FEHILY TIMONEY

CONSULTANTS IN ENGINEERING, ENVIRONMENTAL SCIENCE & PLANNING

APPENDIX 3

Minerex Geophysics Geophysical Survey Report

Ardfert Historic Landfill

Ardfert, Co. Kerry

Geophysical Survey

Report Status: Final

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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 in Ardfert, 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) indicate the area is underlain by Cloonagh Limestone Formation. Historic maps show the site was previously a limestone quarry. The seismic refraction and 2D-Resistivity results show the rapid change from waste material to fresh limestone beneath.

4. **The results of direct ground investigation obtained dafter the draft report tie in well with the geophysical interpretation. The outline and size of the landfill area has been slightly increased after the draft report, based on the observed made ground in the trial pits covering a slightly larger area than previously interpreted from the EM31 data. It is noted that ground conditions are very dry (no water encountered to 14.5 m in the BH1).**

5. The survey located a waste body located within the historic quarry. The extent of the landfill is estimated at **1675 m^2**.

6. The 2D-Resistivity results indicate the depth to the base of the landfill varied around the site from 2.5m around the periphery to 4.2 m near the centre.

7. An estimated volume for the landfill was calculated at **5025 m^3** including material placed over the landfill when it became disused.

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

9. The limestone appears to be fresh around the landfill with one small area where there is possible karstification in the west of the site.

10. There is no indication from the geophysical survey of leachate migrating from the landfill, however the elevations drop quickly north of the survey area and leachate may be able to move in this direction.

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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 an historical landfill in Ardfert, 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. Tier 1 has assigned a risk classification of B: Moderate risk, however the site that was assessed was a field to the west of the correct site.

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 north of the village of Ardfert. The Ardfert Cathedral site is located immediately to the south. A private dwelling to the north and fields to the west and east border the site. Access was gained from a track to the west off the R551.

The site covers an area of approx. 0.18 Ha. The topography drops from the Cathedral site towards the north from 20 mOD to 14 mOD. Immediately north of the site the topography drops quickly to 10 mOD. The site is partially overgrown and appears to have been disused for some time. There is no clear visible evidence of a landfill on the site.

1.4 Geology

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

The quaternary sediments map says the site is on karstified bedrock outcrop while the surrounding subsoil type is described as till derived from Namurian sandstone and shale. The bedrock is the Cloonagh Limestone Formation which is described as bedded bioclastic limestone. This map also noted shallow rock on the site. While this rock is karstifiable, there are no karst features noted in the area on the karst database.

Around the shallow rock, the groundwater vulnerability is described as E (Extreme). Historical Maps from 1888 – 1913 note a disused quarry extending to the north from the site. The map also notes other disused quarries to the west of the site.

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 a topographical map 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 survey 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	27	78
R2	3	11	30
SUM			**108**
S1	3	24	69
S2	3	9	24
SUM			**93**

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 27 electrodes per set-up and a maximum length of 78 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. depth of 15m.

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 28h 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 however due to its small size the profile lengths were quite restrictive.

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. The seismic refraction data is used to identify the base of the landfill material while the 2D-Resistivity data is used to determine the extent of landfill material and possible leachate. The EM31 ground conductivity provides spatial information relating to the horizontal extent of the landfill material.

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 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 are generally low (<10 mS/m) around the periphery of the site which indicate natural ground while the conductivity increases to 60 mS/m in the middle of the site which shows the location of the waste material. The large negative readings in the north of the site may indicate buried metal.

3.2 2D-Resistivity

The 2D-Resistivity data was positioned and inverted with the RES2DINV inversion package. 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 show a rapid change from very low to very high resistivities. The low resistivities (<250 Ohmm) represents waste material while the high resistivities (>1000 Ohmm) indicate fresh limestone encompassing the landfill. Along profile R1 there is a slight decrease in resistivities at depth at Ch 20, this may indicate some karstification of the limestone in this area. This could allow leachate migration from the landfill.

The short length of profile R2 restricts the depth penetration along the line and the base of the landfill was not reached along this profile.

