Investigating Groundwater Contaminant Plumes Using Airborne Electromagnetic Data

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1. Introduction

Subsurface pollution plumes, originating from a variety of sources, pose a significant direct risk to water quality. Adequately capturing a groundwater contaminant plume with invasive monitoring installations can be prohibitively expensive.

This research explores the incorporation of airborne electromagnetic (AEM) data into current assessment tools for the detection and monitoring of subsurface pollution plumes. The airborne data was collected within the scope of the original Tellus and subsequent EU-funded Tellus Border projects.

2. Airborne Electromagnetic (AEM) Data

- AEM measurements provide information on the electrical conductivity of the subsurface.
- Contaminants can modify the electrical conductivity of pore fluid within subsurface materials (bedrock/soils).
- This research relates elevated conductivity levels recorded by the airborne survey to areas possibly affected by groundwater pollution.

3. Field Sites

- Assessment of AEM data allowed the identification of sites containing possible contaminant plumes.
- Five landfill sites were selected - four in Northern Ireland and one in the Republic of Ireland (Fig 1).
- Sites were chosen based on factors including underlying geology, the availability of groundwater monitoring data and recommendations from the relevant monitoring agencies (NIEA/EPA).
- An indicative case study is presented.

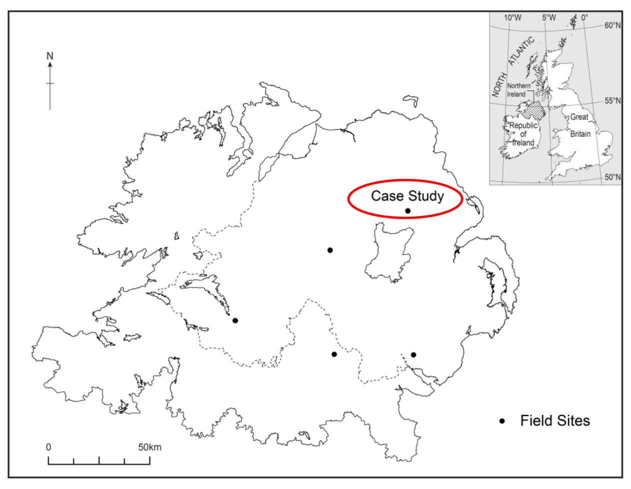

Fig 1: Locations of landfill sites

4. Case Study: Introduction

Location and History

- The landfill, an unengineered "dilute and attenuate" facility, is situated 7km from Ballymena (Co. Antrim).
- Waste was accepted between 1963-2007; predominantly from domestic and commercial sources.
- The site is capped with imported low permeability clays and soils, laid and compacted in layers.
- It is believed that additional tipping was undertaken (1986-1987) to the immediate north of the site.

Geology

- *Drift:* Glacial till beneath peat;
- *Solid:* Basalt (Lower Basalt Formation).

Hydrogeology

- In-situ clay (low permeability) at the base of the site reduces potential for vertical flow of leachate into the underlying aquifer.
- Borehole data suggest groundwater flows in a generally northerly direction.
- Groundwater flow in other directions (such as towards the River Main) however cannot be discounted.

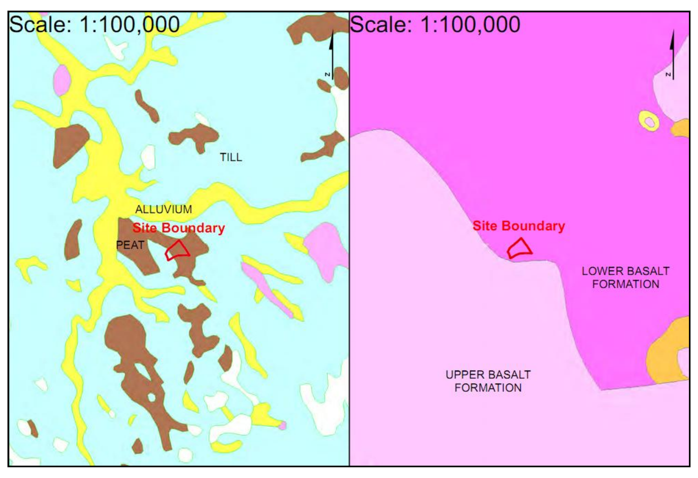

Fig 2: Soil (left) and geology map (right) for the study area (from Land and Property Services, Crown Copyright).

