FEHILY TIMONEY

CONSULTANTS IN ENGINEERING, ENVIRONMENTAL SCIENCE & PLANNING

APPENDIX 4

Geophysical Survey

Castleisland Historic Landfill
Bawnluskaha, Co. Kerry

Geophysical Survey

Report Status: Final

MGX Project Number: 6421

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Confidential Report To:

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Minerex
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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 Castleisland, 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. Historical maps show a limestone quarry on the site of the landfill. The geophysical survey identifies the extent of the quarry which had been filled with waste material. The results also indicate that the rock is likely weathered and karstified near the landfill.
4. **The results of direct ground investigation tie in overall well with the geophysical interpretation, though there are some local variations. The outline and size of the landfill area remain the same. The rock is deep in BH2 and shallow in BH 1, same as in the geophysical interpretation. The top of rock differs between the geophysics and the drilling, highlighting the changeable and irregular nature of the rock. There is some waste in TP 2 outside the interpreted landfill area, so small volumes of waste may be found outside the landfill area but the overall volume is unlikely to be increased by much.**
5. The survey located a waste body located within an historic quarry in the NE of the site. The extent of the landfill is estimated at 2192 m^2.
6. The depth of the waste is about 6 m below ground level which gives a total volume of 13152 m^3 including fill material placed on top of the landfill.
7. The low resistivities and seismic velocities measured are consistent with industrial and domestic waste rather than C & D type waste.
8. There is an indication of leachate within the limestone beneath the landfill. The karstified nature of the rock in the area may assist in allowing leachate to move through the rock. It is recommended to investigate the possible leachate by targeted drilling.

CONTENTS

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 Bawnluskaha, Castleisland, 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 report (Kerry Co.Co. 2011) has assigned a risk classification of B: Moderate risk for this landfill. The report however noted that the exact footprint of the landfill is not yet known as it is not clear in the landscape. A quarry noted in the 1896 ordinance map was assumed to be its location.

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 Castleisland town along the College Road. There is a farm track from the road leading into the site. The track runs through the middle of the survey area which consisted of a number of grass fields divided with wire fences. The north boundary of the site is defined by a hedgerow while the other boundaries are not defined on site. The topography on site rises gently from 41 mOD in the south to 45.5 mOD in the north. The elevations begin to decline again farther to the north. The land to the west of the site was wetter than the rest of the site. There is no clear visible evidence of the footprint of the landfill or quarry.

1.4 Geology

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

The subsoil is described as till derived from Namurian sandstones and shales. The survey area is underlain primarily by the Cracoean Reef Member which is described as unbedded calcilutite limestone. The Rockfield Limestone is found to the immediate south of the site. This is described as well-bedded argillaceous limestone.

There are a number of karst features identified to the west and east at a distance of about 500m from the site including caves, springs and enclosed depressions. These features appear to be located in the Cracoean Reef Member.

The groundwater vulnerability map notes the site is located in an area designated as X (Rock near surface) and is surrounded by E (Extreme) Vulnerability.

Historic maps from 1896 noted a quarry on this site. There are also a number of Limekilns in the vicinity.

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 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	59	174
R2	3	55	162
SUM			**336**
S1	3	48	141
S2	3	48	141
SUM			**282**

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 59 electrodes per set-up and a maximum length of 174 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 the 7th 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.

As the exact location of the landfill was not known, the profiles were extended where possible to ensure the full extent of the of the waste material was identified. Hedgerows along the north edge of the site restricted extending profiles in that direction.

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 additional 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 domestic 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 contains 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.

Most of the area surveyed had conductivities of <10 mS/m with some exception. Towards the west, conductivities gradually increase to 15 mS/m. This is likely due to the change in ground conditions to a marshier wet environment which was noted on site. In the NE corner of the site there is an area with conductivities higher than 10 mS/m. This is the likely location of the landfill 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 lot of disturbance in the ground. Along profile R1 there is an area near the end of the profile where there are lower resistivities. There is a similar area near the end of Profile R2. These two areas conform with the low conductivity results in the NE. As this site is a former limestone quarry, the high resistivities around the landfill is likely limestone around the edge of the quarry. The low resistivity below the landfill along R1 may be leachate escaping into the rock below. Further south along profile R1 and in the west of R2 there are other areas of low resistivity at depth which are likely due to karstification of the rock in these areas.

