Interreg North-West Europe
NWE-REGENERATIS
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D.I3.2 SITE SPECIFIC INVESTIGATION PLAN AND SCHEDULE

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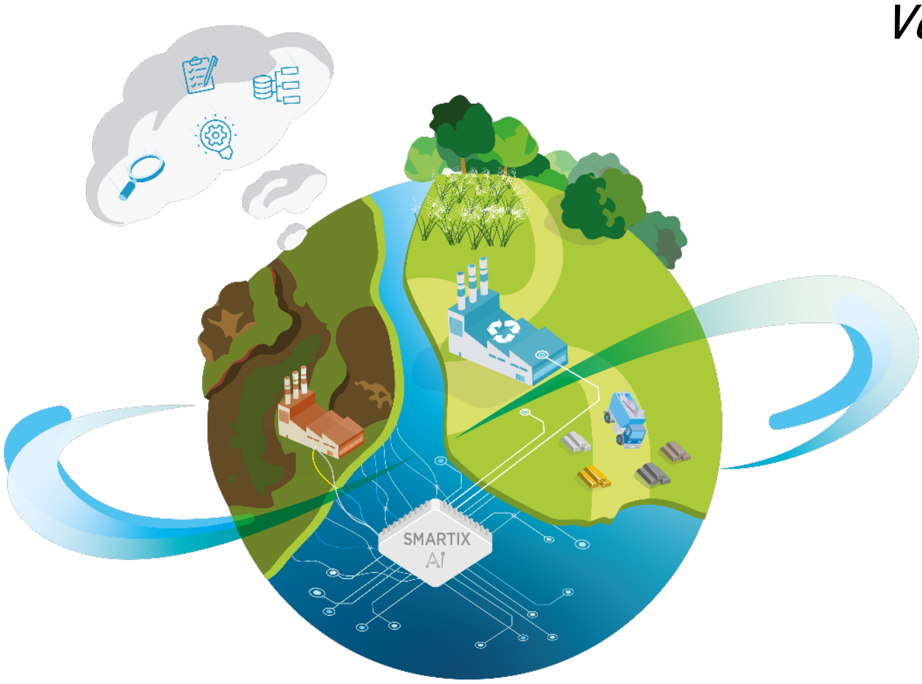
Version 2



SUMMARY

1 INTRODUCTION

This report describes the geophysical survey design for the investigation at the DUFERCO site in La Louvière (Province of Hainaut, Belgium). It is based on a former geophysical survey carried out by the University of Liege in 2017 and on the information collected as part of NWE-REGENERATIS, i.e., site visit, historical report and geographical data. The survey is prepared in close collaboration with the members of DUFERCO Wallonie SA.

Metallurgical activities on the La Louvière site began around 1850 with the construction of a factory in the western and central zones (most of which are now demolished). From 1904 to 1981, the iron and steel plant continued to evolve and expand eastwards, with elements such as the coking plant and blast furnaces (today unassembled), buildings, industrial activities and an agglomeration of co-products and/or raw materials in the north-eastern zone. These residues came from various iron and steelmaking processes. They include steel slag, phosphorous-rich slag and foundry sands. Nowadays the highest elevation of the site is in the northern area (see Figure 1), which has been backfilled over decades of operation. It is mainly composed of black slag (rich in iron and lime), tailings (initially black converter slag that were already recycled) and white slag (ladle slag) tainted with scrap metal, wood, aluminum, plastics, etc. Figure 1 also shows a large area of gas dust deposits from blast furnace ironmaking (rich in iron and coke). Finally, westward, there is a zone with residues from the coke ovens. Detailed information about the past activities and evolution of the site can be found in the historical report (see Deliverable I3.1.1).

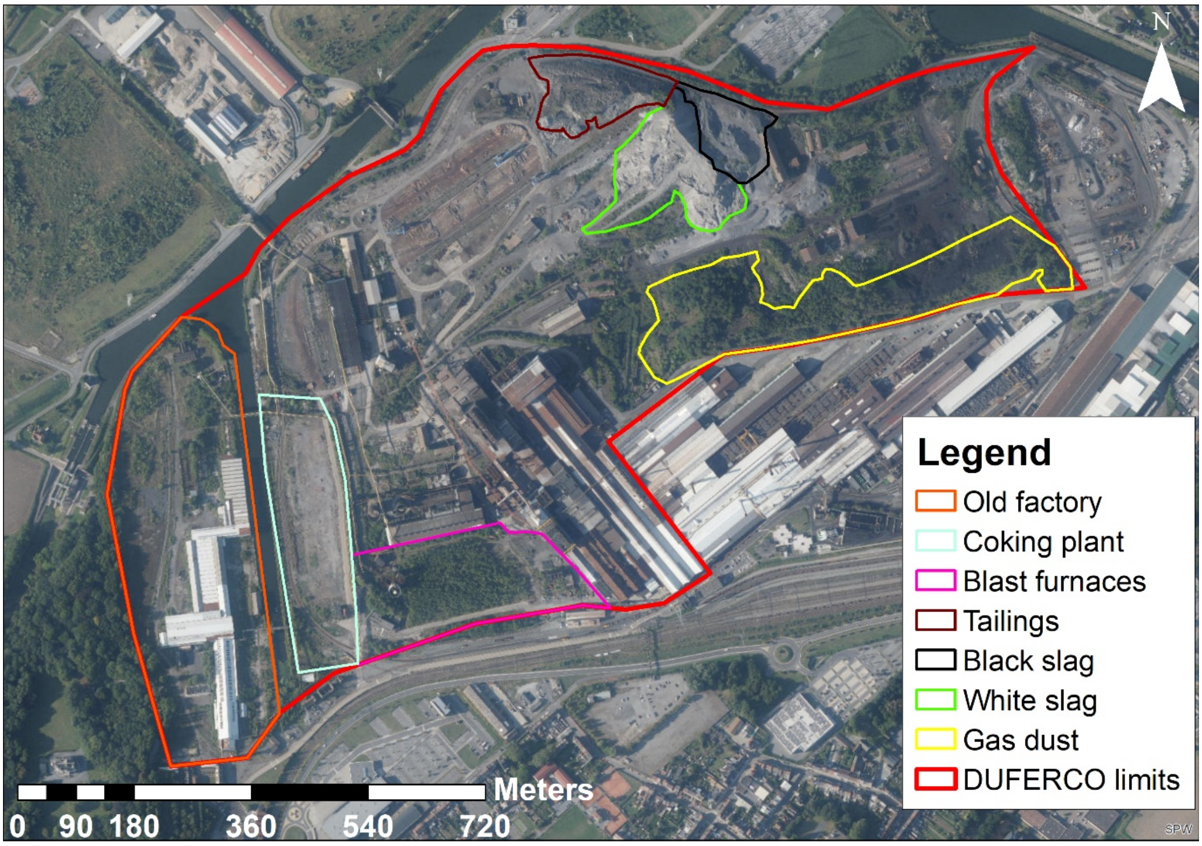


Figure 1 : DUFERCO site (La Louvière).

From a geologic point of view (Figure 2), most of the site lies in a clay-sand complex characterized by very heterogeneous clayey, silty and stony fractions. The slag deposits to the north overlie the alluvial deposits of the Thiriau stream, consisting of alternating sandy and clayey formations with locally gravels. Part of the site also lies on shales and sandstones from the Houiller formation. However, it should be noted that a layer of backfill (composed of slag, tailing, construction waste) between 1 and 30 m thick is present almost all over the site.

