FEHILY TIMONEY

CONSULTANTS IN ENGINEERING, ENVIRONMENTAL SCIENCE & PLANNING

APPENDIX 5

Minerex Geoservices
Geophysical Survey Report

Listowel Historic Landfill

Listowel, Co. Kerry

Geophysical Survey

Report Status: Final

MGX Project Number: 6427

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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 Listowel, 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 geological map of Ireland (GSI, 2019) indicates the bedrock is Visean Limestone in the NW which is described as undifferentiated limestone and the Clare Shale Formation in the SE which is described as mudstone, cherty at base. Historical maps show a limestone quarry located on the site.
4. The results of the direct ground investigation tie in well with the geophysical interpretation. It is noted that BH1 located to the south within the survey site, within a yard area, shows considerable waste material. The landfill seems to extend south from the survey site.
5. The high conductivity readings highlight the main waste body, towards the edge of the landfill the conductivities become lower due to a mix of waste and natural material within the first 6 m bgl.
6. All three resistivity profiles indicate waste material. The edge of the landfill appears to be close to the ends of the profiles and site boundaries to the north, east and west. At the start of profile R1, the resistivities increase closer to the surface which indicates the edge of the landfill. Using all the geophysical data, historical maps and the topography of the site, an approximate area has been drawn on Map 2 which gives an area of 8900 m^2.
7. The 2D-Resistivity survey indicates a depth of 11m for waste material and leachate. This would give a total volume for waste material of 98000 m^3.
8. The 2D-Resistivity profiles show the extent of the landfill but do not extend past the edge of the waste body, therefore, the extent of lateral leachate movement could not determined in this survey. Extended 2D-Resistivity profiles would capture the boundaries of the landfill, especially to the south where BH1 encountered waste material.
9. A 2D-Resistivity profile is also recommended between the landfill and the river Feale to determine if there is leachate movement towards the river.
10. The low resistivities and seismic velocities measured are consistent with industrial and domestic waste rather than C & D type waste.

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 Listowel, 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 is a fast and effective survey 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.

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 historical landfill is located in a public park called ‘The Garden of Europe’. The area consists of paths, monuments, grass and trees. There are playing fields to the west and a golf course to the east. The site was accessed from a road running along the River Feale in the south and running north to the park beside a private site located south of the park.

The site slopes from the North to the south with elevations ranging from 28.6 mOD to 21 mOD. There is a high bank running along the east side of the site which rises to between 31.5 m in the NE and 25.8 m in the SE.

1.4 Geology

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

The quaternary sediments map describes the overburden as urban, bedrock outcrop and till derived from Namurian sandstone and shales. The bedrock is described as Visean Limestone in the NW which is described as undifferentiated limestone and the Clare Shale Formation in the SE which is described as mudstone, cherty at base. The map also indicates shallow rock around the site.

Historic maps from 1837 – 1913 describe a quarry on this site as well as a number of limekilns in the area.

The groundwater vulnerability map describes the site as between X (Rock at or near surface or karst) and E (Extreme).

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 along three profiles due to the elongated nature of the site. One profile running N-S and two profiles running roughly E-W to gain good coverage of 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	25	72
R2	3	48	141
R3	3	40	117
SUM			**330**
S1	3	24	69
S2	3	48	141
S3	3	40	117
SUM			**327**

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 48 electrodes per set-up and a maximum length of 141 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 3th and 12th of April 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 and surrounding public land but not in the golf course or private house to the south 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.

For this final version of the report the logs for two rotary core holes and 8 dynamic sampler bore holes 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.

There is a clear area in the middle of the site where conductivity is above 30 mS/m. Most of the surrounding area has a conductivity range of 10 – 30 mS/m while in some areas the conductivity drops below 10 mS/m.

The area with conductivities above 30 mS/m indicates waste material while the surrounding area with conductivities of 10 – 30 mS/m may consist of waste material or clay rich overburden. Areas where conductivities are below 10 mS/m are likely natural overburden or man-made overburden without typical waste material.

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.

Throughout most of the three profiles to a depth of roughly 11m below ground level the resistivities are below 125 Ohmm which would indicate waste material or leachate. In some areas such as the start and end of profile R1 and the start of profile R3 there are resistivities of between 125 and 350 Ohmm which likely shows natural overburden or non-waste manmade overburden. At the beginning of profile R1, the resistivities decrease with depth before increasing again. This may be due to leachate within the overburden but may also be waste material with overburden fill above it. Below 11 m throughout the three profiles, resistivities rise rapidly above 350 Ohmm which would indicate fresh limestone.

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. Velocities were obtained for the top layer and the average seismic velocities obtained within the layers are annotated on the sections as bold black 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. Therefore, by using both methods together a clearer picture of the waste body is obtained.

The landfill is located within an historic limestone quarry which is shown on historical maps from 1837 – 1913. The 2D-Resistivity survey shows a rapid increase in resistivities at a depth of approx. 11m below ground level. This shows the depth to rock below the waste material and leachate. The seismic survey did not show any refraction with any materials below the surface due to the thickness of the waste material within the landfill. All of this information would indicate that the waste material and leachate into overburden extends to the rock below.