The apparent karstification of the rock noticeable along the profiles may aid in the movement of leachate from the landfill into the rock.

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 up to 4 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. On this landfill these properties were useful to determine the lateral extent of the landfill and to estimate the depth of the waste.

The modelled seismic data has created the following layered ground model:

Layer 1 has a seismic velocity of 300 m/s and is found only in the NE corner of the site. This velocity would represent landfill material which has a lower velocity than the surrounding natural ground

Layer 2 has a seismic velocity range of 400 and 550 m/s. This layer in interpreted as natural overburden material.

Layer 3 is interpreted as overburden or highly weathered Limestone and is only found away from the landfill towards the south. This layer has a seismic velocity of 1000 m/s.

Good rock is indicated by seismic velocities of 2600 – 3000 m/s. This layer is found all around 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 materials. Therefore, by using both methods together a clearer picture of the waste body is obtained.

The landfill material generally consists of low seismic velocity and low resistivity material. There is a clear area in the NE of the survey area which fulfils these criteria. Immediately below the waste body there are low resistivities within the limestone layer. The low resistivities may be due to leachate escaping into the rock below or due to karstification of the limestone. Other areas of low resistivity at depth which are disconnected to the landfill are more likely karstified limestone.

The presence of sandy gravelly overburden and karstified and weathered limestone gives the potential for leachate to move away from the landfill.

Table 2 below summarises the interpretation. Interpreted cross sections are shown in Figure 2. The interpretation has been made from all available information. For overburden layers and the top of the rock the seismic refraction data has been used as seismic refraction is the best method to delineate layer boundaries. The resistivity models have been used to delineate three generalised types of rock and to indicate rock head where no seismic refraction data was acquired. Resistivity data is better suited to show rock types and features within the rock while seismic refraction velocities are indicating the change of compaction, stiffness or rock quality with depth. 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	300	<125	Waste Material
2a	400 - 550	<250	Sandy Gravelly Clay or Silt
2b	400 - 550	>250	Clayey silty Sand or Gravel
3a	1000	<250	Sandy Gravelly Clay or Silt or highly weathered clay infilled Limestone
3b	1000	>250	Clayey silty Sand or Gravel or highly weathered Limestone
4a	2600 - 3000	<125 (close to Landfill)	Leachate or Karstified Limestone
4b	2600 - 3000	<125	Karstified Limestone
4c	2600 - 3000	125 – 500	Weathered Limestone
4d	2600 - 3000	>500	Fresh Limestone

4. CONCLUSIONS

The following conclusions are made:

Geological Background

Historical maps show a limestone quarry on the site of the landfill. The geophysical survey shows that this rock is likely weathered and karstified near the landfill. The overburden becomes thicker away from the landfill and appears to have a high sand and gravel content. The presence of sand and gravel as well as karstified rock can allow the movement of leachate from the landfill.

Boreholes and Trial Pits

The results of direct ground investigation tie in overall well with the geophysical interpretation, though there are some local variations. The outline and size of the landfill area remain the same. The rock is deep in BH2 and shallow in BH 1, same as in the geophysical interpretation. The top of rock differs between the geophysics and the drilling, highlighting the changeable and irregular nature of the rock. There is some waste in TP 2 outside the interpreted landfill area, so small volumes of waste may be found outside the landfill area but the overall volume is unlikely to be increased by much.

Lateral extent of waste and landfill boundary

The EM31 ground conductivity shows the area where landfill material is present however the exact lateral extent of waste is not very clear. The area outlined in magenta on Map 2 shows the interpreted extent of the landfill using all the information available. The interpreted landfill extent covered an area of approx. 2192 m^2.

Vertical extent (depth) of waste

The thickness/depth has been estimated from the seismic refraction and 2D-Resistivity data. Considering the thickness of the interpreted Layer 1, an average thickness of 6 m has been calculated for the landfill material. This estimate includes any capping or natural fill material on top of the main waste body.

