Co-funded by the Walloon region

Deliverable WP T3.1.1. – Resource Distribution Models for site N°1 and N°2

June, 2021

SUBJECT:	…						
☒	report	☐	information	☐	consideration	☐	decision
To:	…			From:	Liège and BGS		

Introduction

In the following, we present the Resource Distribution Models (RDM) for the landfills of Meerhout and Les Champs Jouault. The RDMs were derived based on a subset of the geophysical data measured during the pre-and post-sampling surveys in 2018 and 2019 (reports DI1.2.2 and DI1.2.3 for Meerhout, DI2.2.2 and DI2.2.3 for Les Champs Jouault) and in accordance with the correlation analysis report in which the geophysical data was interpreted and validated based on the ground truth data as well as the conclusions made on the other RAWFILL sites (reports DI1.3.4 and DI2.3.4).

Meerhout site

Summary of investigations

The site of Meerhout, located in the province of Antwerp (Belgium), is a former landfill composed mainly of household (70-80%) and industrial waste (20-30%). The site area is 7.5 ha for a total perimeter of 1250 m. It includes a container park facility, partially located on the older dumping zone. The landfill was developed in five stages that led to different waste thicknesses from 5 m in the eastern zone up to 20 m towards the west (see **Figure 1** and **Figure 2**). During the first phase of the site, no bottom membrane was set up whereas in more recent periods an agricultural foil and a high-density polyethylene (HDPE) membrane were used.

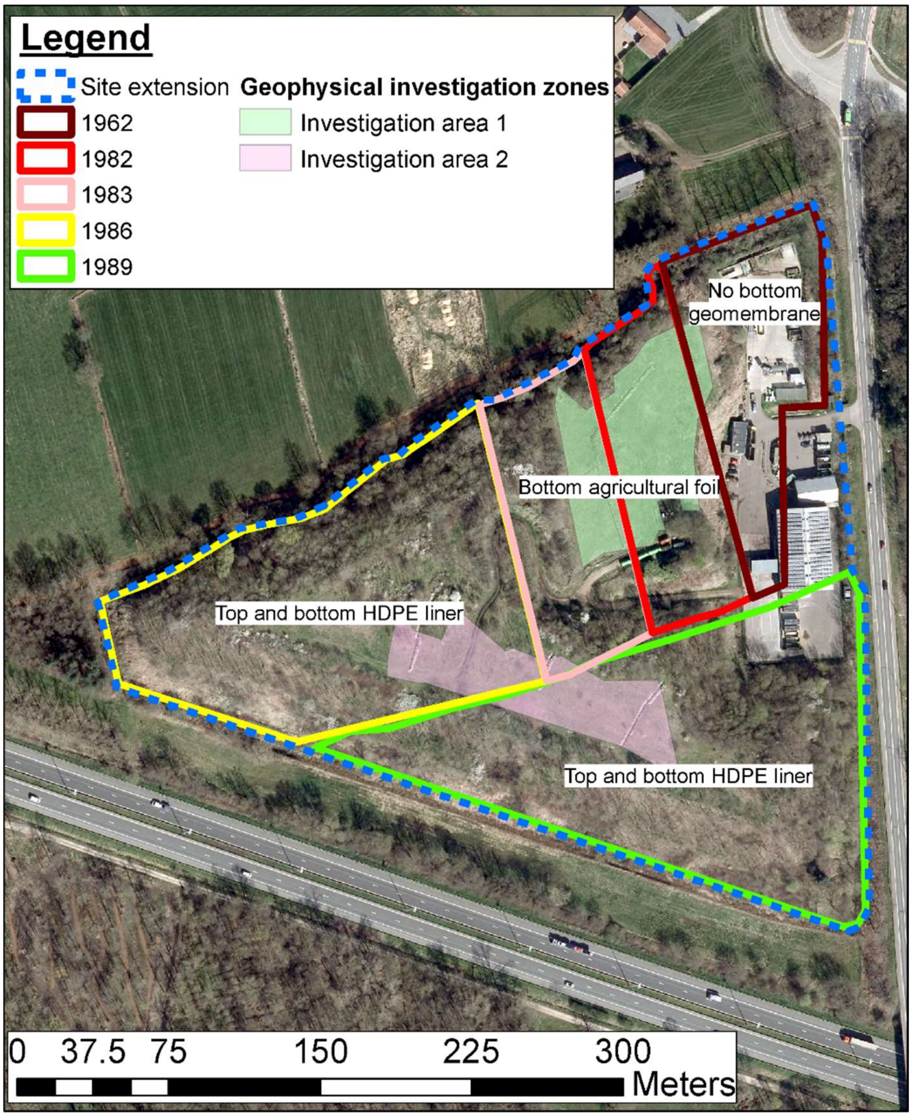

Figure 1: The Meerhout landfill installation with successive development phases of the site.