The horizontal extent of the landfill is not well defined in the survey as profile R1 and the end of profile R3 do not appear to reach the edge of the waste material. BH1 to the south of the survey area located waste material within a yard area. The conductivities are higher in the middle of the landfill but remain relatively high in the surrounding area. The higher conductivities in the surrounding area may also be due to high clay content in the overburden or a thicker capping layer over waste material.

Map 2 shows the interpreted outline of the landfill using all information available. Table 2 summarises the interpretation. Interpreted cross sections are shown in Figure 2. The interpretation has been made from all available information.

Table 2: Summary of Results and Interpretation

Layer	General Seismic Velocity Range (m/sec)	General Resistivity Range (Ohmm)	Interpretation
1	200 – 250	<125	Waste Material **and Leachate**
2	400 - 2200	125 - 350	Sandy Gravelly Clay or Silt
3	4000	>350	Fresh Limestone

4. CONCLUSIONS AND RECOMMENDATIONS

The following conclusions and recommendations are made:

Geological Background

The online bedrock geological map of Ireland (GSI, 2019) indicates the bedrock is Visean Limestone in the NW which is described as undifferentiated limestone and the Clare Shale Formation in the SE which is described as mudstone, cherty at base. Historical maps show a limestone quarry located on the site.

Boreholes and Trial Pits

The results of the direct ground investigation tie in well with the geophysical interpretation. The outline and size of the landfill area has been confirmed on the survey site. It is noted that BH1 located to the south within the survey site, within a yard area, shows considerable waste material. The landfill seems to extend south from the survey site. BH2 did not encountered waste or rock and the geophysical model has been adjusted, the large resistivity changes here are likely created by the landfill boundary. Rock was not encountered in any of the boreholes, which does not match the description as a former quarry given in the historical maps.

Lateral extent of waste and landfill boundary

The EM31 ground conductivity shows the main body of waste while towards the edge of the landfill the conductivities reduce due to the presence of natural material within the top 6 metres below the surface. The 2D-Resistivity data shows the lateral extent of the landfill to be close to the site boundaries to the north, east and south while the start of profiles R1 shows the extent to the west. An approximate landfill boundary has been drawn on Map 2 using all available information while gives an area of 8900 m^2.

Extended 2D-Resistivity profiles would capture the boundaries of the landfill, especially to the south where BH1 encountered waste material.

Vertical extent (depth) of waste and basal leachate

The thickness/depth has been estimated from where the 2D-Resistivity data shows a rapid increase in resistivities. It appears that the waste material and leachate into overburden extends down the rock which would give an average thickness of 11m for the landfill, leachate and capping material above it.

Volume of waste

Considering the areas and average thickness above, the volume of the total waste is estimated at 98000 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

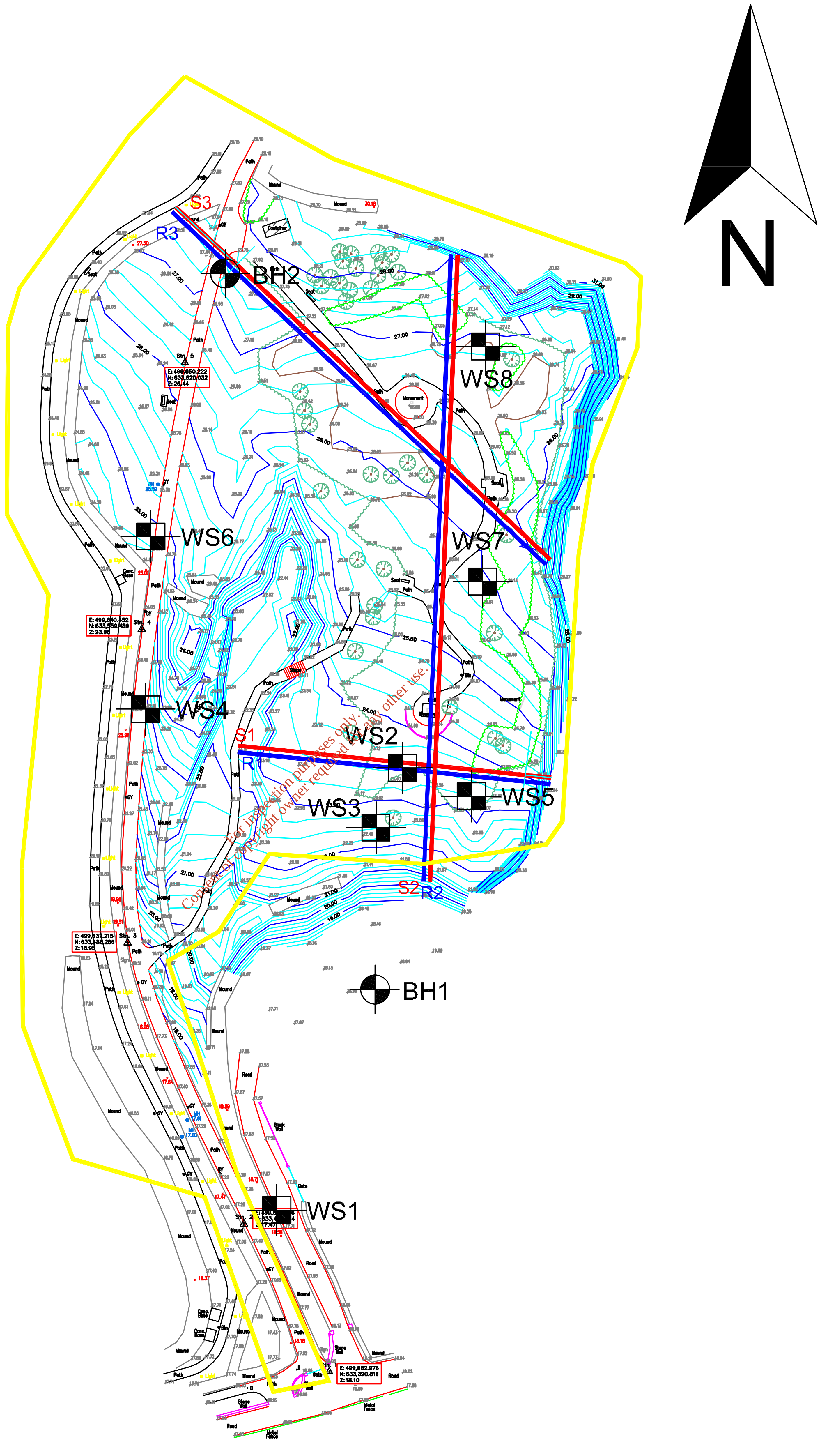
There is no engineered capping layer over the landfill. The low resistivities near the surface indicates there is no significant fill over the waste material.

