A workflow for landfill characterization using geophysics and targeted sampling

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[1] British Geological Survey, Nottingham, UK,
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A short introduction to geophysics

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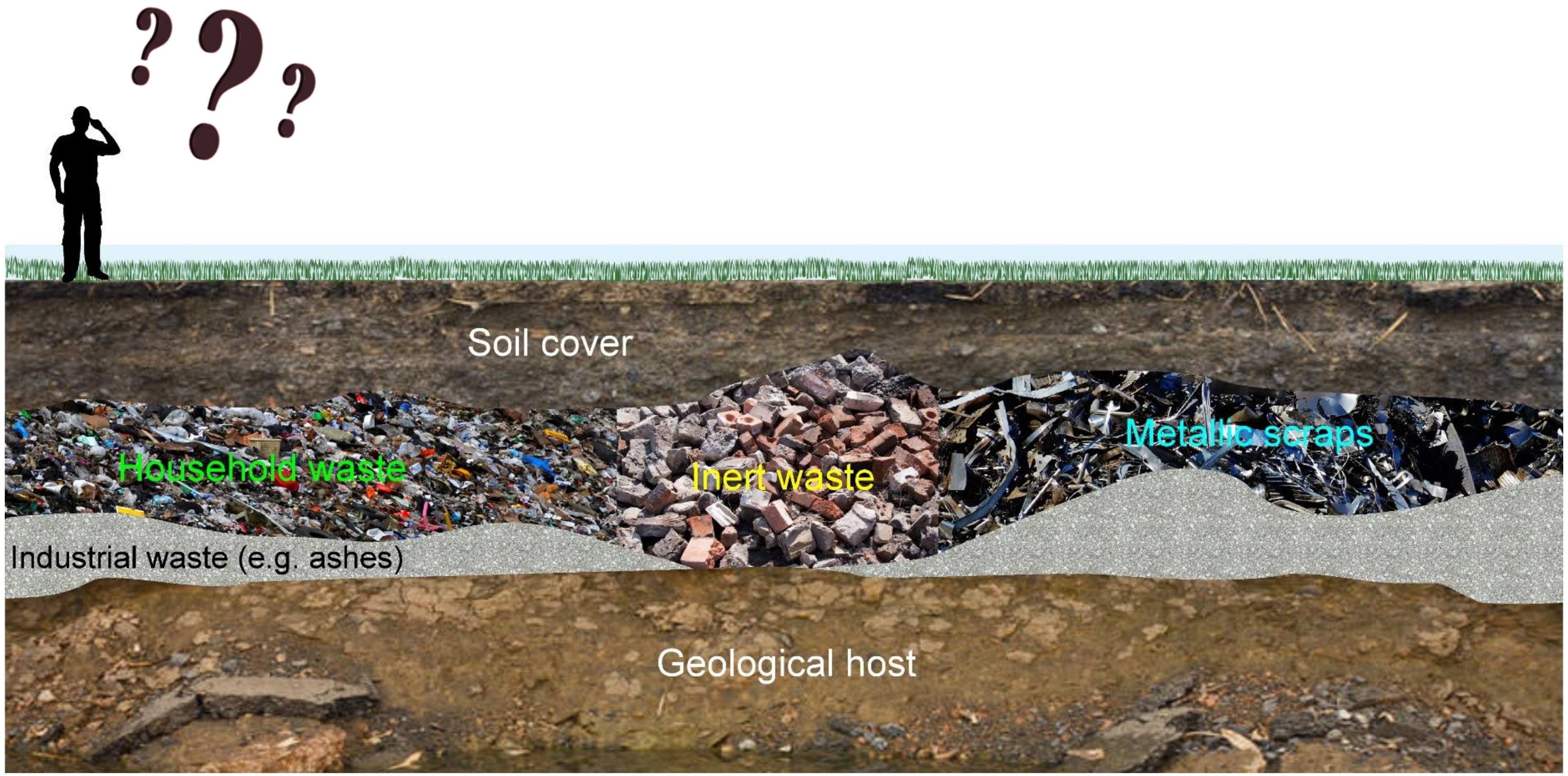
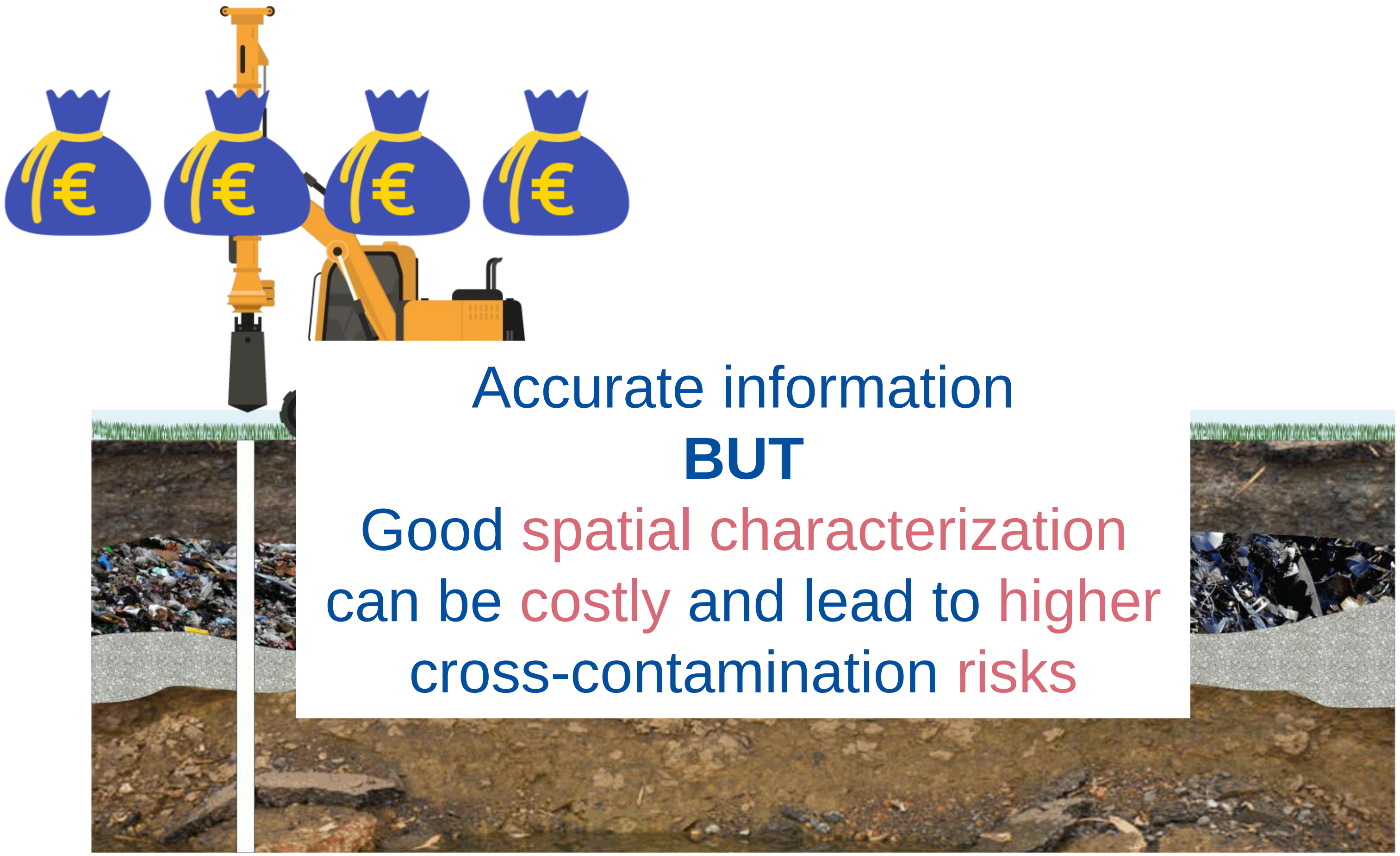
"The subsurface site characterization of the geology, geological structure, groundwater, contamination, and human artifacts beneath the Earth's surface, based on the lateral and vertical mapping of physical property variations that are remotely sensed using non-invasive technologies" (EEGS 2018)

INTRODUCTION

Why geophysics for landfill characterization?



Traditional approach:
drilling – sampling - analysis



Accurate information

BUT

Good spatial characterization can be costly and lead to higher cross-contamination risks

RAWFILL approach

Combine geophysics with traditional techniques

How?

RAWFILL approach

Principle 1:

combine complementary geophysical methods and plan the geophysical survey based on a-priory site information

RAWFILL approach

Principle 1:
combine complementary geophysical methods

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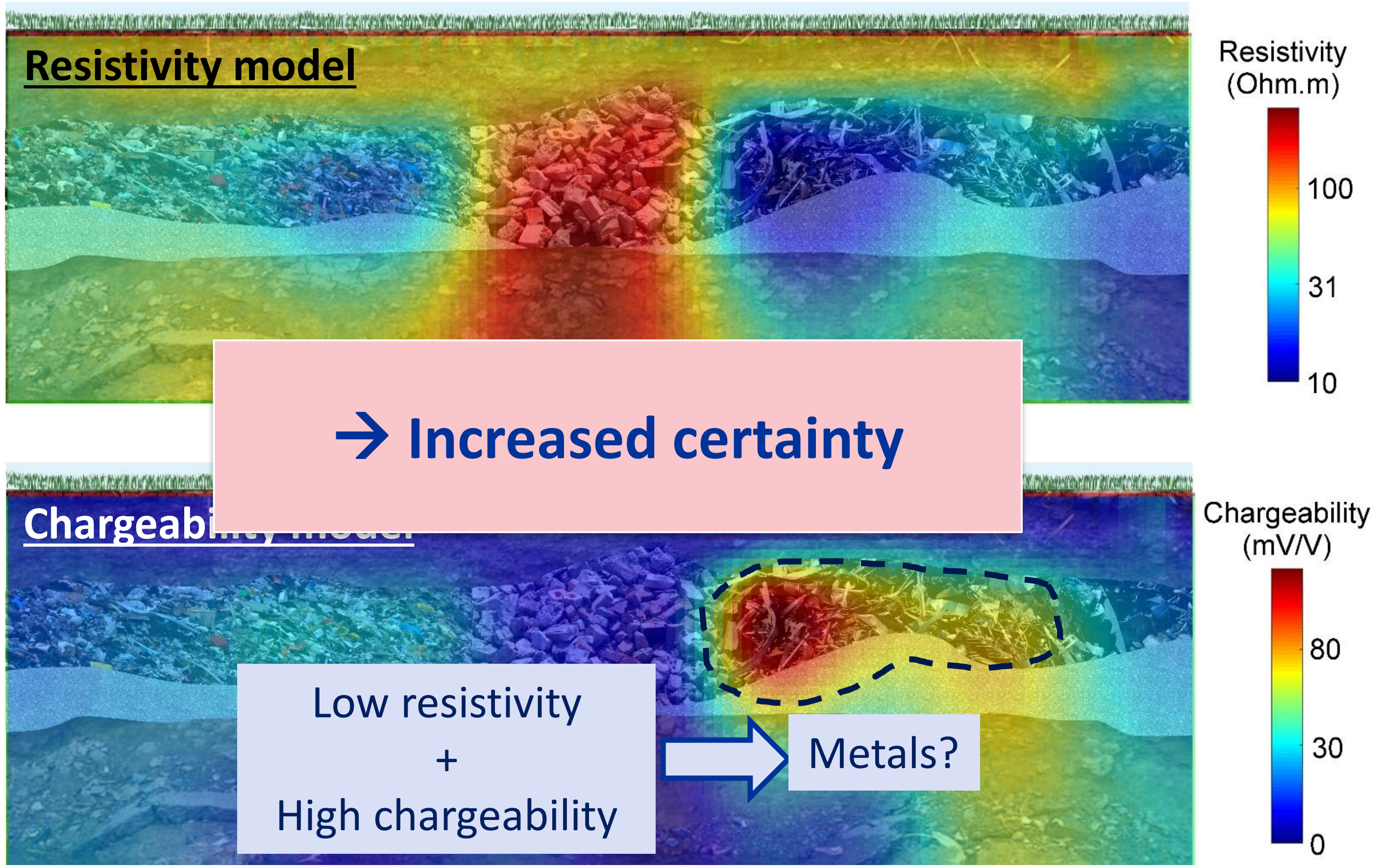
RAWFILL approach

Principle 1: combine complementary geophysical methods



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Principle 2: targeted sampling

Targeted sampling in the zones of interest revealed by geophysics

- Lower costs
- Reduced risk of damaging structures
- Reduced risks of contamination or exposure to hazardous materials

Pros and cons

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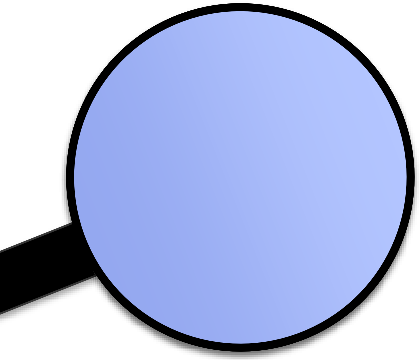
- Non to minimally invasive
- Relatively low cost
- Large coverage
- See through technology

- Indirect information
- Resolution decreases with depth
- Prone to modeling errors (artefacts)
- Ambiguity

Proposed workflow



Archives & inventory report

- Gather and summarize all available information
  → Build conceptual model
  → Assess knowledge gaps

Geophysical characterization

- Use complementary geophysical methods planned according to the conceptual model
  → Interpretation of geophysical results and detection changing properties

Calibration & validation

- Targeted sampling
  → Build sampling plan according to geophysical results
  → Verify and calibrate geophysical measurements to refine conceptual model

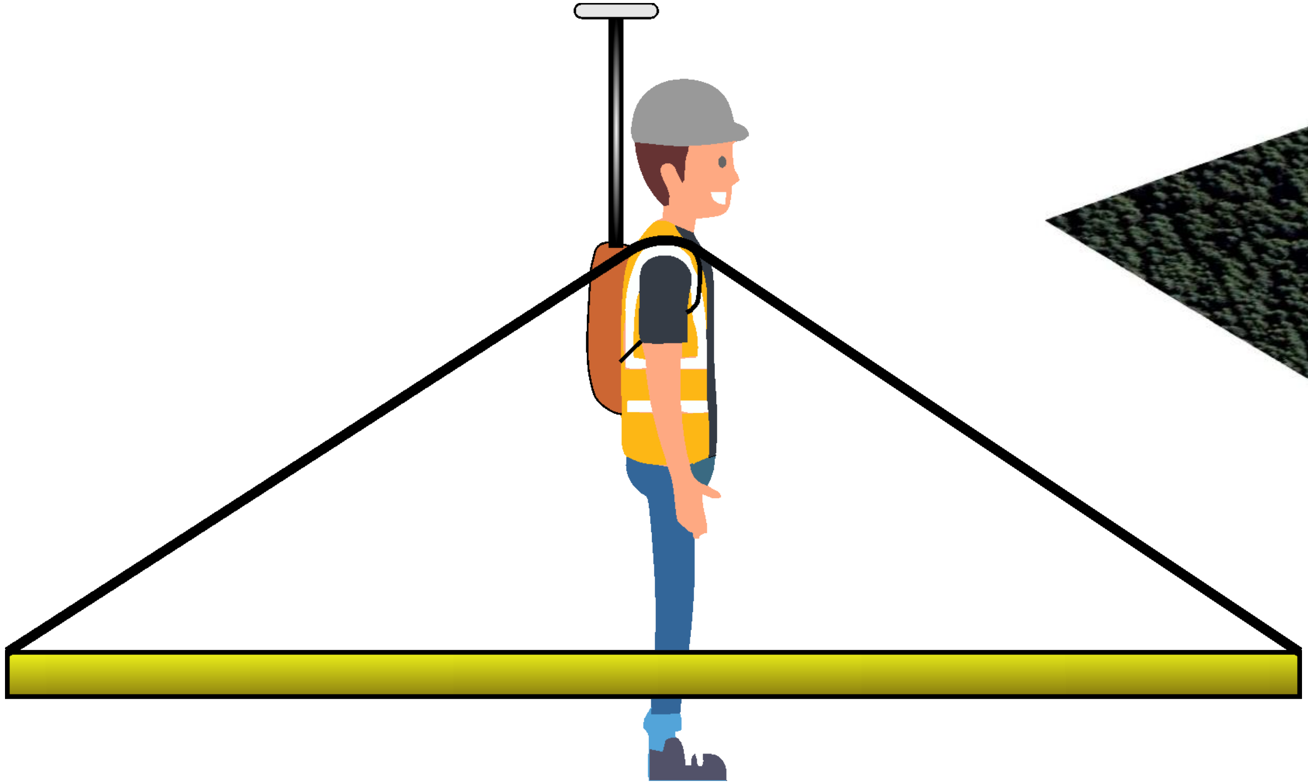
Resource model construction

- Build a resource distribution model based on refined conceptual model

Additional measurements required?