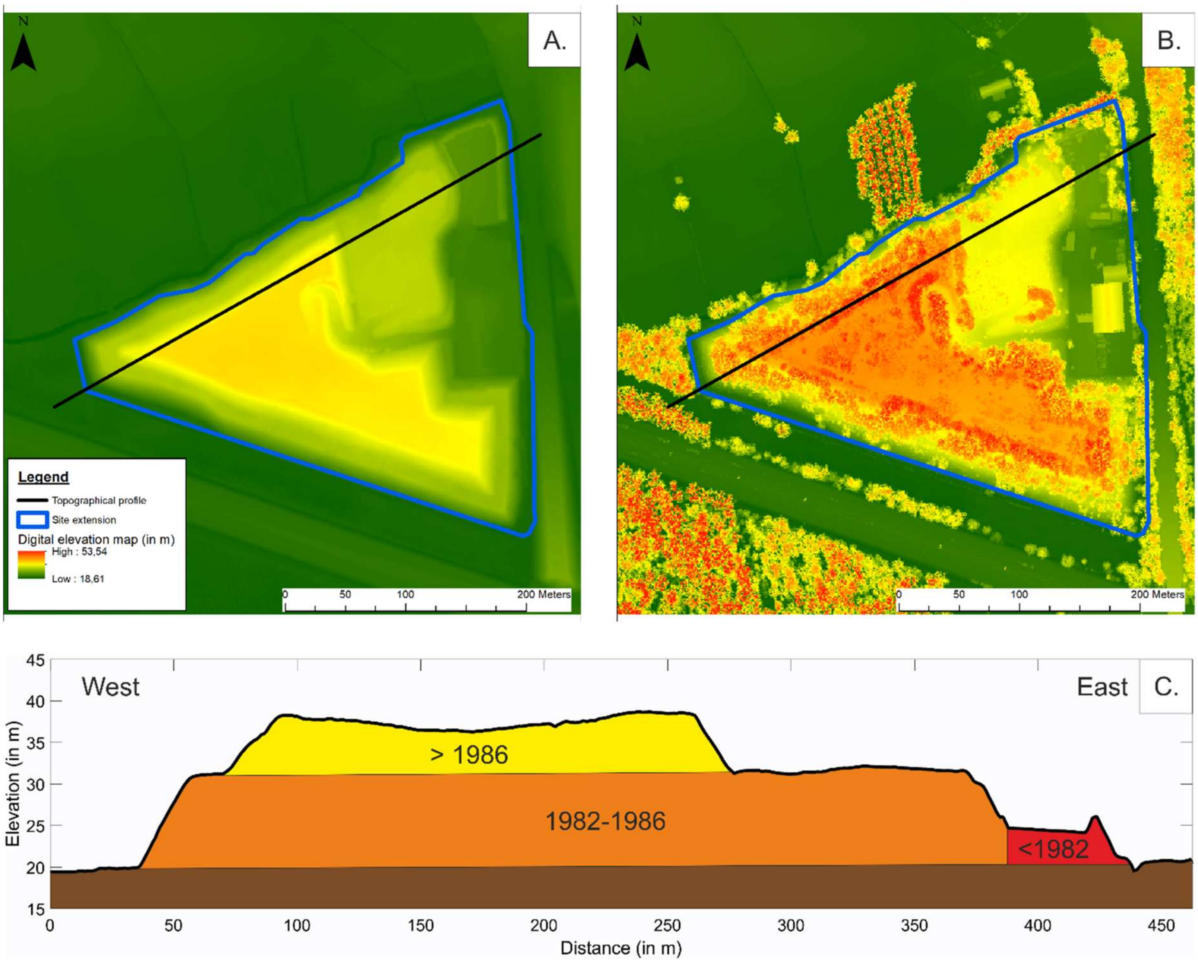

Figure 2: The Meerhout landfill topography: A. DEM soil elevation; B. DEM top of vegetation; C. cross-section

The first geophysical survey carried out on the landfill (see Deliverable I1.2.2: Geophysical imaging pre-sampling) involved different geophysical methods: Electromagnetic Induction (EM), Magnetometry (MAG), Electrical Resistivity Tomography (ERT), Induced Polarization (IP), Seismic Refraction Tomography (SRT), Multichannel Analysis of Surface Waves (MASW), Horizontal to Vertical Noise Spectral Ratio (HVNSR) and Ground Penetrating Radar (GPR). Measurements did not cover the whole landfill due to poor accessibility of certain areas (see zones investigated in **Figure 1**). The objectives of the survey were to explore the potential of selected methods to study the geometry of the waste body, to detect buried infrastructures and to identify zones characterized by homogeneous physical properties possibly related to similar waste composition. EM results mainly delineated the distribution of the biogas extraction pipes and highlighted more saturated zones (see **Figure 3 A** and **B**). Magnetometry was strongly influenced by the pipes system and earth dams. ERT proved to be useful to delineate the cover layer (consisting in a thin layer of coarse sand mixed with inert underlain by a silty-sand layer mixed with waste) and to image the more saturated zones detected with EM. IP method proved to be effective to delineate the upper limit of the waste body that exhibited a strong chargeability contrast with the cover layer. GPR was better suited to investigate shallow targets and to analyse the cover layer(s) geometry. Although the contrast of seismic velocities between the waste body and the underlying geology is not strong, the results obtained with the seismic methods nevertheless provided a rough estimate of the depth of this interface (see **Figure 3 C**).

