CHERTS FOR MONITORING HYDROCARBON CONTAMINATION

L. CAPOZZOLI, V. GIAMPAOLO, AND E. RIZZO
ISTITUTO DI METODOLOGIE PER LE ANALISI AMBIENTALI, CONSIGLIO NAZIONALE DELLE RICERCHE, TITO (PZ), ITALY
Sources of pollution and spread of the problem

- agriculture
- industrialisation
- urbanization

Adapted from Brugnoli et al., 2014
What makes this answer very complex is the large number of features that influence the contaminant migration and the permanence time in the subsoil:

- **type of contaminant**;
- **geological features** (aquifers, faults, aquitards, rock, and soil formations);
- **biodegradation processes**.

How does the concentration of a contaminant change in space and time?

NAPLs are common contaminants at hazardous waste sites and are present in the subsurface in continuous and residual phases.

(Adapted from Jol, 2012)
Important DNAPL and LNAPL transport and fate parameters

Viscosity, Density, Solubility, Vapor Pressure, Interfacial tension, Volatility and Wettability

Capillary forces, Pore size distribution/moisture content, ground water flow velocity, stratigraphic gradient

Volatilization, Dissolution, Sorption and biodegradation
Current practice in the characterization and monitoring of contaminated sites

Field measurement & Soil and water sampling + laboratory analysis

- time consuming and expensive;
  - invasive;
- limited number of collected data;
  - low area coverage;
- uncertainty in the estimation of the pollutant distribution.
## Geophysical Techniques

<table>
<thead>
<tr>
<th>Method</th>
<th>Structure</th>
<th>Dynamics</th>
<th>Contamination</th>
</tr>
</thead>
<tbody>
<tr>
<td>DC resistivity method</td>
<td>++</td>
<td>++</td>
<td>+</td>
</tr>
<tr>
<td>Induced Polarization (IP)</td>
<td>++</td>
<td>++</td>
<td>++</td>
</tr>
<tr>
<td>Self Potential (SP)</td>
<td>+</td>
<td>+</td>
<td>++</td>
</tr>
<tr>
<td>EM Methods</td>
<td>+</td>
<td>++</td>
<td>+</td>
</tr>
<tr>
<td>Ground Penetration Radar (GPR)</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Magnetics</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
</tbody>
</table>

### Electromagnetic Methods
- Transmitter creates primary electromagnetic field.
- GPS tracks location.
- Receiver measures secondary field created in the ground (which is a function of the electrical conductivity of the ground).

### GPR
- Transmitted wave is reflected at a buried object.
- Antennas detect the wave reflection.

### Magnetics
- Earth's magnetic field interacts with conductive objects.
- Subsurface anomalies are detected.

### Self Potential
- Fixed reference electrode.
- Moving measurement electrode.

### DC e IP
- Electrode configuration for electrical probing.
- Contaminant detection at depth.
DC Resistivity Method

We measure resistance (R) in Ω or Ohm (depends on geometry) but we wish to determine the resistivity (ρ) in Ωm or Ohm·m (intrinsic property).

Resistivity basic measurement principles

Inversion of resistivity (res2D-inv, R2, etc.)
Calculating the resistivity distribution that is ‘consistent’ with the observed (measured) resistances.
Cross-hole Electrical Resistivity Tomography (ERT)

- Cross-borehole geoelectrical measurements (ERT and IP) are the methods most commonly used in environmental and hydrogeological application.
- Apparent resistivity measurements are made using electrodes in two or more boreholes;
- It has a better resolution at depth compared to geoelectrical measurements made on the ground surface;
- The method suffers from a number of disadvantages:
  1. boreholes are required;
  2. the images cover only the region between the boreholes;
  3. the boreholes must not be too far apart otherwise sensitivity is reduced: the aspect ratio (S) defined as the ratio between the depth of the wells (D) and their distance (L) should be greater than 1.5
  4. the borehole and the electrodes characteristics cause a data noise levels usually higher than those using surface electrodes
Focus of the research

- Study of the LNAPL contamination in vadose zone;
- Spillage of 500 ml of diesel at a depth of 20 cm from the surface;
- Analysis of electrical behaviour of the subsoil for 1 years

Methodology

- Time lapse cross borehole resistivity tomographies
EXPERIMENTAL PHASES

**Phase 1:** CHERTs are performed with the phreatic level located at a fixed depth (22.5 and 24 cm from the surface respectively in piezometer A and B) in an uncontaminated background;

**Phase 2:** The geophysical analysis are performed in saturated and unsaturated zones with a continuous monitoring after the oil spillage for more than 350 days.