Short recap on the geophysical methods

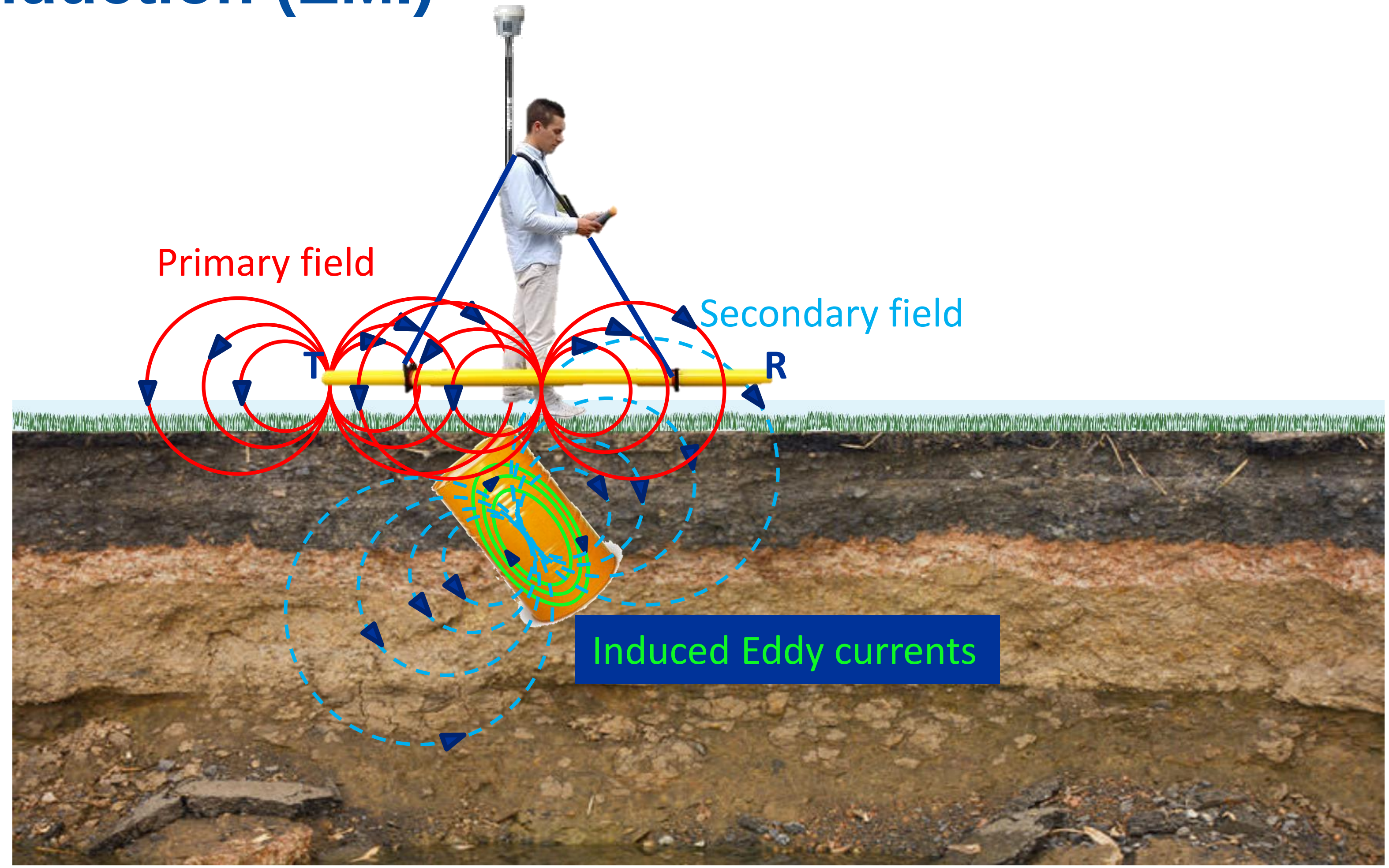
Mapping methods



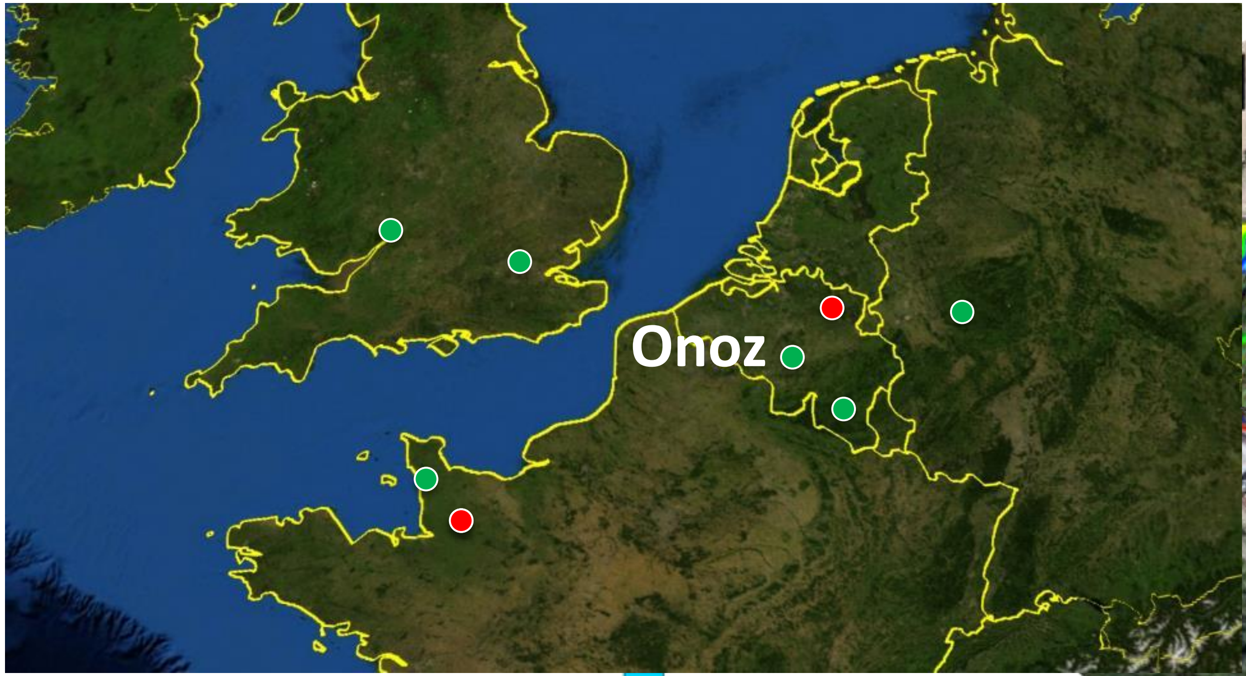
Mapping methods:
Electromagnetic induction (EMI)

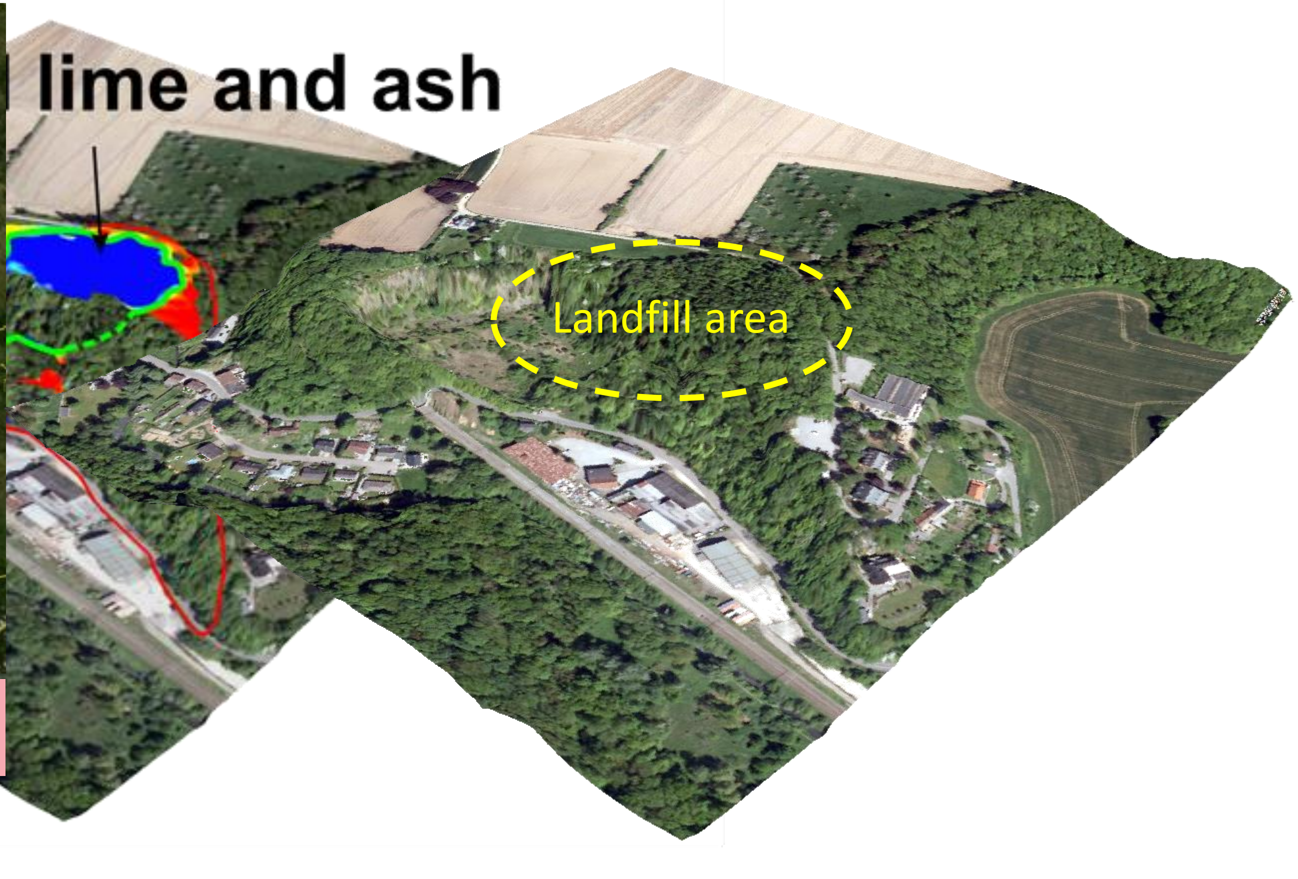
Parameters measured:
- Electrical conductivity
- Magnetic susceptibility

Sensitive to:
- Leachate content
- Pore fluid conductivity
- Metal content



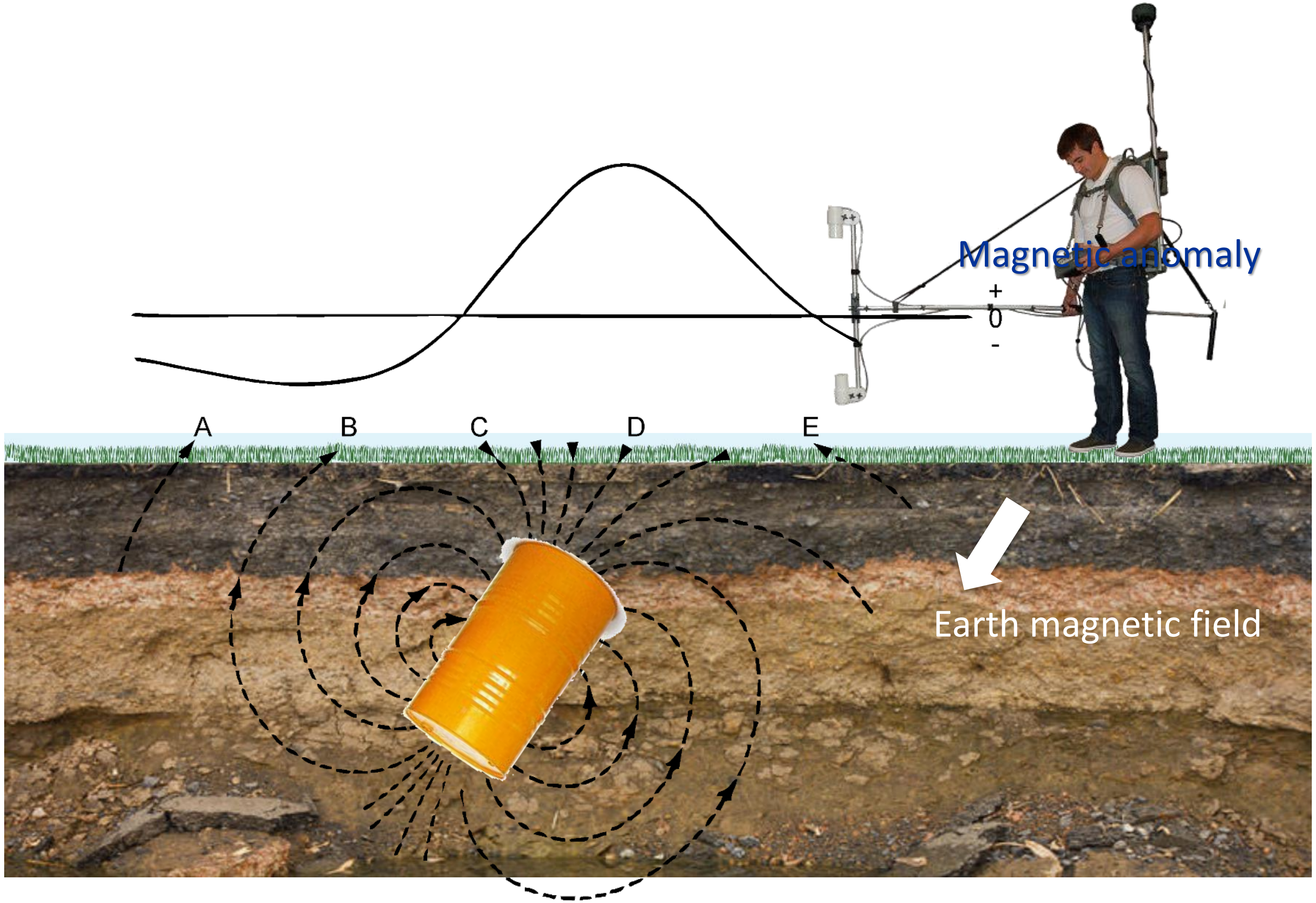
Mapping methods:
Electromagnetic induction (EMI)