5. Case Study: Groundwater Monitoring Data

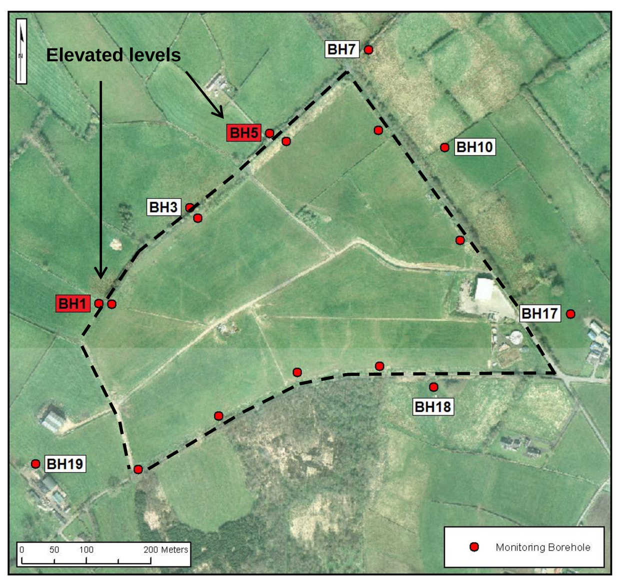

Fig 3: Borehole locations at case study site

- Groundwater monitoring data (Fig 3 – points labelled "BH") were analysed to identify boreholes with elevated levels of key leachate indicators.
- Consistently elevated levels of ammoniacal nitrogen, iron and electrical conductivity in BH1 and BH5 during 2005-11 (labelled red in Fig 3) and are possibly indicative of leachate migration.
- The location of these boreholes corresponds with the expected groundwater flow direction.
- BH18 recorded elevated levels of ammoniacal nitrogen and electrical conductivity but only for 2007.

6. Case Study: AEM Data (Part I)

- Fig 4 and Fig 5 show both point (along NNW-SSE flightlines) and interpolated maps of low (3.005kHz) and high (11.962kHz) frequency airborne conductivity data, respectively. The frequency of electromagnetic (EM) energy is inversely related to the depth of investigation.
- Point AEM data in Fig 4 and Fig 5 are presented as conductivity profiles in Fig 6.
- A common bin colour classification (Fig 7) is used throughout.

