FEHILY TIMONEY
30 YEARS

CONSULTANTS IN ENGINEERING, ENVIRONMENTAL SCIENCE & PLANNING

APPENDIX 3

Minerex Geoservices Geophysical Survey Report

New Inn Historic Landfill

New Inn Co. Galway

Geophysical Survey

Report Status: Draft

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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 the New Inn historic landfill, County Galway.
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 under the site is Lucan Formation, described as dark limestone and shale. Historic maps show gravel pits within the survey area as well as a children's burial ground to the west.
4. The EM31 Ground Conductivity survey shows low conductivities across most of the survey area with one area in the south containing higher conductivities. This indicates natural overburden underlying most of the site with some domestic and industrial waste material in the south. The extent of the waste material on the site covers an area of 2,600 m^2 indicated on Map 3.
5. The depth of the waste layer is interpreted as being the depth of seismic layer 1 which is an average of 4 m in this area, however, this layer likely also contains natural overburden material as well.
6. Total volume of waste material is calculated as 10,400 m^3.
7. Outside this area indicated above the interpretation indicates topsoil with little or no waste.
8. The area in the east (Profile R3/S3) does not show a waste body, the heaps here are interpreted as topsoil with little or no waste.
9. It is recommended to investigate the waste area outline on Map 3 using trial pits to determine the presence and nature of any waste found.

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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 historic landfill in New Inn, Co. Galway. 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 a part of the survey. This survey is part of the Tier 2 site investigation and test report.

1.2 Objectives

The main objectives of the geophysical survey were:

- Identify the extent and depth of the former landfill
- Quantify the volume of the waste
- Provide information on the 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 along the R348, south west of the village of New Inn. The survey area is a long stretch of scrub land along the north side of the road. Elevations fall sharply from the road and continue to fall towards the north.

1.4 Geology

The online bedrock geological map of Ireland (GSI, 2019) describes the quaternary sediments are described as gravels derived from limestone. There is peat close to the site to the north. The survey area is underlain by the Lucan Formation, described as dark limestone and shale.

Historical maps show gravel pits within the survey area as well as a children's burial ground near the western edge of the survey area.

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 is outlined in the tender documents and consisted of EM31 Ground Conductivity measurements across the site to map and determine targets for additional geophysical methods including 2D-Resistivity Profiling, Seismic Refraction Profiling. These profiles were carried out in different directions through the middle of the waste body as identified through the EM31 ground conductivity survey.

The survey locations are indicated on Map 1. The profiles and 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	64	189
R2	3	24	69
R3	3	28	80
SUM			**338**
S1	3	72	213
S2	3	24	69
S3	3	24	69
SUM			**351**

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 below ground level (bgl). and over a radius of approx. 5 m around the instrument.

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.

Set-ups were acquired in longer continuous profiles using common shot points between set-ups and concatenating into longer profiles at the processing stage.

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 shadow zones are present (e.g. below solid ground surface) or where layers dip with more than 20 degrees angle the accuracy becomes much less.

2.5 Site Work

The data acquisition was carried out on the 21st May and the 12th of June 2020. The weather conditions were variable throughout the acquisition period. Health and safety standards were adhered to at all times.

The locations and elevations were surveyed with a Carlson NR3 RTK-GPS to accuracy < 0.05 m.

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.

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 (D/I) sources generally contain more decomposable or dissolvable material than waste from construction or demolition (C&D). Therefore D/I Waste will have lower resistivities and higher conductivities than C&D waste.

The scale used is higher than would typically be used for natural materials. Most of the survey area shows low conductivities (<20 mS/m) which indicates no waste or possibly C&D waste. There is one area in the south where conductivities rise to generally 20 – 40 mS/m. These conductivities would indicate some D/I waste material but the conductivities do not increase to very high levels which are typically found over deep landfills.

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.

Profiles R1 and R2 show some low conductivities near the middle of the profiles, with medium - high resistivities along the side of the profiles and high resistivities below. Profile R3 has medium - high resistivities near the surface underlain by high resistivities.

Low resistivities (<62.5 Ohmm) indicate mainly D/I waste material or leachate but may also indicate clay-rich or peat overburden. Medium resistivities (62.5 – 500 Ohmm) indicate boulder clay overburden while high resistivities (>500 Ohmm) indicate sand and gravel near the surface and fresh limestone at depth indicate.

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 number of layers has been determined by analysing the seismic traces and 3 - 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 or yellow 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 waste material below it.

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

Layer 1 has a thickness of 0.75 – 6.5 m and seismic velocities of 300 - 400 m/s. This velocity would topsoil material and is generally higher than would be expected for waste material. The layer may contain waste or made ground as well however.