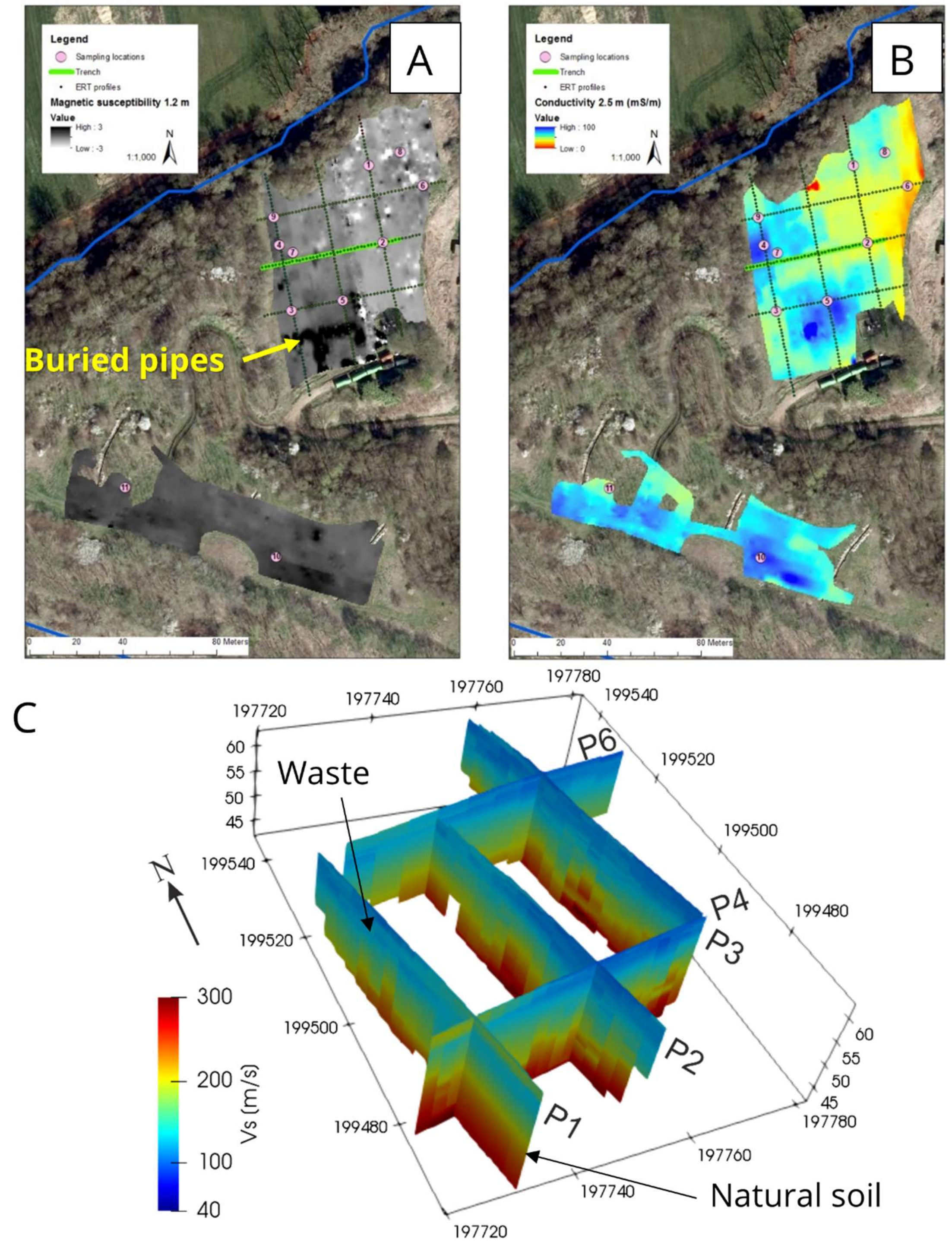

Figure 3: Examples of geophysical results obtained after the first geophysical survey. A) Magnetic susceptibility map derived from the in-phase data measured at an approximated depth of 1.2 m showing buried infrastructures (gas pipes), B) electrical conductivity map derived from the quadrature-phase data at an approximated depth of 2.5 m showing more saturated zones, C) MASW profiles from the northern investigation area 1 showing a contrast of shear-wave velocity (Vs) between the natural soil and the waste

After data analysis, a sampling plan was proposed to provide ground truth data to validate the interpretation made and reduce uncertainties. The first sampling phase consisted of 9 boreholes (see **Figure 4**) that all reached the natural ground. A water table was found at -7.5 m in the boreholes located in the lower zone of the landfill. In the northern investigation area, boreholes revealed a cover layer whose thickness ranges between 1 to 2 m and a waste body with a thickness of 10.5 m to 12.5 m in the northern investigation area. In the southern investigation area, the layer of waste is thicker (22.4 to 23 m).

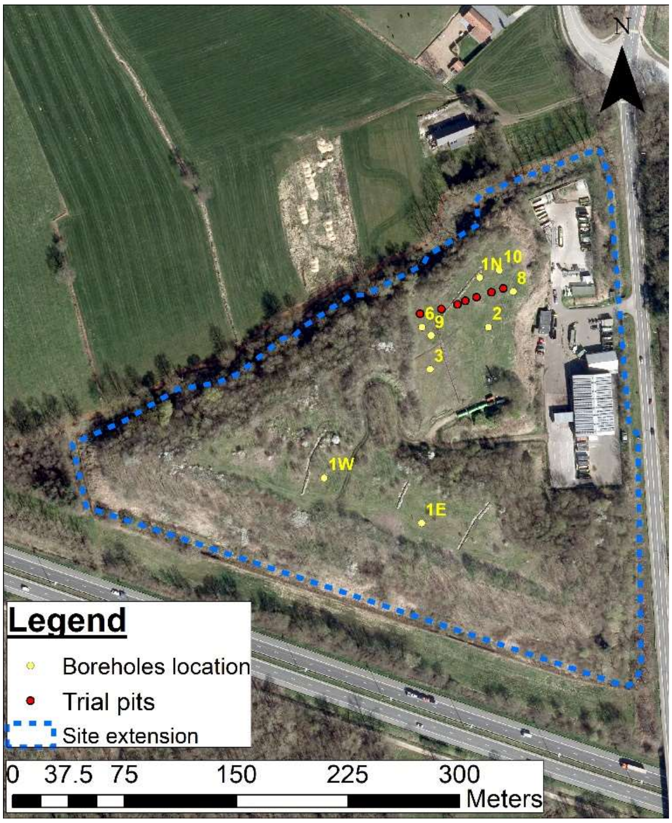

Figure 4: Sampling carried out in Meerhout consisting in 9 boreholes and 7 trial pits.

A second geophysical survey was conducted after the sampling to calibrate the data and explore variations of physical properties with time. Due to the previous results, the applied geophysical methods were EM, GPR, 3D ERT survey (**Figure 5**) and a high-resolution ERT/IP profile collocated along 7 shallow trial pits (**Figure 6**) excavated to validate the data afterwards.

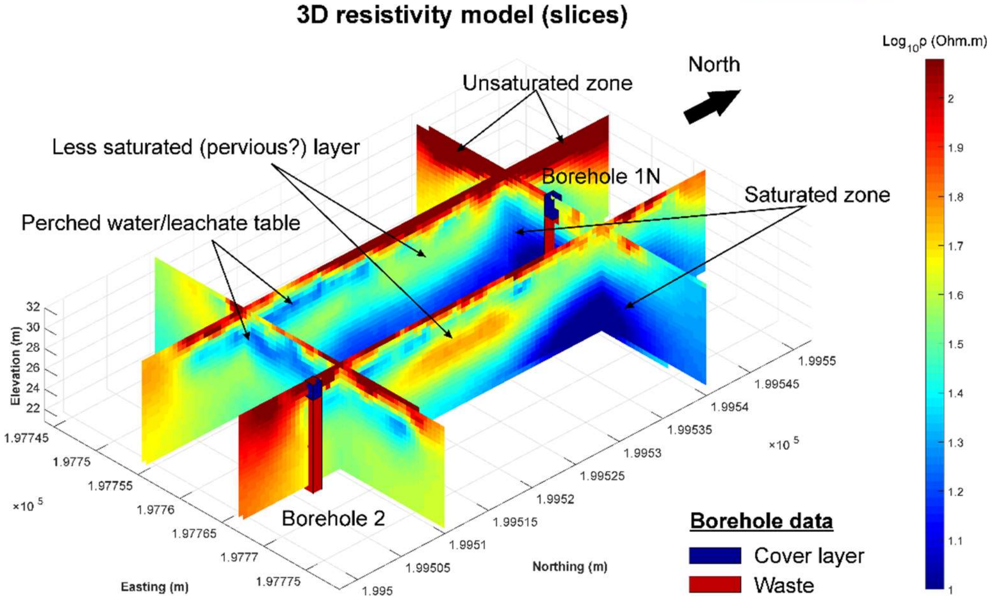

Figure 5: Electrical resistivity transects extracted from the 3D ERT model

Overall, the geoelectrical methods (ERT and IP) proved to be useful to detect different layers as well as some heterogeneities within the waste body. However, both methods could only be applied in the landfill zone without top HDPE liner and without buildings (see **Figure 1**). In the zones with an upper geomembrane, the combination of seismic methods MASW and HVNSR could roughly estimate the transition between the waste body and the underlying natural soil. Finally, it was difficult to relate geophysical properties to waste composition measured during sampling. This is mainly due to the punctual nature of sampling measurements compared to geophysical measurements that rather integrate larger volumes.