3.3 Seismic Refraction

The seismic refraction data was positioned and processed with the SEISIMAGER software package to give a layered model of the subsurface. The numbers of layers has been determined by analysing the seismic traces and 2 layers were used in the models. All seismic profiles were subject to a standardised processing sequence which consisted of a topographic correction which was based on integrated elevation data, first break picking, tomographic inversion, travel-time computation via ray-tracing and velocity modelling. Residual deviations of typically 0.4 to 1.8 msec RMS have been obtained for each profile. Following each processing stage QC procedures were adhered to. The resulting layer boundaries are shown as thick lines overlaid on the 2D-Resistivity cross sections (Figure 1). The average seismic velocities obtained within the layers are annotated on the sections as bold black numbers.

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.

Landfill material typically has very low seismic velocities and high wave energy attenuation as it is not as compacted as natural ground. This makes penetration of landfill material with seismic waves very difficult.

Layer 1 has seismic velocities of between 230 m/s and 450 m/s which indicates waste material.

Layer 2 has seismic velocities of 2500 m/s which represents a rock layer immediately below the landfill.

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. Therefore by using both methods together a clearer picture of the waste body is obtained.

The landfill material can be assumed to consist of low velocity, low resistivity material. Seismic layer 1 and the 2D-Resistivity data generally follow a similar trend which indicate the contrast between low velocity, low resistivity waste material and high velocity, high resistivity limestone.

Table 2 summarises the interpretation. Interpreted cross sections are shown in Figure 2. The interpretation has been made from all available information. The base of the waste material and the depth to rock have been estimated from the seismic refraction results. The 2D-Resistivity data has been used to identify waste material, any leachate migration from the landfill and to determine features within the rock. Along short profile parts where only one data type is available an interpolation for the interpreted layers was made.

Table 2: Summary of Results and Interpretation

Layer	**General Seismic Velocity Range (m/sec)**	**General Resistivity Range (Ohmm)**	**Interpretation**
1	230 - 450	<250	Waste Material and **Made Ground**
2a	2500	<1000	Possibly Karstified Limestone
2b	2500	>1000	Fresh Limestone

4. CONCLUSIONS

The following conclusions are made:

Geological Background

Historic maps show the site was previously a limestone quarry. The GSI online geological maps indicate the area is underlain by Cloonagh Limestone Formation. The geophysical survey indicates that the landfill is surrounded by fresh limestone rock.

Boreholes and Trial Pits

The results of direct ground investigation tie in well with the geophysical interpretation. The outline and size of the landfill area has been slightly increased after the draft report, based on the observed made ground in the trial pits covering a slightly larger area than previously interpreted from the EM31 data. It is noted that ground conditions are very dry (no water encountered to 14.5 m in the BH1) and therefore the ground conductivities are quite low towards the edge of the landfill.

Lateral extent of waste and landfill boundary

The EM31 ground conductivity indicates the landfill material covers the majority of the site with some areas along the periphery appearing to be natural material. The total area covered by the waste body is approx. **1675 m^2.**

Vertical extent (depth) of waste

The thickness/depth has been estimated from the seismic refraction and 2D-Resistivity data. Along profile 1 the landfill reaches a depth of 4.2 m. The base of the landfill near the start of the profile however is 2.5 m on average. 2D-Resistivity Profile R2 does not reach the base of the landfill however profile S2 indicates it reaches depths of 4.2 m while becoming shallower towards the end of the profile.

Volume of waste

An accurate measurement of the volume of waste is difficult due to the changes in thickness of the landfill. Using different depths for a peripheral area and the centre of the waste body, estimated from the conductivity map gives an estimated volume of waste of **5025 m^3. This corresponds to an average thickness of waste and made ground of 3m.**