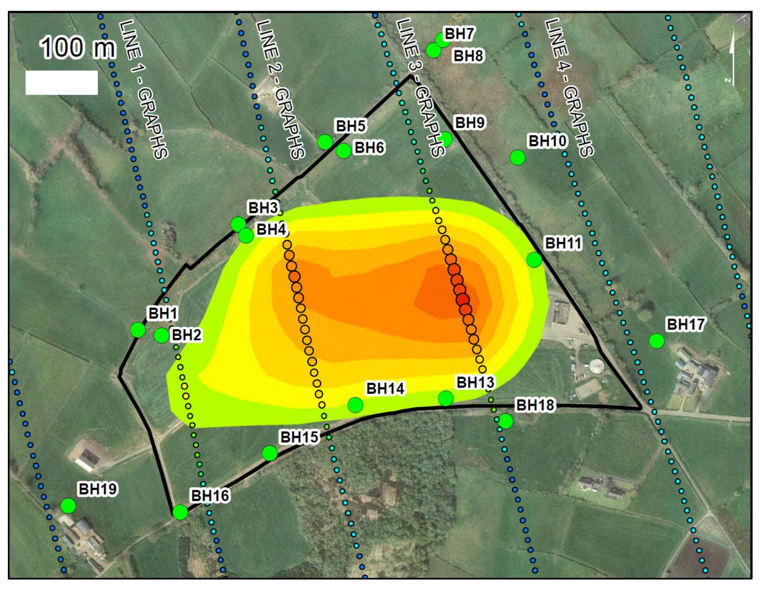

Fig 4: AEM low frequency conductivity (3.005kHz) - Deeper

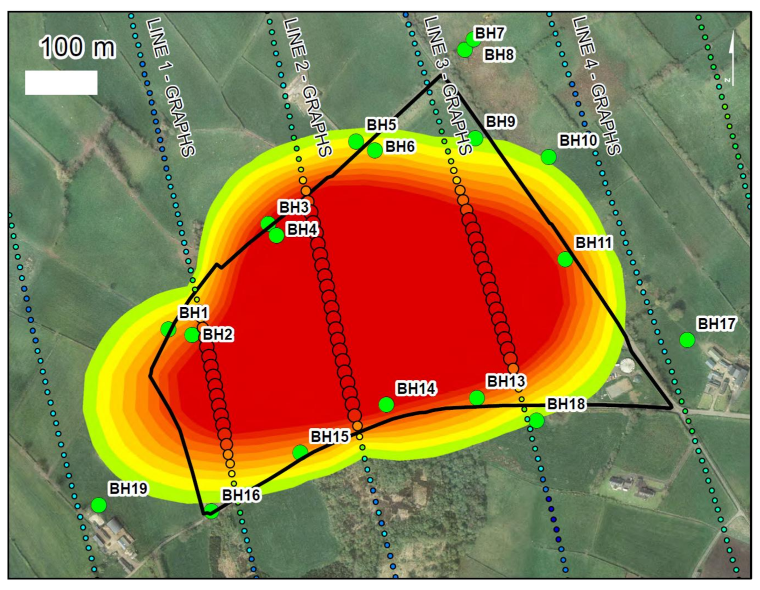

Fig 5: AEM high frequency conductivity (11.962kHz) - Shallower

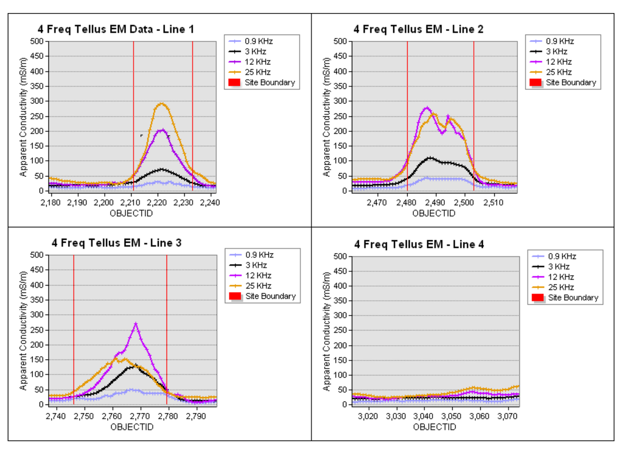

Fig 6: Conductivity transects along AEM flightlines

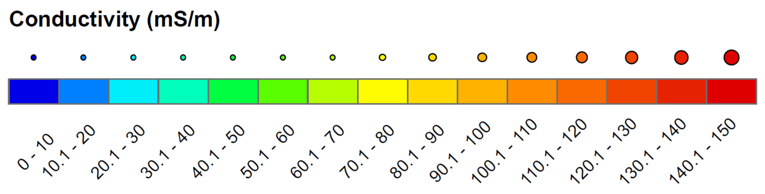

Fig 7: Common bin colour classification for Fig 4-5, 8-10, 12

6. Case Study: AEM Data (Part II)

- Higher values were recorded at the higher frequency (Fig 5) due the high conductivity of near-surface material, including landfill waste and clay capping.
- Near-surface material had a greater impact on the higher frequency measurements.
- Fig 4 and 5 show elevated conductivity levels outside the landfill boundary, possibly indicating groundwater contamination.
- The elevated values however may be an artefact related to the resolution of the airborne data.
- Ground-based electromagnetic surveying was therefore performed to analyse the site at a greater resolution.