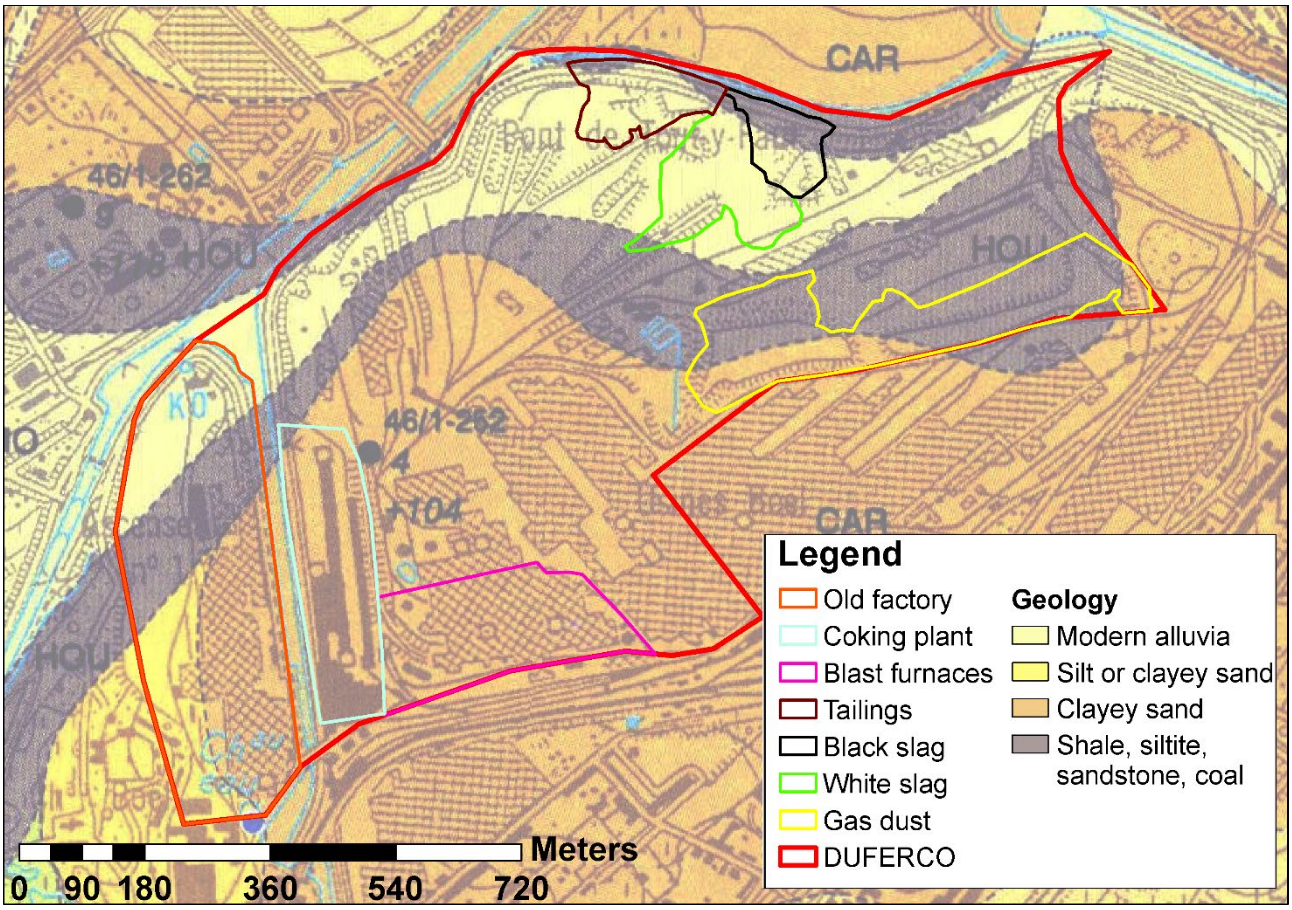


Figure 2 : Excerpt from the geological map of the Duferco site.

2 Previous geophysical survey (2017)

2.1 Spatial coverage

In September 2017, the University of Liege conducted an exploratory geophysical survey focusing on the zone of white slag deposits. The methods of electrical resistivity tomography (ERT) and induced polarization (IP) were used for 2D acquisitions along five long profiles (P13, P14, P15, Pf and Pr) and one small grid with 12 short profiles (see Figure 3). The area was also mapped with a magnetometer, but due to the high magnetic response, the signal was saturated and unusable.

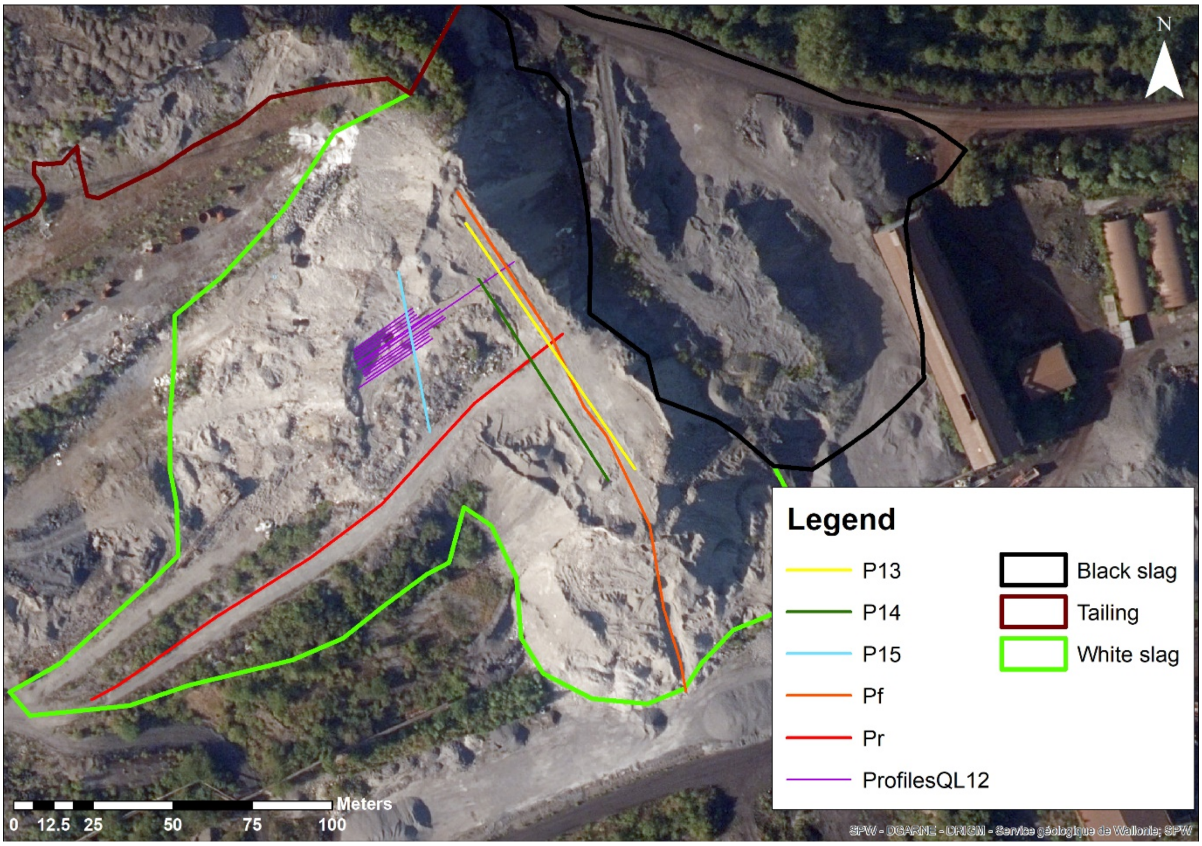


Figure 3. Location of the geoelectric profiles measured in 2017.

2.2 SUMMARY OF RESULTS

In general, the resistivity models presented intermediate values comprised between 30 Ohm.m up to 1000 Ohm.m. High chargeability values have also been observed, especially near the surface, and could be related to an increase in metallic objects or the presence of semiconducting minerals.

For example, Figure 4 shows the inverted ERT and IP models of the profile Pr (see location in Figure 3). This profile is located along the slope of the white slag accumulation and is oriented southwest-northeast. For this acquisition, a multiple gradient array was applied using 64 electrodes spaced 3 m apart. The data were inverted with BERT (Günther et al., 2006) using a robust constraint on the data and a blocky constraint on the model. The inverted models satisfied the error weighted chi-square, $\chi^2 = 1$ meaning that the data are fitted to their estimated error level. In both ERT and IP models, the natural soil is partially delineated with a transition from low to large resistivity and high to low chargeability values. In the resistivity model, low resistivity structures with a thickness of around 10 m can be observed below an intermediate resistive layer present at the soil surface. On the other hand, the chargeability model shows a shallow layer of high chargeability close the surface that covers a layer with intermediate values collocated with the conductive layer imaged in the resistivity model. This could highlight an effect of different iron oxides (e.g., magnetite, hematite) or an increase in the volume fraction of metal. However, sampling and laboratory measurements are needed to better understand and interpret the geoelectric models provided.