Nature of waste

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

Capping layer

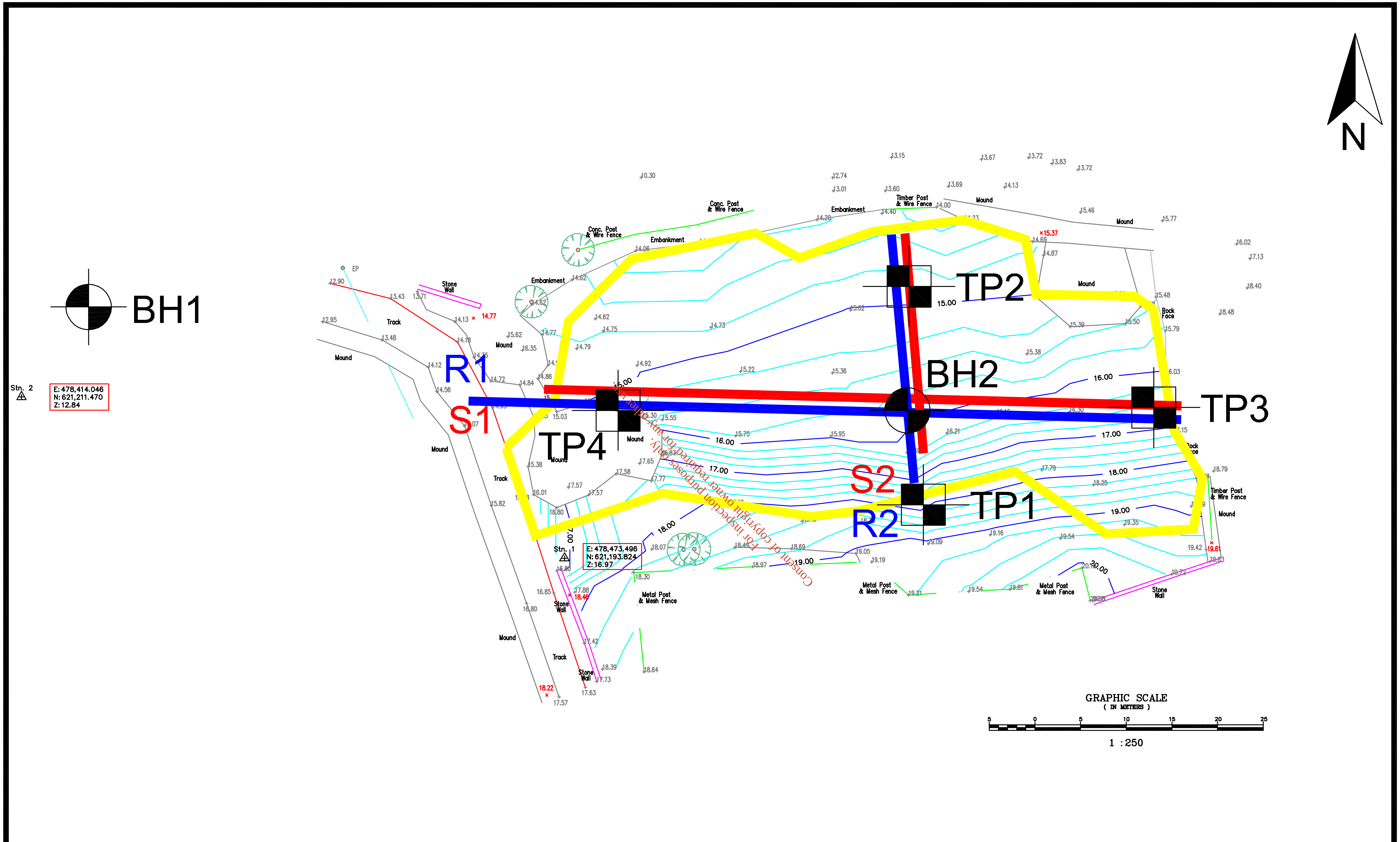
There is no engineered capping layer over the landfill. Very low resistivities at the ground surface indicates that the topsoil layer on site is very thin.

Leachate

There does not appear to be any leachate movement from the landfill. The limestone surrounding the quarry appears to keep it contained. A small possible karstified area near the start of Profile 1 could allow the migration of leachate from the landfill. Immediately north of the survey area the ground drops rapidly towards a stream. It may be possible that leachate can migrate in this direction as there is not a limestone “barrier” restricting it. Further investigations should include the area to the North.