- Mainly industrial waste

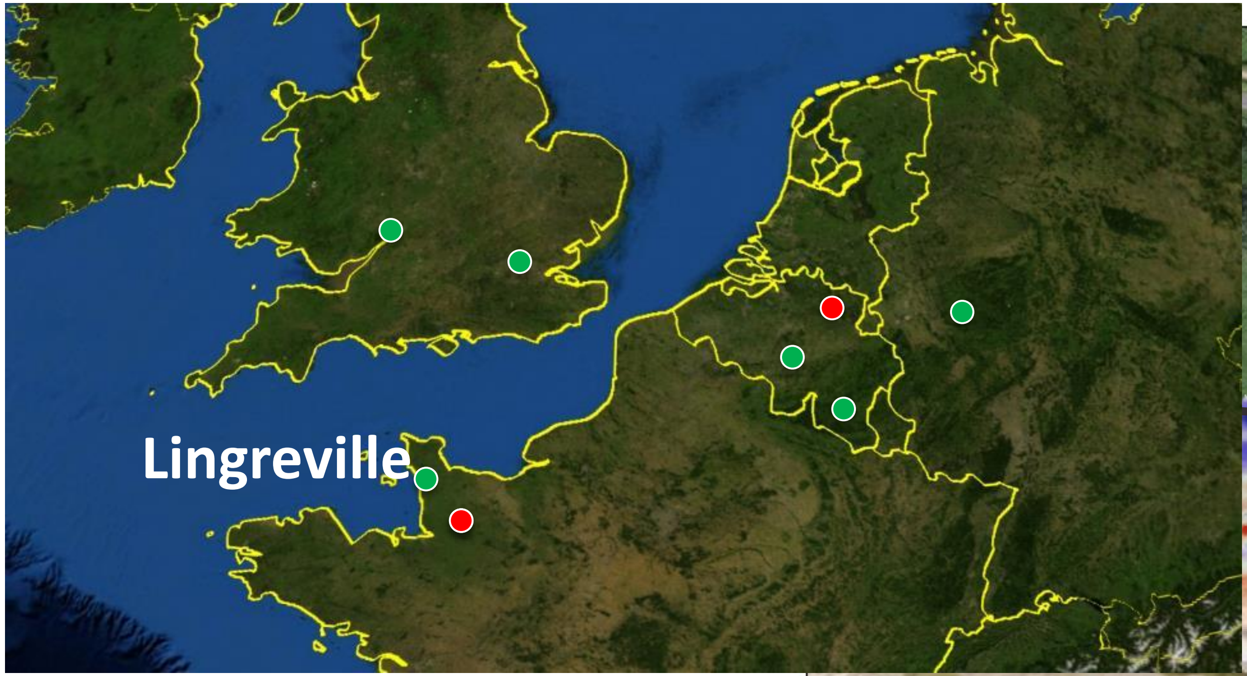
Mapping methods: Magnetics

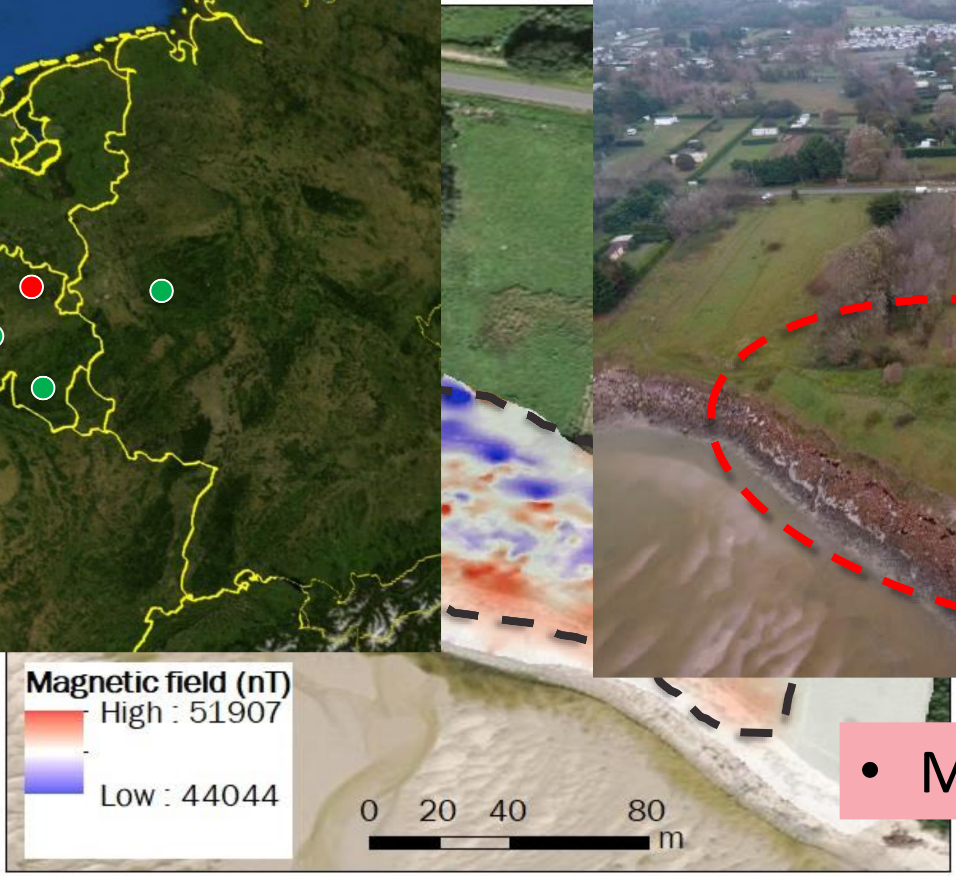


Parameters measured:
- Earth's magnetic field intensity
- Magnetic susceptibility

Sensitive to:
- Metallic items
- Metal content

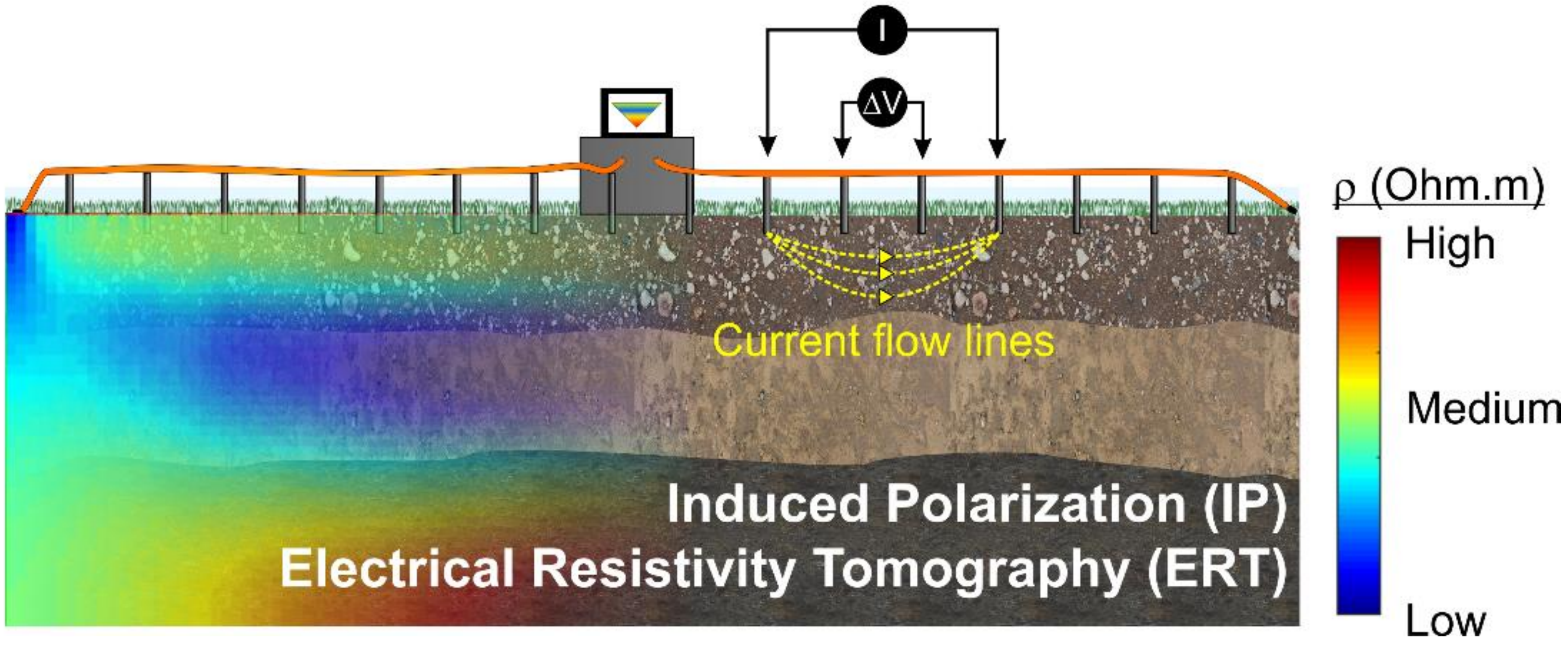
Mapping methods: Magnetics





- Municipal solid waste

Profiling methods:
Electrical Resistivity Tomography (ERT) / Induced Polarisation (IP)



Target properties

Parameters measured:
- Electrical resistivity (ERT)
- Chargeability (IP)

Sensitive to:
- Leachate/water content
- Pore fluid composition
- Metal content
- Size and shape of grains/pore space
- Connectivity of pores