7. Case Study: Ground-based Geophysics

Field EM Investigations

- Field EM conductivity data was collected with an EM 34-3 system, using both horizontal and vertical dipoles at a coil separation of 20m.
- Depths of investigation were up to 30m for the vertical dipole and 15m for the horizontal dipole.
- Measurements were taken along transects in areas of interest at each site (data points in Fig 8 & 9), with expected groundwater direction, location of elevated airborne conductivity values and access constraints influencing survey design.
- Fig 8 and Fig 9 show data collected using vertical (deep) and horizontal (shallow) dipole configurations, respectively. Point data were gridded and interpolated using natural neighbour with a 5m cell size.

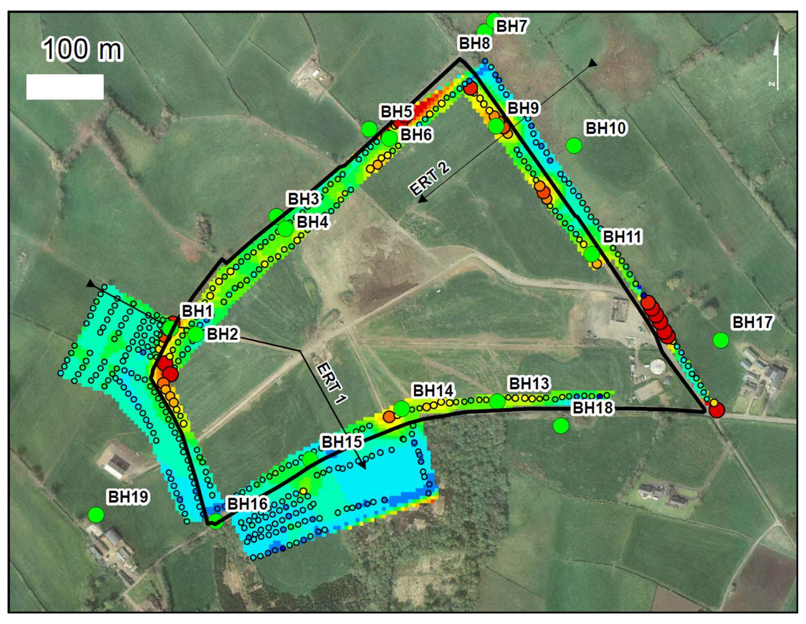

Fig 8: Ground-based conductivity (vertical dipole) – 1.6kHz; ~30m

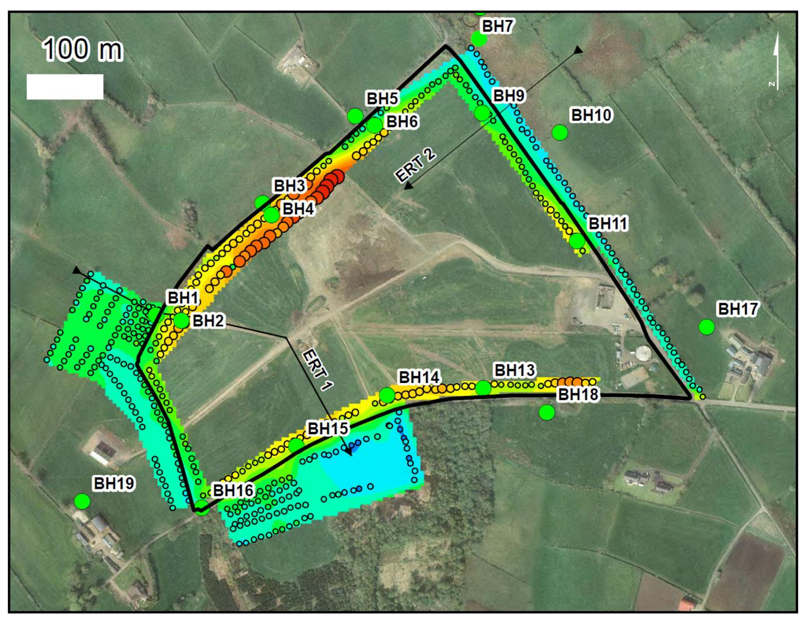

Fig 9: Ground-based conductivity (horizontal dipole) – 1.6kHz; ~15m

Interpretation:

- High conductivity levels recorded to the north of the site (near BH3) may be related to tipping (1986-1987).
- Both images show a small section of elevated values near BH1 - a borehole with continued exceedance issues.
- The ground survey can be broadly related to the AEM data, with both datasets showing lower conductivity values beyond the boundary of the landfill.
- Other anomalies: Elevated values to the east of the site may relate to a metal shed and an anomaly located close to BH5 to overhead powerlines.

Field Electrical resistivity tomography (ERT):

- ERT profile locations were determined based on the field EM survey and AEM data.
- Acquisition employed a SYSCAL-Pro72 with five 60m cables, utilising an optimised Dipole-Dipole array with a 5m electrode spacing.
- Fig 10 and 12 show the processed profiles ERT 1 and ERT2, with Fig 8 and 9 indicating the location and direction of each line. IP profiles were produced for each line with IP 1 and IP 2 matching ERT1 and ERT 2, respectively.

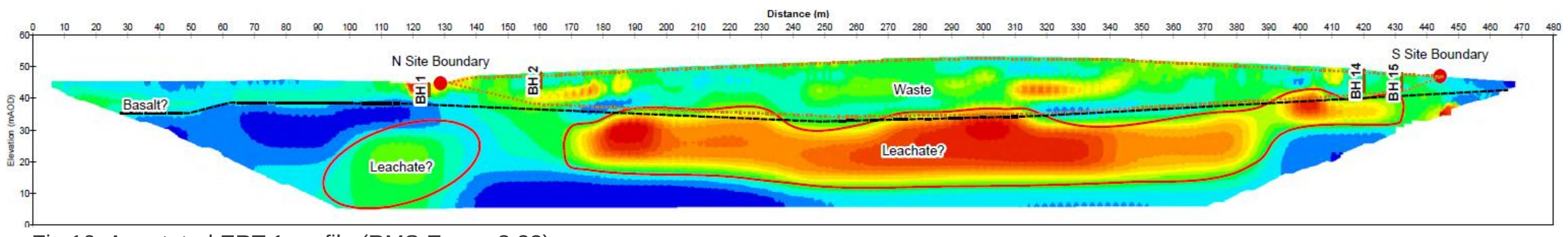

Fig 10: Annotated ERT 1 profile (RMS Error: 3.22)

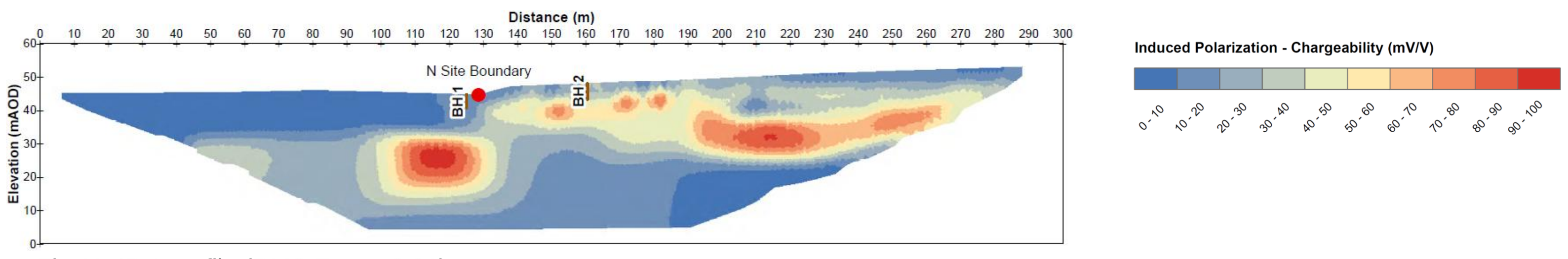

Fig 11: IP 1 profile (RMS Error: 2.91)