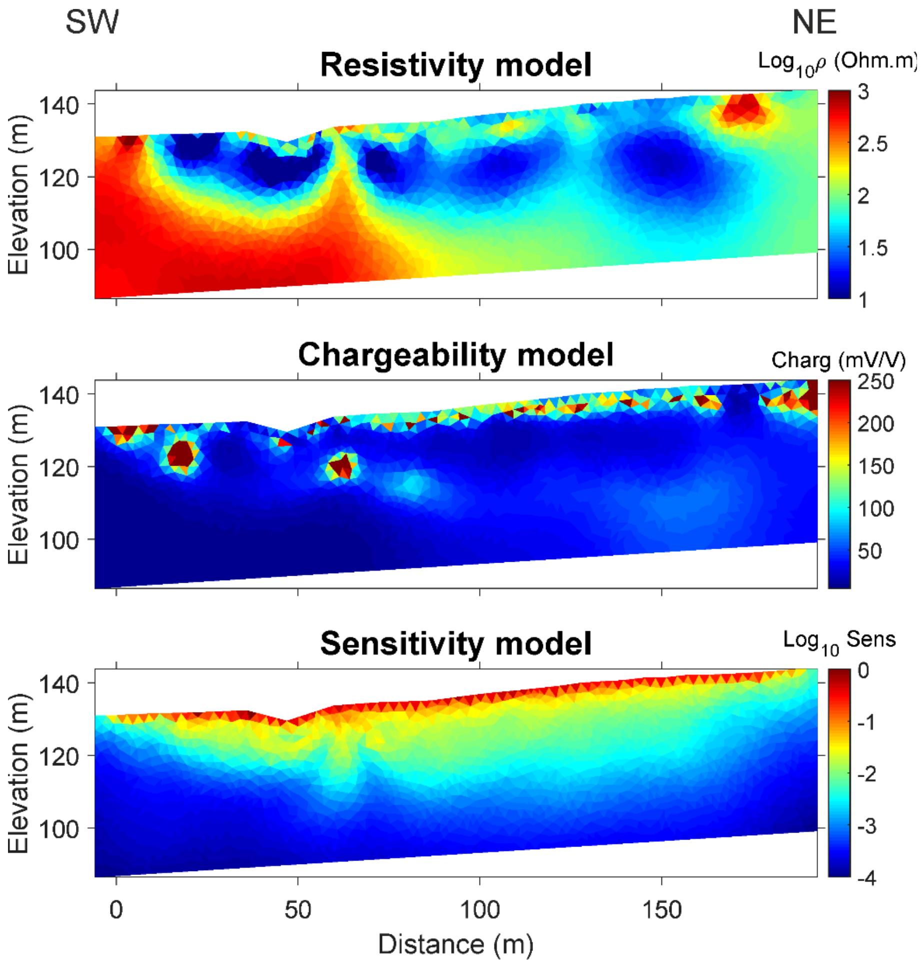


Figure 4 : Resistivity model (top), chargeability model (middle) and normalized sensitivity (bottom) of the profile Pr southwest-northeast oriented (see Figure 3).

Another example is the profile Pf, located in the upper part of the white slag deposits (see Figure 3). For this acquisition, only 55 electrodes (3 m spacing) could be used due to the steep slope and the dryness or hardness of the surface. In this case, a multiple gradient protocol was used. The data were again inverted with BERT (Günther et al., 2006) using a robust constraint on the data and a blocky constraint on the model. The inverted models satisfied the error weighted chi-square, $\chi^2 = 1$. Figure 5 shows the inverted resistivity, chargeability and sensitivity models. The resistivity model presents a discontinuous layer of large resistivity values and a conductive body at around 80 m (distance along profile). Like the profile Pr, the chargeability model in Pf shows high chargeability close to the surface. It is possible that the low resistivity observed is related to the saturated alluvial soils (natural soil) which are expected to be at an elevation between 110 and 113 m along this profile. Large resistivity zone is attributed to the presence of refractory material.

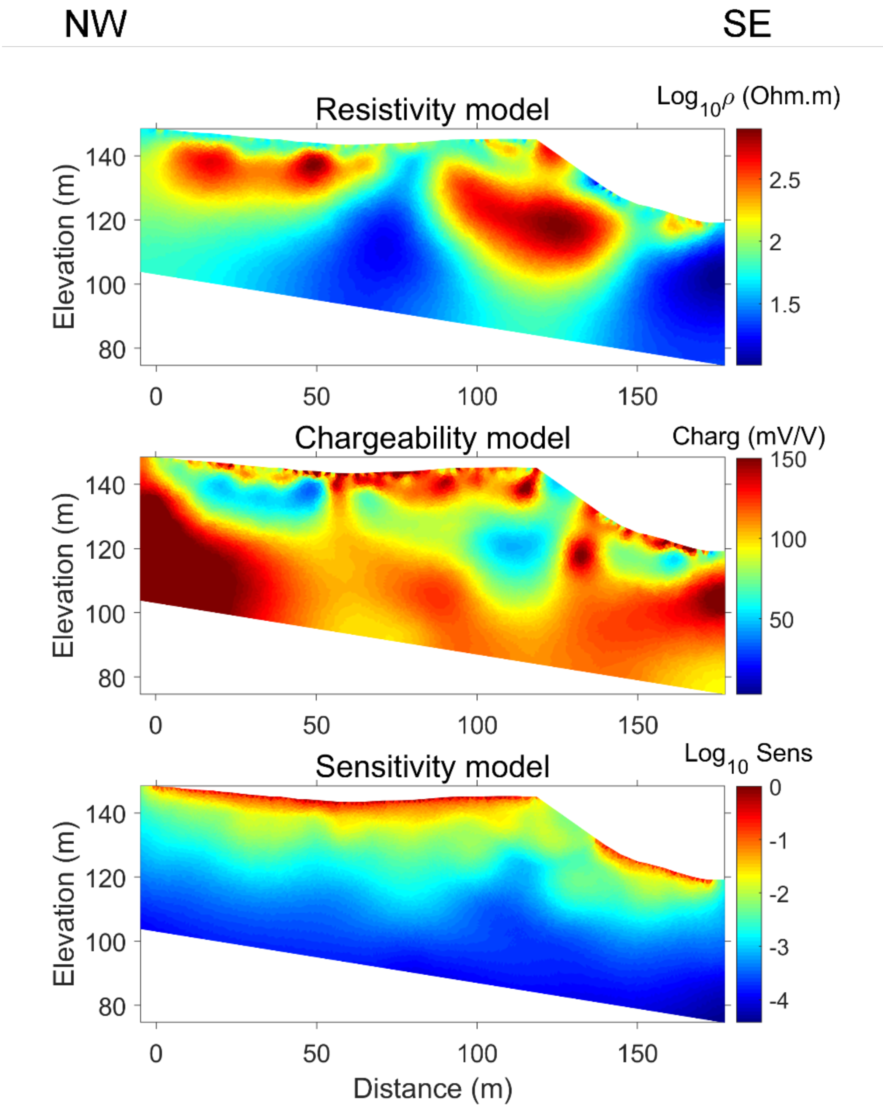


Figure 5 : Resistivity model (top), chargeability model (middle) and normalized sensitivity (bottom) of the profile Pf northwest-southeast oriented (see location in Figure 3).

3 Geophysical survey design

3.1 Coverage

For the first geophysical survey within the framework of NWE-REGENERATIS, the focus will be made on the white slag area and the old factory (see Figure 1). In the slag area, a combination of geoelectric and MASW/SRT methods will be used to highlight material zonation within the slag dump. In the old factory area, electromagnetic induction (EM) and magnetic (MAG) methods will be used to identify anomalous zones possibly related to different backfill compositions. ERT and IP will also be applied to get more resolution with depth.

In the following, the survey design for each geophysical method is described. Note changes may occur during the survey if new measurement opportunities arise or if site constraints do not allow measurements to be made in safe conditions.

3.1.1 Geophysical methods

3.1.1.1 Magnetometry (MAG)

The area of the old factory will be covered with a grid of several 5 m spaced lines and at least three perpendicular lines (Figure 6).

For the positioning, a GPS will be attached to the magnetometer device. In order to ensure consistent coverage and positioning with respect to the other surveying methods, tape measures will be used and start, centre and endpoints will be marked.

Acquisition system: portable caesium magnetometer model G-858 from Geometrics with GPS positioning (no RTK).

Possible modification: Increase/decrease the amount of survey lines according to the vegetation or site accessibility.

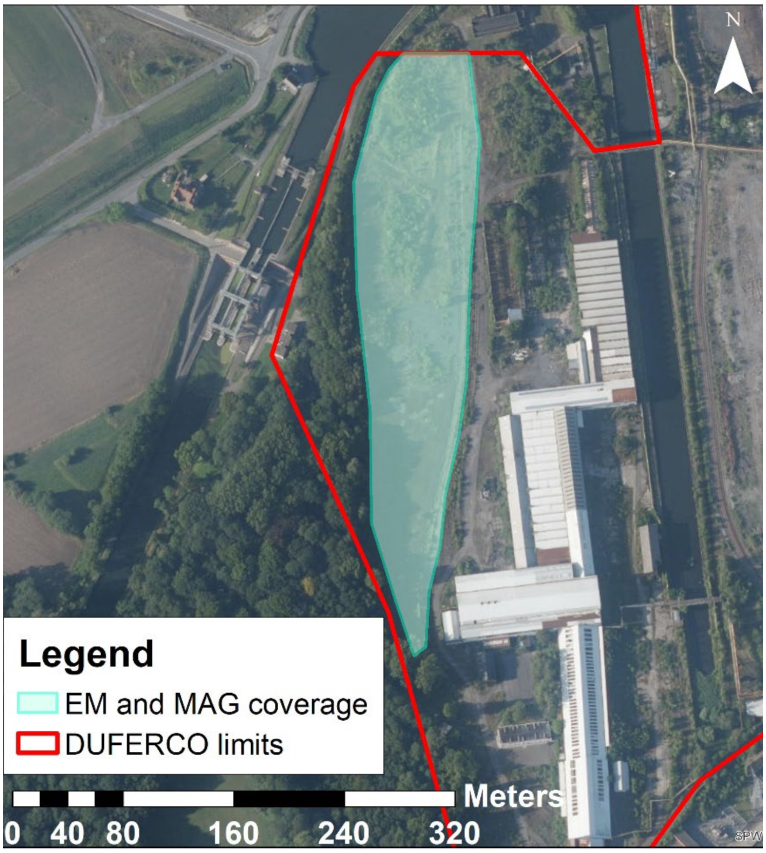


Figure 6 : Area to cover with mapping methods (MAG and EM).