Profiling methods: ERT/IP

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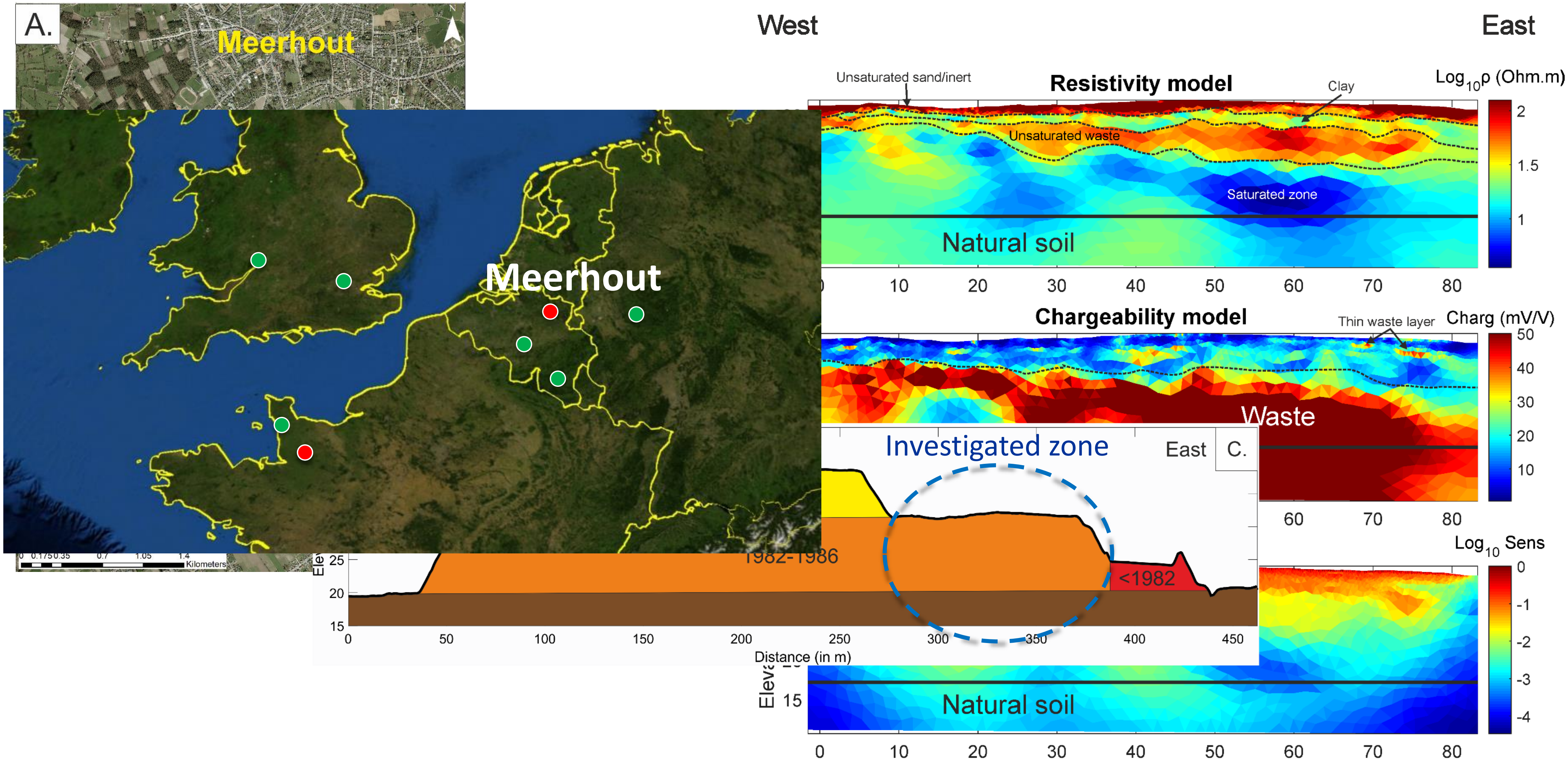
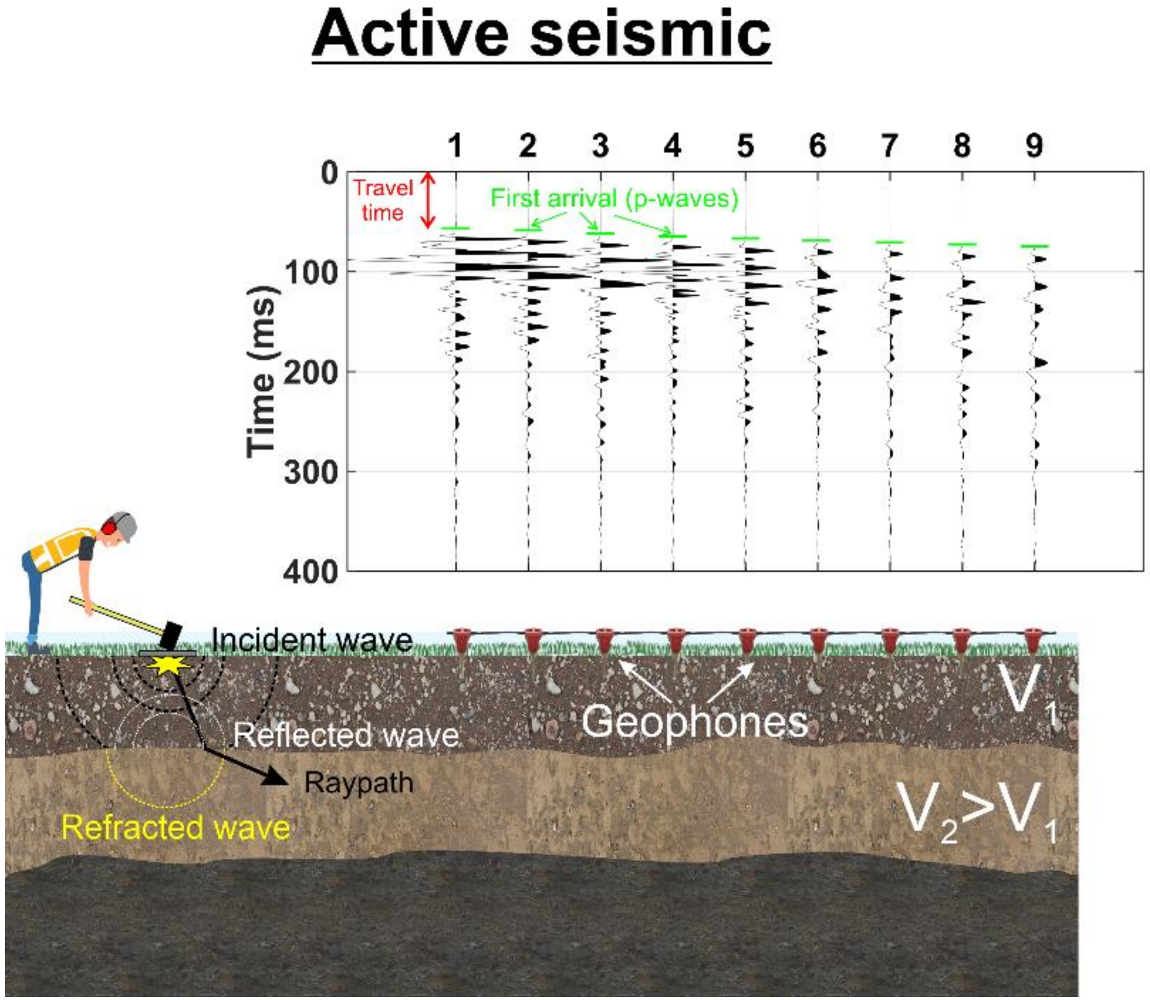


Profiling methods: Seismics



Target properties

Parameters measured:

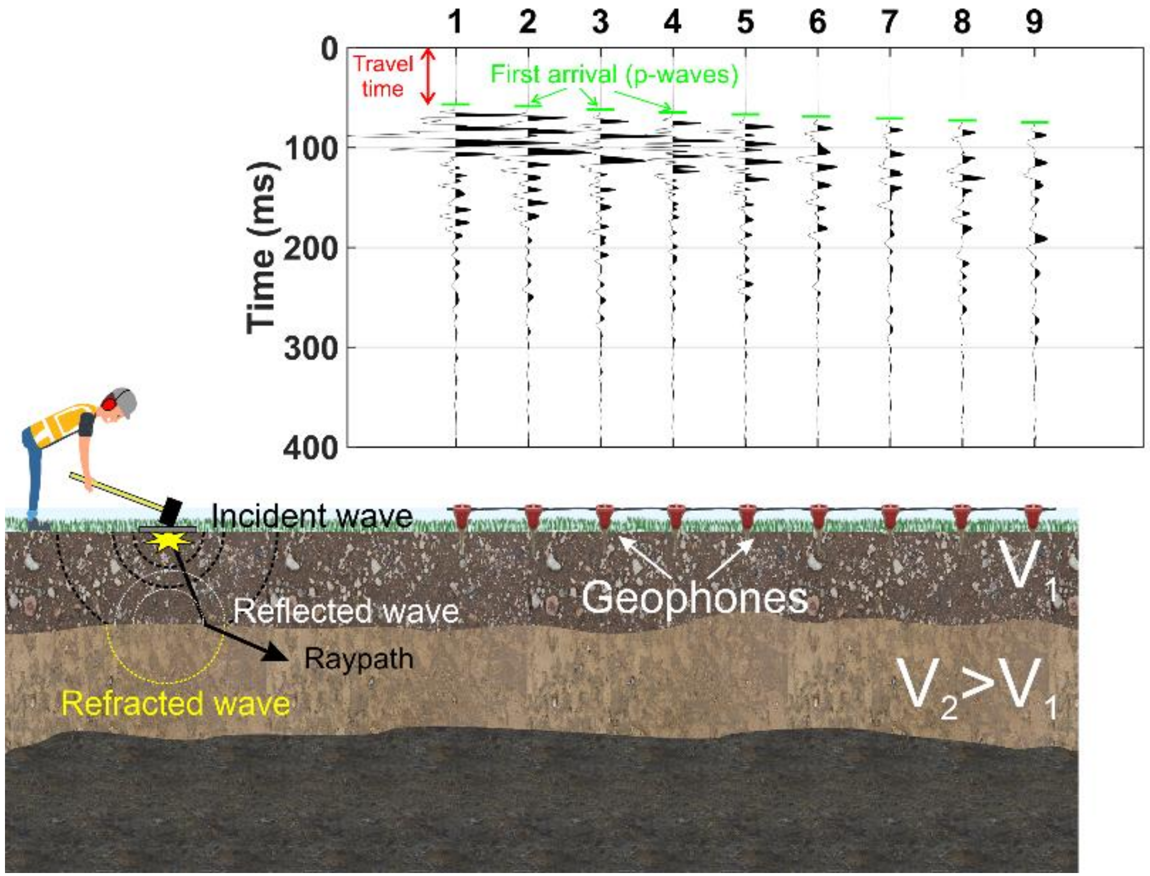
- propagation velocity of seismic waves

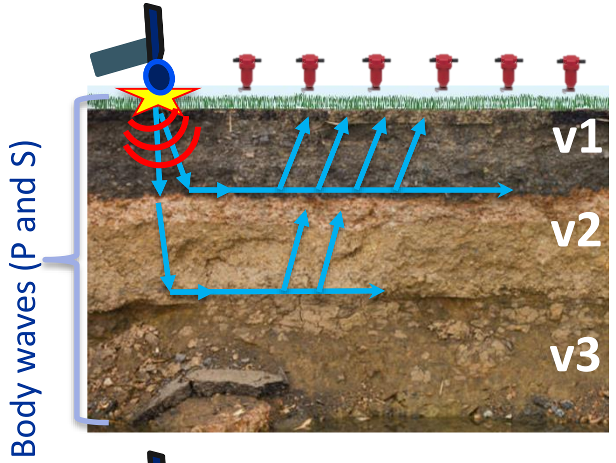
Sensitive to:

- ground stiffness, elasticity and density (mineral content, lithology, porosity pore fluid saturation and degree of compaction)

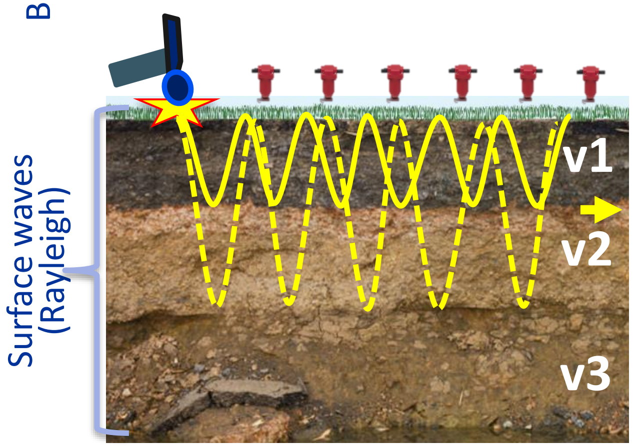
Profiling methods: Seismics

Active seismic



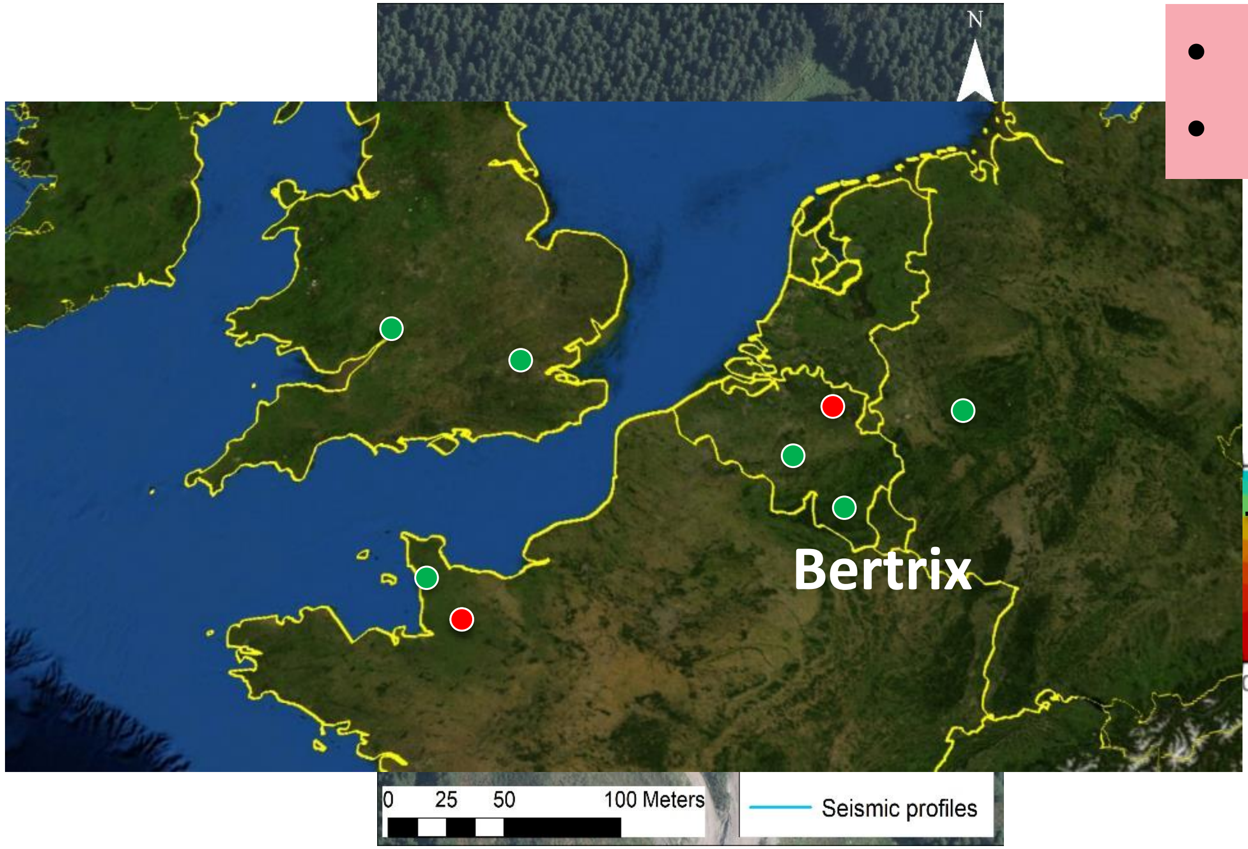


Refraction seismics (SRT)



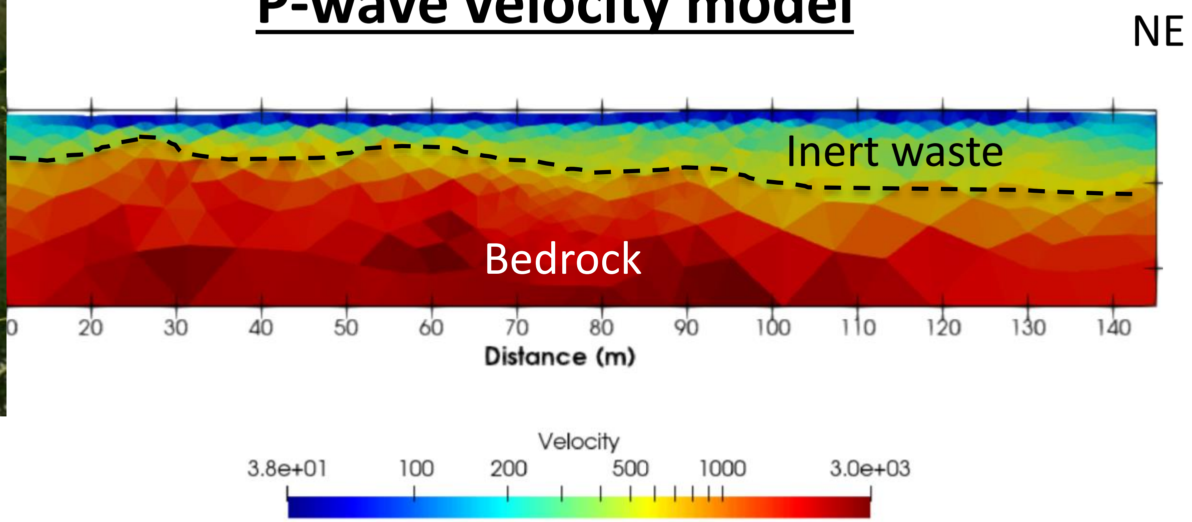
Multi-channel Analysis of Surface Waves (MASW)