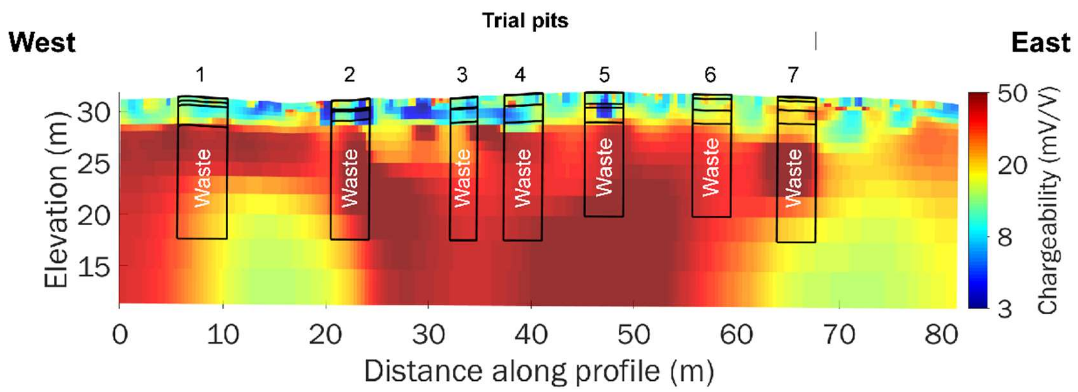

Figure 6: High-resolution chargeability profile obtained just before the last phase of the sampling (trial pitting). The high chargeability corresponds to the main waste body.

RDM development

The presented RDM extends only in the lower zone of the landfill which was accessible for the geophysical surveys and does not have a geomembrane. This zone has a mean waste thickness of 11 m. The RDM was mainly derived from the combination of ERT and IP data co-located with the excavated trial pits, through a post-inversion probabilistic approach based on Hermans and Irving (2017), see Deliverable I1.3.4: Correlation analysis report.

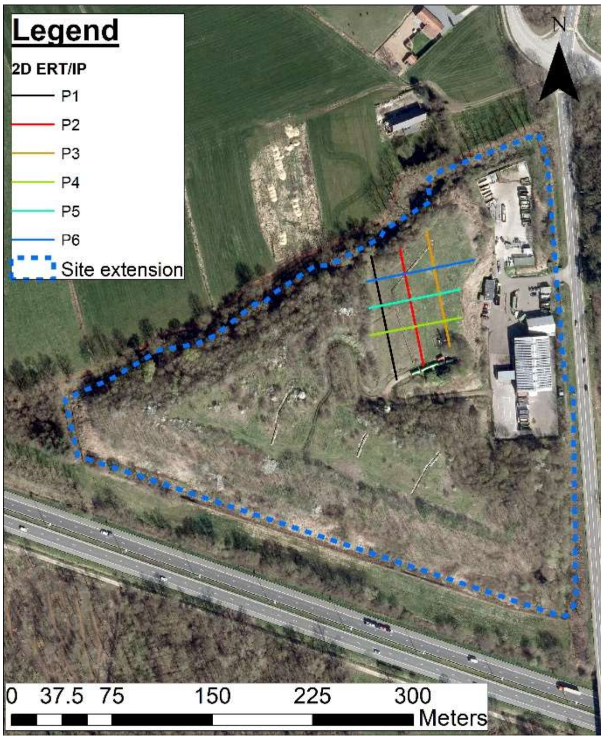

Figure 7: ERT and IP profiles used to derive the RDM in the lower zone of the landfill.

Figure 8 presents a 3D view of the RDM together with the distribution of the boreholes. The interpreted layer of waste is displayed in green, in yellow the shallowest cover layer is represented (associated with a larger sand content) and in blue a second cover layer (silty sand mixed with waste) is displayed. Zones with very low sensitivity are not displayed.

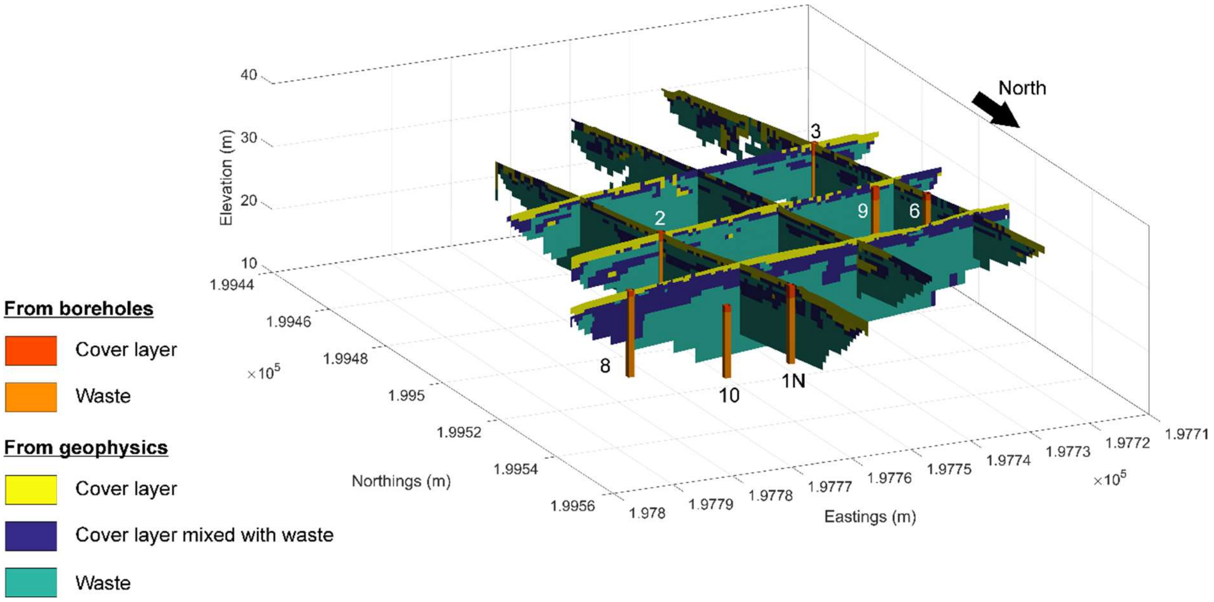

Figure 8: RDM in the lower zone: the waste body is represented in green, yellow is the cover layer and blue is the cover layer material mixed with waste. Boreholes are the bars where red is the cover layer found and orange the waste extension.

<u>Estimation of waste volume and composition</u>

Using the Digital Elevation Model (DEM) of the landfill (shown in **Figure 9**) and the information from the boreholes it was possible to estimate the total volume of the landfill which is approximately 850 000 m^3. Assuming a homogeneous cover layer of 1.5 m all over it, the maximum volume of waste present in Meerhout is 630 000 m^3. However, this amount also encompasses the dikes that were setup to stabilize the waste. Unfortunately, we lack information about the geometry of the latter to infer their volume. Assuming that the boreholes drilled in the investigated zone are representative of the composition of the entire landfill and neglecting the dikes, it is possible to estimate the following content:

- Plastic (16.7 %): 145 000 T
- Metal (2.39 %): 20 800 T
- Stones (4.42 %): 38 400 T
- Glass (0.18 %): 1565 T
- Rubber (0.42%): 3650 T
- Paper (0.07%): 610 T

To calculate these numbers, a mean waste density of 1.38 T/m^3 was assumed. It was estimated based on the collected samples.

