FEHILY TIMONEY

CONSULTANTS IN ENGINEERING, ENVIRONMENTAL SCIENCE & PLANNING

APPENDIX 3

Minerex Geophysical Survey

Ahascra Historic Landfill
Ahascra, Lisselton, Co. Kerry

Geophysical Survey

Report Status: Final

MGX Project Number: 6426

MGX File Ref: 6426f-005.doc

17th November 2019

Confidential Report To:

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Minerex Geophysics Limited

Subsurface Geophysical Investigations

EXECUTIVE SUMMARY

1. Minerex Geophysics Ltd. (MGX) carried out a geophysical survey consisting of EM31 ground conductivity, 2D-Resistivity and seismic refraction (p-wave) surveying for the ground investigation of an historic landfill at Ahascra, Lisselton, County Kerry.

2. The main objectives of this survey were to identify the extent and depth of the former landfill site, quantify the volume of the waste, provide information on nature of the waste body, waste type and composition, look for evidence of leachate migration from the site and provide information on the underlying subsoil and bedrock.

3. The online bedrock geological map of Ireland (GSI, 2019) indicates the bedrock is Waulsortian Limestone while the overburden in the area is peat. The 2D-Resistivity indicates that the limestone is at a depth of approx. 12m.

4. The survey indicates that there is waste material under the whole site. The extent of the landfill is estimated at 23000 m^2.

5. If the waste was initially dumped on the peat at the same elevation as the surrounding topography, this would give an average thickness of 2.75 m for waste material. This would give a volume of 63250 m^3.

6. It is difficult to differentiate between waste material and peat, with or without leachate. Assuming the peat below the landfill contains leachate to its full depth this would give a depth for the landfill and basal leachate of 12m, which would give a total volume of 276000 m^3 for waste material and overburden with leachate.

7. The low resistivities and seismic velocities measured are consistent with industrial and domestic waste rather than C & D type waste.

8. The results of direct ground investigation tie in well with the geophysical interpretation. The five trial pits all encountered waste and made ground.

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List of Tables, Maps and Figures:

1. INTRODUCTION

1.1 Background

Minerex Geophysics Ltd. (MGX) carried out a geophysical survey at a historical landfill at Ahascra, Co. Kerry. The survey consisted of EM31 ground conductivity, 2D-Resistivity and seismic refraction (p-wave) measurements. The survey was commissioned by Fehily Timoney & Co.

The survey employed various geophysical methods that complement each other and improve the interpretation. The role of geophysics as a non-destructive fast method is to allow later targeted direct investigations. Those results can be used to improve the initial results and interpretation.

A geophysical survey is a fast and effective way to investigate the waste size, extent and possible leachate from the landfill in a non-invasive manner. The geological background is also investigated as part of the survey.

The geophysical survey is part of the tier 2 assessment of historical landfills. The Tier 1 Assessment (Kerry Co. CO. 2013) has assigned a risk classification of B: Moderate risk. It also notes that in 1986 there was an annual intake of 1,638 tones with 4 years remaining capacity. Waste activities had ceased before the completion of the 1998 Waste Management Plan for Kerry.

1.2 Objectives

The main objectives of the geophysical survey were:

- Identify the extent and depth of the former landfill site
- Quantify the volume of the waste
- Provide information on the depth and extent of the capping layer
- Provide information on nature of the waste body, waste type and composition
- Look for evidence of leachate migration from the site
- Provide information on the underlying subsoil and bedrock

1.3 Site Description

The site is located in the townland of Ahascra, Lisselton. It covers an area of 2.65 Ha consisting of one large grass field with an old compound in the east. The field is dome shaped and is higher than the surrounding landscape. Elevations on the site range generally from 12.2 mOD near the centre to 11 mOD near the edge. Around the edge of the field the elevations drops to 8m in the NW and 10.3 in the SE corner. Assess was from a gravel track in the north and through a gate in the NE corner of the field.

The site is surrounded by boggy agricultural land on all sides, there is a ditch running along the western and southern edge of the site.

1.4 Geology

The following information was obtained from the online bedrock geological map of Ireland (GSI, 2019).

The subsoil is described as cut over raised bog while the bedrock is Waulsortian Limestone which is described as massive unbedded lime-mudstone. This type of rock is karstifiable but there are no karst features noted in the area.

The ground water vulnerability in this area is designated as being moderate.

1.5 Report

This report includes the results and interpretation of the geophysical survey. Maps, figures and tables are included to illustrate the results of the survey. More detailed descriptions of geophysical methods and measurements can be found in GSEG (2002), Milsom (1989) and Reynolds (1997).

The client provided maps of the site and the digital version was used as the background map in this report. Elevations were surveyed on site and are used in the vertical sections.

The interpretative nature and the non-invasive survey methods must be taken into account when considering the results of this survey and Minerex Geophysics Limited, while using appropriate practice to execute, interpret and present the data, give no guarantees in relation to the existing subsurface.