Profiling methods: Seismics



- Municipal solid waste
- Inert waste

P-wave velocity model



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High resolution mapping : from resource to reserve, a case study from NWE

David Caterina[2], Jonathan Chambers[1], Ben Dashwood[1], Cornelia Inauen[1], Itzel Isunza Manrique[2], Frederic Nguyen[2], Arnaud Watlet[1]

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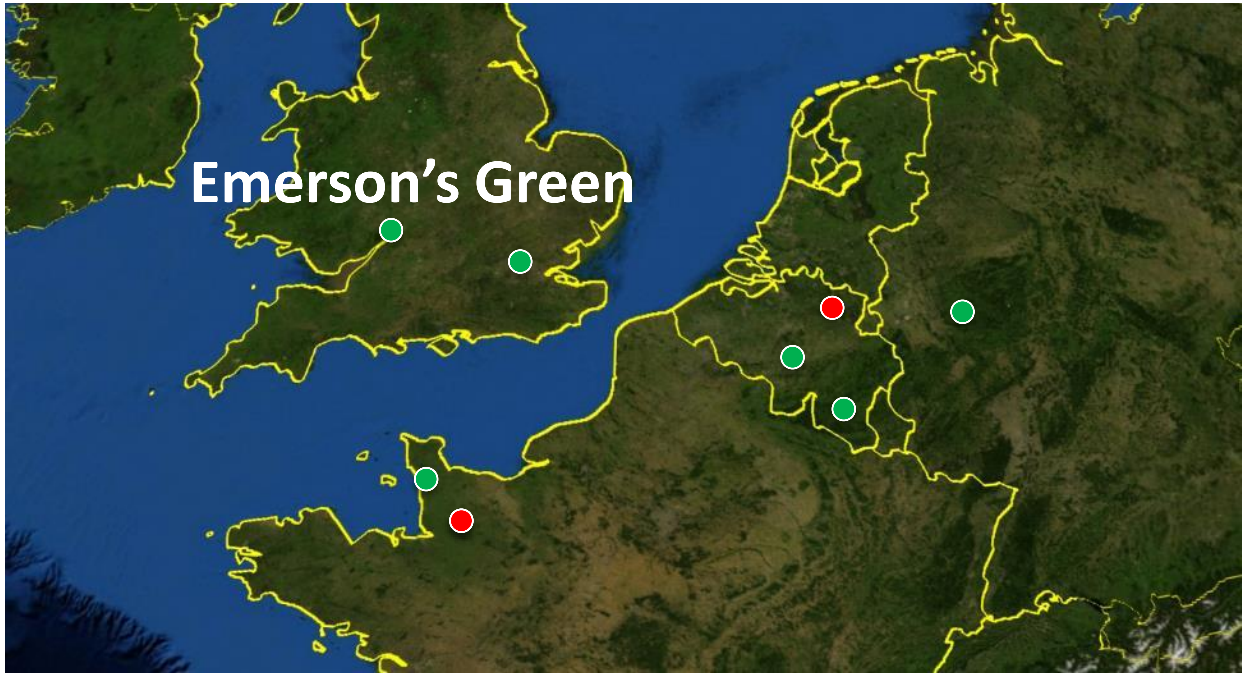
RAWFILL methodology applied to a real case study: Emerson's Green (UK)



Case study: Emerson’s Green (UK)

- Location: UK, near Bristol
- Excavated for new housing in 2019

Case study: Emersons Green

- Location: UK, near Bristol
- Excavated for new housing in 2019

→ ground truth data to calibrate geophysics

Archives & inventory report

Geophysical characterization

Calibration & validation

Resource model construction

Step 1) Information gathering

Desk study

- Historical reports
- Aerial photography archives
- Maps

Site visits

- Interview with land owner, local authorities etc.
- Walk over survey: changes in vegetation, topography etc.

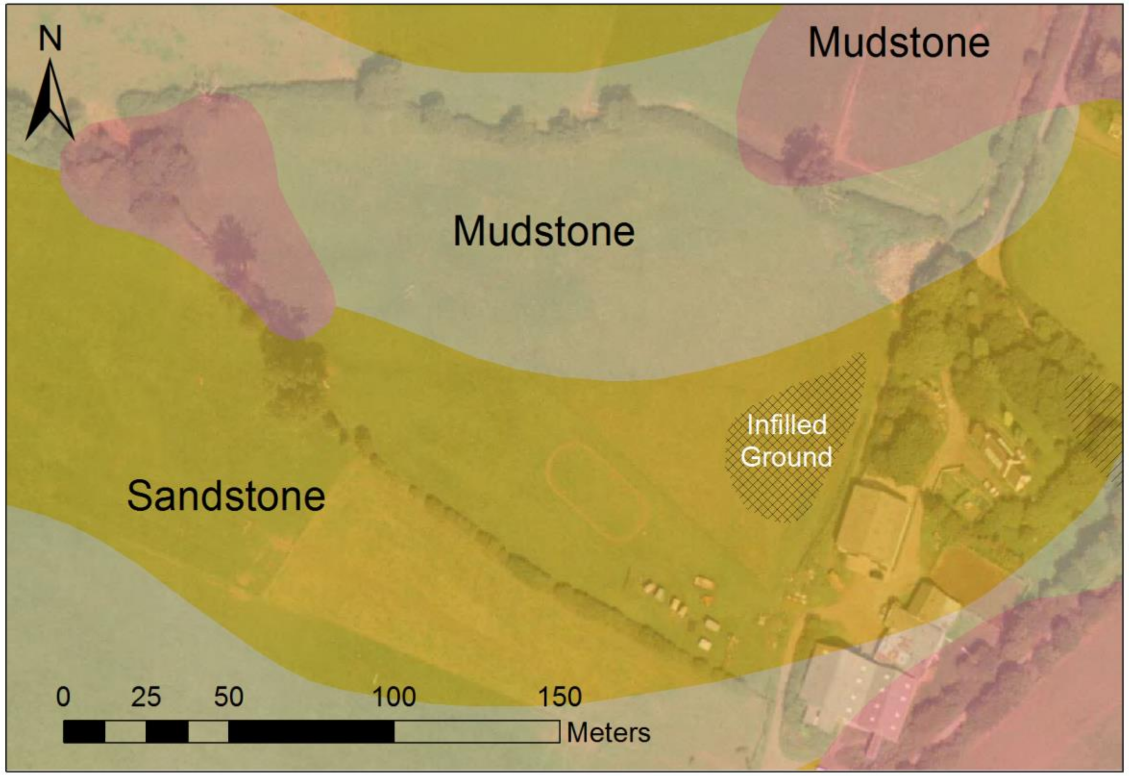
Landfill size: 23,000m^2

Landfill operation (1984 – 1991)

- Inert & industrial/commercial waste
- Dilute & disperse basis

Geology:

- North: Mudstone
- South: Sandstone
- East: historic quarry



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Step 1) Information gathering: Ground truth data

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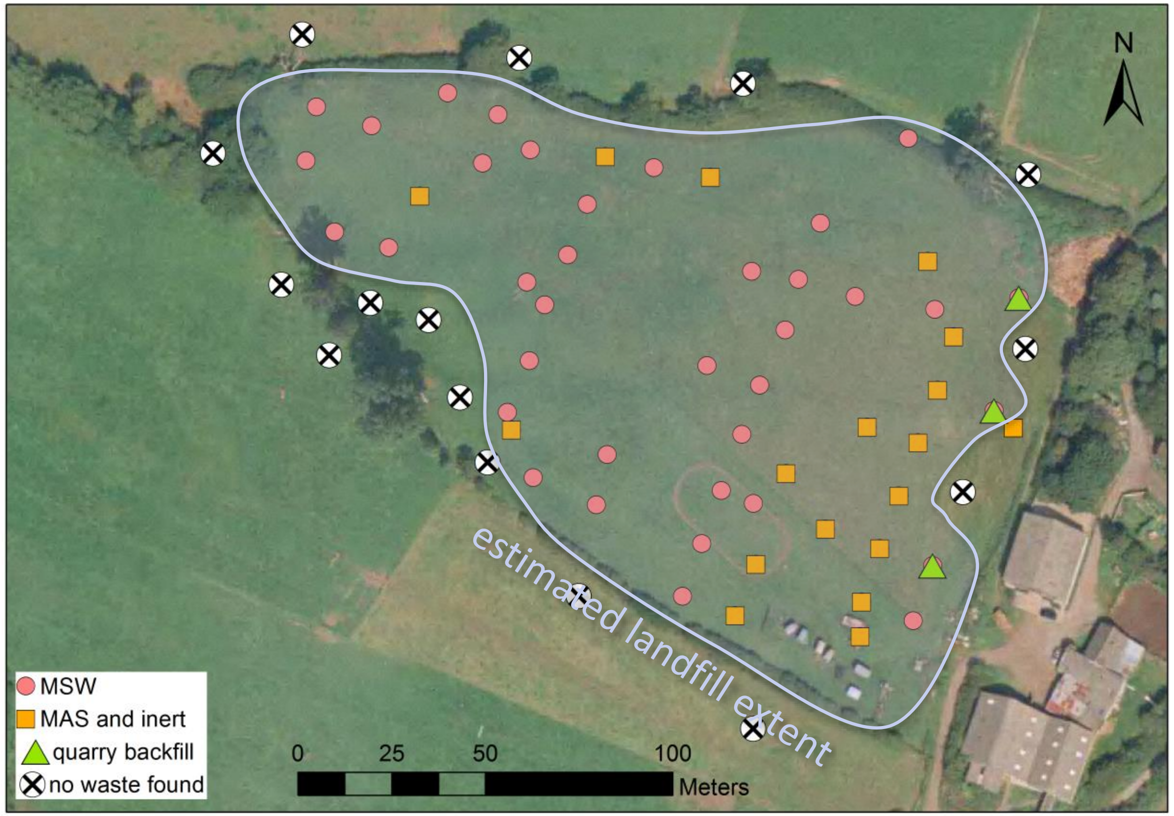
Ground truth data available across site:

- 59 Trial pits
- 12 Boreholes

	Name	Thickness
Cap	Clay cap	up to 2.6m average: 1.1m
Waste material	Municipal solid waste (MSW)	min: 0.3m max: > 4.1m
Waste material	Municipal solid waste (MSW) + inert content	min: 0.6m max: > 3.4m
Waste material	Quarry backfill	0.7m to 2m
Host	Clay	-
Host	Mudstone	-
Host	Sandstone	-



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Step 1: Identification of knowledge gaps

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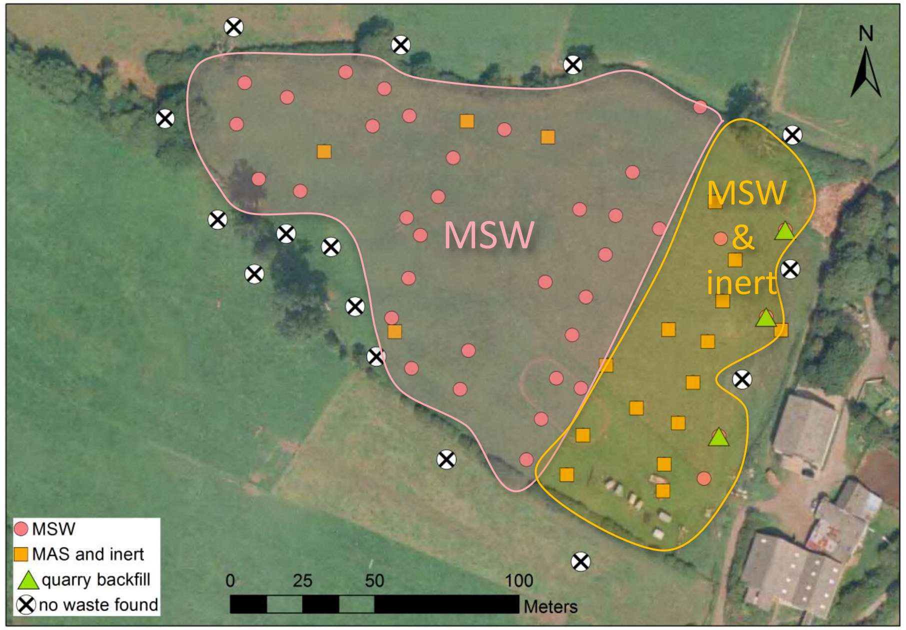
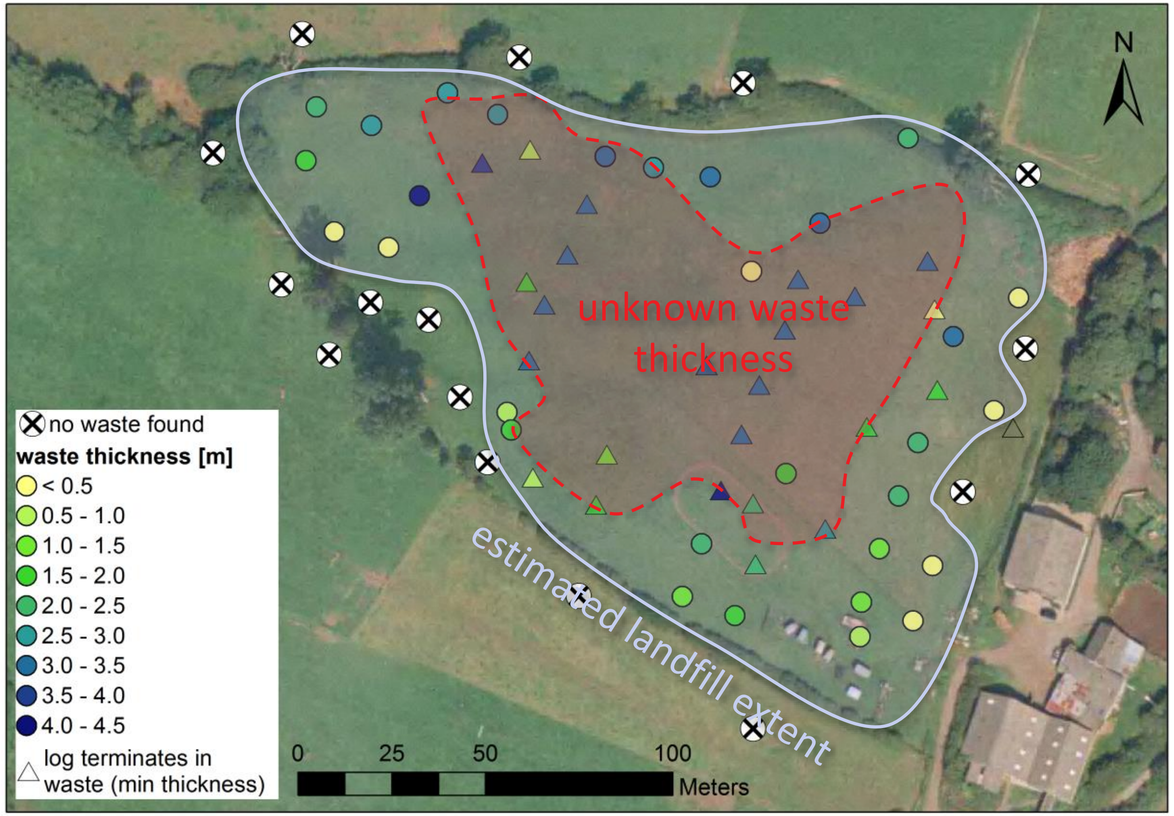
1. Waste thickness unknown towards centre of landfill
   → difficult to estimate waste volume