Layer 2 was modelled with a velocity range of 900 - 1200 m/s and represents natural overburden. This layer is between 0.5 and 4 m thick.

Layer 3 has a velocity of 2000 m/s and is the deepest layer modelled along profiles S1 and S2. This layer is interpreted as compact overburden or weathered limestone. The top of layer 3 is between 1 and 9 m deep.

Layer 4 is interpreted as the Limestone layer and is between 5 and 6.5 m deep along profile S3.

3.4 Interpretation of Resistivity and Seismic Refraction

The seismic refraction and 2D-Resistivity provide information on two physical parameters of the waste material, however as discussed above the waste 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.

Waste material generally consists of low velocity, low resistivity material. The 2D-Resistivity data shows an area of low resistivity along profiles R1 and R2. This area conforms with the high conductivity area shown on map 2. Resistivities at the end of those profiles and across profile R3 are higher than would be expected for commercial and domestic waste.

The shallowest seismic velocity layer of 300 – 400 m/s is more typical or topsoil rather than waste material which generally has a lower velocity. This would indicate that there is likely topsoil or overburden material as well as waste material in the landfill sections highlighted on figure 2. Waste material within this area may not penetrate to the bottom of this layer.

High resistivities throughout the survey area indicate sand and gravel overburden or unweathered limestone.

Table 2 summarises the interpretation. The interpretation has been made from all available information. The resistivity models have been used to delineate between waste and natural material and the depth to rock. 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.

Table 2: Summary of Interpretation

Layer	General Seismic Velocity Range (m/sec)	General Resistivity Range (Ohmm)	Interpretation
1a	300 – 400	<62.5	Waste (Mainly D/I)
1b	300 – 400	>62.5	Topsoil with little or no Waste
2a	900 – 1200	<62.5	Overburden with Leachate
2b	900 – 1200	>62.5	Overburden
3	2000	>62.5	Compact Overburden or weathered Limestone
4	4000	>62.5	Limestone

4. CONCLUSIONS AND RECOMMENDATIONS

Geological Background

The geophysical survey indicates the site is underlain by sandy gravelly overburden over fresh limestone. The survey does not indicate any karst features within the survey area.

Lateral extent of waste and landfill boundary

The area outlined in magenta on Map 3 shows the interpreted extent of the interpreted waste using all the information available. This waste is interpreted as containing mainly domestic and industrial waste. The interpreted waste area covers an area of approx. 2,600 m^2.

Outside this area indicated above the interpretation indicates topsoil with little or no waste.

The area in the east (Profile R3/S3) does not show a waste body, the heaps here are interpreted as topsoil with little or no waste.

Vertical extent (depth) of waste

The thickness and depth has been estimated from the seismic refraction and 2D-Resistivity data. Considering the thickness of the interpreted Layer 1, an average thickness of 4 m has been calculated for the waste material. This estimate includes any capping or natural fill material on top of the main waste body. It is likely that this estimate includes significate natural material below the waste body.

Volume of waste

Considering the areas and average thickness above, the volume of the waste body is estimated at 10,400 m^3.

Nature of waste

The resistivities within the interpreted waste area would indicate primarily industrial and domestic waste but as the resistivity are not generally extremely low it may also contain C & D type waste.