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.



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CLIENT: Fehily Timoney & Co.
Kerry Co. Co.

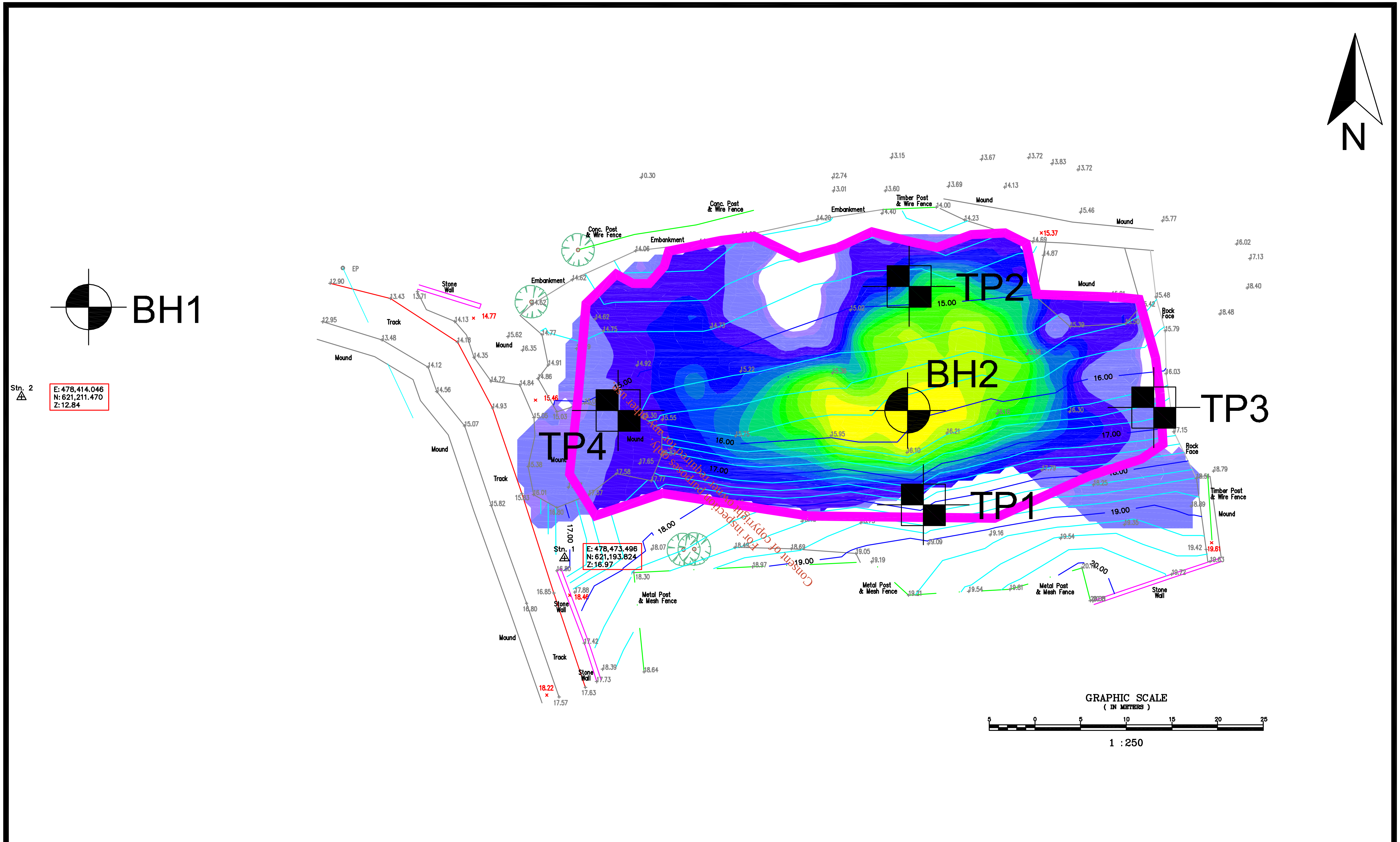
PROJECT: Ardfert Historic Landfill
Geophysical Survey

