The value of geophysics as a non-intrusive method for site characterisation

Matt Harris, Golder Associates (NZ) Ltd.
Presentation Outline

- What is geophysics and how can it help me?
- Electrical Resistivity Imaging (ERI)
  - Landfill case study
- Electromagnetic (EM) surveying
  - Landfill case studies
- Ground Penetrating Radar (GPR)
  - Service detection case study
- Magnetic surveying
  - Buried waste case study
- Considerations for geophysical surveying
- Conclusions
- Question Time
What is Geophysics and How Can It Help Me?

- Approach: Non-intrusive, remote-sensing
- Advantages:
  - Complements intrusive investigation
  - Covers large areas easily (fills in the gaps)
  - Manages the risk in the selection of boreholes/test pits
  - Fast way to identify localised impacts (drums, services, UST…)
- Limitation: Physical contrast (electrical, electromagnetic, magnetic, density or other properties) required between the target and host material
Introduction to Geophysical methods

- Electrical Resistivity Imaging (ERI)
- Electromagnetic (EM) surveying
- Ground Penetrating Radar (GPR)
- Magnetic surveying
Electrical Resistivity Imaging (ERI)

THEORY

- ERI maps differences in the electrical properties of subsurface.
- Differences can result from variations in rock type, water content, water chemistry (i.e. leachate, salinity), buried material, or voids.

APPLICATIONS

- Hydrogeological investigations
- Contaminant plumes
- Landfill investigations
- Geological mapping
- Depth to bedrock
Electrical Resistivity Imaging (ERI)

EQUIPMENT
- Modern ERI systems consist of a switching unit connected to an array of 48-120 electrodes emplaced in the ground.
- Powered by batteries or generator.
- Laptop used to download data
- Survey in 2D or 3D

ACQUISITION RATE
- ~120 min / 100 m

COST
- ~$1000-1500 / 100 m
Sample 3D ERI Results
ERI Example – Landfill #1

- ERI used to provide supporting information for a hydrogeological model at boundary of landfill site

- Objective was to identify preferential pathways for leachate flow

- The results correlated with data from boreholes

- The results refined the interpolation between boreholes, contributing to the conceptual site model
ERI Example – Landfill #1

Potential flowpaths

Relatively impermeable

Profile collected at 90° to presumed flowpath, adjacent to landfill
Electromagnetic (EM) Surveying

THEORY

- Method is sensitive to changes in ground conductivity.
- Alternating current used to produce a time-varying magnetic field. This field in turn induces current to flow in the ground. The induced currents produce a secondary time-varying magnetic field, which is sensed by a receiver coil.
- No electrodes or ground contact necessary

APPLICATIONS

- Metals, moisture, clays, dissolved ions
- Leachate if conditions allow (low noise)
Several different approaches to EM surveying exist:

- **EM31**: 0-6 m depth. Quadrature (ground conductivity), in-phase (metal) responses
- **EM34**: up to 60 m depth. Groundwater, contaminant plumes
- **EM61**: 3-4 m depth. Buried metal (TEM)
- Large time domain loops (TDEM) can be used for hydrogeologic studies.

**ACQUISITION RATE**

- ~ 5-10 min / 100 m

**COST**

- ~$50 / 100 m (EM31)
Electromagnetic (EM) Surveying Equipment

SHALLOW - EM31 (length = 4 m)

INTERMEDIATE - EM34

DEEP - terraTEM
Electromagnetic (EM31) and resistivity surveys carried out over historic waste site at former sand/gravel quarry

Investigation to identify lateral and vertical extent of waste

EM line spacing 3m (~6 m depth penetration)

ERI electrode spacing 2 m (~30 m depth penetration)

Three days of surveying on site
Landfill #2 – EM31 Quadrature Response
Landfill #2 – ERI Results (Line 3)

- Moderately low and variable resistivity indicative of waste materials, thickness up to 5 m. Higher values likely represent C&D waste.
- Low resistivity clay zone interpreted to be original base of the quarried sand/gravel.
Electromagnetic (EM31) and resistivity surveys carried out over historic waste site at former rock quarry

Investigation to identify lateral, vertical extents of waste. Used to guide intrusive investigations.