Volume of waste

Considering the areas and average thickness above, the volume of the total waste body is estimated at 13152m^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

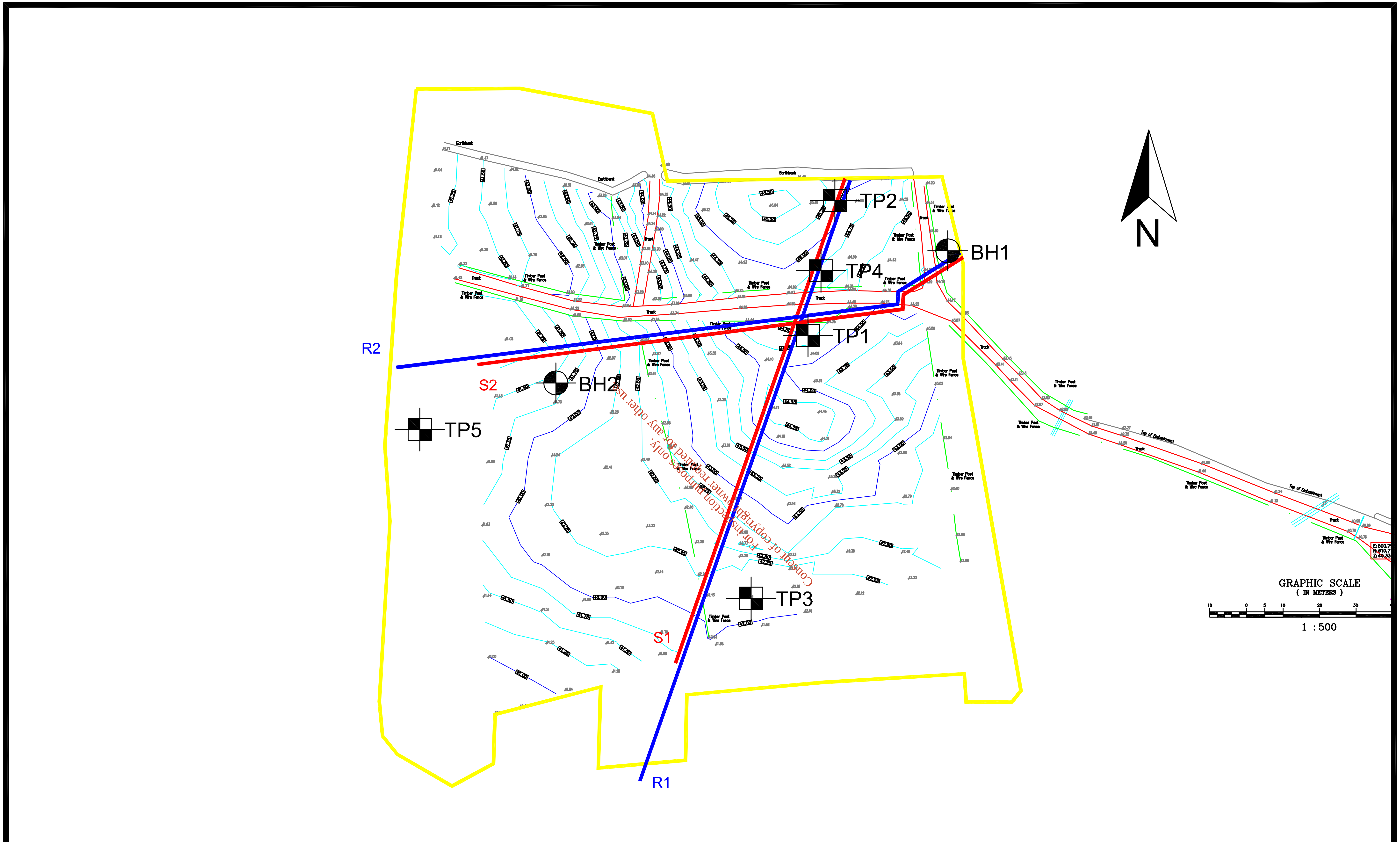
There is no engineered capping layer over the landfill and the geophysics survey does not show any significant natural material over the landfill.