3.1.1.2 EM

The EM survey will be conducted on the same grid as the magnetic survey (Figure 6). The measurements will be done with two antennas to reach investigation depths of 0.5 m, 1 m and 1.8 m. Both, quadrature (related to apparent electrical conductivity) and in-phase (related to apparent magnetic susceptibility) will be recorded simultaneously.

Acquisition system: Mini-explorer from GF-instruments with GPS positioning (no RTK).

Possible modification: Increase/decrease the amount of survey lines according to the vegetation or site accessibility.

3.1.1.3 ERT and IP surveying

White slag area

As a great heterogeneity is expected in the white slag area, as revealed by the 2017 survey, a 3D ERT/IP acquisition will be preferred to a 2D acquisition. In order to get sufficient resolution and depth of investigation, 4 profiles of each 64 electrodes will be deployed as parallel as possible to cover the area where most of the slag is deposited. The spacing between the electrodes will be set to 2 m. The protocol that will be used is a combination of gradient and bipole-bipole. Reciprocal measurements will also be acquired to estimate data quality. At this stage it is difficult to already provide a map with the location of the profiles because the topography on site is very uneven. Instead, their location will be decided during the field campaign based on the accessibility of the area.

Old factory area

The location of the ERT/IP profile in the old factory area will be decided based on the results of the EM and MAG survey. Given the expected limited thickness of the backfill deposits, a high-resolution configuration (*i.e.,* small electrode spacing) will be preferred. Reciprocal measurements will also be acquired to estimate data quality.

Acquisition system: ABEM Terrameter LS system.

Possible modification: Change the number of ERT/IP profiles according to the accessibility of the surveyed areas or the time constraint.

3.1.1.4 MASW and refraction tomography surveying

MASW and refraction tomography methods will be applied along several profiles in the white slag area. For each profile, 48 vertical geophones will be deployed (with possibly roll-along acquisition) and a 5 kg sledgehammer will be used as a source together with a ground-coupled nylon plate. MASW and refraction tomography data will be collected in the area covered by the ERT/IP measurements in order to provide additional information on the stiffness/structure of the different deposits and to map the natural soil (where accessible).

Acquisition system: DAQlink 4 system, 48 vertical geophones (4.5 Hz natural frequency).

3.1.1.5 Positioning

Differential GPS with real time kinetic (RTK) corrections will be used to ensure precise positioning of electrodes and geophones.

Acquisition system: Trimble R10.

3.2 Timing and staff

The survey will involve four people and will be carried from September 28th to October 2nd, 2020.

Planned schedule:

Day 1: *White slag area*

Security instructions: 4 people

Setting up of ERT/IP profiles: 4 people

ERT/IP acquisition: 1 people

Day 2: *White slag area*

Setting up of ERT/IP profiles: 4 people

ERT/IP acquisition: 1 people

Seismic acquisition along Pr: 3 people

Day 3: *White slag area*

Setting up of ERT/IP profiles: 4 people

ERT/IP acquisition: 1 people

Seismic acquisition along P13: 3 people

Day 4: *White slag area and old factory*

ERT/IP acquisition: 1 people

Seismic acquisition along P14: 2 people

EM/MAG grid layout: 2 people

EM/MAG mapping: 2 people

Removal of ERT/IP profiles: 4 people

Day 5: *Old factory*

Setting up of ERT/IP profile: 4 people

ERT/IP acquisition: 1 people

Removal of ERT/IP profiles: 4 people

4 SAMPLING PLAN (UPDATE JANUARY 2020)

This section of the deliverable was written after the geophysical survey that took place from September 28th to October 2nd, 2020.

4.1 SAMPLING MAPS

Interpretation of data collected during the field campaign allowed to design the sampling plan presented here below. Details of acquisition setup and results can be found in Deliverable I3.2.1.

In the white slag area, 9 sampling locations were identified - 4 boreholes and 5 trial pits (see Figure 7). In the old factory area, 4 trial pits will be conducted (see Figure 8). Trial pitting is scheduled in January 2021. An explanation of the sampling plan is provided in the next section based on the geophysical results. In general, the position of the samples was chosen to have at least one sample per "homogeneous" zone identified in the geophysical models obtained.