Capping layer

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

Leachate

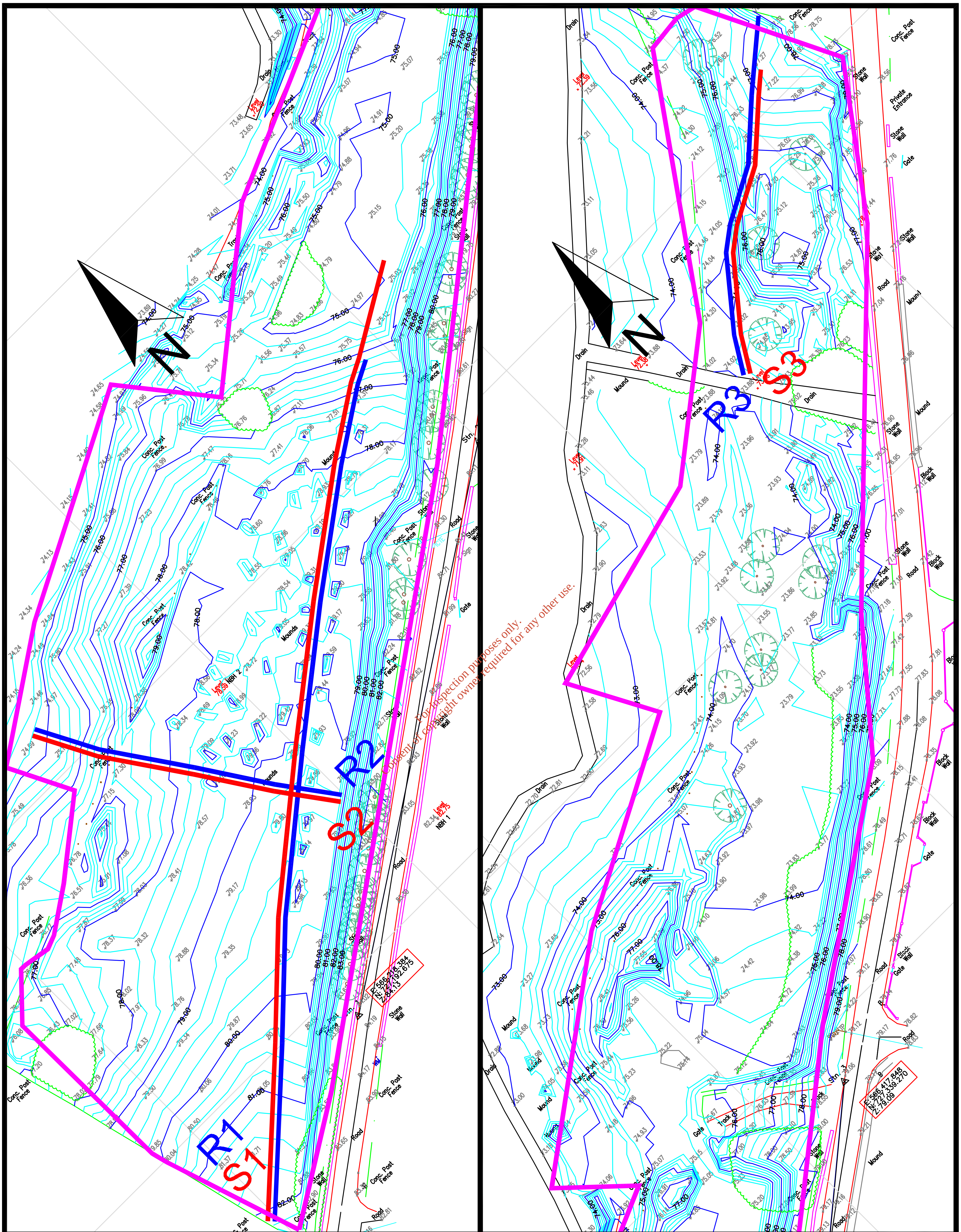
Low resistivities do not penetrate much deeper than layer 1. While there may be some minor leachate penetration below the landfill it is not interpreted as significant.

Recommendations

It is recommended to investigate the waste area outline on Map 3 using trial pits to determine the presence and nature of any waste found.

5. REFERENCES

1. **GSEG 2002.** Geophysics in Engineering Investigations. Geological Society Engineering Geology Special Publication 19, London, 2002.
2. **GSI, 2019.** Online Bedrock 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 & Company