Leachate

Possible leachate is identified along profile R1. This leachate is in the rock layer and may have been made possible by weathered or karstified limestone. Leachate from the landfill may be restricted by the fresh limestone surrounding most of the landfill. However sand and gravel in the overburden and weathering and karstification of the limestone provide the potential for the movement of leachate. It is recommended to investigate the possible leachate by targeted drilling.

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 2011.** Tier 1 Review Report – Bawnluskaha (Castleisland) Killarney S22 - 02668



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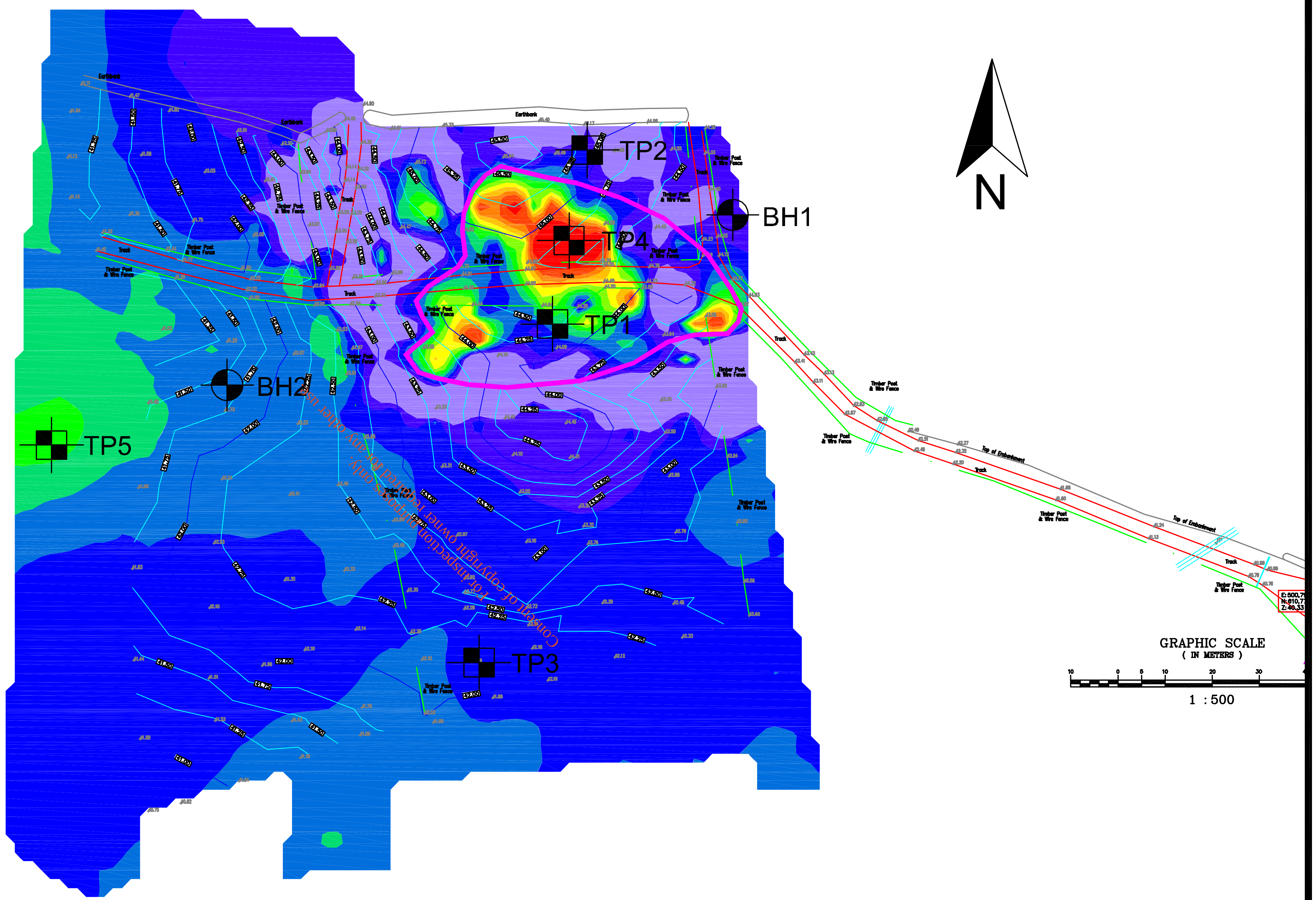
CLIENT	Fehily Timoney & Co. Kerry Co. Co.
PROJECT	Castleisland Historic Landfill Geophysical Survey
TITLE	Map 1: Geophysical Survey Location Map