2. GEOPHYSICAL SURVEY

2.1 Methodology

The methodology consisted of an EM31 Ground Conductivity measurements to map the site. 2D-Resistivity Profiling and Seismic Refraction Profiling were carried out perpendicular to each other through the middle of the waste body as identified from the EM31 ground conductivity results and the existing information.

The survey locations are indicated on Map 1. The profiles and their parameters are tabulated in Table 1 below.

All geophysical surveys are acquired, processed and reported in accordance with British Standards BS 5930:1999 +A2:2010 ‘Code of Practice for Site Investigations’.

Table 1: Geophysical Survey Locations and Acquisition Parameters

Profile Name	**Electrode/Geophone Spacing/m**	**Number of Electrodes/Geophones**	**Profile Length/m**
R1	3	86	255
R2	3	32	93
SUM			**297**
S1	3	86	255
S2	3	32	93
SUM			**297**

2.2 EM31 Ground Conductivity

The EM31 ground conductivity survey was carried out over the area indicated in Map 1 on lines nominally 10 m apart. Along each line a reading of ground conductivity was taken every second while walking along, thereby resulting in a survey grid of nominally 10 x 2 m. The locations were measured with a sub-meter accuracy SERES DGPS system attached to the EM31 and all data was jointly stored in a data logger. The conductivity meter was a GEONICS EM31 with Allegro data logger and NAV31 data acquisition software. The instrument was checked at a base station, the readings were stable and no drift occurred.

EM31 ground conductivity determines the bulk conductivity of the subsurface over a typical depth between 0 and 6 m bgl. and over a radius of approx. 5m around the instrument. The measurements are disturbed by metal and other conductive objects within the range of the instrument. Overground metal objects such as fences and metal posts were noted on site to differentiate them from waste metal buried underground during interpretation.

2.3 2D-Resistivity

2D-Resistivity profiles were surveyed with electrode spacing of 3 m, up to 64 electrodes per set-up and a maximum length of 189 m per profile. The readings were taken with a Tigre Resistivity Meter, Imager Cables, stainless steel electrodes, laptop and ImagerPro acquisition software.

During 2D-Resistivity surveying, data is acquired in the form of linear profiles using a suite of metal electrodes. A current is injected into the ground via a pair of electrodes while a potential difference is measured across a second pair of electrodes. This allows for the recording of the apparent resistivity in a two-dimensional arrangement below the profile. The data is inverted after the survey to obtain a model of subsurface resistivities. The generated model resistivity values and their spatial distribution can then be related to typical values for different geological and manmade materials.

The penetration depth of a resistivity profile increases towards the centre where it reaches an approx. value of 1/6th of the layout length.

2.4 Seismic Refraction

Seismic refraction profiles were surveyed with geophone spacing of 3 m and 24 geophones per set-up resulting in a 69 m length per set-up. The recording equipment consisted of a 24 Channel GEOMETRICS ES-3000 engineering seismograph with 4.5 Hz vertical geophones. The seismic energy source consisted of a hammer and plate. A zero delay trigger was used to start the recording. Normally 7 shot points per p-wave profile were used.

In the seismic refraction survey method a p-wave is generated by a source at the surface resulting in energy travelling through surface layers directly and along boundaries between layers of differing seismic wave velocities. Processing of the seismic data allows geological layer thicknesses and boundaries to be established.

Seismic Refraction generally determines the depth to horizontal or near horizontal layers where the compaction/strength/rock quality changes with an accuracy of 10 – 20% of depth to that layer. Where low velocity layers or where layers dip with more than 20 degrees angle the accuracy becomes much less.

2.5 Site Work

The data acquisition was carried on 8th and 29^{h} of March 2019. The weather conditions were good throughout the acquisition period. Health and safety standards were adhered to at all times. The locations and elevations were surveyed with a TRIMBLE RTK-GPS to accuracy < 0.05 m.

Access was available on the historic landfill site but not in the periphery of the site.

3. RESULTS AND INTERPRETATION

The interpretation of geophysical data was carried out utilising the known response of geophysical measurements, typical physical parameters for subsurface features that may underlay the site, and the experience of the authors. The interpretation is based on all the methods carried out on site.

For this final version of the report the logs for trial pits and boreholes were received. The locations are shown on the maps and the abbreviated logs for trial pits are indicated on the figures.

3.1 EM31 Ground Conductivity

The EM31 ground conductivity values were merged into one data file for the survey area and contoured and gridded with the SURFER contouring package. The contours are created by gridding and interpolation and care must be taken when using the data. The contour map is overlaid over the location and base map (Map 2) and the values in milliSiemens/metre (mS/m) are indicated on the colour scale bar.