TITLE: Map1: Geophysical Survey
Location Map

SCALE:	1:400 @ A3
PROJECT:	6425
DRAWN:	JC
DATE:	14/11/2019
MGX FILE:	6425f_MapsFigs.dwg
STATUS:	Final

LEGEND: Geophysical Survey Locations:

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



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

SCALE:	1:400 @ A3
PROJECT:	6425
DRAWN:	JC
DATE:	14/11/2019
MGX FILE:	6425f_MapsFigs.dwg
STATUS:	Final

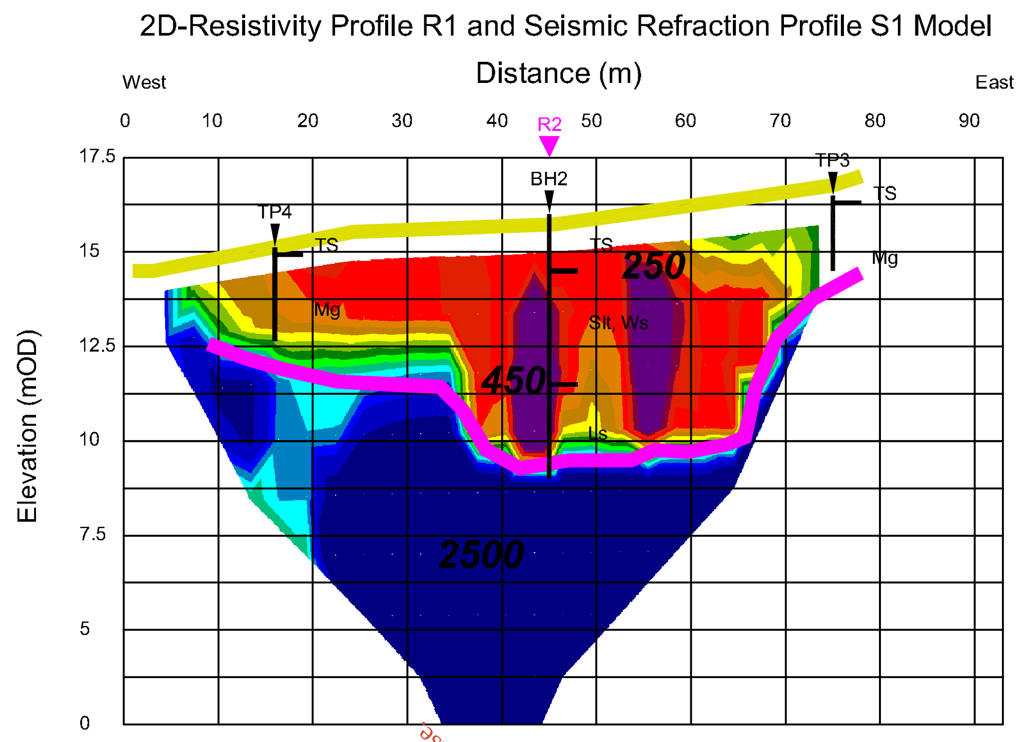
LEGEND:

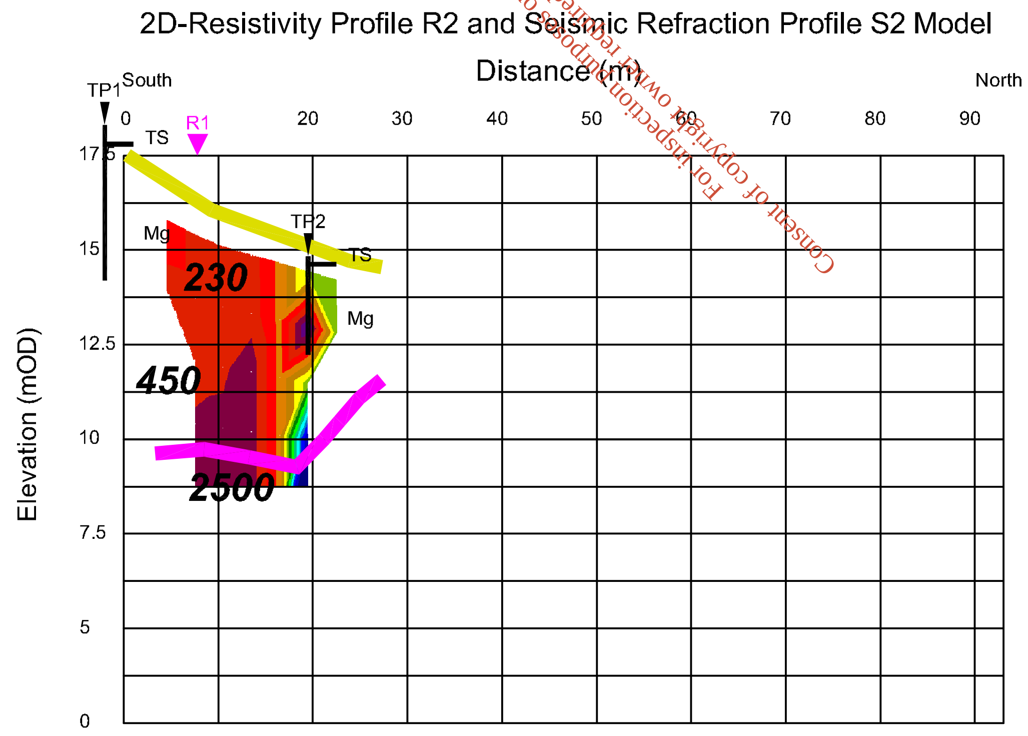
Interpreted Outline of Landfill

EM31 Ground Conductivity Scale in mS/m:

0 10 20 30 40 50 60 70 80 90 100

The map shows the EM31 ground conductivity contours mS/m. The low (light blue) conductivities indicate natural ground. The middle range (dark blue - green) values indicate some landfill material. Negative readings (Blank) in the north indicate buried metal.





Abbreviated GI Logs:

TS	Topsoil
Ws	Waste Material
Mg	Made Ground
Slt	Silt
Ls	Limestone

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

SCALE:	1:800 @ A3, VE x4
PROJECT:	6425
DRAWN:	JC
DATE:	14/11/2019
MGX FILE:	6425f_MapsFigs.dwg
STATUS:	Final

LEGEND:

Layers from Seismic Refraction Model:

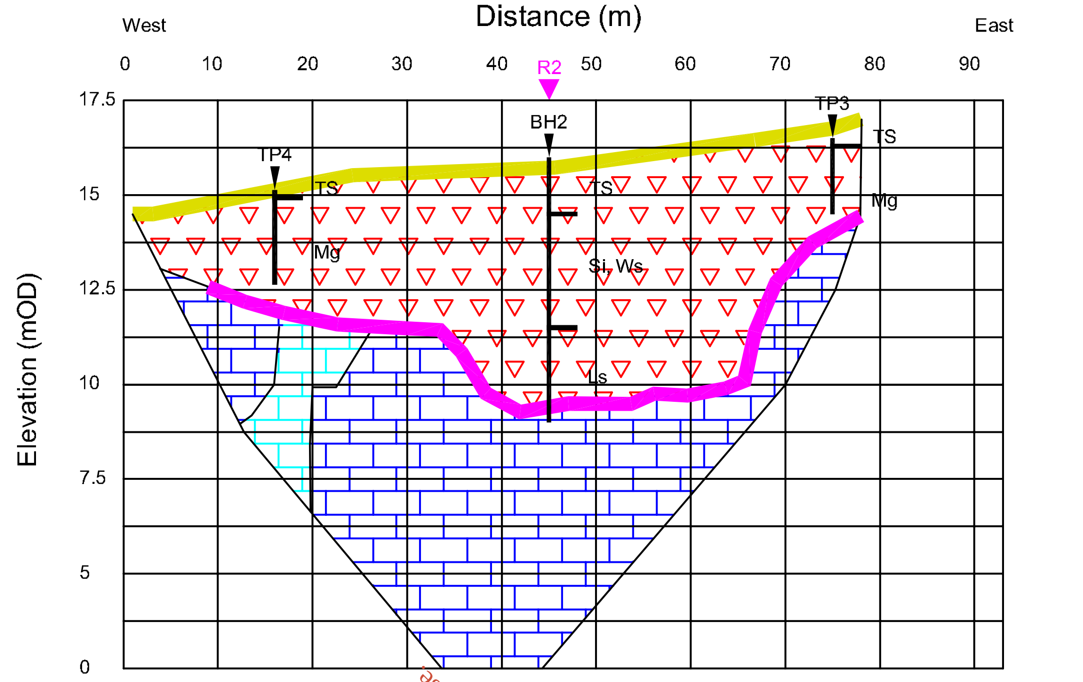
- Ground Surface/Top of Layer 1 (230 - 450 m/s)
- Top of Layer 2 (2500 m/s)
- **1800** Seismic Velocity in m/s