Leachate

The limestone below the landfill generally has high resistivities which indicates that there is little or no leachate movement into the rock. Leachate likely occurs into a layer of overburden between the waste material and the rock. One possible area where leachate movement may be indicated is at the start of profile R1 where low resistivities below higher resistivities may be due to leachate movement. As the profiles do not extend past the edge of the landfill, no information concerning lateral leachate could be obtained. It is recommended to carry out a 2D-Resistivity profile between the landfill and the river to determine if there is leachate movement toward the river.

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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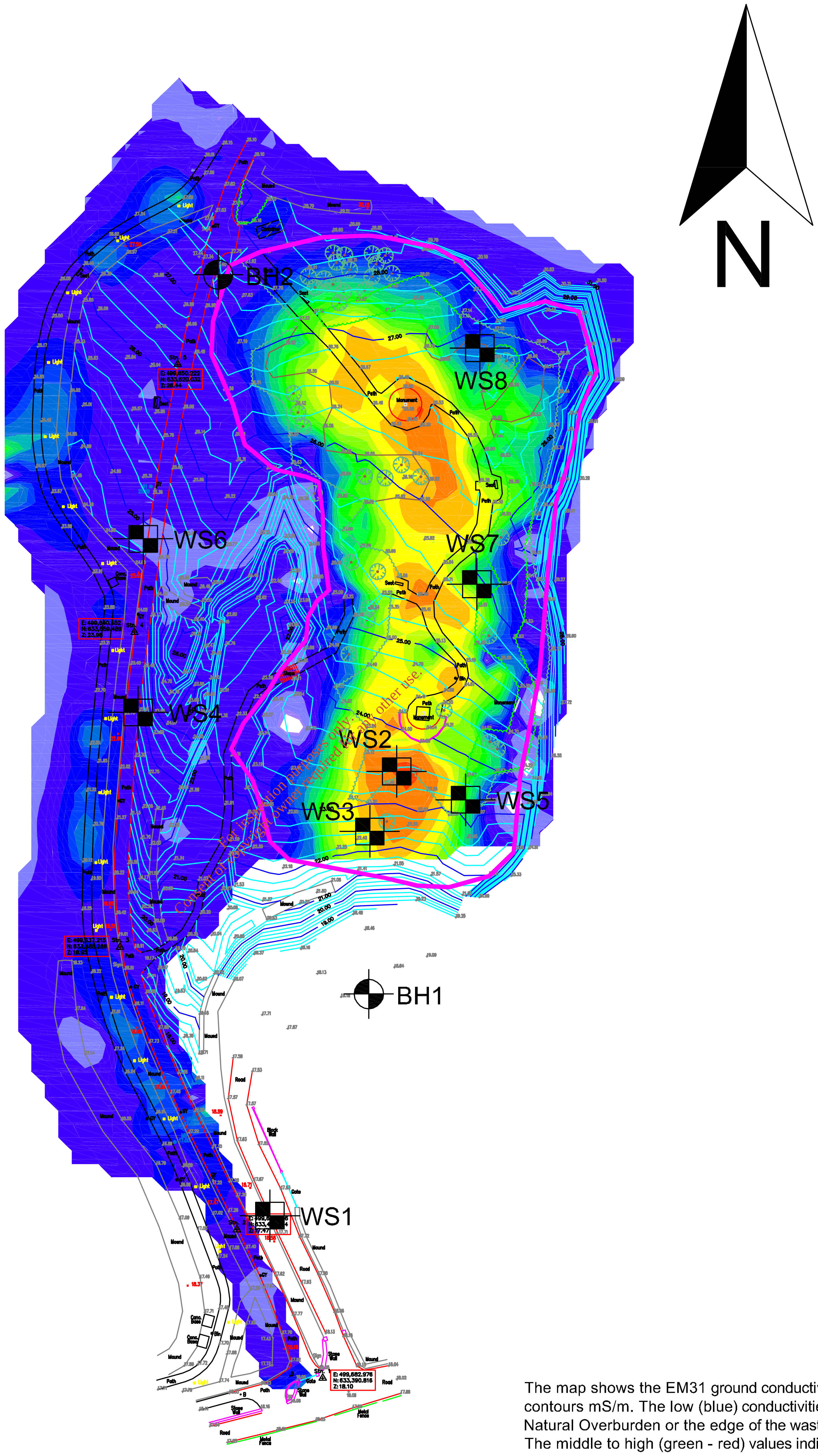
CLIENT	Fehily Timoney & Co. Kerry Co. Co.	SCALE:	1:1000 @ A3
PROJECT	Listowel Historic Landfill Geophysical Survey	PROJECT:	6427
		DRAWN:	JC
		DATE:	18/11/2019
TITLE	Map 1: Geophysical Survey Location Map	MGX FILE:	6427f_MapsFigs.dwg
		STATUS:	Final