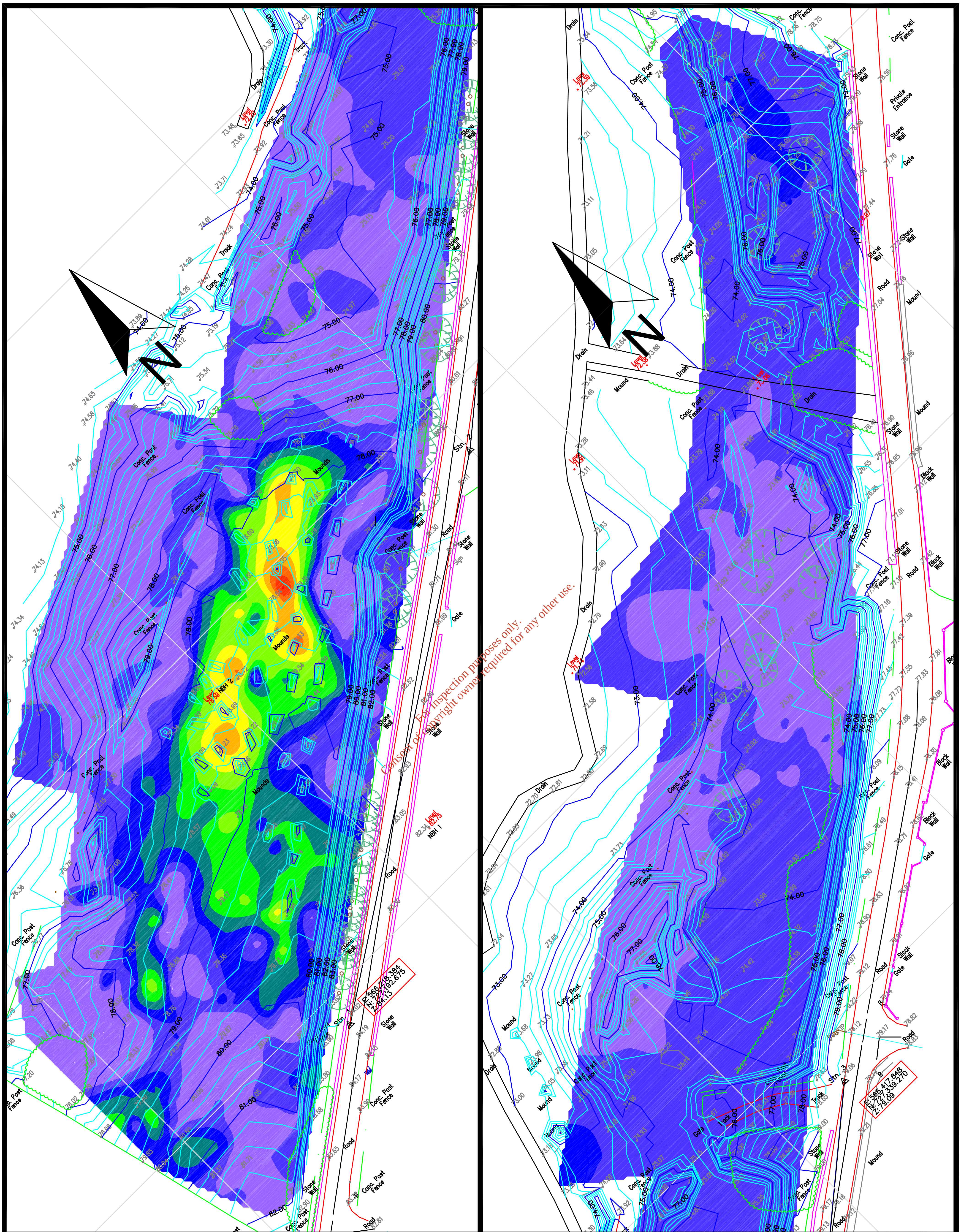
PROJECT New Inn Historic Landfill Geophysical Survey

TITLE Map 1: Geophysical Survey Location Map

SCALE:	1:500 @ A3
PROJECT:	6499
DRAWN:	JC
DATE:	22/05/2020
MGX FILE:	6499d_New_MapsFigs.dwg
STATUS:	Draft

LEGEND: Geophysical Survey Locations:

R2	2D-Resistivity Profile
S1	Seismic Refraction Profile
	EM31 Survey Area



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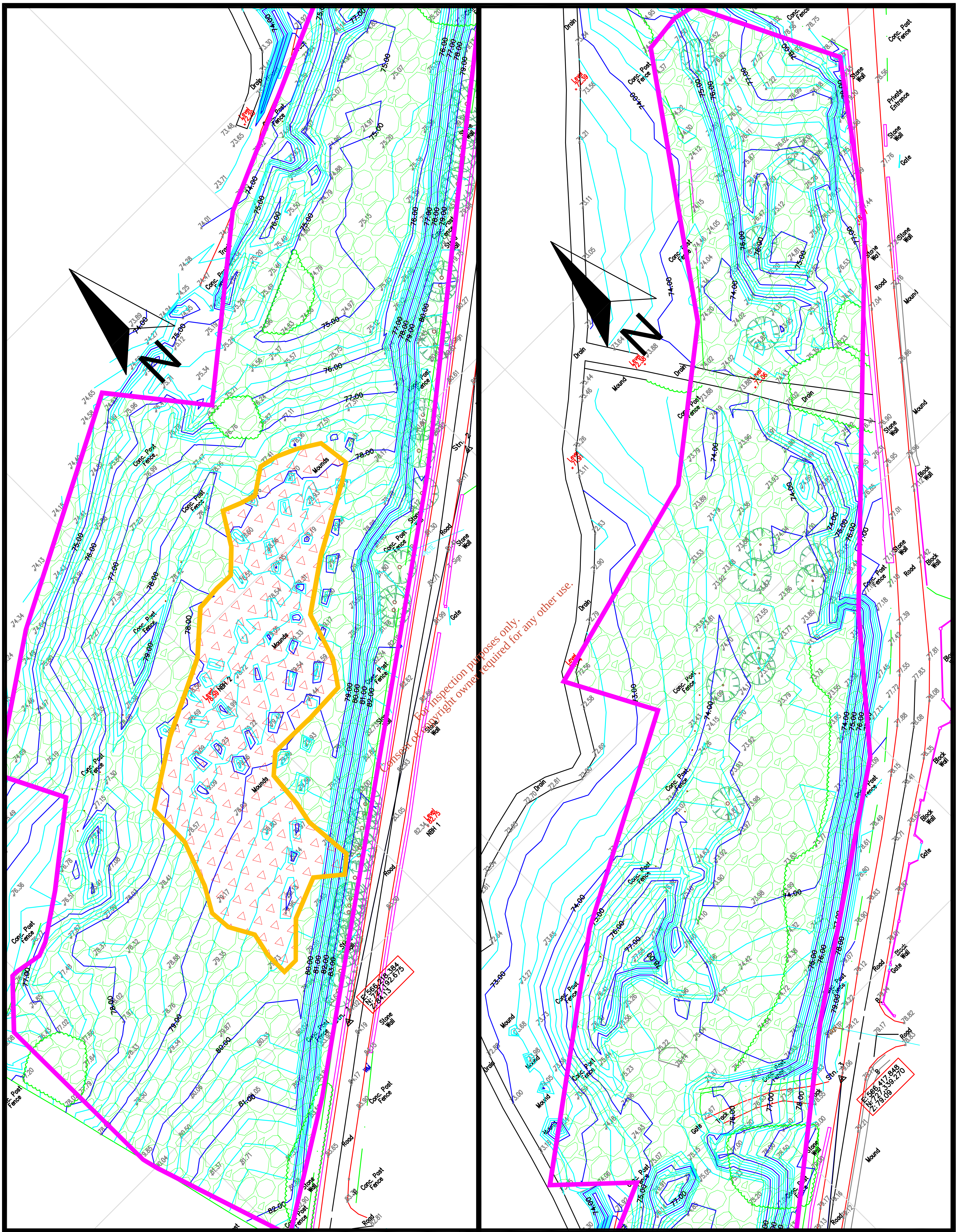
CLIENT	Fehily Timoney & Company
PROJECT	New Inn Historic Landfill Geophysical Survey
TITLE	Map 2: EM31 Ground Conductivity Contour Map