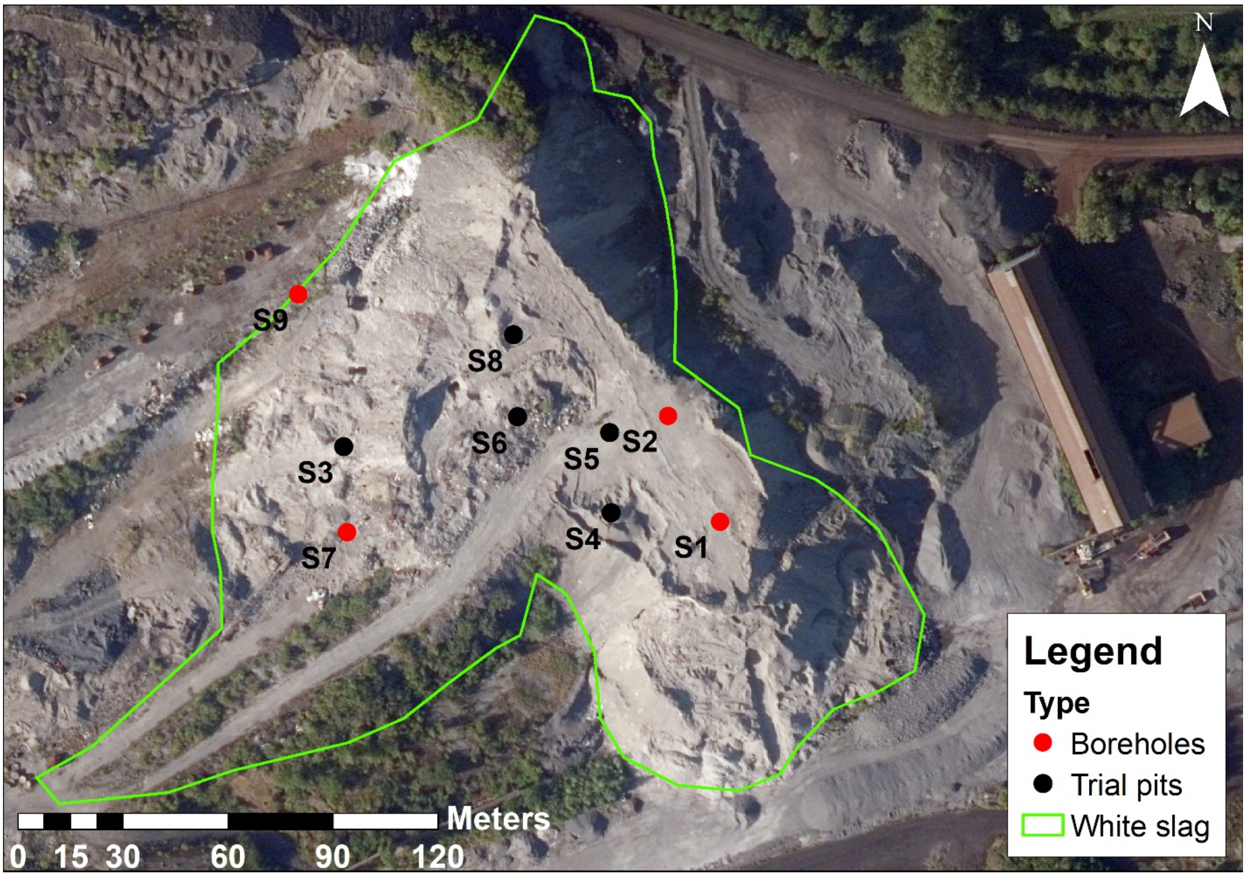


Figure 7 : Location of sampling points in the white slag area

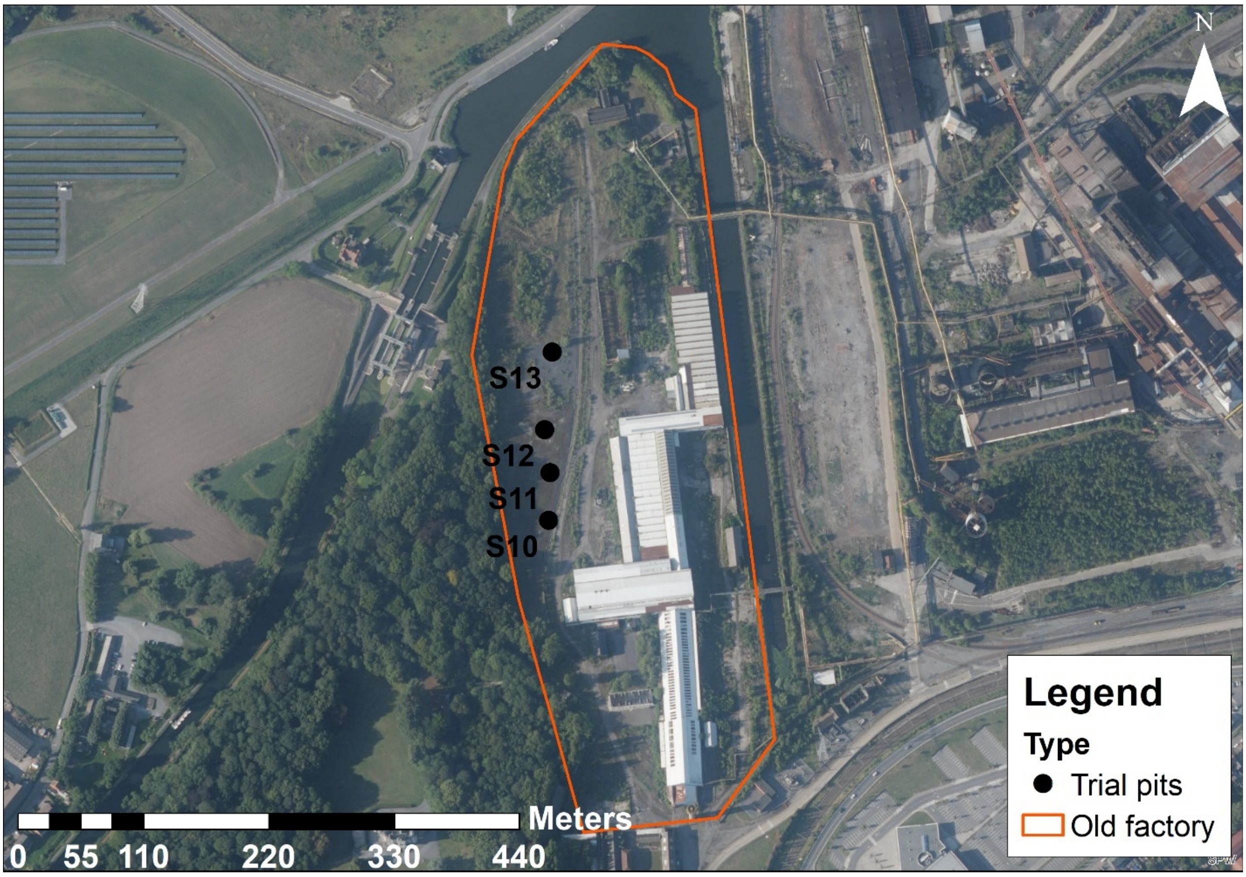


Figure 8 : Location of sampling points in the old factory area

4.2 White slag area

S1 and S2 mainly target the high chargeability anomaly located at an altitude between 130 and 140 m (see Figure 9) which could correspond to a horizon containing more metallic objects. In terms of electrical signature, it is also interesting to understand the difference between the top 10 m of S1 which are characterized by low resistivity and low chargeability and the top 3.5 m of S2 which are characterized by medium resistivity and medium chargeability. S1 also aims to reach the natural ground which will be useful for the estimation of the volume of the whole slag deposit.

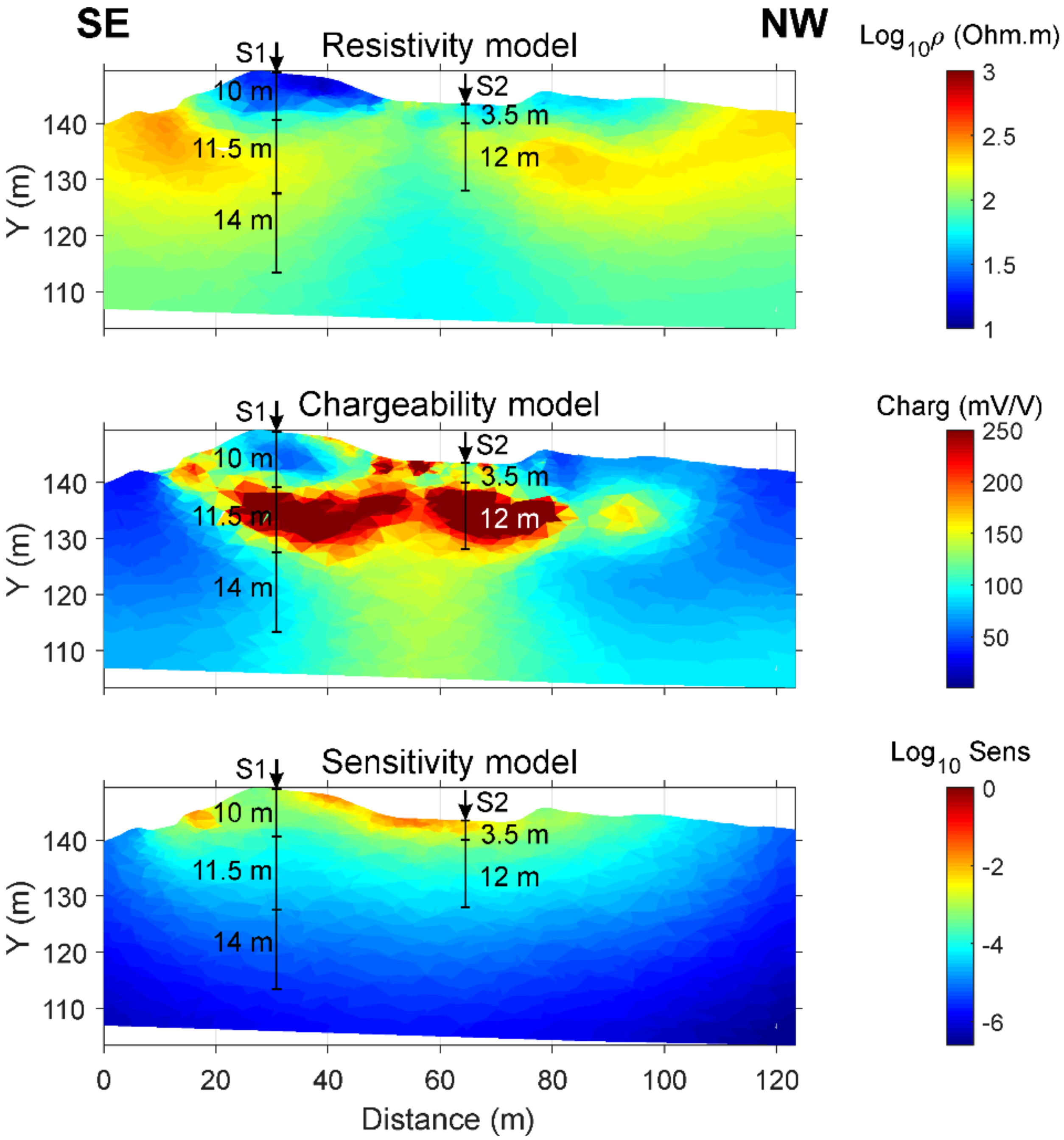


Figure 9 : Cross-section through 3D models of resistivity (top), chargeability (middle) and sensitivity (bottom) through S1 and S2.

S3 and S4 exhibit similar electrical signature, *i.e.,* relatively low electrical resistivity and low chargeability (Figure 10). They may indicate the presence of white slag with few metallic objects.

Note that S4 is close to a zone with medium resistivity which may also suggest the presence of refractory material in the vicinity (S3 also but with slightly more heterogeneity).

