tbody>
</table>

1.2 Geo-electrical tomography
It is a combination of resistivity profiling and sounding where simultaneously a combination of 4 electrodes out of a large number of electrodes is selected. With increasing distance between the electrodes, the penetration depth increases.

1.3 Borehole logging
Borehole logging in GB1 (polluted)

2 Application in soil and groundwater pollution
Particularly in industrial areas, there is a reasonable risk that the groundwater reservoir has been polluted accidentally due to spills or leakages. Unfortunately, some pollutions are deliberately caused (illegal dumping or discharge) and it will be more difficult to trace the source of pollution when the discharge is underground. It is a controversial issue to identify the owner of the waste, but in the first place, the source of the pollution needs to be traced. Therefore, it is advised to implement the electromagnetical profiling method because of its fast exploitation capability. Based on these results, areas with increased conductivity can be deducted and correspond most likely with pollution. To collect more detailed information, it is recommended to implement the geoelectrical tomography along selected profiles. It will result in the vertical delimitations and the quantification of the true resistivity, from which the degree of pollution can be deduced.

2.1 Site 1
The soil and groundwater are polluted at a former site of oil used for road-deicing. The pollution is caused by infiltration of dissolved salt that reaches the groundwater table. Nowadays, the plot is fallow, but the adjacent plots are in use for agriculture (see picture).

2.2 Site 2
An extensive geophysical investigation has been carried out at an abandoned industrial site. In the following, the results of the borehole logging will be presented as an example.

Detecting and delimiting source of pollution
b) Geo-electrical tomography
vertical distribution of resistivity

2.2.1 Site 2
An extensive geophysical investigation has been carried out at an abandoned industrial site. In the following, the results of the borehole logging will be presented as an example.

Detecting and delimiting source of pollution
Borehole logging

Both the natural gamma radiation and the resistivity logging show the contrasting lithology for GB2, located in the polluted area. By boring GB1 located in the polluted area, from top to bottom, the resistivity is very low (< 10 ohm) and the variation in resistivity is hardly noticeable, i.e. all layers have the same or almost the same resistivity. It seems the groundwater reservoir consists of one lithological unit, but regarding the results deduced from the natural gamma radiation, different units can be interpreted. It is clear that at GB1, the whole groundwater reservoir is equally polluted. Pollution is clearly expressed by low resistivities.

Monitoring of remediation
Once the pollution has been determined and the remediation has started, it is recommended to monitor the evolution of the remediation. The conductivity/resistivity, which is measured several times and is plotted together with the results of the electromagnetic investigations (see above) and the geoelectrical tomography (see p.), will result in the vertical delimitations and the quantification of the true resistivity, from which the degree of pollution can be deduced.

3 Conclusion
Geophysical investigation is a useful tool to trace and delimitate pollution. The electromagnetic profiling method and the geoelectrical tomography make it possible to locate the pollution and deduce possibly the source of it. Also conductivity/resistivity measurements in boreholes are useful to delimitate the pollution in the vicinity of the borehole as long as these results are used in combination of natural gamma logging, in order to differentiate lithological differences from pollution. The approach to use geophysical investigations in monitoring remediation has just started; the authors are concentrating on it in their research, as the results are promising.

A great advantage for the surface geophysical methods applied to soil pollution consists in avoiding direct contact with pollution, resulting in a reduction of health risks. These methods are non-destructive and fairly fast investigations are possible.