Within the top 6 m bgl. the conductivities are characteristic for certain overburden and rock types. If there is a high content of clay minerals (which are electrically conductive) then the overburden conductivity will be higher than as if there is a high content of clastic grains like sand or gravel. The purer the clay and the lower the sand/gravel content the higher the conductivity. The water content in the overburden also influences the conductivity but generally the clay content has a larger effect.

Non-natural material like waste or leachate will generally have a high conductivity or increase the conductivity of the natural geological material. Many waste materials decompose or dissolve in the ground and enrich the ground and water with ions, which increase the conductivity and decrease the resistivity. Waste material from domestic and industrial sources generally contain more decomposable or dissolvable material than waste from construction or demolition. Therefore D/I Waste will have lower resistivities and higher conductivities than C&D waste.

Conductivities through most of the sit are high (>40 mS/m), there is a decrease in conductivity along the edge of the site, particularly along the eastern edge of the site where conductivities drop to 15 mS/m. A number of negative (Blank) readings are also seem throughout the site which indicates the presence of buried metal. The large area of negative readings in the east are due to the old compound which had large metal fences around it. The conductivities indicate waste material located through the entire extent of the site.

3.2 2D-Resistivity

The 2D-Resistivity data was positioned and inverted with the RES2DINV inversion package. Roll-along profiles were concatenated for a joint inversion. The programme uses a smoothness constrained least-squares inversion method to produce a 2D model of the subsurface model resistivities from the recorded apparent resistivity values. Three variations of the least squares method are available and for this project the Jacobian Matrix was recalculated for the first three iterations, then a Quasi-Newton approximation was used for subsequent iterations. Each dataset was inverted using seven iterations resulting in a typical RMS error of <3.0%. The resulting models were colour contoured with the same resistivity scale for all profiles and they are displayed as cross sections (Figure 1). A vertical exaggeration of 4 is used for the sections.

The resistivities are the inverse value of the conductivities therefore remarks made above for the conductivity are also valid for the resistivity. It has to be considered that the conductivity is determined as a single bulk value for a depth range from 0 - 6 m bgl. while the 2D-Resistivity method determines the values based on depth levels.

Resistivities are characteristic for certain overburden and rock types. If there is a high content of clay minerals (which are electrically conductive) then the overburden resistivity will be lower than as if there is a high content of clastic grains like sand or gravel. The purer the clay and the lower the sand/gravel content the lower the resistivity. The water content in the overburden also influences the resistivities but generally the clay content has a larger effect.

The resistivities on this site shows a rapid change from low resistivities (<125 Ohmm) to high resistivities (>1000 Ohmm) at an elevation of between -2.5 and 1 mOD. The lower resistivities indicate landfill material, leachate and also possibly peat. The higher resistivities below indicate fresh limestone underlaying the site. Near the surface the resistivities are higher, particularly near the start of profile R1 which indicates drier landfill material or a thicker layer of topsoil covering the landfill in this area.

3.3 Seismic Refraction

The p-wave seismic velocity is closely linked to the density of subsurface materials and to parameters like compaction, stiffness, strength and rock quality. The higher the density of the subsurface materials the higher the seismic velocity. Similarly for the other parameters it is generally valid that a more compacted, stiffer and stronger material will have a higher seismic velocity. For rock, the seismic velocity is higher when the rock is stronger, less weathered and has a higher quality. If the rock is more weathered, broken, fractured, fissured or karstified then the seismic velocity will be reduced compared to that of intact fresh rock.

Because of the above relationship, the seismic refraction method and seismic velocities are suitable to investigate ground where the layers get denser, more compacted and stronger with depth. A disadvantage is that some materials may have the same seismic velocity, in particular any capping material over the landfill will have a similar seismic velocity range as the landfill material below it.

The seismic refection data was analysed using the SEISIMAGER software package. The data shows very low seismic velocities near the surface but did not identify any higher velocity layers within the parameters of the survey. This is be due to the thickness of the waste material or due to the minimal difference in seismic velocities between waste material and peat. Velocities were obtained for the top layer and the average seismic velocities obtained within the layers are annotated on the sections as bold green numbers on Figure 1.

3.4 Interpretation of Resistivity and Seismic Refraction

The seismic refraction and 2D-Resistivity provide information on two physical parameters of the landfill material, however as discussed above the landfill material may share some of these physical parameters with other material.

Interpreted cross sections are shown in Figure 2. The first layer represents waste material with the bottom of this layer being derived from the surrounding natural elevations. This layer is interpreted as waste material. The second layer represents low resistivities below the assumed original ground elevations. This layer is likely peat with leachate however it is possible some or all of the peat was removed before the landfill was opened. This layer would then be comprised of waste material as well. The higher resistivities within layer 3 are interpreted as fresh limestone. There does not appear to be any leachate within this layer.

4. CONCLUSIONS

The following conclusions are made:

Geological Background

The online bedrock geological map of Ireland (GSI, 2019) indicates the overburden in this area is cut raised peat while the bedrock is Waulsortian Limestone. The 2D-Reistivity indicates the limestone is at a depth of ~12m bgl.