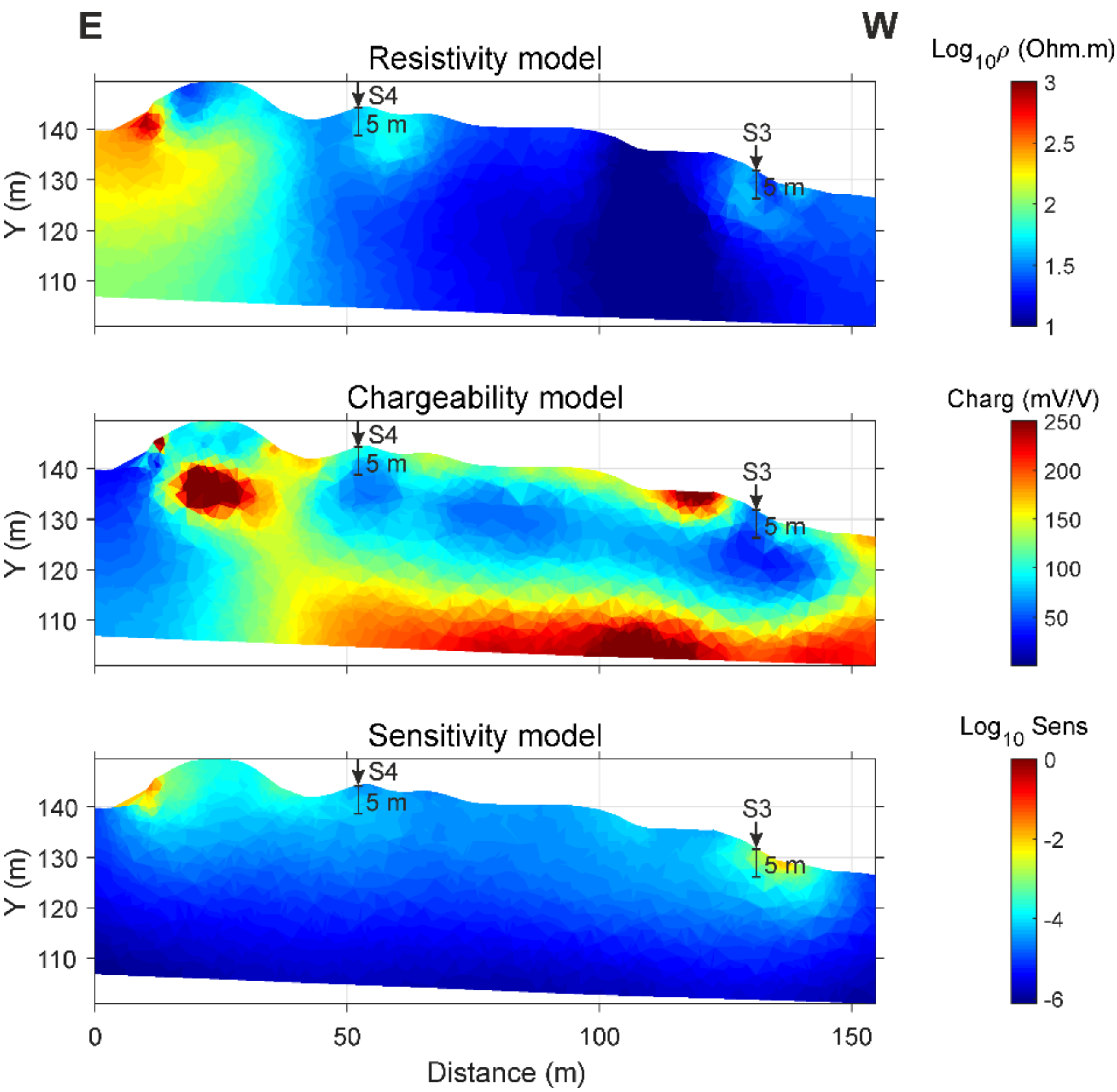


Figure 10 : Cross-section through 3D models of resistivity (top), chargeability (middle) and sensitivity (bottom) through S3 and S4.

S5 is clearly in the middle of a large zone with high resistivity and low chargeability (Figure 11). Given the context, this zone should contain construction waste/refractory block material with very few metallic objects.

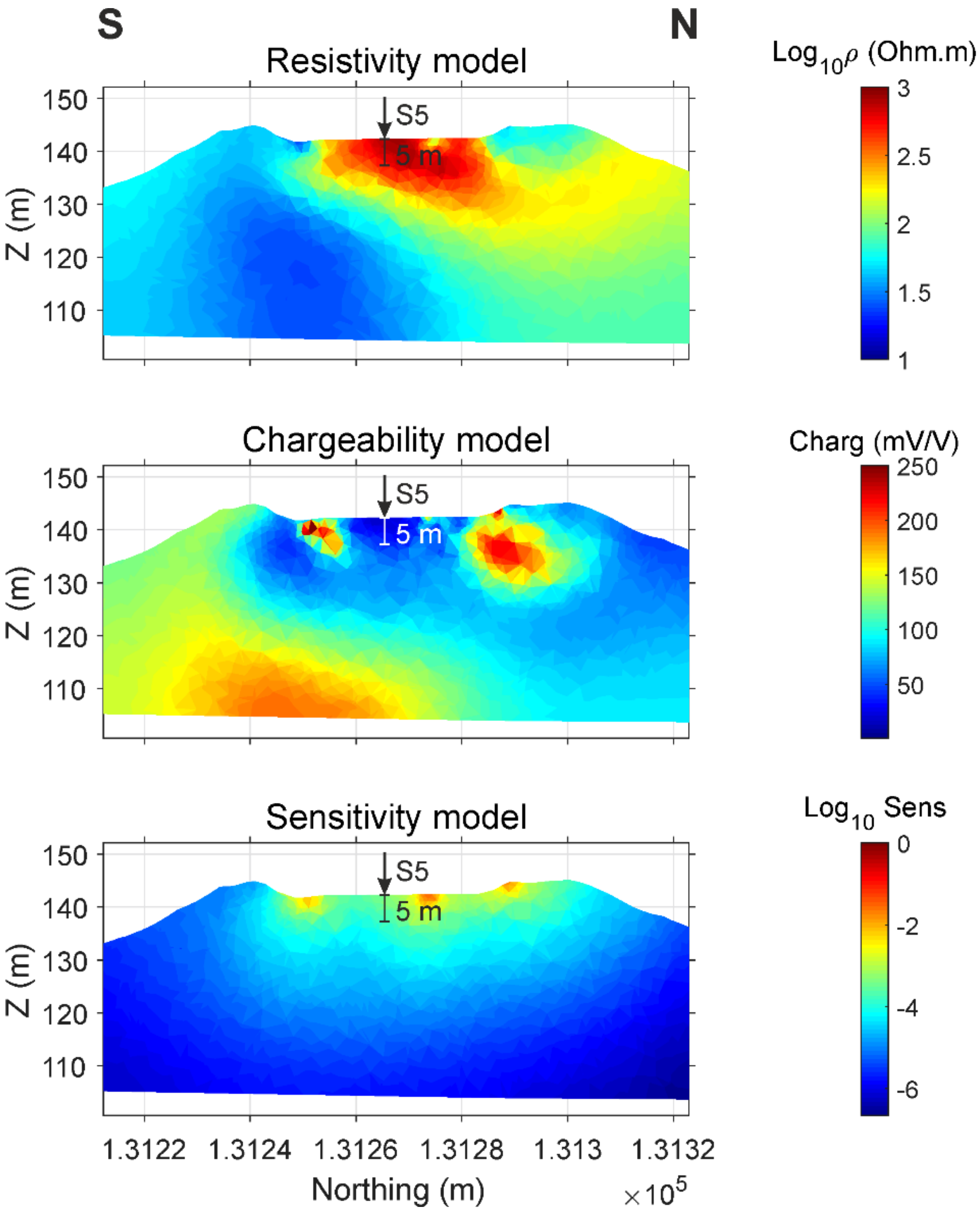


Figure 11 : Cross-section through 3D models of resistivity (top), chargeability (middle) and sensitivity (bottom) through S5.

At the location of S6, high chargeability and low to medium resistivity values are observed (Figure 12). These may indicate the presence of white slag mixed with metallic objects.