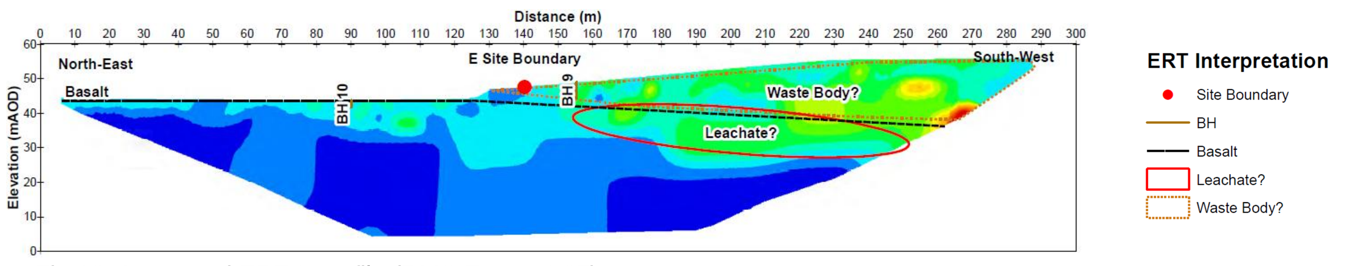

Fig 12: Annotated ERT 2 profile (RMS Error: 3.27)

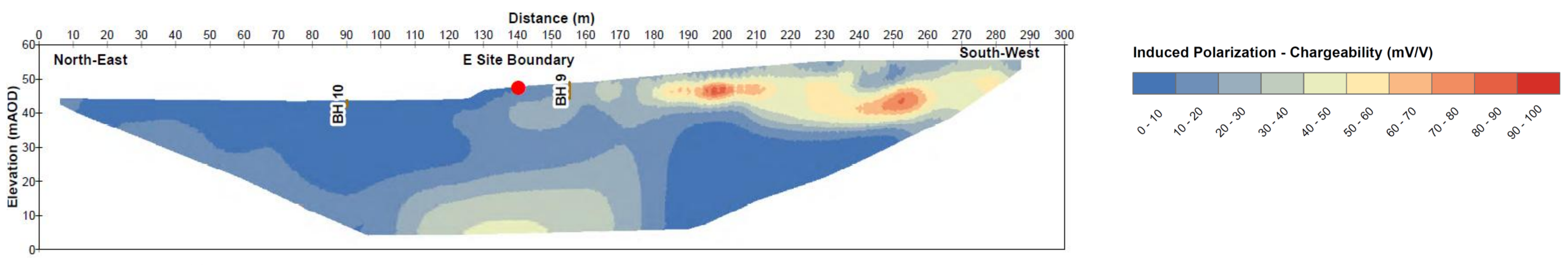

Fig 13: IP profile (RMS Error: 1.73)

Interpretation

- Conceptual interpretation of field results incorporates shallow borehole information however no conclusive data could be found to validate the depth of waste – deeper boreholes required to validate anomaly to the north.
- IP can be used to assist in the differentiation of waste/leachate and till.

8. Conclusion

- The Tellus and Tellus Border AEM data allow the rapid characterisation of sites possibly affected by groundwater contamination.
- Surface geophysics provides good depth and spatial anomaly detection at a local scale, guided by airborne and desktop studies. These in turn can be used to accurately target intrusive validation via boreholes.
- The analysis of AEM data provides a useful supplement to existing assessment tools within the established process of identification, characterisation and monitoring of sites affected by landfilling activities and groundwater pollution.

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References can be provided on request