Boreholes and Trial Pits

The results of direct ground investigation tie in well with the geophysical interpretation. The five trial pits all encountered waste and made ground.

Lateral extent of waste and landfill boundary

The EM31 ground conductivity indicates the landfill material extends throughout the survey area to where the ground slopes off towards the natural ground around it. There appears to be an area towards the middle of the site near the road where there was an old compound where there is less or no waste material. The total area covered by the waste body is approx. 23000 m^2.

Vertical extent (depth) of waste and basal leachate

The thickness/depth has been estimated from the seismic refraction and 2D-Resistivity data and historical maps. A thickness of 2.75 m for the landfill has been taken using the surrounding natural topography. Using the low resistivities, an average thickness of 12m has been calculated for a combined layer representing landfill material and leachate in peat.

Volume of waste and basal leachate

Considering the areas and average thickness above, the volume of waste material (Layer 1) has been calculated as 63250 m^3. The volume of the total waste and basal leachate is estimated at 276000 m^3.

Nature of waste

Low resistivities and seismic velocities measured are consistent with industrial and domestic waste rather than C & D type waste.

Capping layer

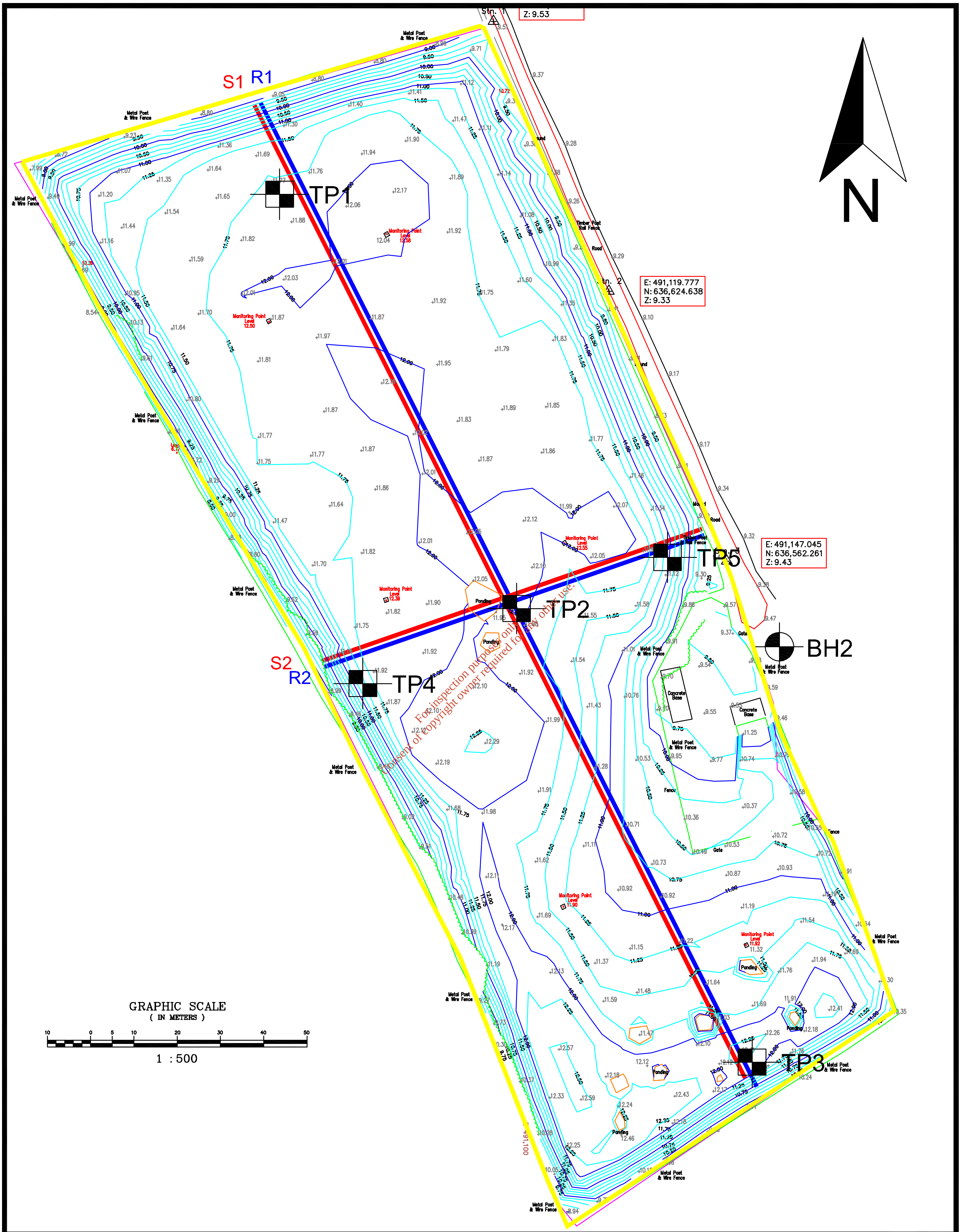
There is no engineered capping layer over the landfill but higher resistivities near the surface along some of the site such as near the start of profile R1 may indicate a thicker capping layer in this area.