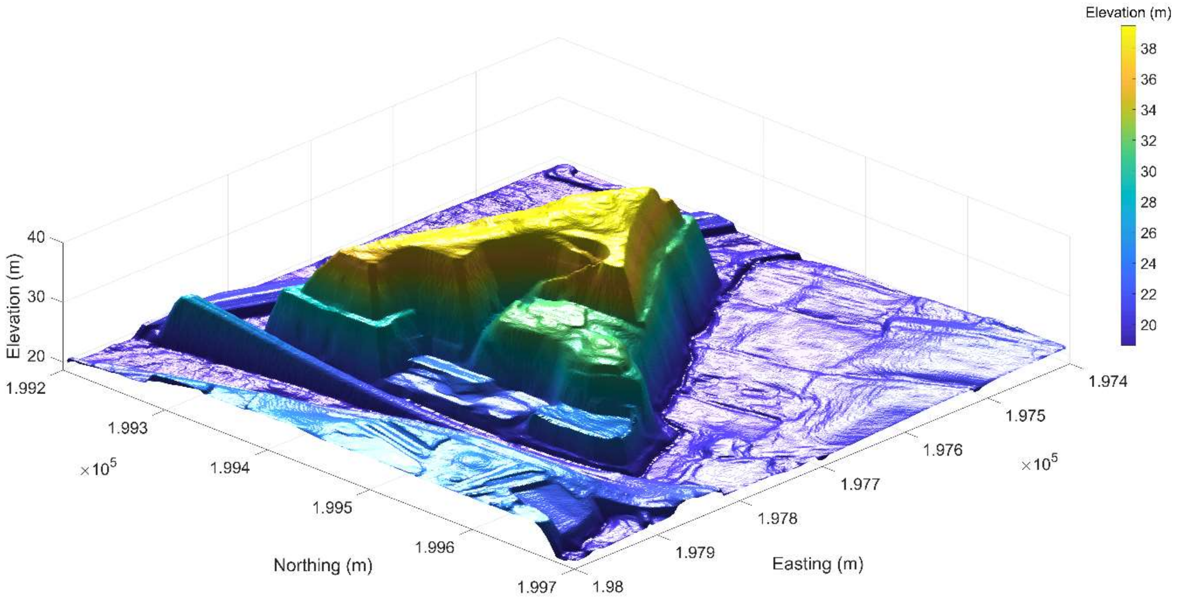

Figure 9: Digital Elevation Model (DEM) of the Meerhout landfill obtained from LIDAR data (vertical view exaggerated).

Les Champs Jouault site

In comparison to the other RAWFILL landfill sites, the RDM of the Les Champs Jouault landfill is less detailed providing only estimates about the waste volumes of each cell but no information about heterogeneities or compositional changes within the cells. This is mainly due to the presence of the HDPE membrane limiting the amount and spatial distribution of ground truth data that could be taken. Furthermore, the HDPE membrane prohibited the use of the ERT and IP methods directly on the landfill cover and therefore reduced the spatial coverage of complementary geophysical measurements available.

Derivation of the Resource Distribution Model

In order to delineate the waste cells and estimate waste volumes we used the MASW, the GPR and the EM data. The ERT and IP measurements were not included since they are of very limited extent being confined to the location of the trenches only where the electrodes could be pushed through the HDPE membrane (see **Figure 11**). Similarly, as seen in **Figure 10**, the sampling data is very sparse and was therefore only included for interpretational reasons in the correlation analysis but was not directly used to constrain the delineation of the waste volume.

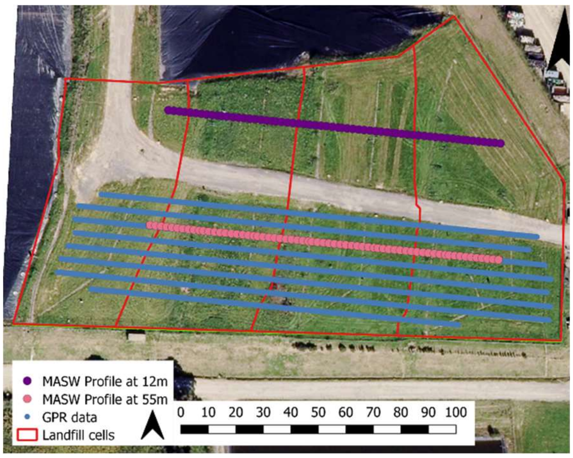

Figure 11: Extent of the geophysical data (MASW and GPR) to create the RDM

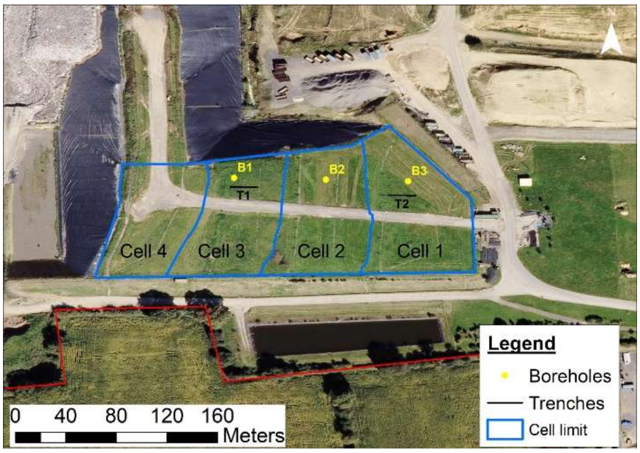

Figure 10: Map showing the location of the available ground truth data.

In order to create the 3D model of the waste volume (RDM), the geophysical data was included as follows:

- **GPR data to derive top boundary of waste cells**
  The GPR data was used to derive the top boundary of the waste cells as the dielectric contrast between the cover layer and waste material provided a clear reflector allowing to derive the cover layer thickness of the area to the south of the road (**Figure 12**). However, the cover layer thickness to the North of the road had to be extrapolated, as this area was not covered by dense GPR measurements.