SCALE:	1:1000 @ A3
PROJECT:	6421
DRAWN:	JC
DATE:	19/11/2019
MGX FILE:	6421f_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	Castleisland Historic Landfill Geophysical Survey
TITLE	Map 2: EM31 Ground Conductivity Contour Map

SCALE:	1:1000 @ A3
PROJECT:	6421
DRAWN:	JC
DATE:	19/11/2019
MGX FILE:	6421f_MapsFigs.dwg
STATUS:	Final

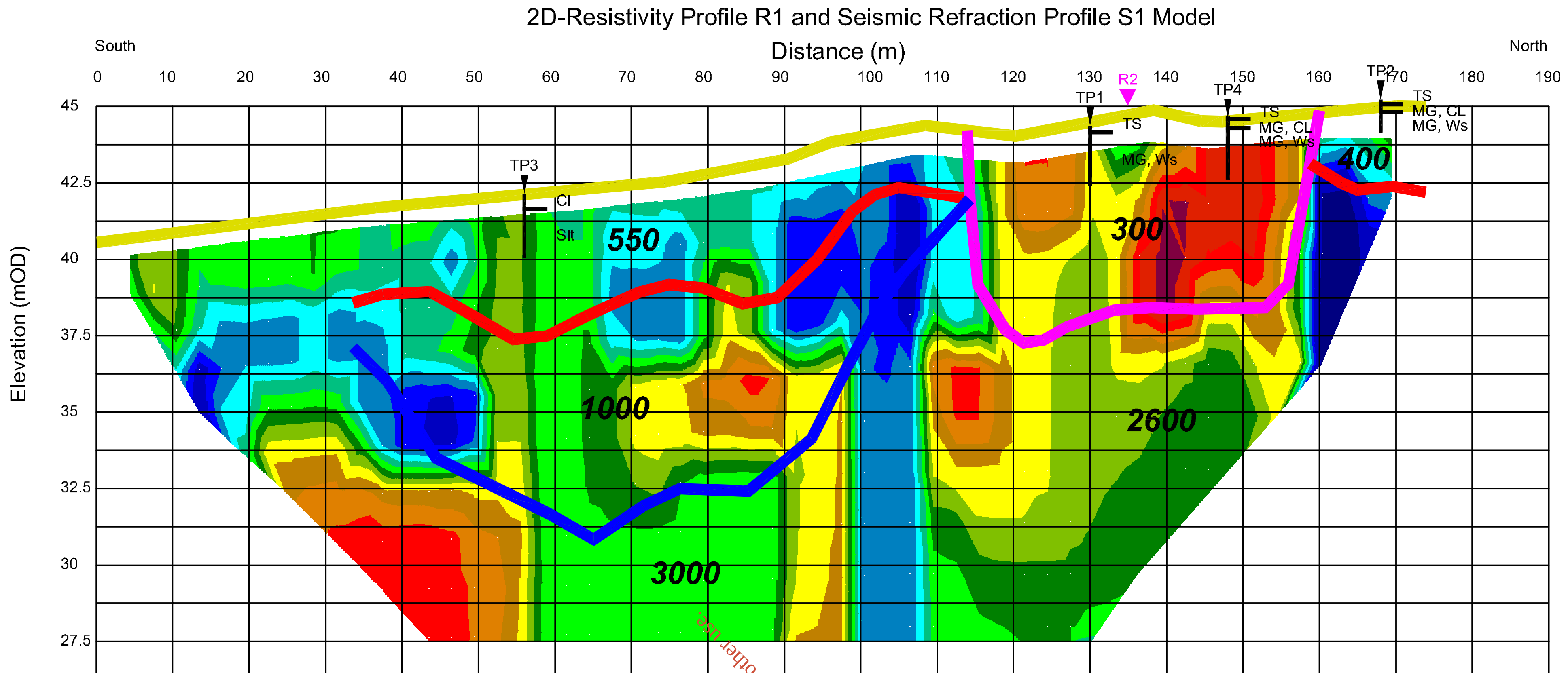
LEGEND:

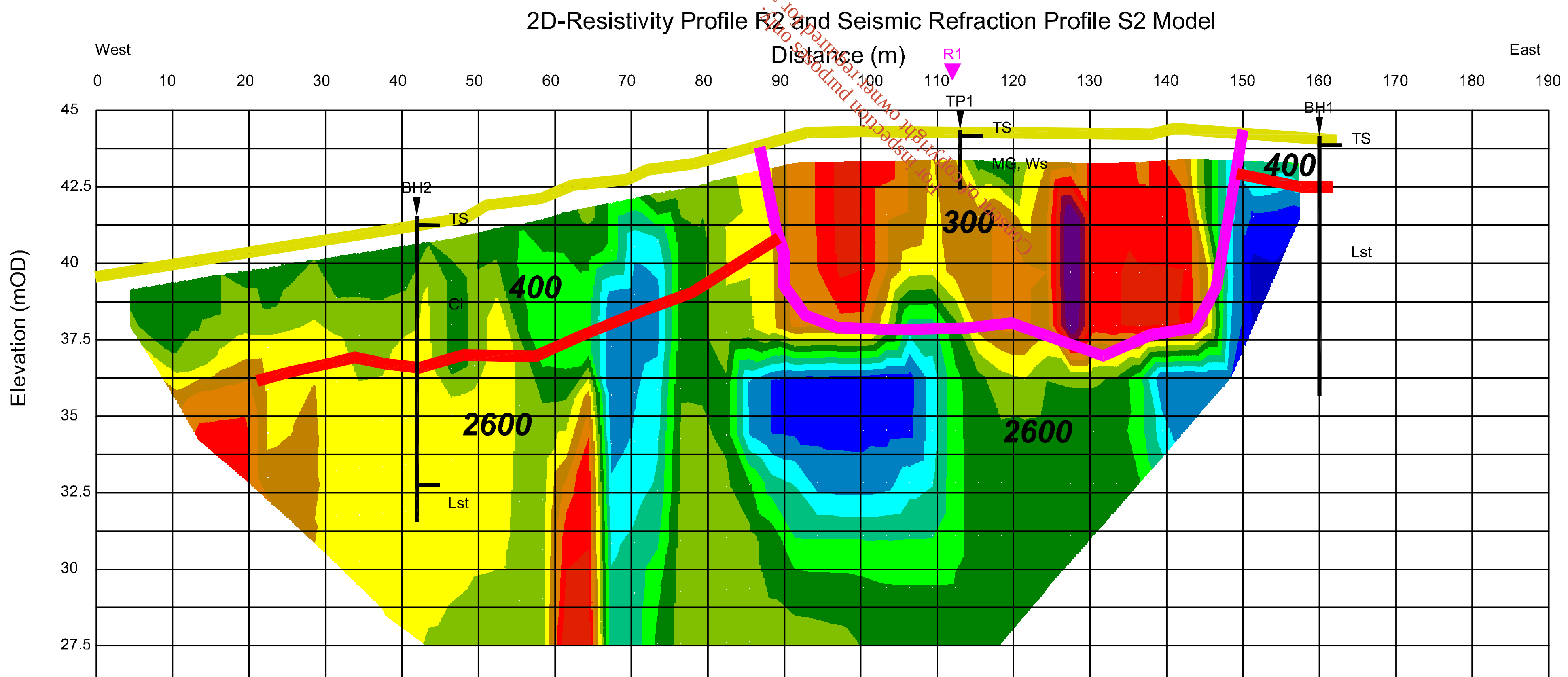
Interpreted Outline of Landfill

EM31 Ground Conductivity Scale in mS/m:

5 10 15 20 25 30

The map shows the EM31 ground conductivity contours mS/m. The low (blue) conductivities indicate natural ground. The middle range (green) values indicate some landfill material. The high (red) values indicate the presence of metal objects or highly conductive landfill material.