Leachate

There is likely significant leachate movement below the landfill. This movement does not appear to penetrate into the bedrock below.

5. REFERENCES

1. **GSEG 2002.** Geophysics in Engineering Investigations. Geological Society Engineering Geology Special Publication 19, London, 2002.
2. **GSI, 2019.** Online Geological Map of Ireland. Geological Survey of Ireland 2019.
3. **Milsom, 1989.** Field Geophysics. John Wiley and Sons.
4. **Reynolds, 1997.** An Introduction to Applied and Environmental Geophysics. John Wiley and Son.
5. **Kerry Co. Co 2013.** Tier 1 Review Report – Ahascra, Lisselton S22 - 02664



Minerex Geophysics Limited	
CLIENT	Fehily Timoney & Co. Kerry Co. Co.
PROJECT	Ahascra Historical Landfill Geophysical Survey
TITLE	Map 1: Geophysical Survey Location Map
SCALE:	1:800 @ A3
PROJECT:	6426
DRAWN:	JC
DATE:	17/11/2019
MGX FILE:	6426f_MapsFigs.dwg
STATUS:	Final

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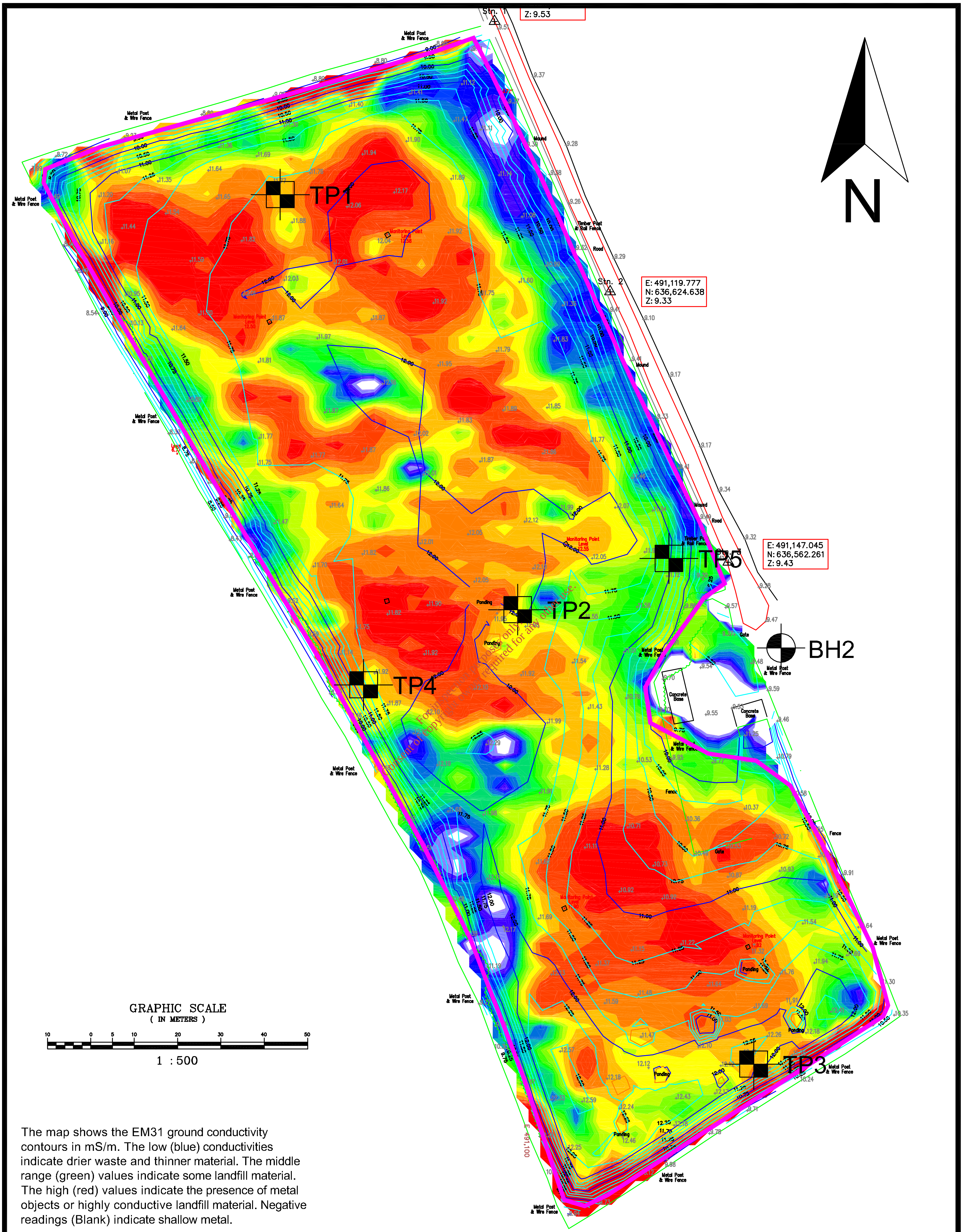
LEGEND: Geophysical Survey Locations:

- R2 — 2D-Resistivity Profile
- S1 — Seismic Refraction Profile
- EM31 Survey Area
- BH1 — Borehole
- TP1 — Trial Pit



The map shows the EM31 ground conductivity contours in mS/m. The low (blue) conductivities indicate drier waste and thinner material. The middle range (green) values indicate some landfill material. The high (red) values indicate the presence of metal objects or highly conductive landfill material. Negative readings (Blank) indicate shallow metal.

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CLIENT	Fehily Timoney & Co. Kerry Co. Co.
PROJECT	Ahascra Historical Landfill Geophysical Survey
TITLE	Map 2: EM31 Ground Conductivity Contour Map

SCALE:	1:800 @ A3
PROJECT:	6426
DRAWN:	JC
DATE:	17/11/2019
MGX FILE:	6426f_MapsFigs.dwg
STATUS:	Final

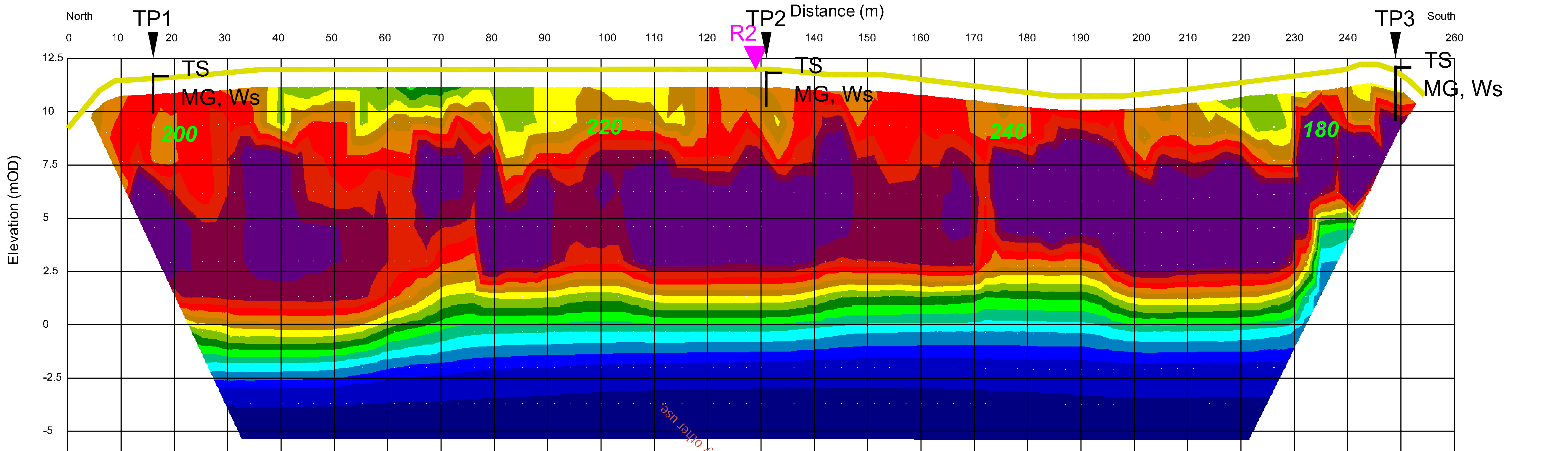
LEGEND:

Interpreted Outline of Landfill

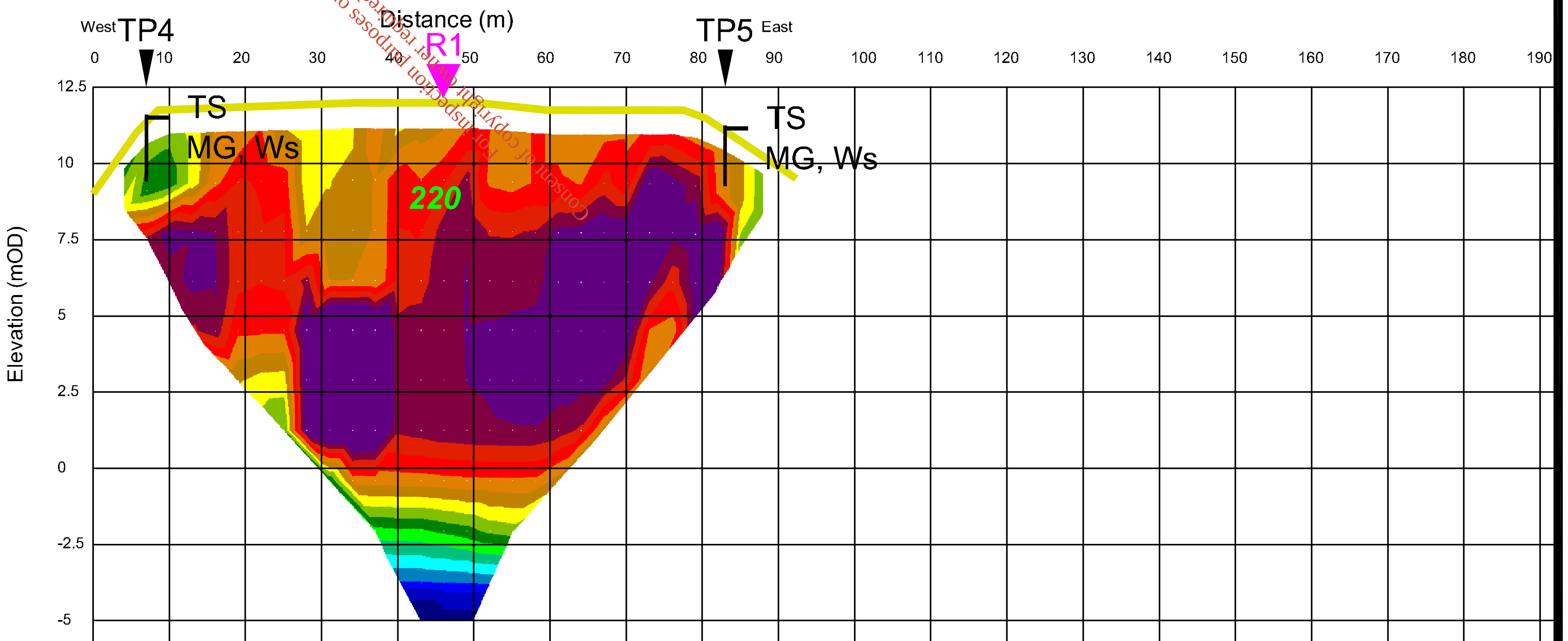
EM31 Ground Conductivity Scale in mS/m:

0 10 20 30 40 50 60 70 80 90 100

2D-Resistivity Profile R1 and Seismic Refraction Profile S1 Model



2D-Resistivity Profile R2 and Seismic Refraction Profile S2 Model



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CLIENT	Fehily Timoney & Co. Kerry Co. Co.
PROJECT	Ahascra Historical Landfill Geophysical Survey
TITLE	Figure 1: Models of Geophysical Survey

SCALE:	1:800 @ A3, VE x 4
PROJECT:	6425
DRAWN:	JC
DATE:	17/11/2019
MGX FILE:	6425f_MapsFigs.dwg
STATUS:	Final

LEGEND:

2D-Resistivity Model Values:

Resistivities (Ohmm) for 2D-Resistivity Model

15.6 31.2 62.5 125 250 500 1000 2000

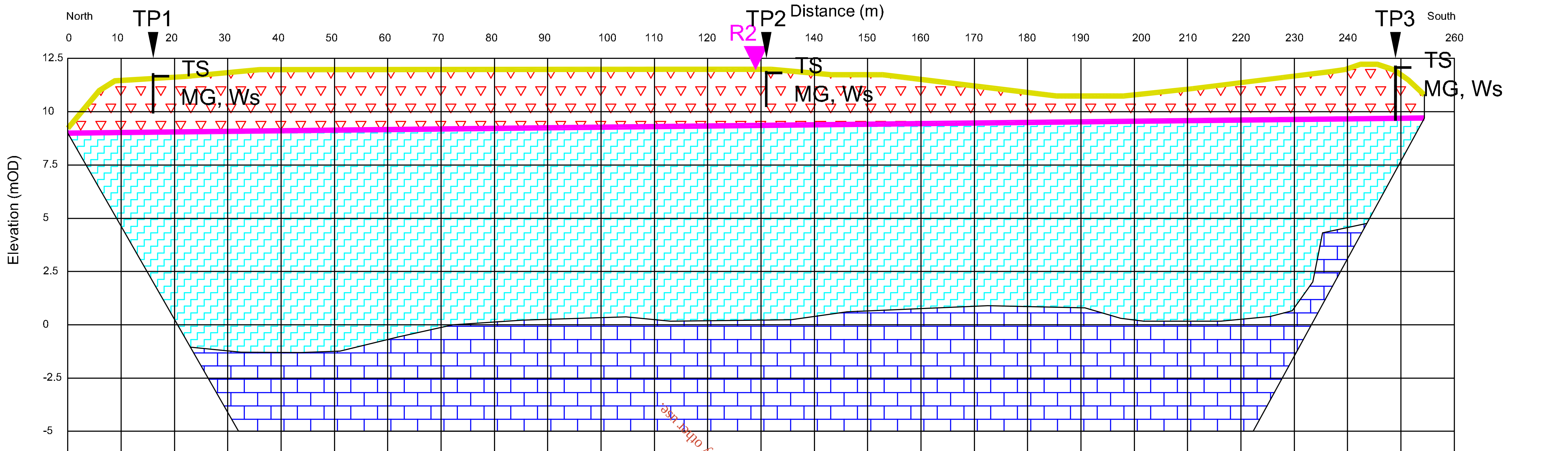
Seismic Velocities below the Surface:

220 Seismic Velocity in m/s (Direct Wave)

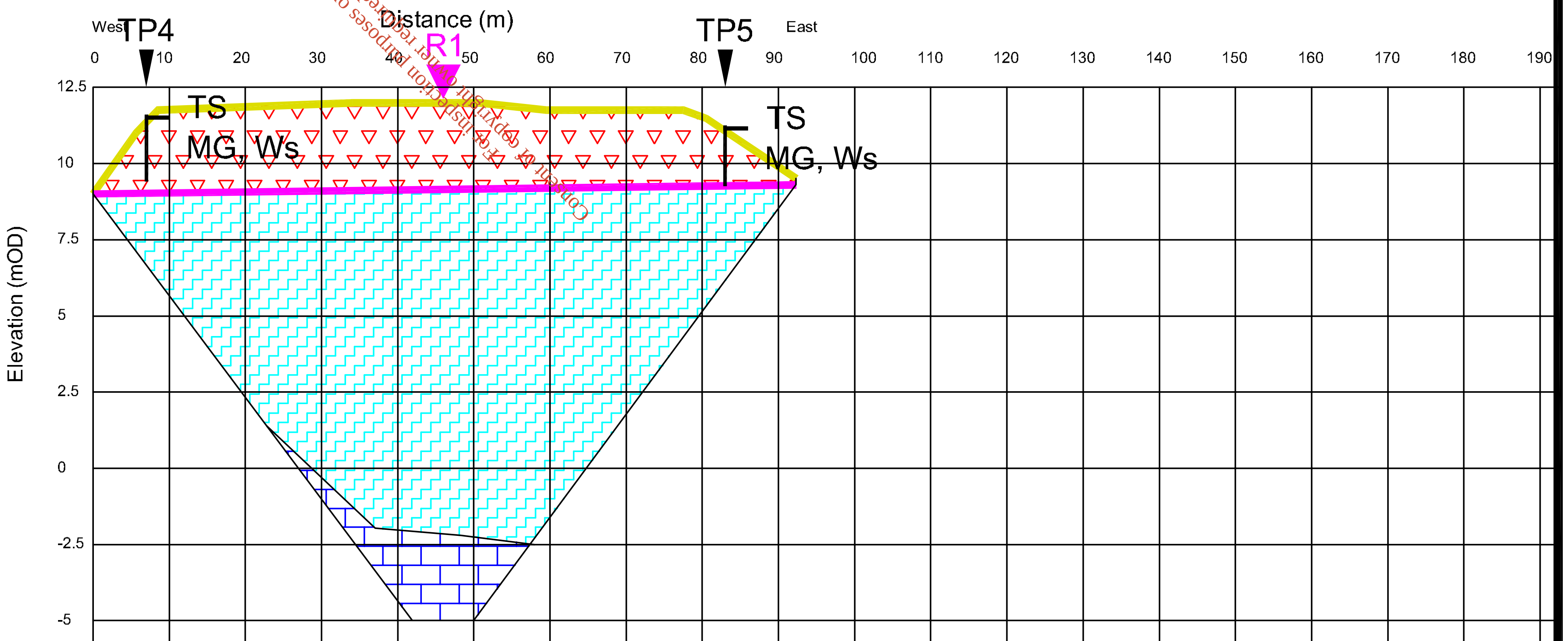
Abbreviated GI Logs:

TS	Topsoil
Ws	Waste Material
Mg	Made Ground

2D-Resistivity Profile R1 and Seismic Refraction Profile S1 Interpretation



2D-Resistivity Profile R2 and Seismic Refraction Profile S2 Interpretation



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CLIENT	Fehily Timoney & Co. Kerry Co. Co.
PROJECT	Ahascra Historical Landfill Geophysical Survey
TITLE	Figure 2: I nterpretation of Geophysical Survey

SCALE:	1:800 @ A3, VE x 4
PROJECT:	6425
DRAWN:	JC
DATE:	17/11/2019
MGX FILE:	6425f_MapsFigs.dwg
STATUS:	Final

LEGEND:

Interpretation:

1 Waste Material
2 Waste Material or Peat with Leachate
3 Fresh Limestone

Abbreviated GI Logs:

TS	Topsoil
Ws	Waste Material
Mg	Made Ground