- **MASW data to derive the base of the waste cells**
  As described in the correlation analysis, the shear wave velocity distribution is clearly bimodal at Les Champs Jouault landfill. Unsupervised clustering is therefore suitable to categorise the MASW data into the low velocity waste material and the higher velocity natural ground as seen in **Figure** 13,

where two clustering algorithms are compared. Including both, the shear wave velocity (logarithm and standardised data) as well as the depth (standardised data) provided a smooth image categorising the MASW profiles into waste and natural ground as seen in **Figure 14**, which was derived with KMeans clustering. Very similar result were obtained with the Gaussian mixture model and are therefore not displayed. From the two categorised MASW profiles, it was then possible to extract and extrapolate the bottom waste interface as an input for the RDM.
It should be noted that the cover layer thickness indicated by the white line in **Figure 14** as well as the lateral extent of the waste cells could not be resolved with the MASW data.

- **EM data to delineate the extent of the waste cells**
  The lateral extent of each waste cells was derived from the EM data, which delineates the waste cells very clearly as the clay dams surrounding the cells exhibit significantly lower conductivities (**Figure** 15).

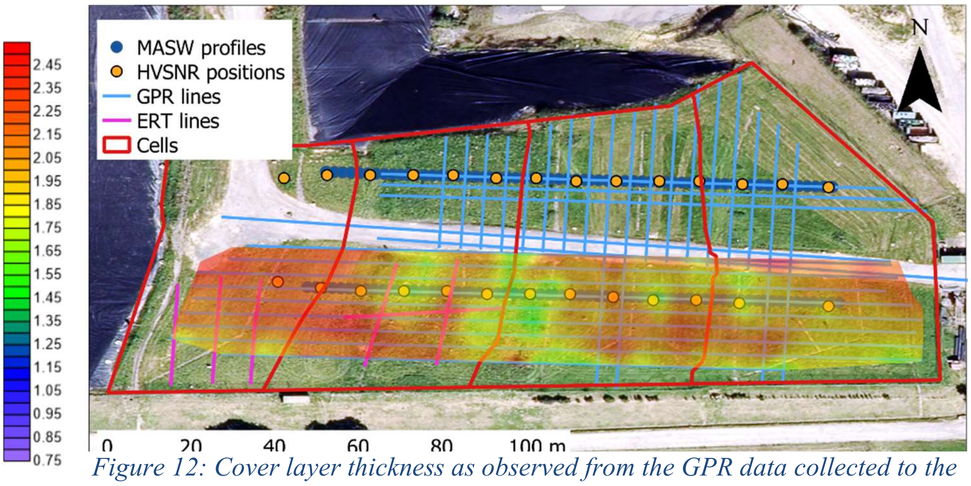

Figure 12: Cover layer thickness as observed from the GPR data collected to the South of the access road. This data was extrapolated to construct the upper waste boundary of the RDM.

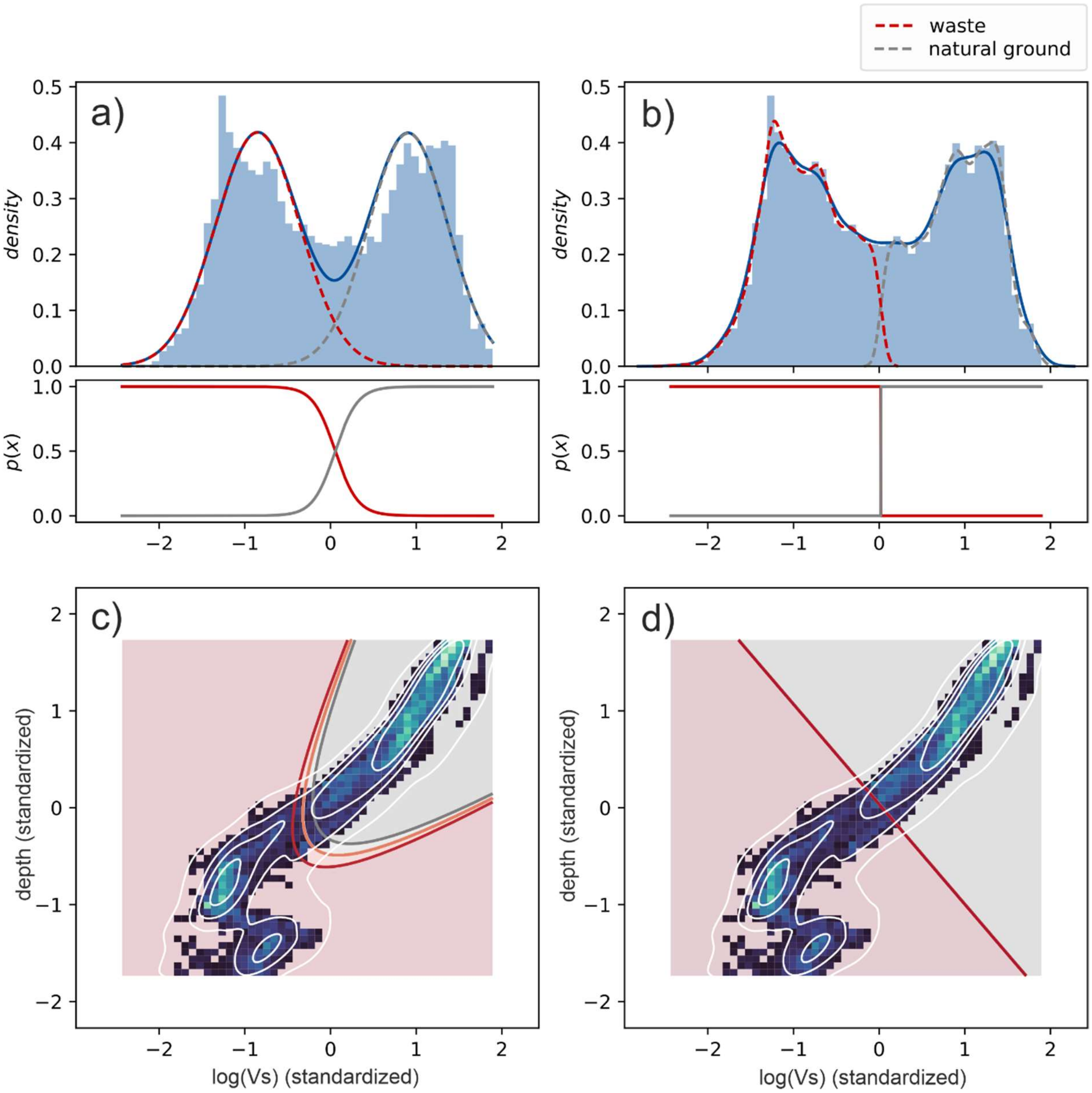

Figure 13: Comparison of different clustering approaches to categorise the MASW data into waste and natural ground. The conditional probabilities in a & c were derived by using a Gaussian mixture model. b & d were derived by KMeans clustering. In c & d, the depth was included as an additional attribute.