LEGEND: Geophysical Survey Locations:

R2 (blue line)	2D-Resistivity Profile
S1 (red line)	Seismic Refraction Profile
(yellow outline)	EM31 Survey Area
BH1	Rotary Core Hole
WS1	Borehole Dynamic Sampler



The map shows the EM31 ground conductivity contours mS/m. The low (blue) conductivities indicate Natural Overburden or the edge of the waste body. The middle to high (green - red) values indicate landfill material.

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

SCALE:	1:1000 @ A3
PROJECT:	6427
DRAWN:	JC
DATE:	18/11/2019
MGX FILE:	6427f_MapsFigs.dwg
STATUS:	Final

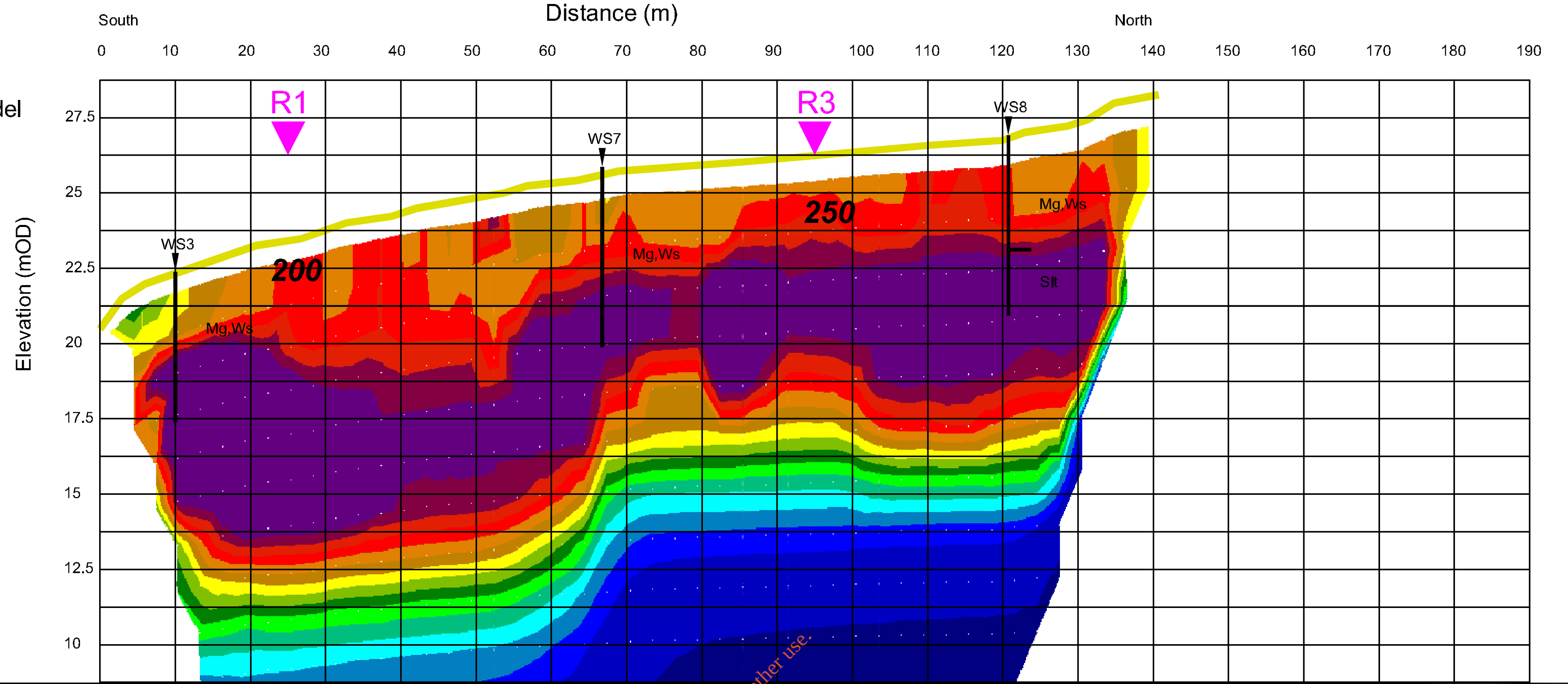
LEGEND:

Interpreted Outline of Landfill

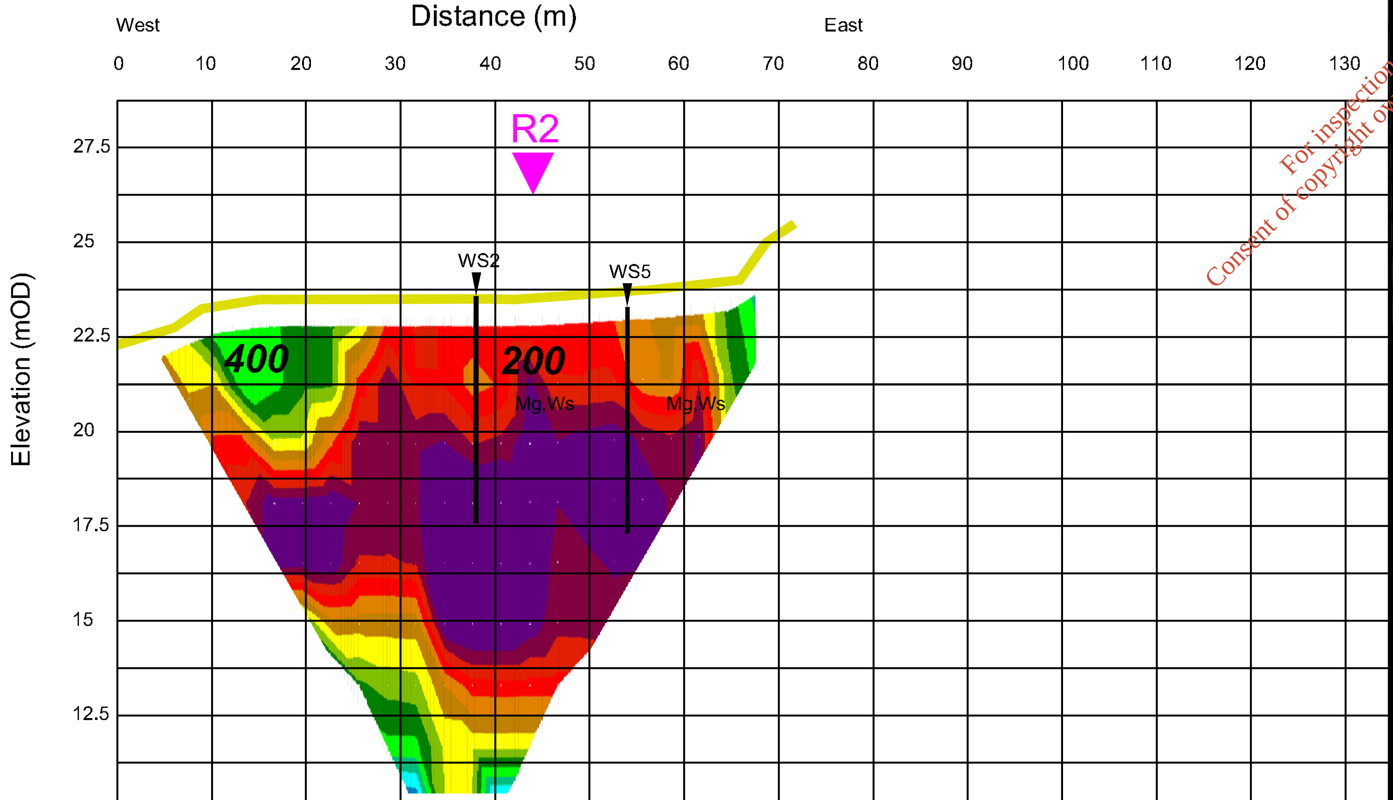
EM31 Ground Conductivity Scale in mS/m:

0 10 20 30 40 50 60 70 80 90 100

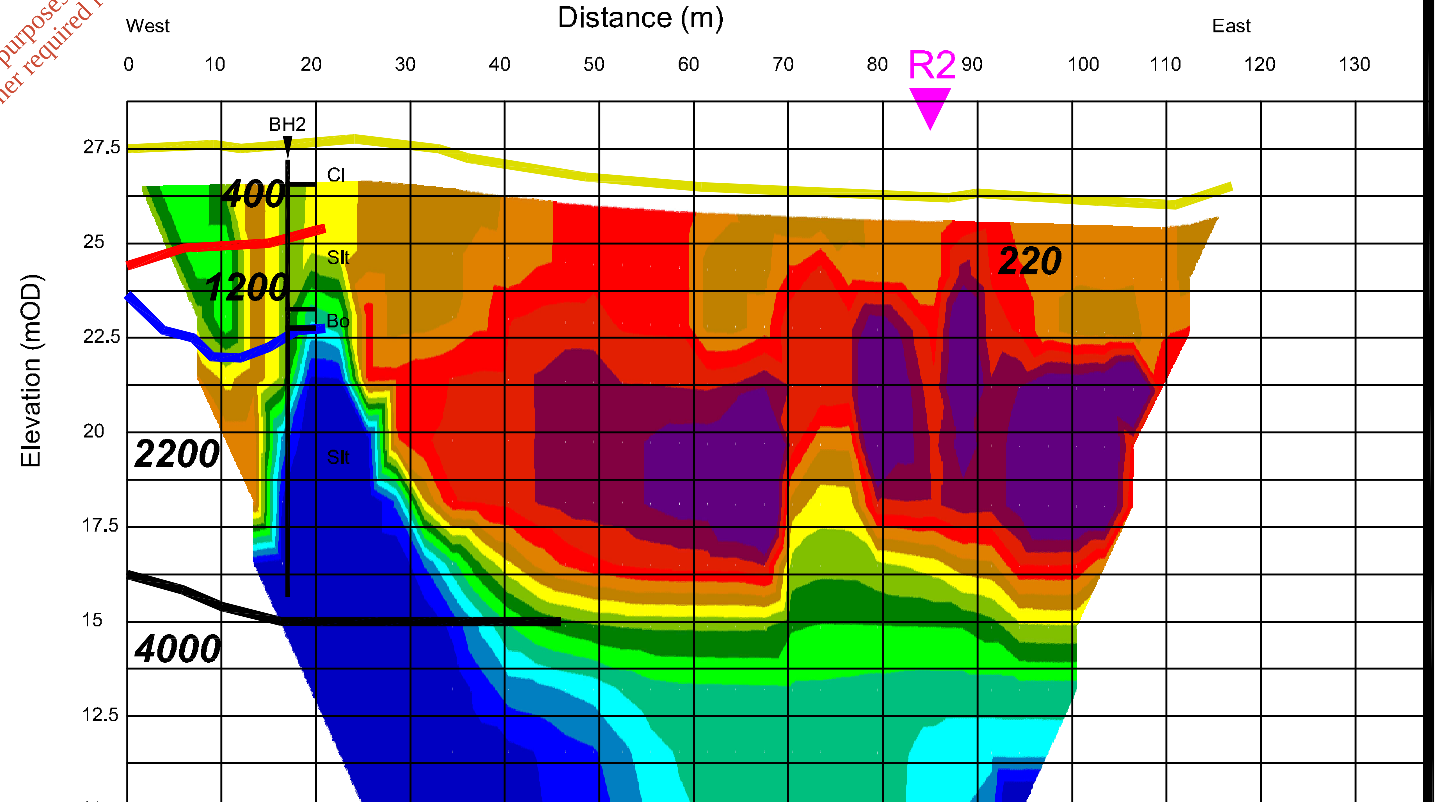
2D-Resistivity Profile R2 and Seismic Refraction Profile S2 Model



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



2D-Resistivity Profile R3 and Seismic Refraction Profile S3 Model



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

SCALE:	1:800 @ A3, VE x 4
PROJECT:	6427
DRAWN:	JC
DATE:	18/11/2019
MGX FILE:	6427f_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

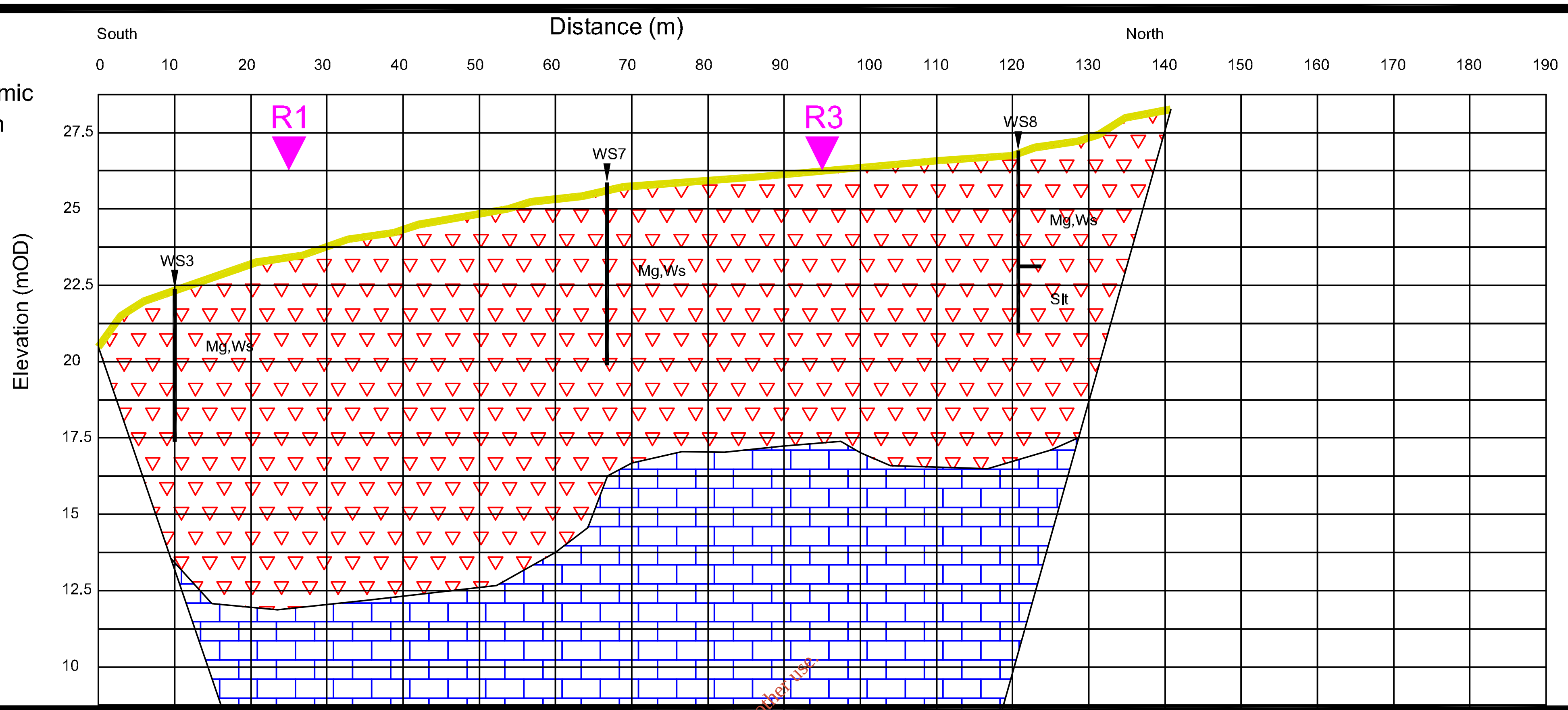
Abbreviated GI Logs:

Cl	Clay	Mg	Made Ground
Ws	Waste Material	Slt	Silt
		Bo	Boulder

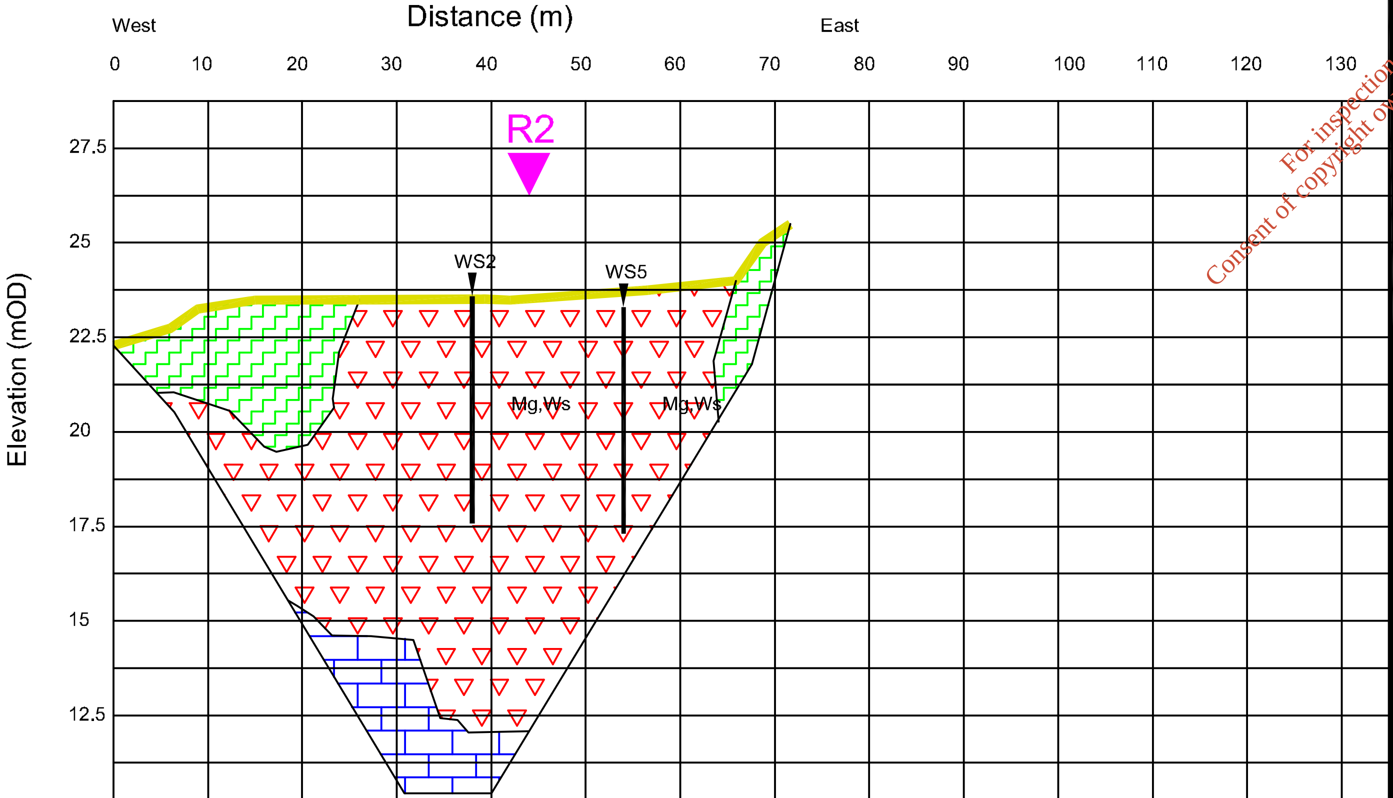
Seismic Velocities Below the Surface:

200 Seismic Velocity in m/s
Top of Layer 1 (200 - 400 m/s)
Top of Layer 2 (1200 m/s)
Top of Layer 3 (2200 m/s)
Top of Layer 4 (4000 m/s)

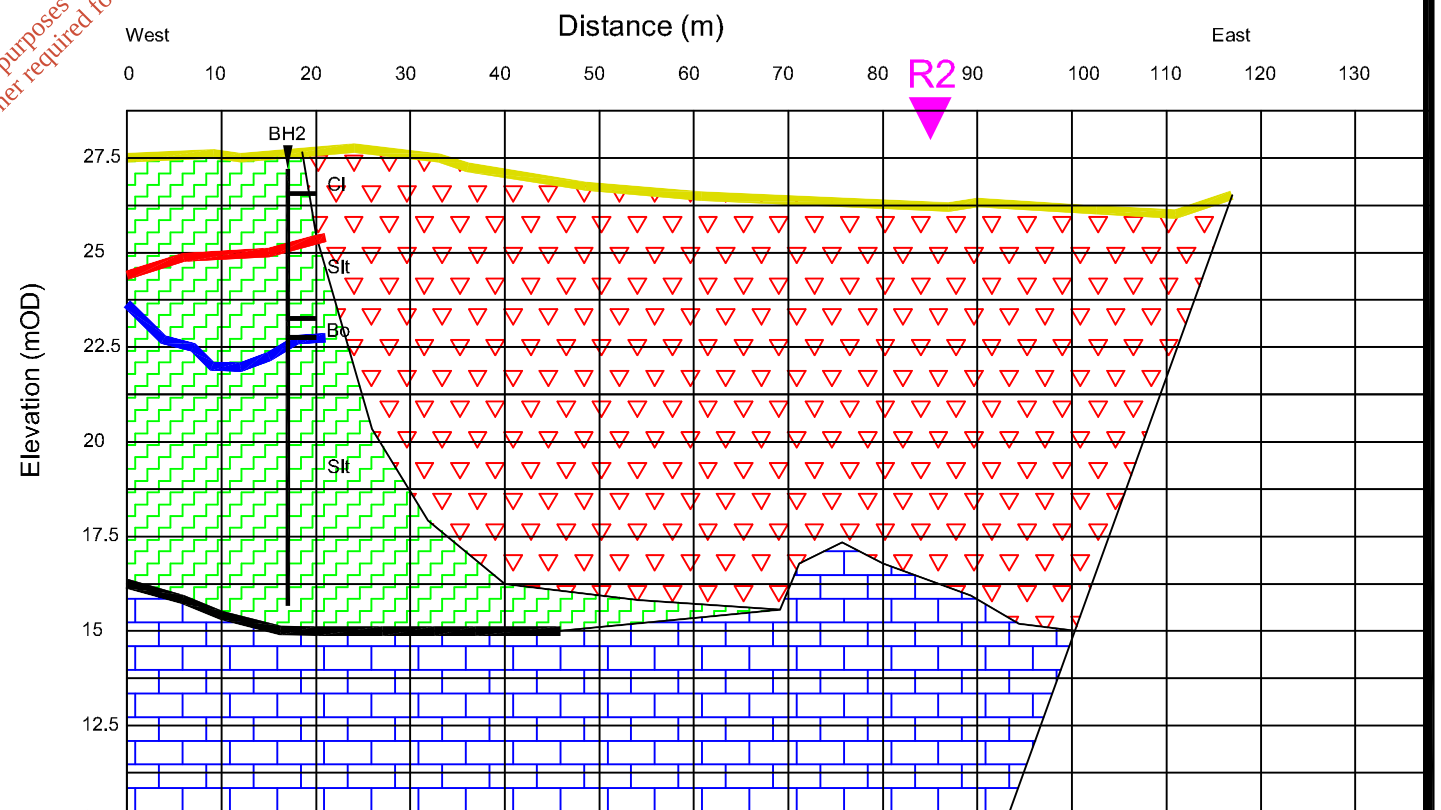
2D-Resistivity Profile R2 and Seismic Refraction Profile S2 Interpretation



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



2D-Resistivity Profile R3 and Seismic Refraction Profile S3 Interpretation



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

SCALE:	1:800 @ A3, VE x 4
PROJECT:	6427
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STATUS:	Final

LEGEND:

Interpretation:

1 Waste Material and Leachate
2 Sandy Gravelly Clay or Silt
3 Fresh Limestone

Abbreviated GI Logs:

Cl	Clay
Ws	Waste Material
Mg	Made Ground
Slt	Silt
Bo	Boulder