2. Structure of landfill unclear.
   Is there a change in waste composition towards East?





→ Use geophysics to fill these knowledge gaps

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Geophysical characterization

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Step 2) Geophysical characterisation: Planning

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Site conditions

Top soil stripped off (about 30cm)

In some places waste visible

High groundwater table

→ Site well accessible for all geophysical measurements

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Geophysical characterization

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Resource model construction

Step 2) Geophysical characterisation: Selecting methods

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MAPPING METHODS

Lateral extent

Metallic items

Metal content

Lateral extent

Leachate content

Metal content

Goal:

- Improve knowledge of lateral landfill geometry
- Delineate zones of different waste composition

PROFILING METHODS

Goal:

- Delineate landfill thickness
- Delineate layers of different waste composition and leachate content

Waste types

Leachate content

Thickness of landfill

Layers of different stiffness

Thickness of landfill

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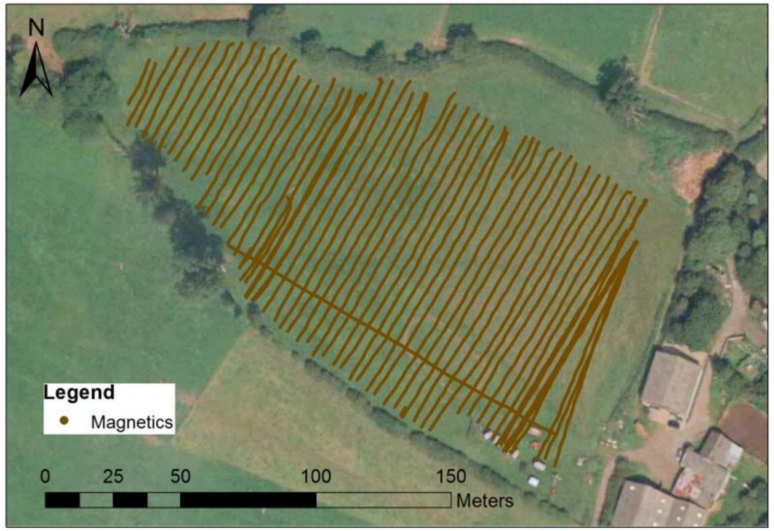
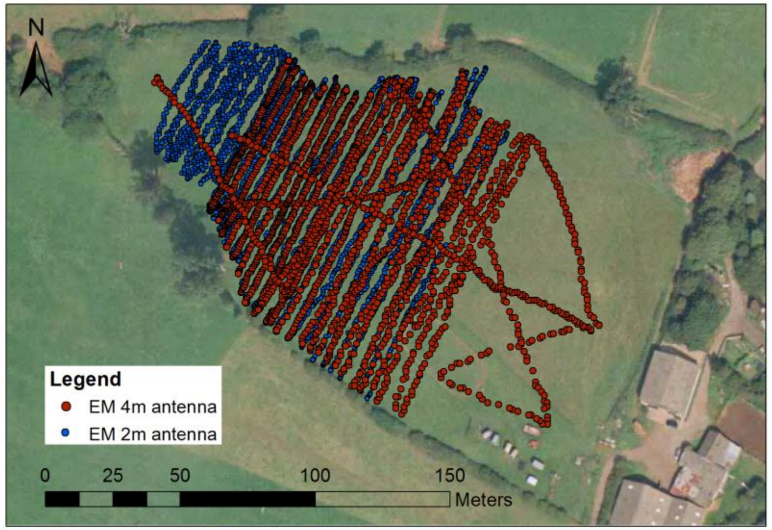
Geophysical characterization

Step 2) Geophysical characterisation: Measurement extent

Magnetics



EM: depths: 1.5m, 2.5m, 3m, 6m



ERT/IP and MASW

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Geophysical characterization

Calibration & validation

Resource model construction

Step 2) Geophysical characterisation: Results Magnetics

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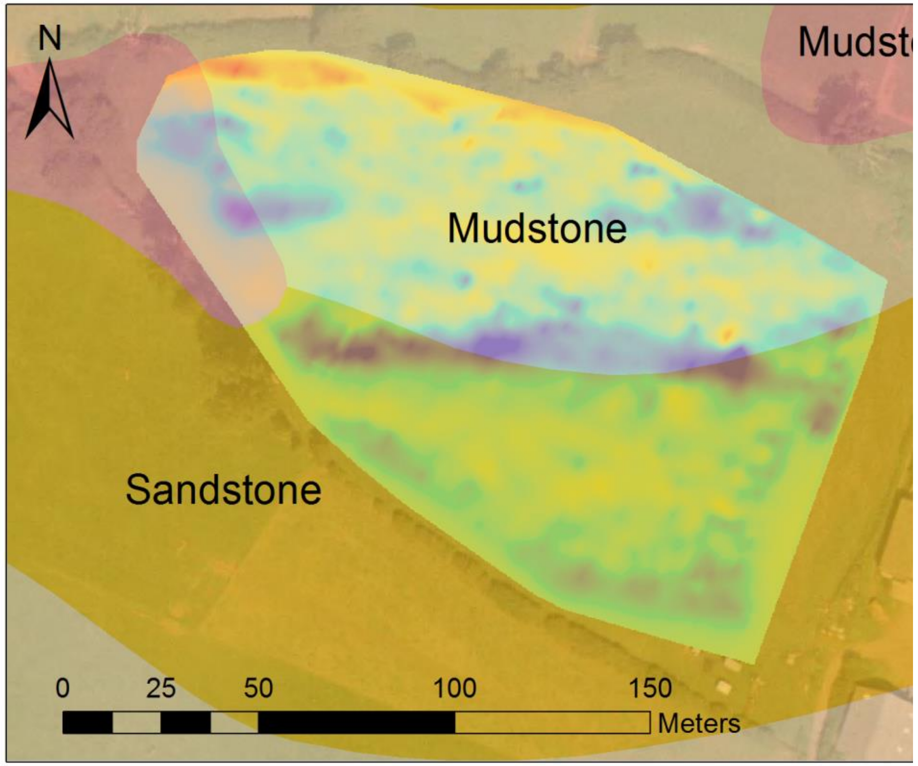
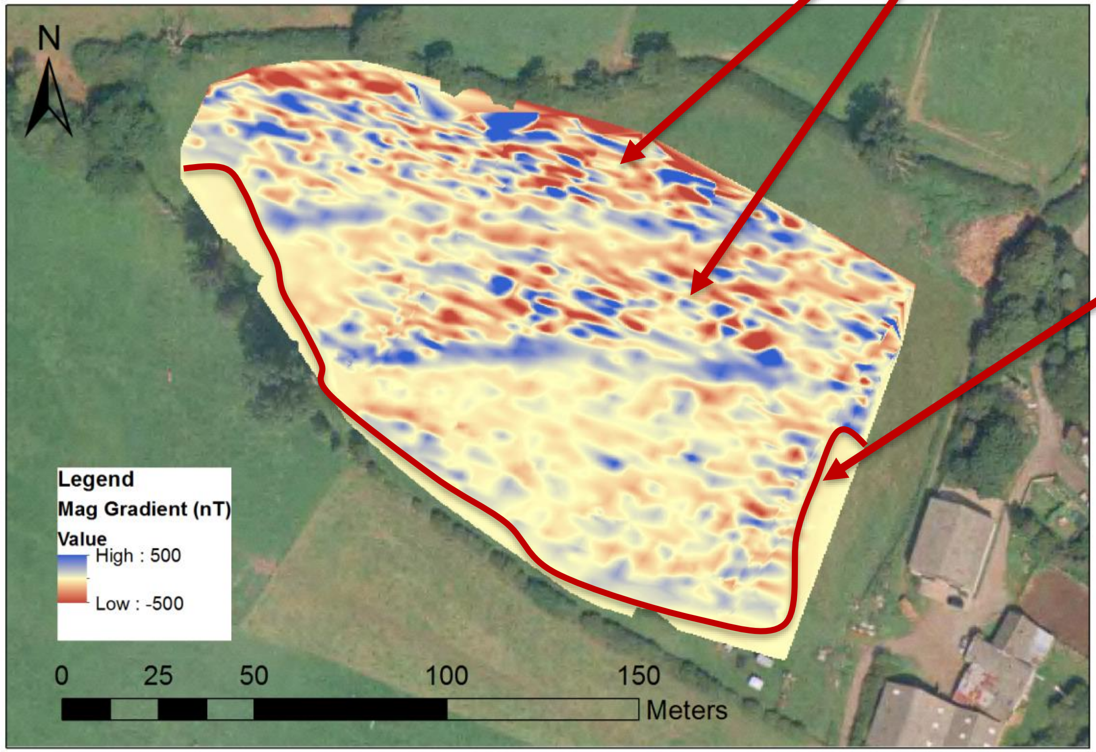
Total magnetic field (nT)



Vertical magnetic Gradient (nT)



Increased metal content?

Landfill boundary?

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Geophysical characterization

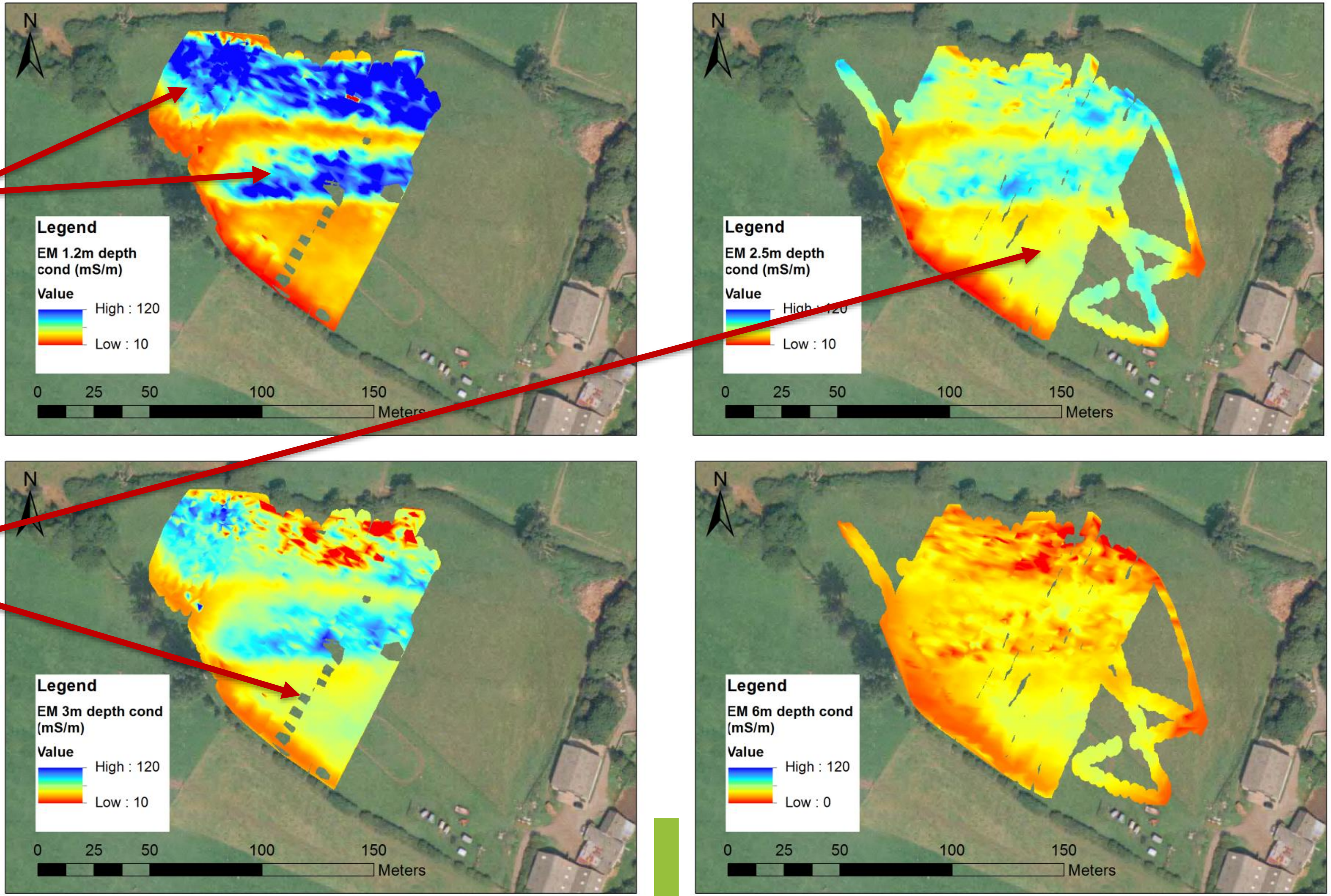
Calibration & validation

Resource model construction

Step 2) Geophysical characterisation: Results EM

Cell type structure?

Additional cell with less metal content or thicker cover layer?