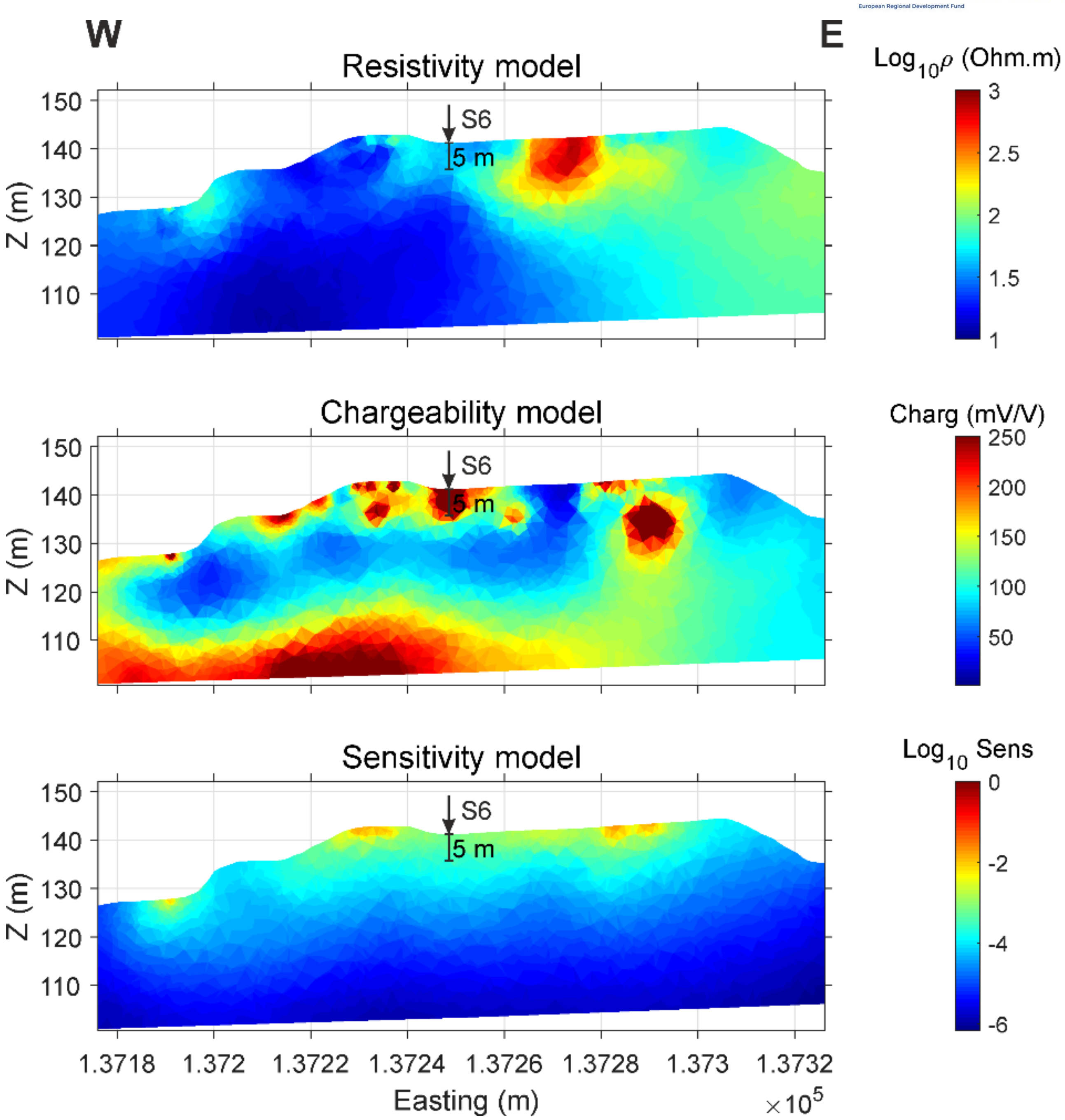


Figure 12 : Cross-section through 3D models of resistivity (top), chargeability (middle) and sensitivity (bottom) through S6.

S7 passes through a high chargeability and low resistivity zone (Figure 13) which can correspond to white slag with a lot of metallic objects (similarly to S6). The idea of drilling at this location is to detect the natural ground level in order to estimate the thickness of the anthropogenic deposits which can later be used to infer the volume of the entire slag dump.

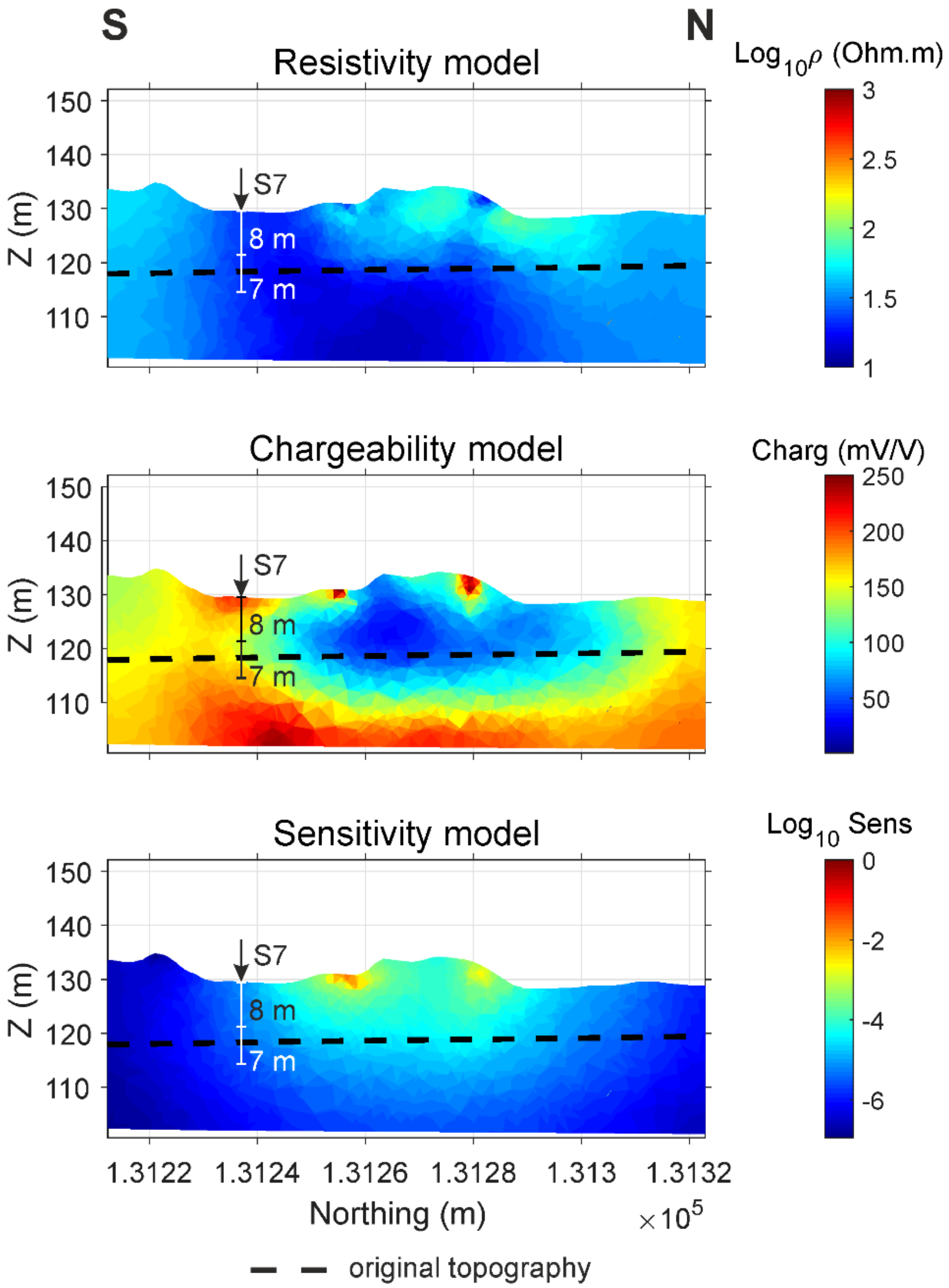


Figure 13 : Cross-section through 3D models of resistivity (top), chargeability (middle) and sensitivity (bottom) through S7.

S8 is in a zone with low to medium resistivity and low to medium chargeability (Figure 14). It may indicate white slag mixed with construction/refractory waste containing relatively few metallic objects.

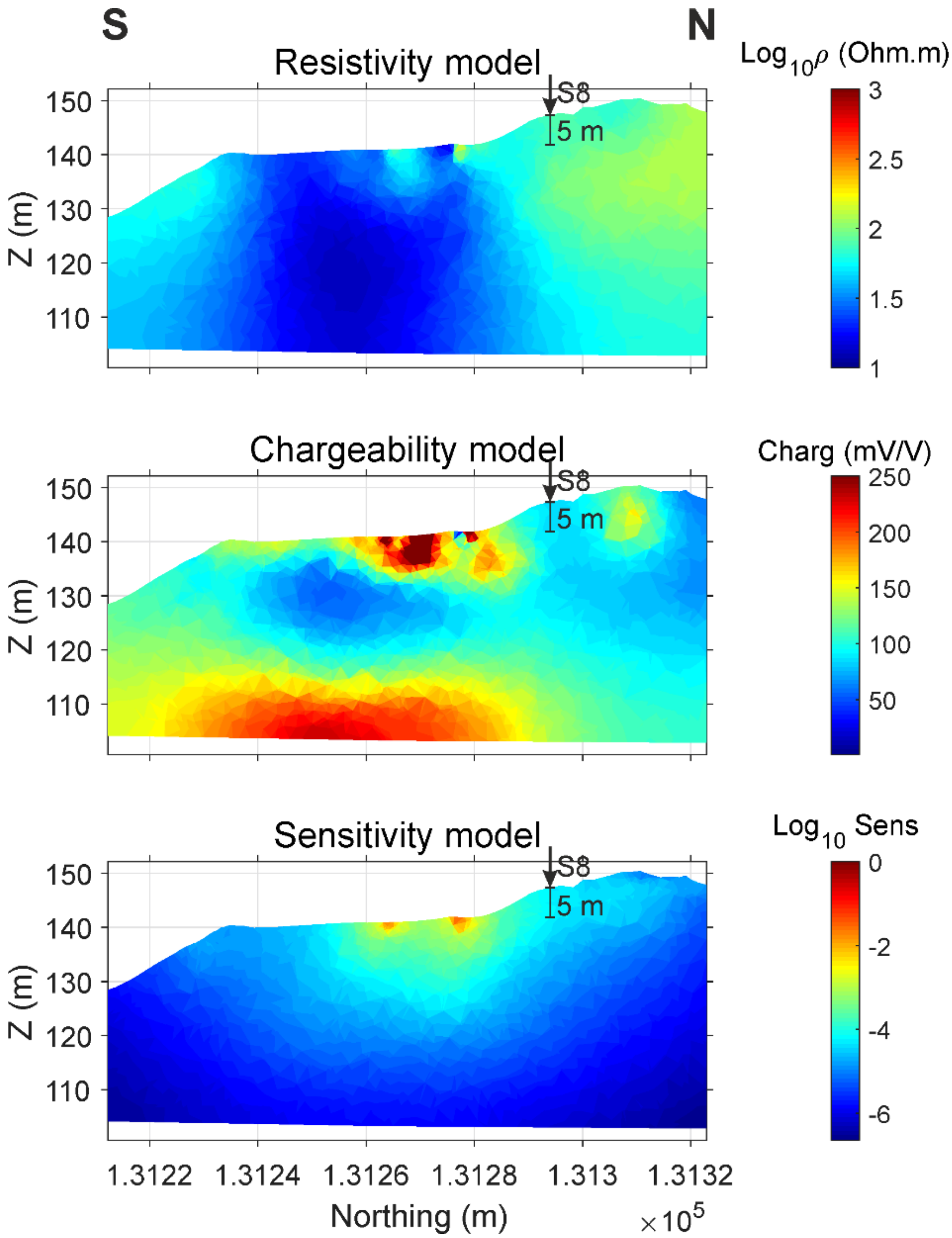


Figure 14 : Cross-section through 3D models of resistivity (top), chargeability (middle) and sensitivity (bottom) through S8.