Abbreviated GI Logs:

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

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

SCALE:	1:800 @ A3, VE x 4
PROJECT:	6421
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DATE:	19/11/2019
MGX FILE:	6421f_MapsFigs.dwg
STATUS:	Final

LEGEND:

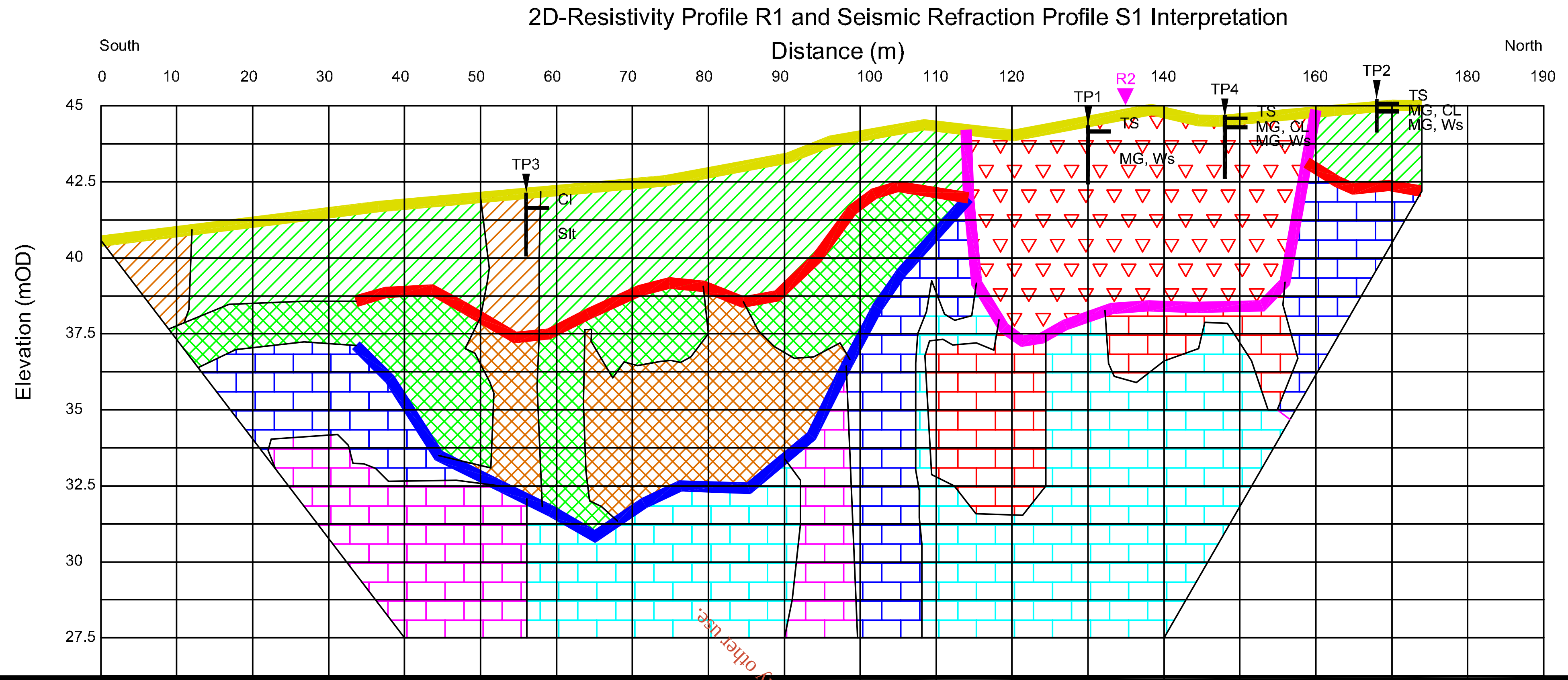
Layers from Seismic Refraction Model:

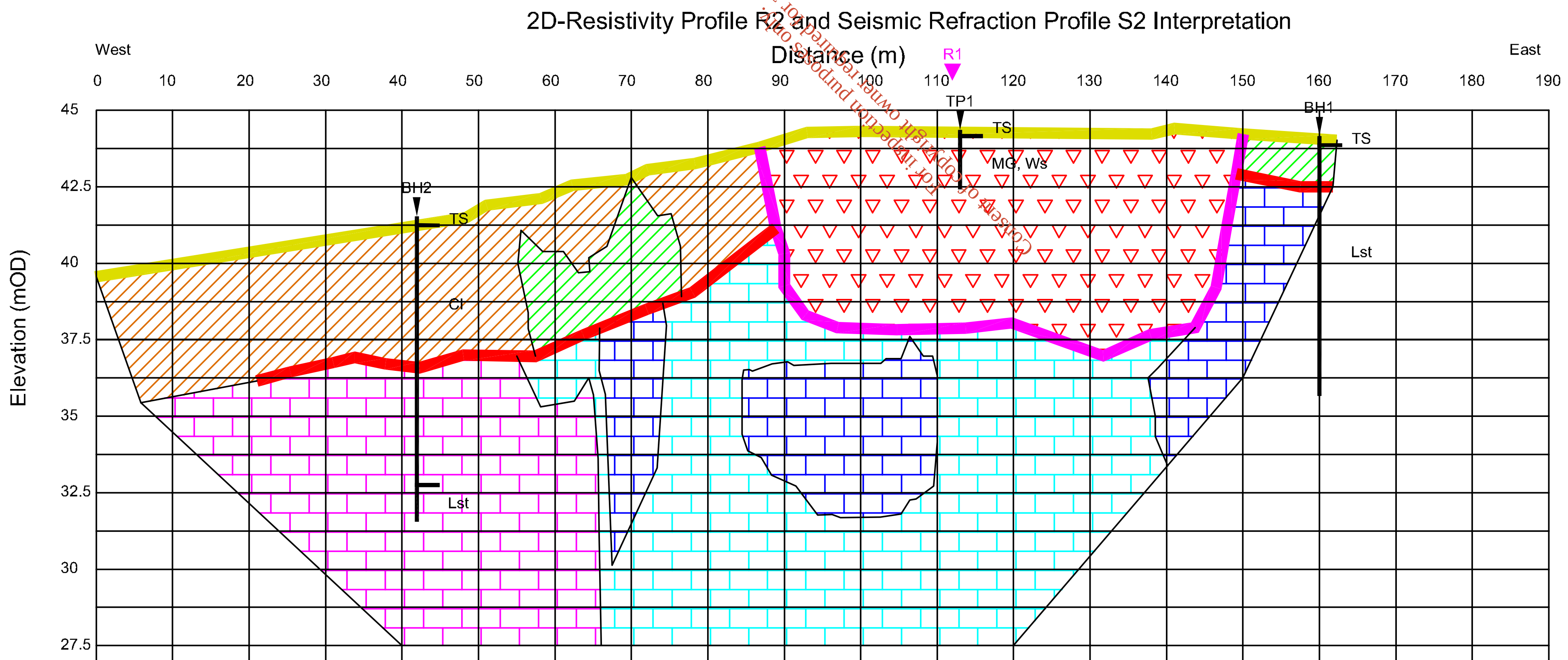
- Ground Surface
- Base of Layer 1 (Landfill) (300 m/s)
- Bottom of Layer 2 (400 - 550 m/s)
- Bottom of Layer 3 (1000 m/s)
- *1800* Seismic Velocity in m/s

2D-Resistivity Model Values:

Resistivities (Ohmm) for 2D-Resistivity Model

15.6 31.2 62.5 125 250 500 1000 2000





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CLIENT	Fehily Timoney & Co. Kerry Co. Co.
PROJECT	Castleisland Historic Landfill Geophysical Survey
TITLE	Figure 2: Interpretation of Geophysical Survey

SCALE:	1:800 @ A3, VE x 4
PROJECT:	6421
DRAWN:	JC
DATE:	19/11/2019
MGX FILE:	6421f_MapsFigs.dwg
STATUS:	Final

LEGEND:

Interpretation:

- 1 Waste Material
- 2a Sandy gravelly Silt or Clay
- 2b Clayey silty Sand or Gravel
- 3a Sandy gravelly Silt or Clay or highly weathered clay infilled Limestone
- 3b Clayey silty Sand or Gravel or highly weathered Limestone
- 4a Leachate or Karstified Limestone
- 4b Karstified Limestone
- 4c Weathered Limestone
- 4d Fresh Limestone