SCALE:	1:500 @ A3
PROJECT:	6499
DRAWN:	JC
DATE:	22/05/2020
MGX FILE:	6499d_New_MapsFigs.dwg
STATUS:	Draft

LEGEND: EM31 Ground Conductivity Values:

0 5 10 15 20 25 30 35 40 45 50

The map shows the EM31 ground conductivity contours mS/m. The low (blue) conductivities indicate the no waste material. The middle range (green) values indicates some waste material. The high (red) values indicates the deepest waste area.



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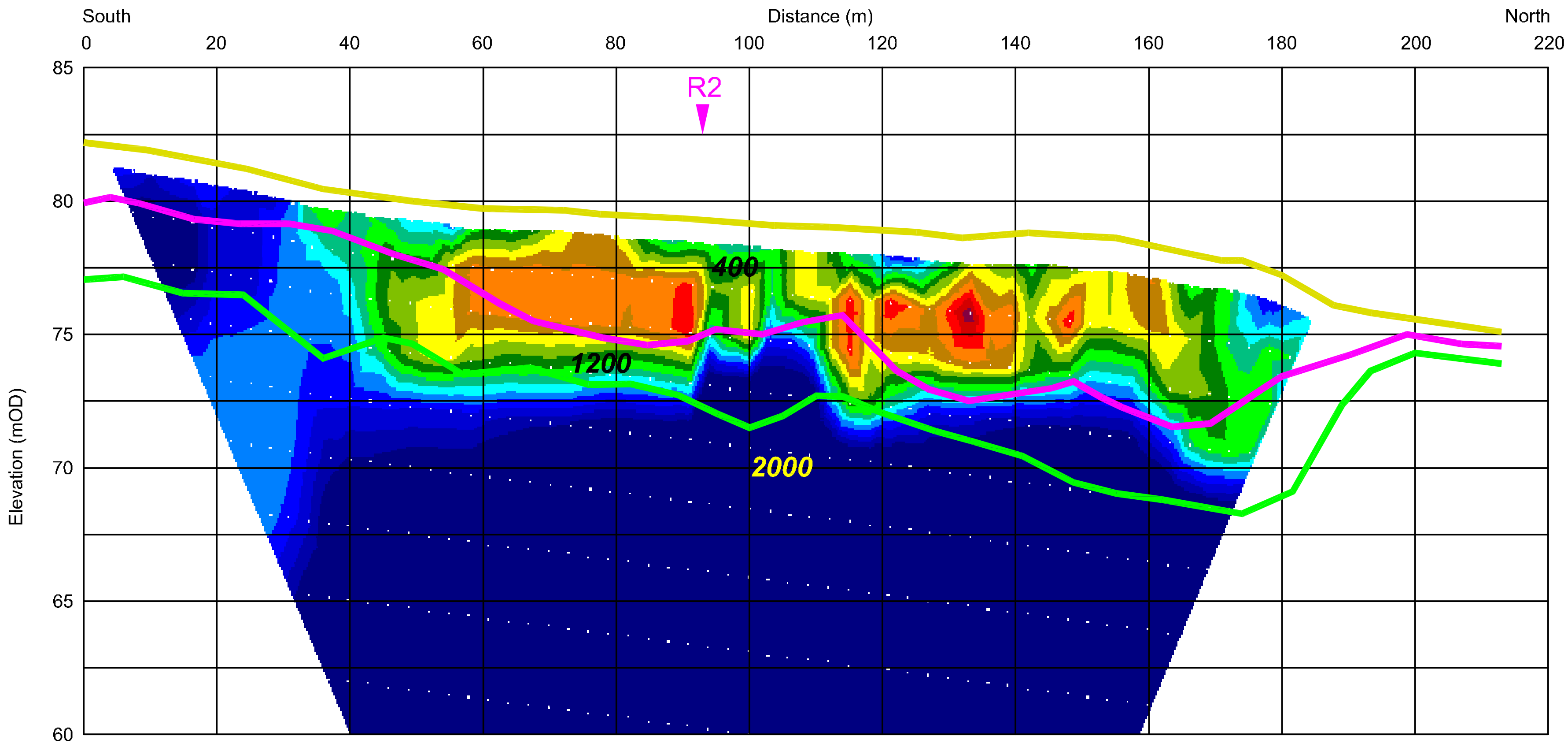
CLIENT	Fehily Timoney & Company
PROJECT	New Inn Historic Landfill Geophysical Survey
TITLE	Map 3: Geophysical Survey Interpretation Map