Finally, S9 exhibits high resistivity and low chargeability (Figure 15) which suggests a different type of material (construction/refractory waste?). The drilling in S9 also aims at identifying the natural ground level for volume estimation.

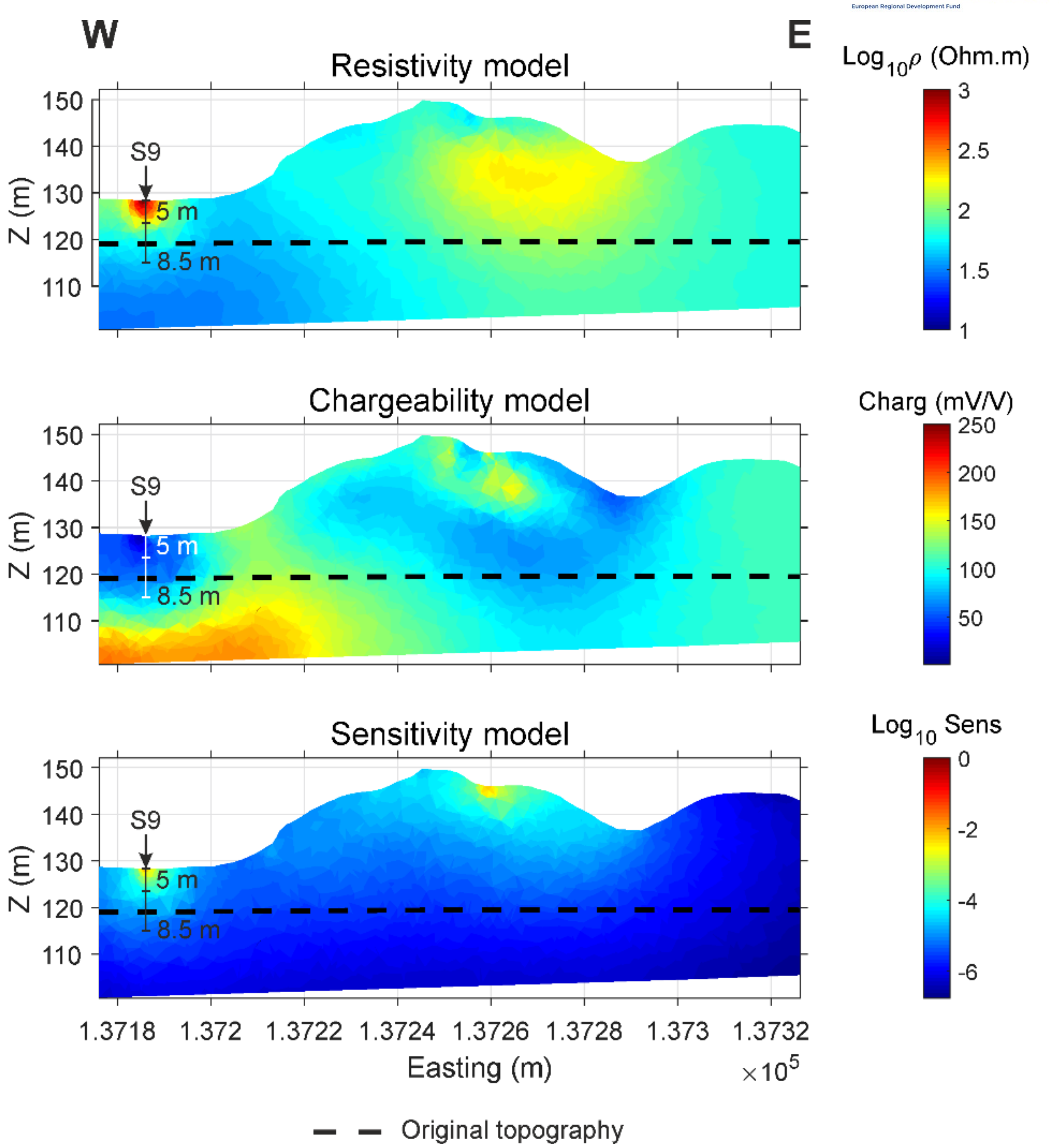


Figure 15 : Cross-section through 3D models of resistivity (top), chargeability (middle) and sensitivity (bottom) through S9.

4.3 Old factory area

Sampling locations in the old factory area were chosen based on the results provided by the EM method at an approximate depth of 1.8 m (Figure 16). The southern area (S10 and S11) exhibits higher quad-phase (meaning higher electrical conductivity – top map) and in-phase (meaning higher magnetic susceptibility – bottom map) values than those further north (S12 and S13). This contrast of electromagnetic properties may indicate different materials with possibly higher metallic content in the south.

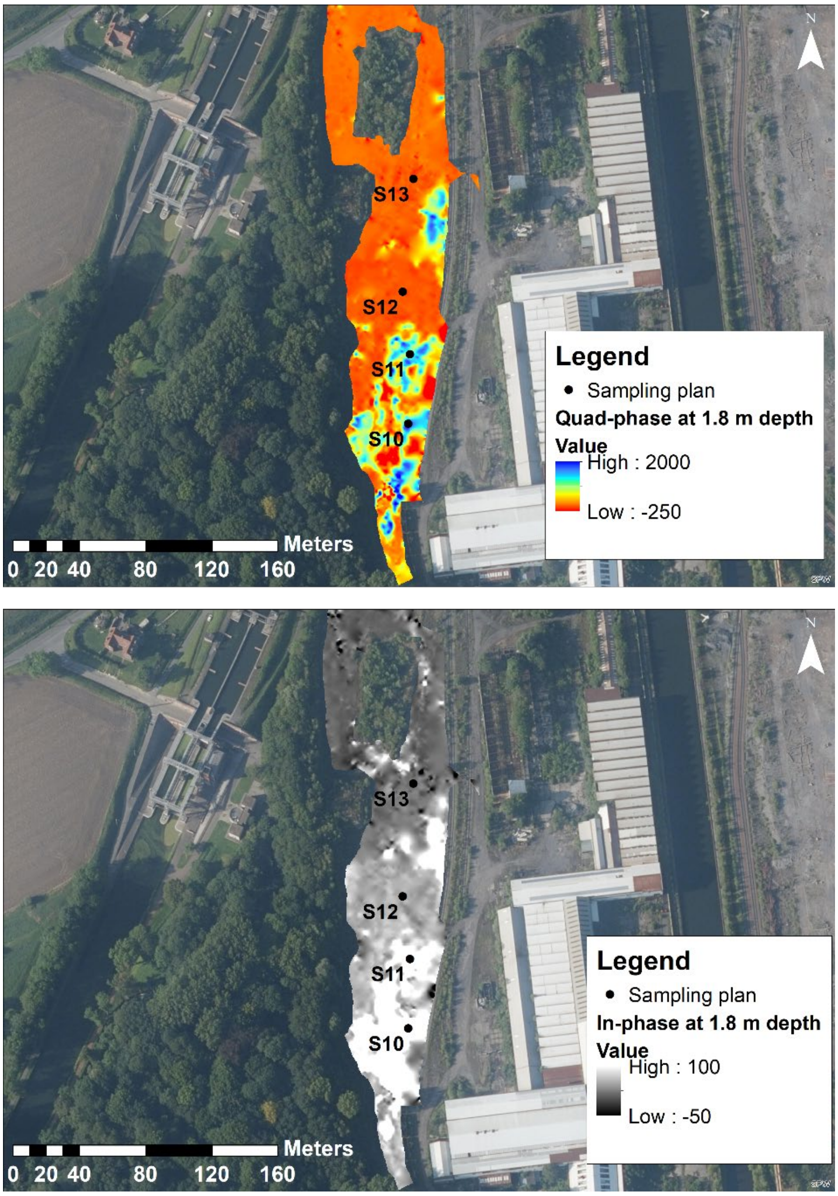


Figure 16 : Location of trial pits S10-S13 with the Quad-phase (related to electrical conductivity – top) and the in-phase (related to magnetic susceptibility – bottom) maps obtained with the EM method.