EM line spacing 3 m, referenced by DGPS (~6 m depth penetration)

ERI electrode spacing 2 m (~30 m depth penetration)

Two days of surveying on site

Resistivity effective at delineating vertical extents of waste, EM surveys useful for lateral extents.
Landfill #3 – EM31 Quadrature Response
Landfill #3 – EM31 Interpretation
Landfill #3 – ERI Results (Line 3)

- Boulder clays (till) at 3 m to 7 m depth, indicated by higher resistivity
- Lower resistivity indicative of waste materials, thickness 5 m to 7 m
- ERI results correspond well with EM results
Ground Penetrating Radar (GPR)

**THEORY**
- Use of radar pulses to image the subsurface (0-30 m depth)
- Sensitive to changes in the dielectric properties of the ground
- Typical frequencies employed are 25 MHz to 1000 MHz
- Frequency depends on desired depth penetration - Lower frequencies give greater penetration, but decreased resolution
- Depth penetration is influenced by ground conductivity – highly conductive ground (clay, water) will reduce penetration significantly

**APPLICATIONS**
- Effective at identifying buried utilities, also defining landfill boundaries (clay). If conditions allow, hydrocarbon plumes may be delineated
- Also archaeological and forensic investigations, shallow geology work
Ground Penetrating Radar (GPR)

**ACQUISITION RATE**
~ 15 min / 100 m

**EQUIPMENT**

- 200 MHz draggable GPR antenna with survey wheel
- 400 MHz cart-mounted GPR antenna

**COST**
~$100 / 100 m
GPR Example – Service Detection

- Large site that had seen a range of industrial land use activities for over a century
- Site featured multiple fuel storage areas and numerous service lines
- GPR was deployed as one component of comprehensive site investigation between two Golder teams
- Objective – to identify potential sources and pathway for contaminant migration, develop site conceptual model
Two days of GPR data acquisition
8.4 km acquired
GPR Example – Service Detection Results

Diffractions off underground services

GPR signal observed over underground storage tank (UST)
Magnetic Surveying

THEORY
- Sensitive to magnetic minerals, iron bearing materials
- Total magnetic field or gradient may be measured
- Gradient more sensitive to small variations, removes need for base measurements
- Typical anomalies of single bodies are dipolar

APPLICATIONS
- Can be effectively used to identify locations of buried iron/steel. e.g. buried drums, cars, etc.
- Also geological mapping, archaeology, mineral exploration
Magnetic Surveying

EQUIPMENT
- Photo shows a magnetic gradiometry survey in progress
- Two sensors are mounted a fixed distance apart, to measure the vertical gradient of the magnetic field
- Standard magnetometry uses a single sensor

ACQUISITION RATE
- ~5-15 min / 100 m

COST
- ~$50 / 100 m
Investigation of a site that was suspected to contain illegally dumped waste in steel drums

Essential that investigations carried out in non-intrusive manner

Rapid survey required

Magnetic gradiometry survey conducted, complemented by a 200 MHz GPR survey

Surveys located using DGPS

Results indicated one area worthy of further investigation
Magnetic/GPR Example - Buried Waste

Magnetic Gradient

GPR slice

Dipolar anomaly

Coincident GPR anomaly

Steel fence
CONSIDERATIONS

- Anticipated physical contrast - dictates selection of appropriate geophysical technique
- Depth of target and geology
- Time and cost
- Sources of noise (e.g. power lines – EM methods. Steel – magnetometry)
- Site access - vegetation and topography can present problems
- Timing of survey – best to carry out geophysics early in site investigation

BENEFITS

- Extensive 2D or 3D data, as opposed to 1D data achieved by drilling
- Large, continuous areal coverage
- Non-intrusive, relatively discreet
- Speed of investigation
Conclusions

- Geophysics can be used to complement or to target intrusive investigations
- Aids in development of site conceptual model
- Wide range of techniques available
- Technique and survey parameters must be selected to suit site conditions, desired depth penetration and survey objectives
Question Time