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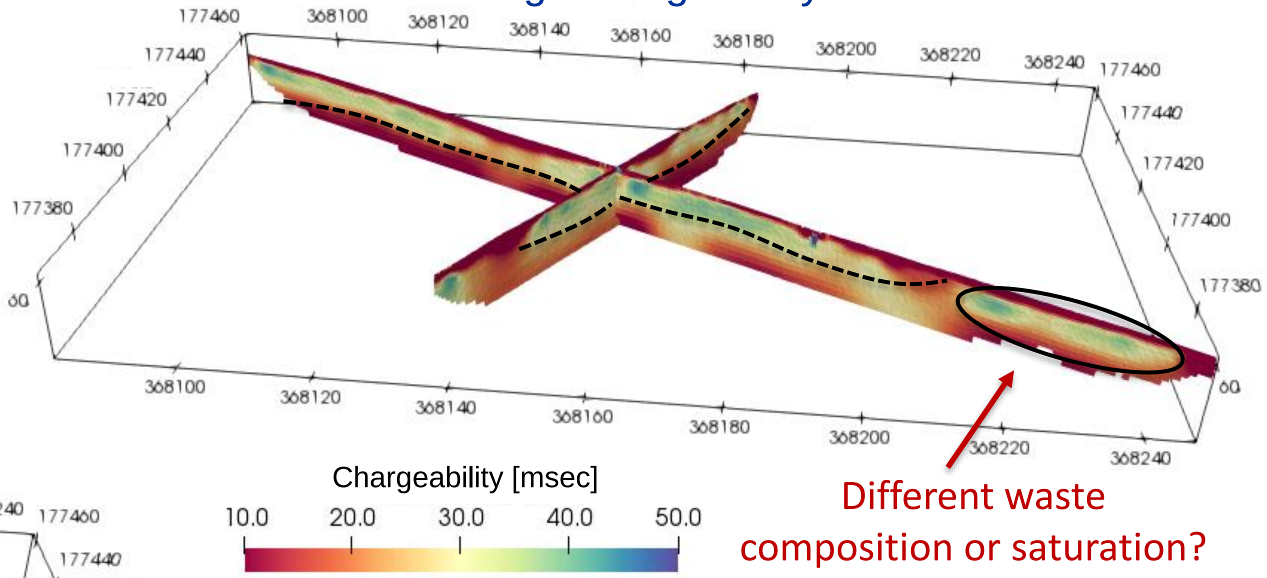
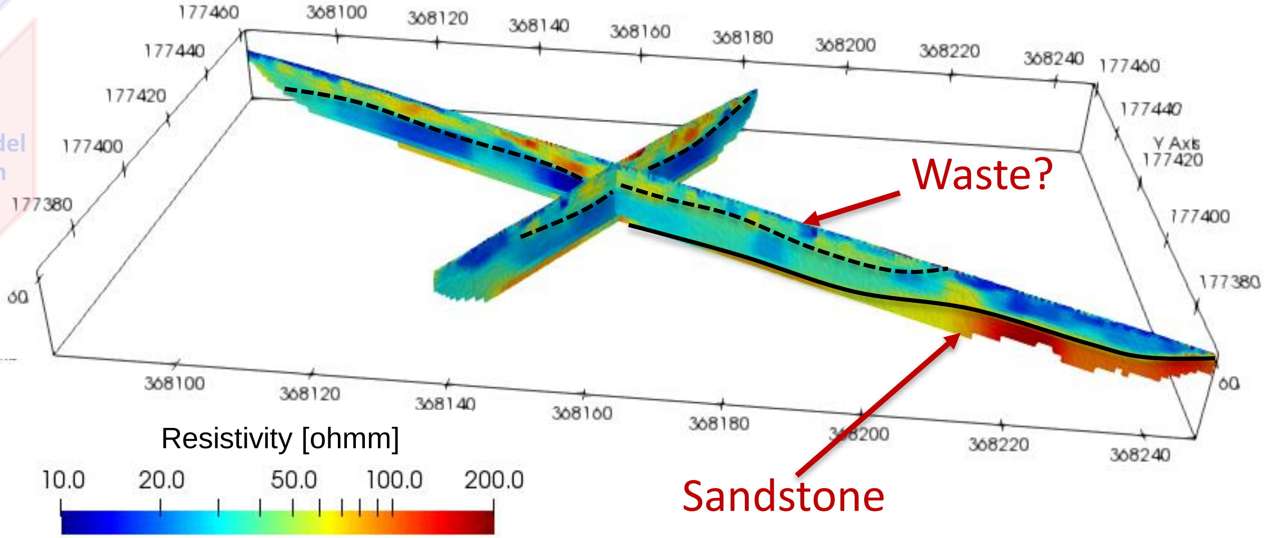
Resource model construction

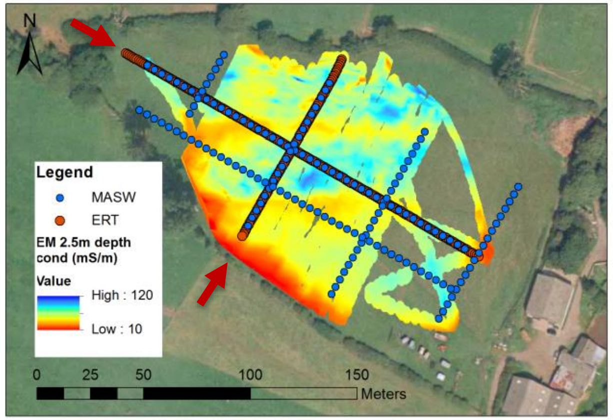
Step 2) Geophysical characterisation: Results ERT and IP

IP: high chargeability indicates waste



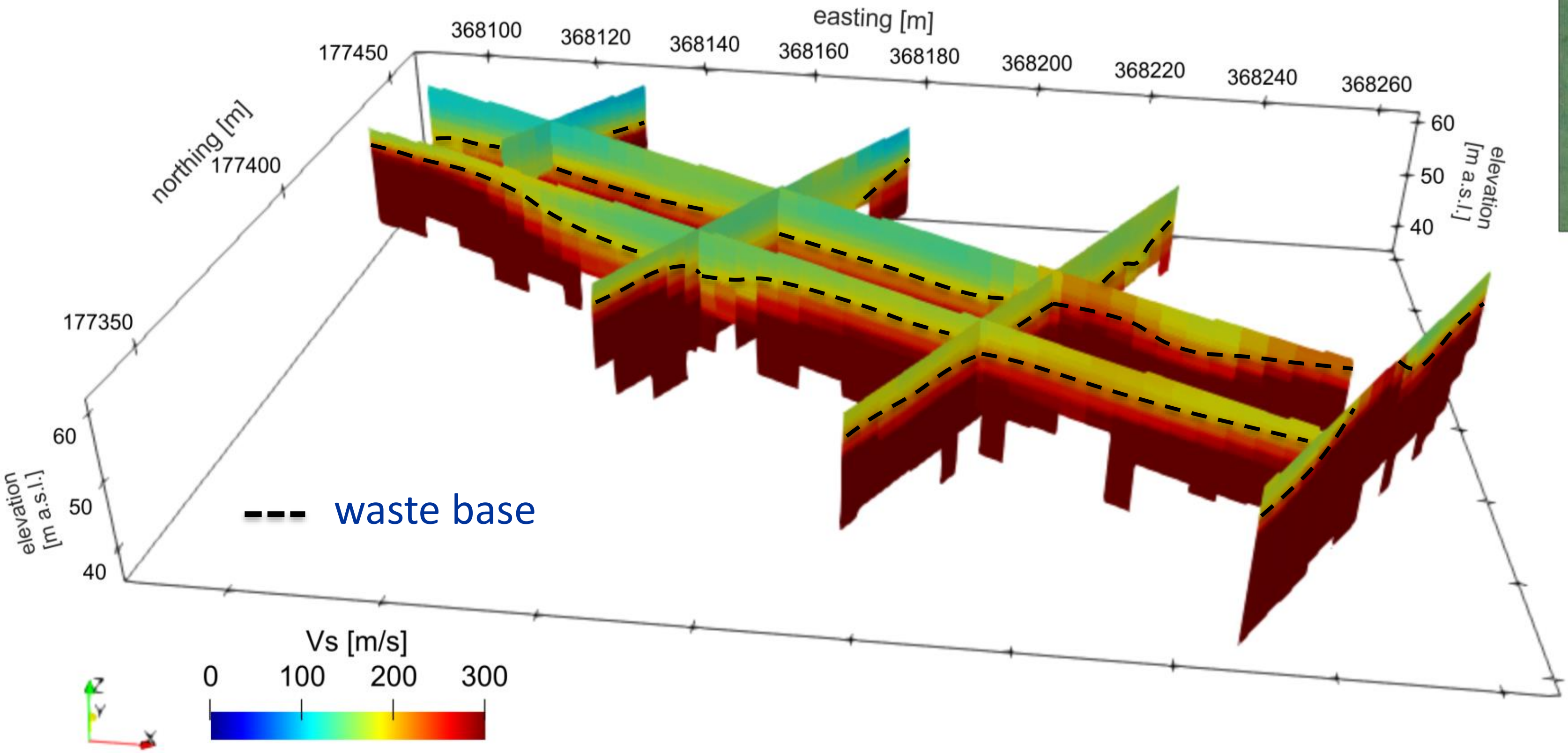
ERT: Layered structure

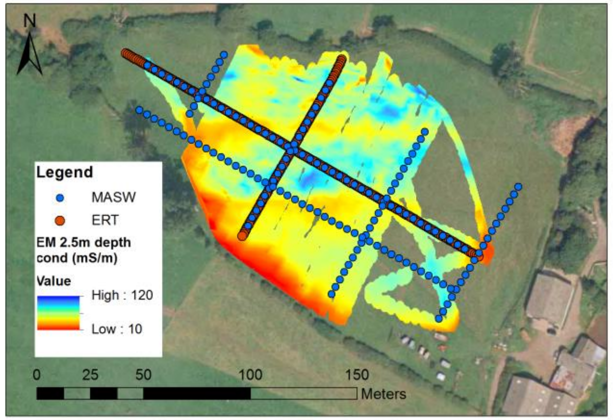




Step 2) Geophysical characterisation: Results MASW

Low velocities correspond to waste layer





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Geophysical characterization

Calibration & validation

Step 3) Calibration and Validation

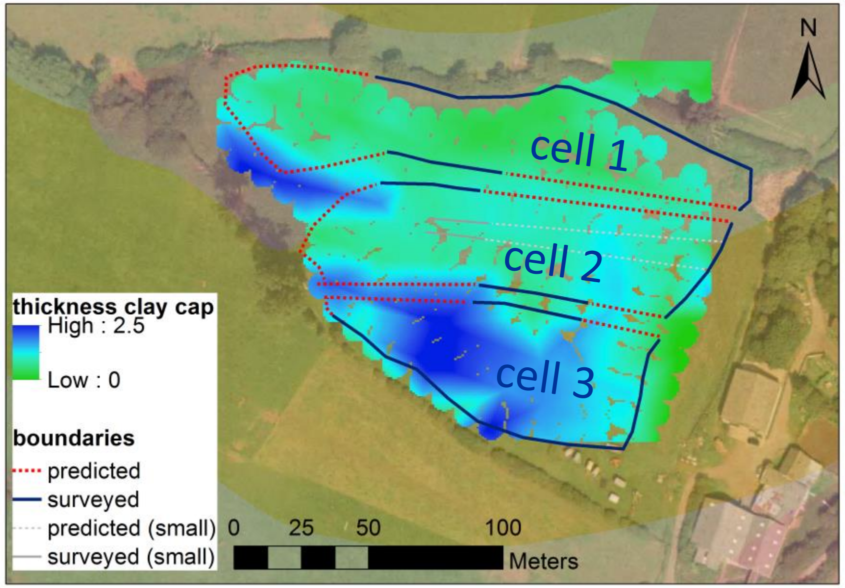
Additional ground truth data through excavations

- The landfill was separated into three cells. These cells were excavated into the natural clayey ground and filled with waste.
- A thicker clay cap and a thinner waste layer was found in cell 3.
- A step in the landfill base between cells 2 and 3 might be associated with the underlying sandstone.

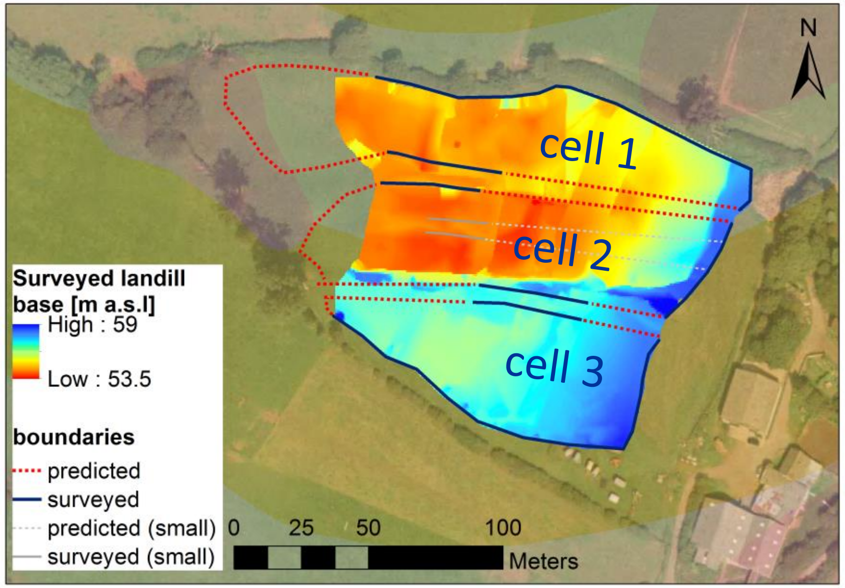
- The waste composition was a mix of plastic, metal, wood, paper, fabric, inert with no strong compositional changes across the site.

clay stank dividing the waste cells

clay cap thickness



base of waste layer



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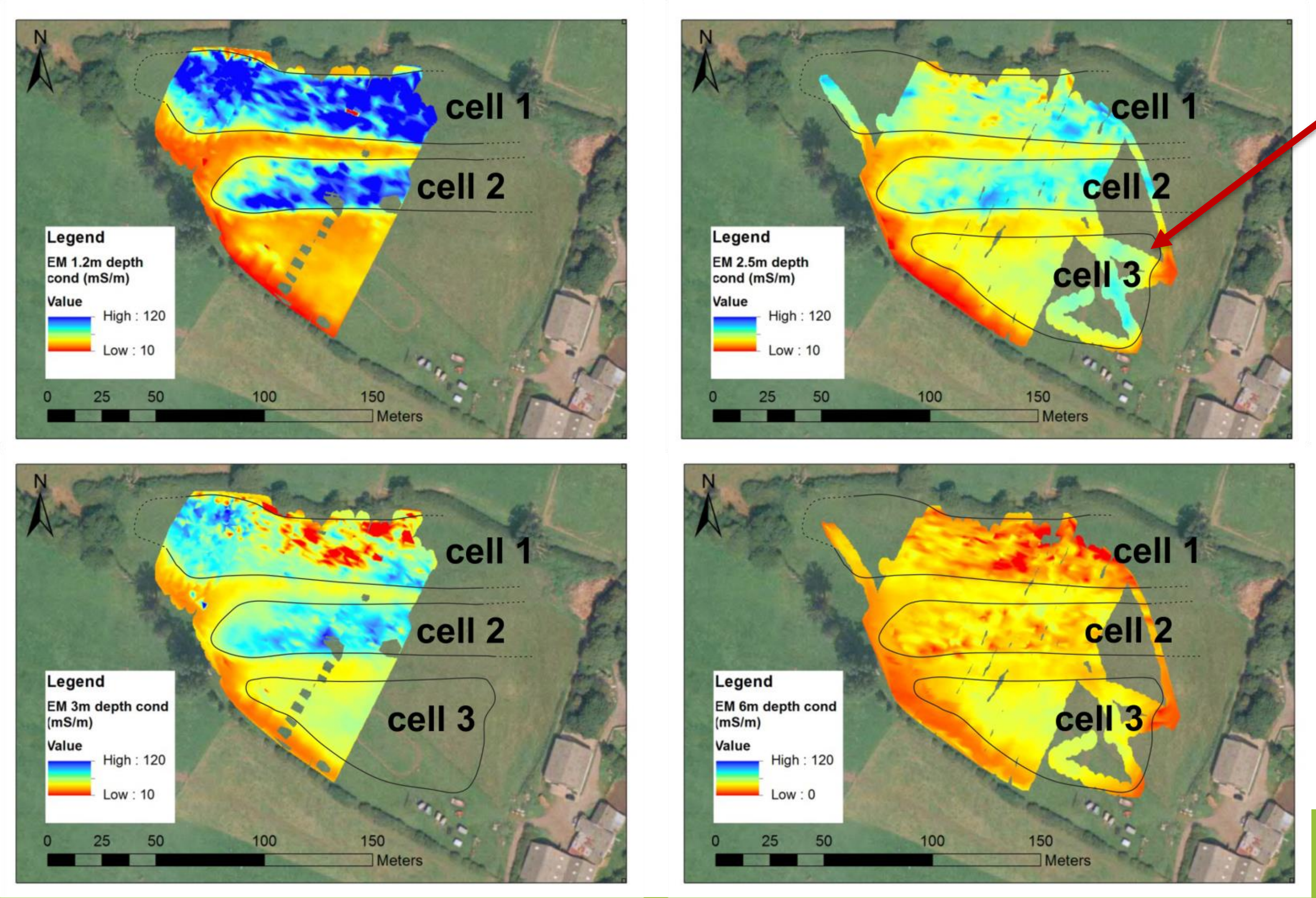
Geophysical characterization