<table>
<thead>
<tr>
<th>Chemical analysis, Particle size analysis, Hydrogeological properties</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Chemical analysis results</strong></td>
</tr>
<tr>
<td><strong>Chemical analysis results</strong></td>
</tr>
<tr>
<td>%</td>
</tr>
<tr>
<td>----------------</td>
</tr>
<tr>
<td>%</td>
</tr>
<tr>
<td><strong>Particle size analysis</strong></td>
</tr>
<tr>
<td>d (mm)</td>
</tr>
<tr>
<td>%</td>
</tr>
<tr>
<td><strong>Hydrogeological properties</strong></td>
</tr>
<tr>
<td>dₘ (mm)</td>
</tr>
</tbody>
</table>

**CHERTS FOR MONITORING HYDROCARBON CONTAMINATION**
Hydrogeophysical system realized in laboratory

- Plan of test site
  - Labels: A, B, C, D, E, F, drainage system (inlet), drainage system (outlet), source of contamination, ERT cables.
- Longitudinal section
  - Labels: EF, CD, AB, phreatic level, outlet, inlet, flow direction.
HYDROGEOPHYSICAL SYSTEM REALIZED IN LABORATORY

Sand-box investigated

Remote control via PC

Recharge tank

Piezometeric control

Discharge tank

Georesistivimeter Syscal Pro

Outlet point (0.02 ml/min)
INCREASE OF RESISTIVITY VALUES IN THE A-B AND C-D TRANSECTS
After contamination with LNAPL

AFTER 10 DAYS

AFTER 21 DAYS

AFTER 51 DAYS

AFTER 70 DAYS

Resistivity ratio
\[ \Delta \rho = 1 - \frac{\rho_c}{\rho_{unc}} \]
After contamination with LNAPL

AFTER 81 DAYS

AFTER 180 DAYS

AFTER 260 DAYS

AFTER 320 DAYS

Resistivity ratio

\[ \Delta \rho = 1 - \frac{\rho_c}{\rho_{unc}} \Delta \rho \]
Results from electrical measurements reveal a **bulk resistivity increase** in the early period after the contamination, due to NAPL presence, as expected. Then ERTs reveal a temporal decrease in resistivity values that results in the occurrence of a **conductivity behaviour after 18 days from the spillage**.
First Phase  _Increase  of bulk resistivity in the early period after the LNAPL this phase lasted until the eighteenth day.

Second Phase  Inversion of the electrical response caused by degradation processes including evaporation, dissolution, dispersion, emulsification, adsorption on suspended material and microbial activity (Wang et al., 2004)
**Mean Resistivity Ratio Temporal Variation**

**Third Phase** Increase of resistivity values due to the movement of the oil spilled into the sand

**Fourth Phase** Increase of conductivity values according to the results showed by other authors that hypothesized that microbial activity may also be the cause of this behaviour.
Conclusion

- Our study confirms the link between **hydrocarbons contamination** and **geophysical signal** and the capability of cross-hole electrical resistivity tomographies to realize a non-invasive characterization of LNAPL contamination of the media;
- The ERT boreholes can offer **a key to understand the complexity** of transport processes that induce changes in the electrical images reducing the number of direct measurements (very expensive) in situ to quantify the primary transport properties at a study site;
- The results show the **difficulties of interpretation** related to geophysical techniques which nevertheless can be resolved by analysing the phenomena in a longer time so as to eliminate any measurements disturbs and repeating the same over a greater period and comparing the results with direct analysis
- In any case, the geo-electrical measures appear to be a very **high resolution support** for analysis of environmental type specially if related to dynamic issues.
GRAZIE PER L’ATTENZIONE