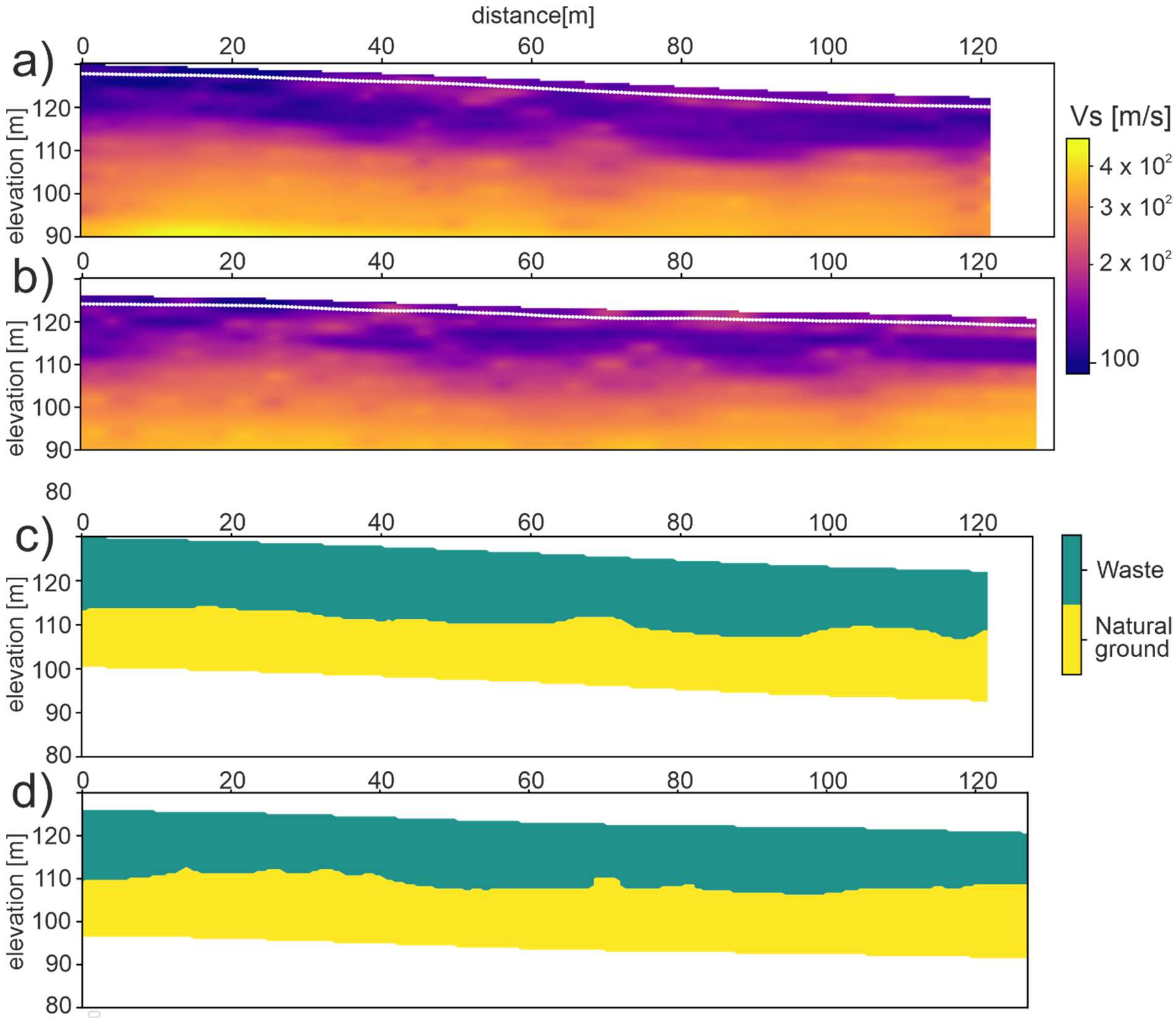

Figure 14: a & b) Shear wave velocity of the two West-East aligned MASW profiles. c & b) Delineation of the waste material derived by KMeans clustering including the shear wave velocities as well as the depth of the two profiles in a & b. It should be noted that the cover layer thickness indicated by the white line in a & b as well as the lateral cell boundaries could not be resolved with the MASW data.