2D-Resistivity Model Values:

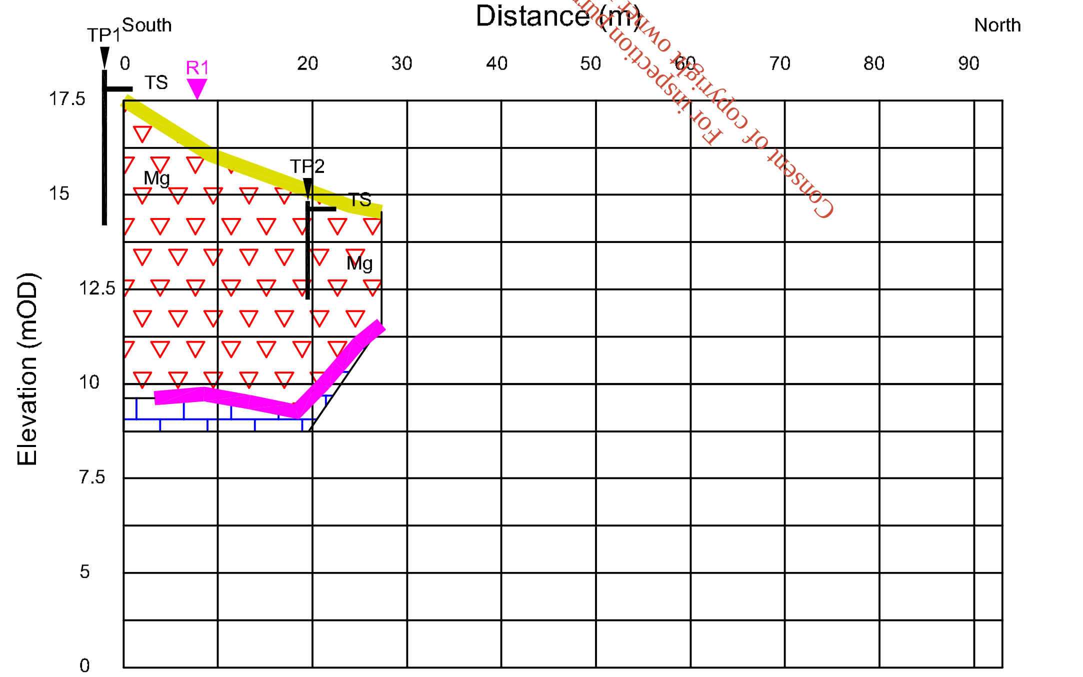
Resistivities (Ohmm) for 2D-Resistivity Model

15.6 31.2 62.5 125 250 500 1000 2000

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	Ardfert Historic Landfill Geophysical Survey
TITLE	Figure 2: Interpretation of Geophysical Survey

SCALE:	1:800 @ A3, VE x4
PROJECT:	6425
DRAWN:	JC
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STATUS:	Final

LEGEND:

Interpretation:

1 Waste Material and Made Ground
2a Possibly Karstified Limestone
2b Fresh Limestone

Abbreviated GI Logs:

TS	Topsoil
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