Calibration & validation

Resource model construction

Step 3) Calibration and Validation

EM: good delineation of waste cell extent and cover layer thickness



Lower conductivities of cell 3 are probably associated with a thicker cover layer and a thinner waste layer

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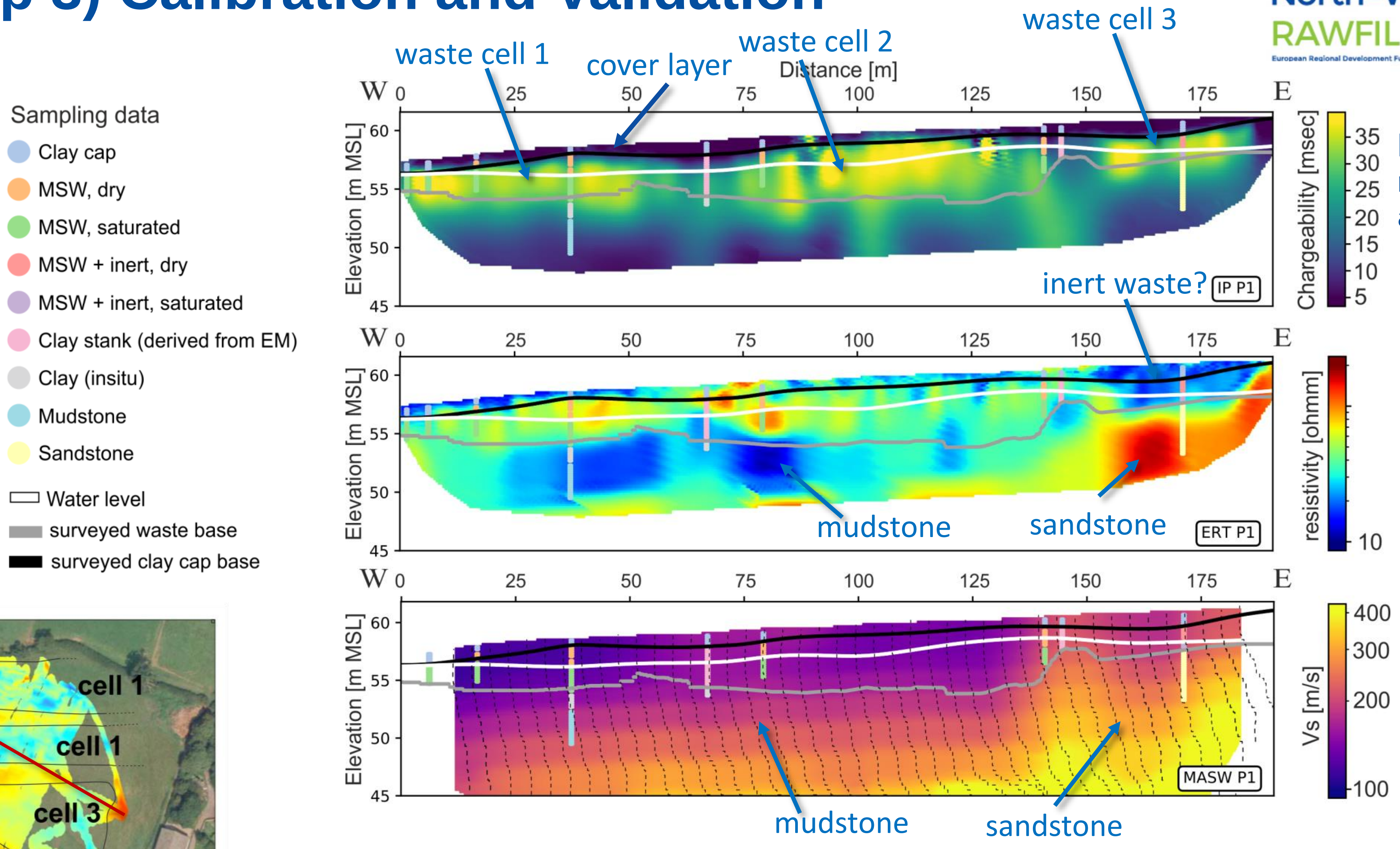
Geophysical characterization

Calibration & validation

Resource model construction

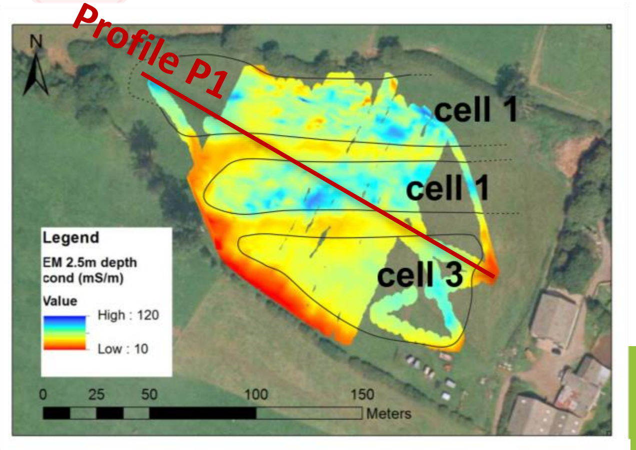
Step 3) Calibration and Validation



IP
resolves clay cap and waste cells

ERT
resolves sandstone interface

MASW
resolves sandstone interface, mudstone interface less clear



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Step 4) Building Resource Distribution Model

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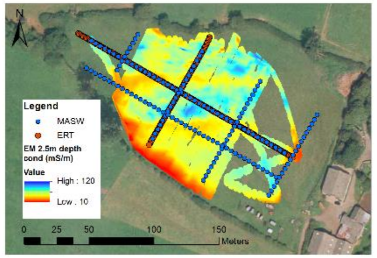
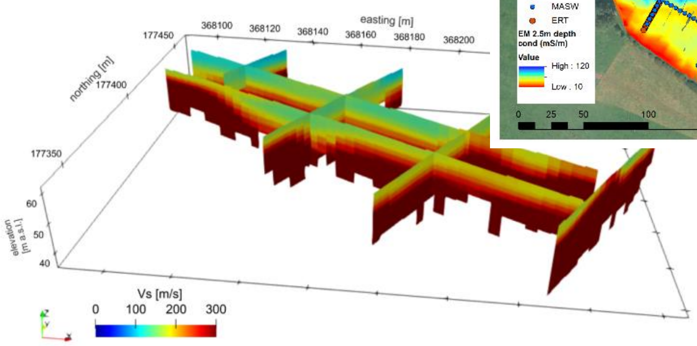
Geophysical characterization

Calibration & validation

Resource model construction

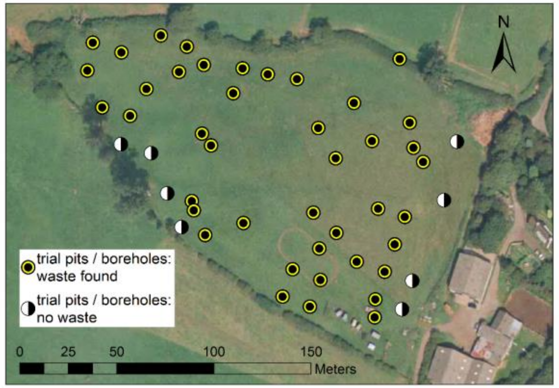
Geophysical data





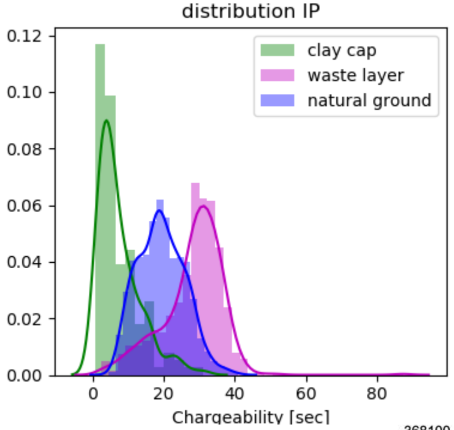
extract geophysical data in vicinity of samples

Trial pits & boreholes



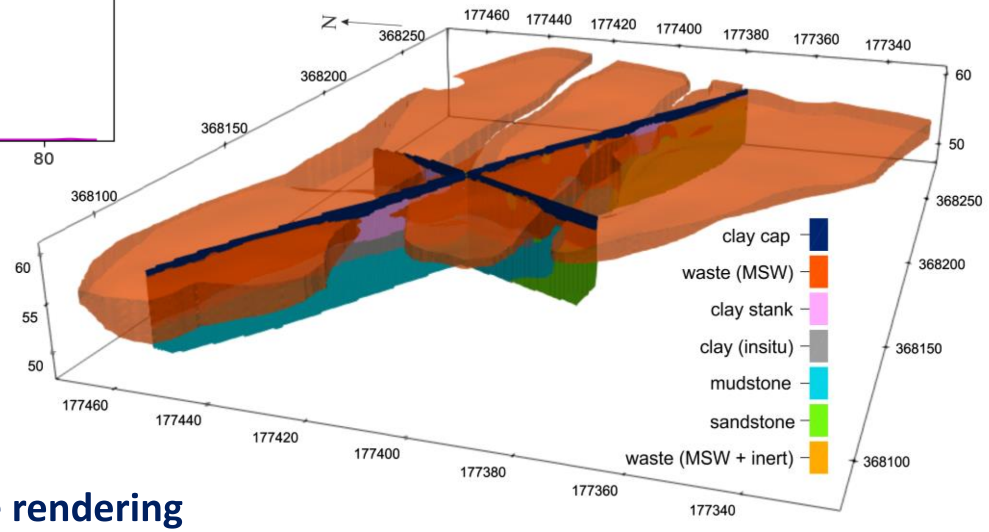
discretize sampling logs into relevant categories (e.g. clay cap, saturated waste…)

Correlation analysis



choice of relevant geophysical parameters

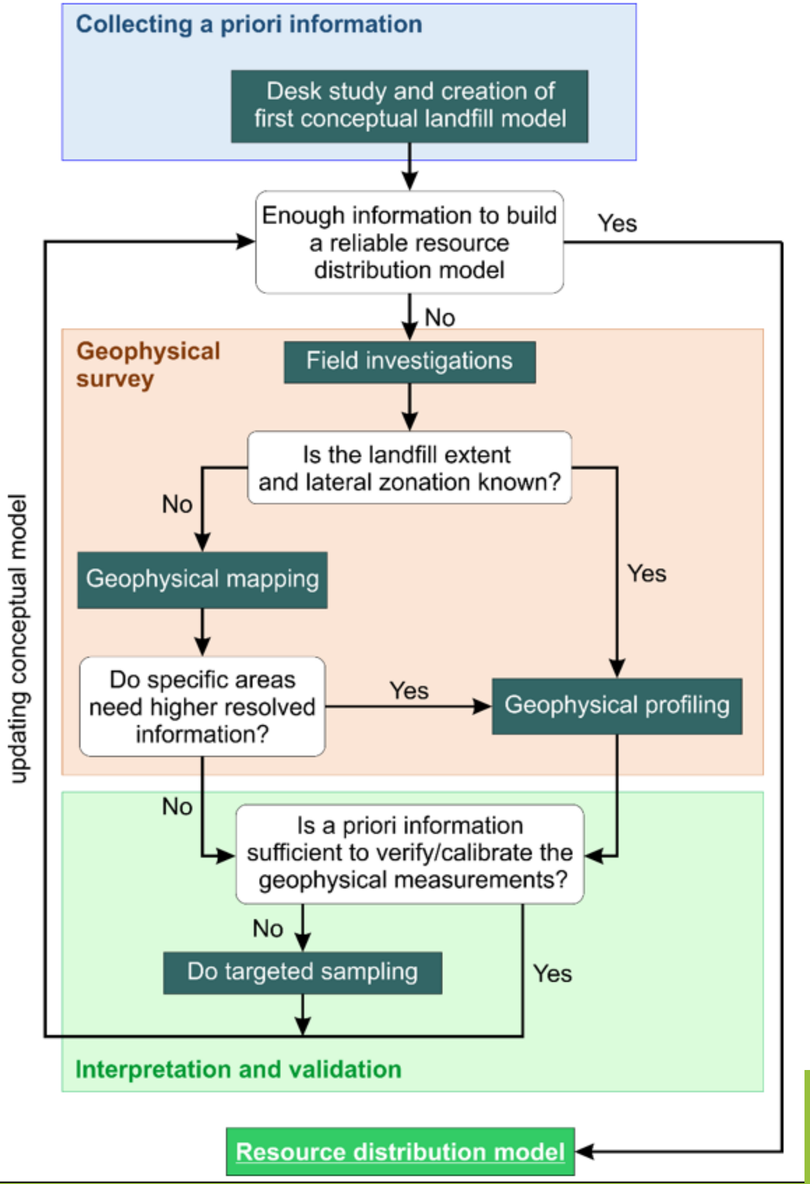
Model building through supervised machine learning (classification)



Volume rendering

	Cell 01 (North)	Cell 02 (centre)	Cell 03 (South)	Total
Volume of waste material (m3)	15’258	10’654	9’547	35’450

Take-home message



Using geophysics:

- is cost effective
- allows targeted sampling
- delivers relatively high resolution data (when mapping and profiling techniques are combined)

Our proposed workflow:

- integrates *a priori* information, geophysics and targeted sampling to build a resource distribution model specific to each landfill
- Provides “ready-to-use” information for decision makers (DST 2)

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Thank you!

Raw materials recovered from landfills

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