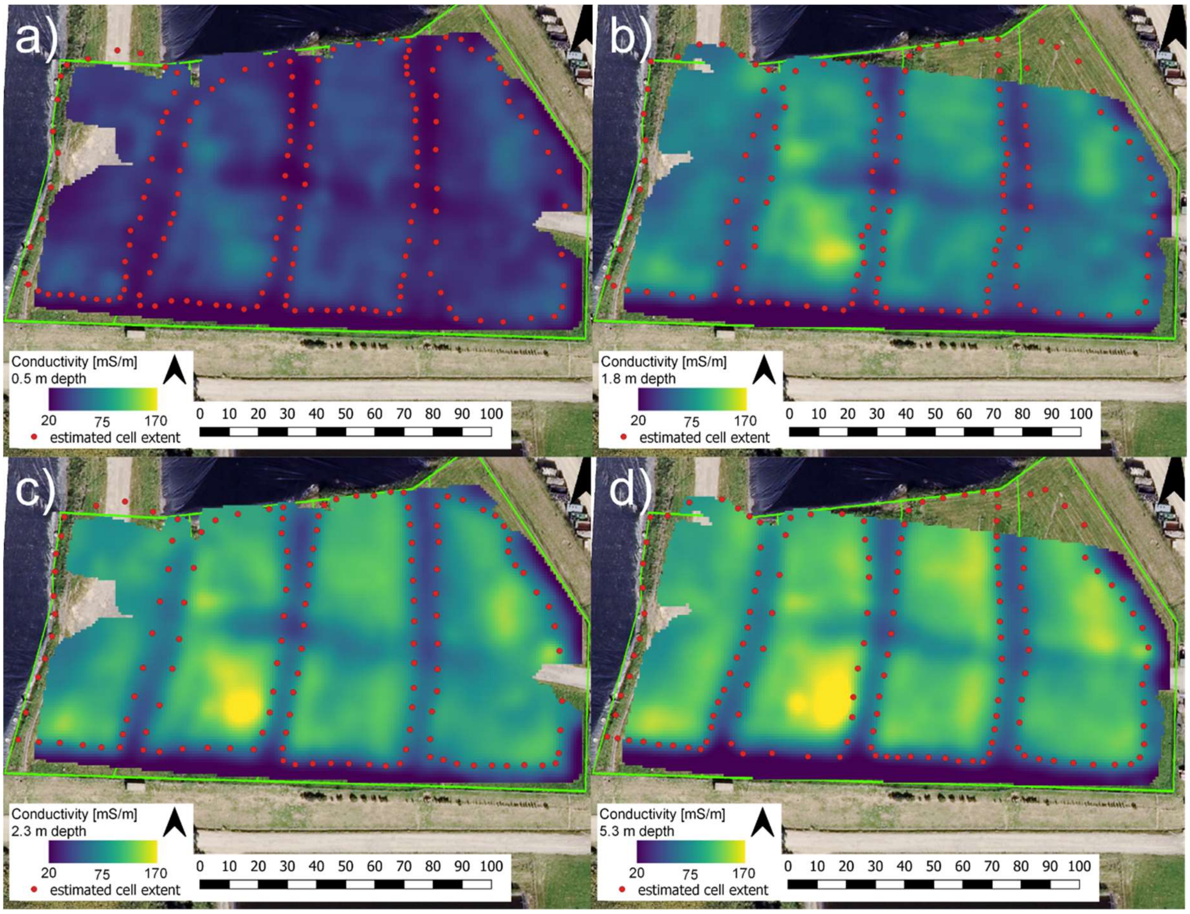

Figure 15: a to d) Conductivity maps derived from the EM measurements. The EM data was used to estimate the lateral extent of the waste cells as indicated with red dots.

Waste volume estimation and Resource Distribution Model

The RDM with the resulting waste cells is displayed in **Figure 16** and the estimated volumes per cell are shown in
Table 1. It has to be noted that the volume estimates are very rough approximations. This is due to the limited spatial coverage of the GPR limiting the available information about cover layer thickness to the southern part of the landfill only. Similarly, the uncertainty of the landfill base is relatively high firstly because it was estimated from two MASW profiles only and secondly because the landfill base could not be validated and calibrated due to the lack of available ground data. Furthermore, according to the landfill construction plan, the cell boundaries are actually not vertical but inclined towards West meaning that the waste materials of older cells were overlain with the waste material of the newer cells. However, the geophysical data could not resolve the inclined cell boundaries at depth and we therefore approximated the cell boundaries of the landfill model to be vertical.

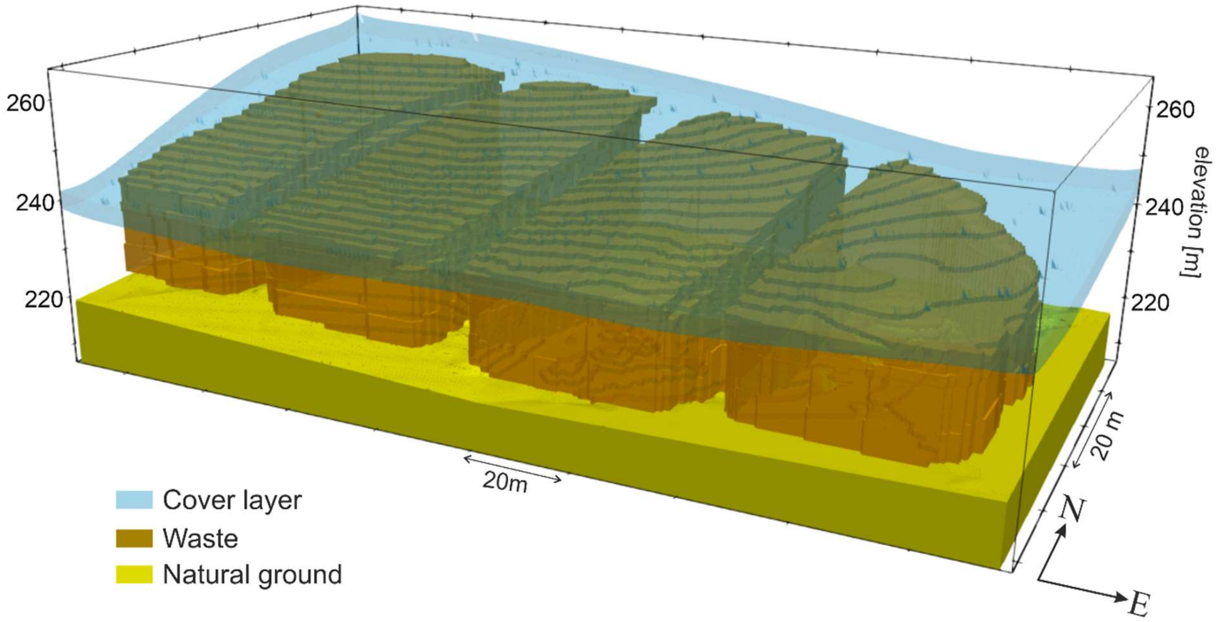

Figure 16: Resource Distribution Model

Table 1: Estimated waste volumes

	Cell 1	Cell 2	Cell 3	Cell4	Total
Volume [m^3]	31’158	42’201	32’859	38’588	144’806

Conclusion

The studies at the two pilot sites have shown that complementary geophysical methods in combination with targeted sampling can be effective tools to derive 3D Resource Distribution Models (RDM).

The studies highlight the importance of co-located geophysical measurements and ground truth data in order to provide a thorough and reliable interpretation. Targeted Sampling co-located with the geophysical measurements and ideally targeting all major geophysical anomalies/characteristics allow understanding and assigning the geophysical signatures to different landfill materials and building a 3D RDM.

In comparison to the pilot study at the Meerhout landfill, the study at Les Champs Jouault only allowed obtaining a simplified RDM differentiating between clay cap, waste material and natural ground. The main cause for this is the presence of the HDPE membrane, which limits the availability and spatial distribution of co-located ground truth data. Furthermore, the HDPE membrane prohibits the use of ERT and IP directly on the landfill cover and therefore reduced the spatial coverage of complementary geophysical measurements. Therefore, HDPE membranes, mainly present on recent landfills, limit the applicability of our proposed approach to derive a RDM. However, more recent landfills with HDPE membranes were often managed in a more controlled manner resulting in a better a-priori knowledge about the landfill structure and waste composition and therefore a smaller amount of targeted samples might be required to provide a reliable interpretation. Another option to deal with landfills where limited ground truth data is available could be to use observations made on other landfill sites of similar compositions. However, such cross-site interpretation would require further case studies and building a geophysical database for different landfill types.

For both pilot sites, we focused mainly on the material composition rather than other physical-chemical properties (e.g. bulk density, moisture content, material strength). Especially, moisture content influences the geophysical signature significantly. To better understand such relationships, we recommend doing further laboratory tests on waste samples allowing to derive petrophysical relationships to quantify changes in geophysical properties caused by transient conditions such as changing moisture content.

For a more detailed discussion on the effectiveness of using complementary geophysical methods with targeted sampling, please refer to the lessons learned and recommendations report (Deliverable T3.3.1).

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