SCALE:	1:500 @ A3
PROJECT:	6499
DRAWN:	JC
DATE:	22/05/2020
MGX FILE:	6499d_New_MapsFigs.dwg
STATUS:	Draft

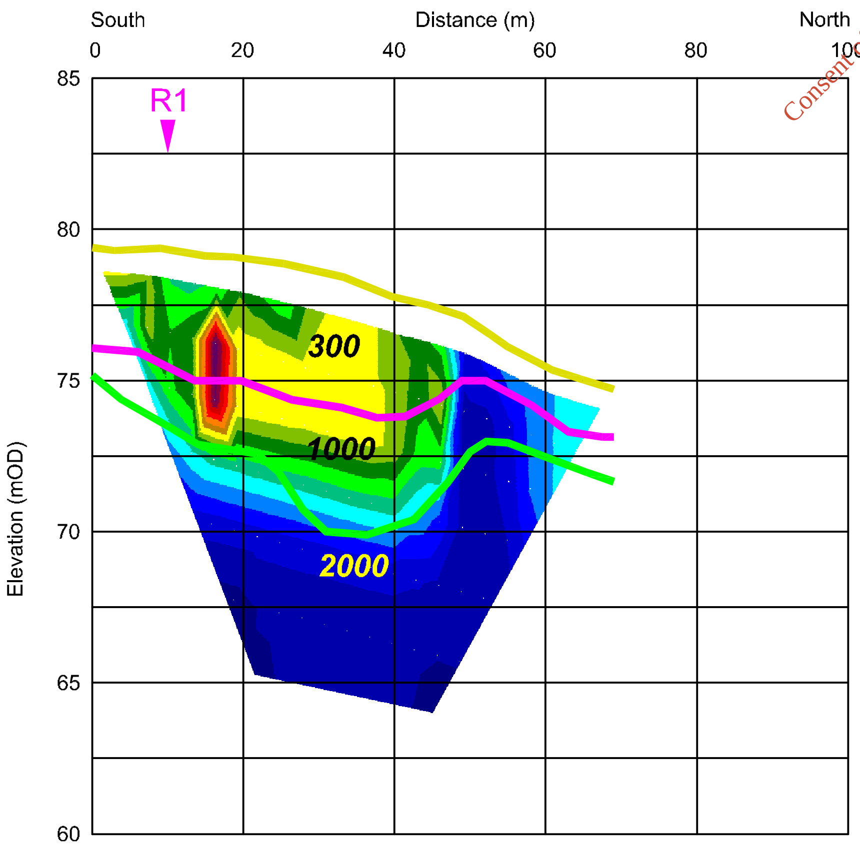
LEGEND:

- Extent of Waste Material
- Little or no Waste Material

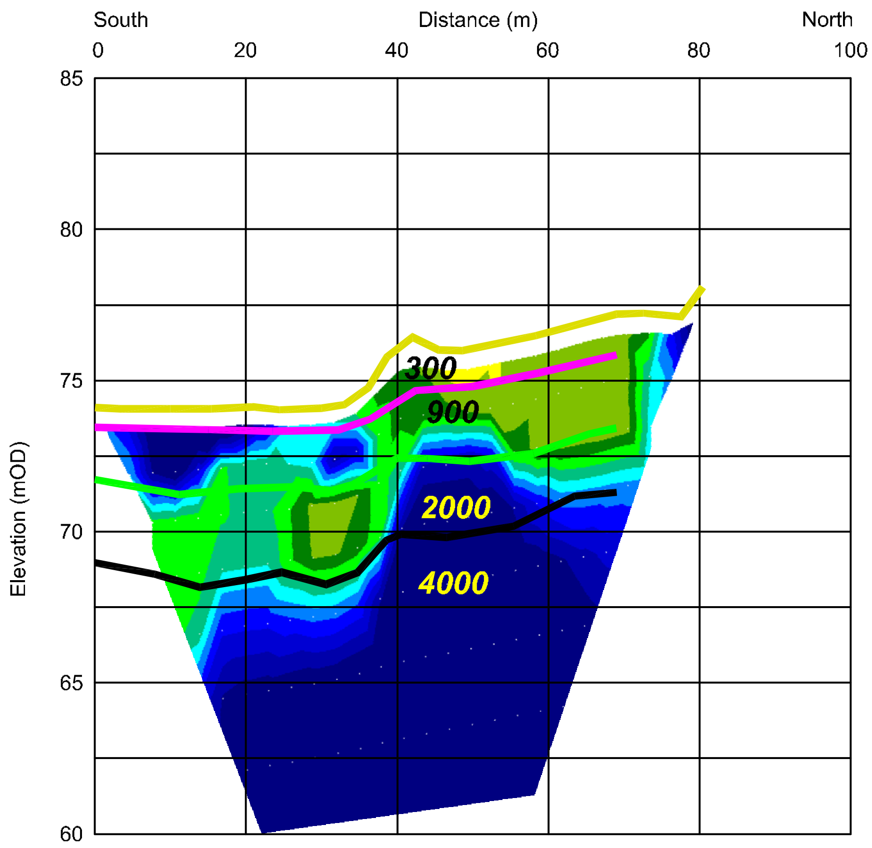
2D-Resistivity Profile R1 and Seismic Refraction Profile S1 Model



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

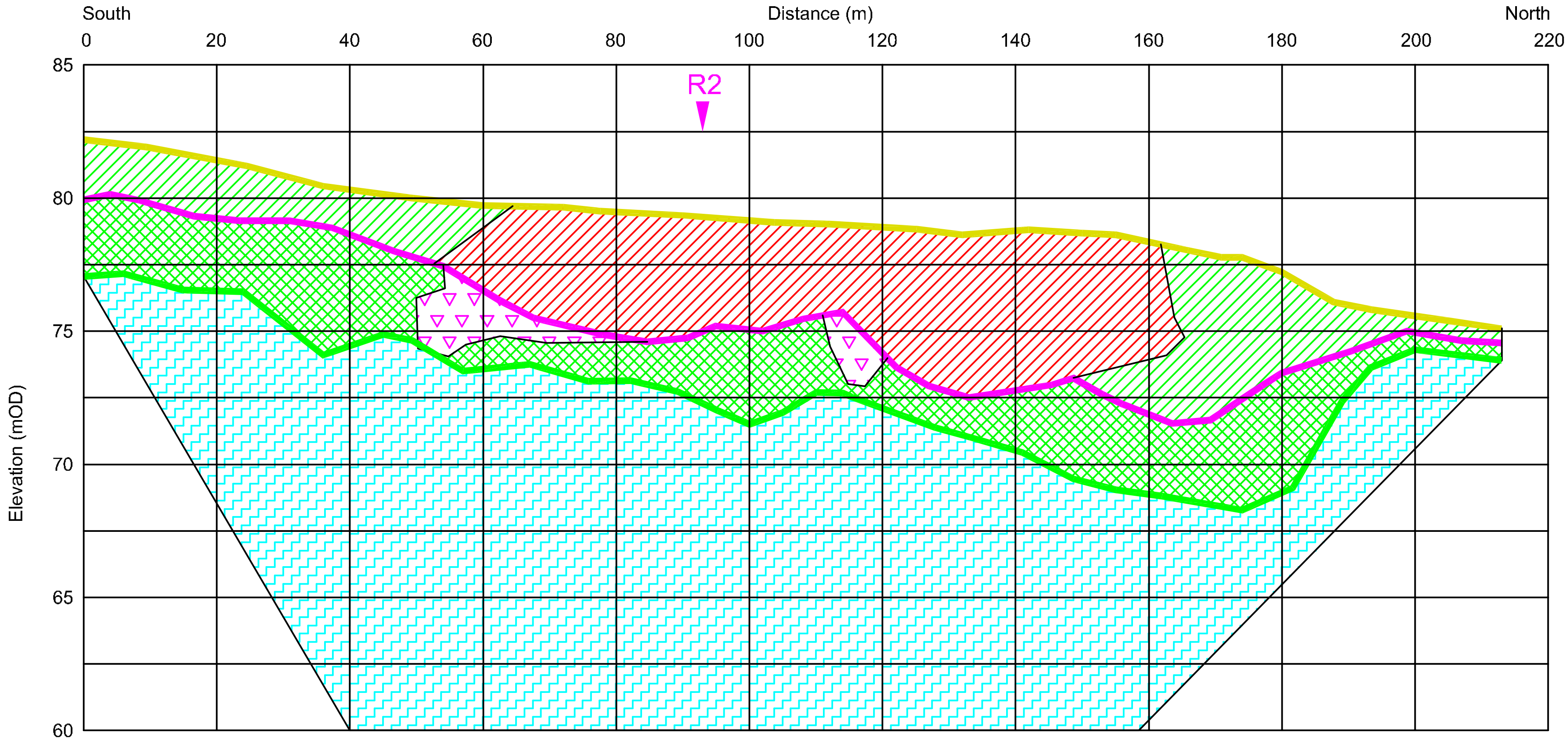


2D-Resistivity Profile R3 and Seismic Refraction Profile S3 Model

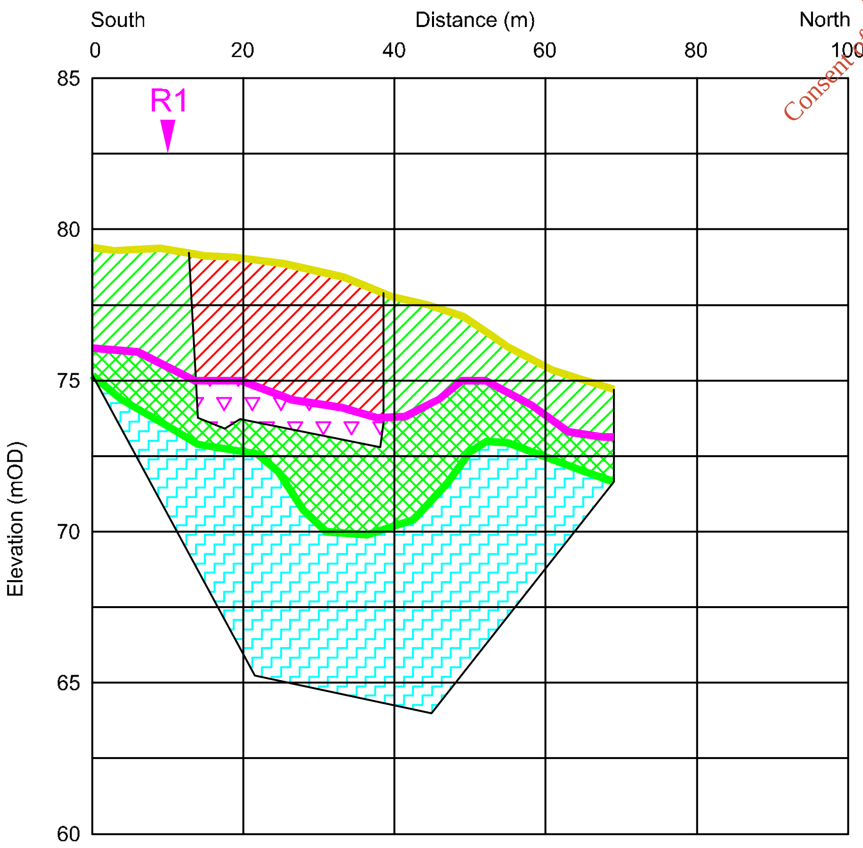


Minerex Geophysics Limited Unit F4, Maynooth Business Campus Maynooth, Co. Kildare Tel. (01) 6510030 Email: info@mgx.ie Web: www.mgx.ie	CLIENT Fehily Timoney & Company	SCALE: 1:500 @ A3	LEGEND: Layers from Seismic Refraction Model:
	PROJECT New Inn Historic Landfill Geophysical Survey	PROJECT: 6499	Ground Surface/Top of Layer 1 (300 - 400 m/s)
		DRAWN: JC	Top of Layer 2 (900 -1200 m/s)
		DATE: 22/05/2020	Top of Layer 3 (2000 m/s) Top of Layer 4 (4000 m/s)
	TITLE Figure 1: Models of Geophysical Survey	MGX FILE: 6499d_New_MapsFigs.dwg	2D-Resistivity Model Values:
		STATUS: Draft	7.82 15.6 31.3 62.5 125 250 500 1000

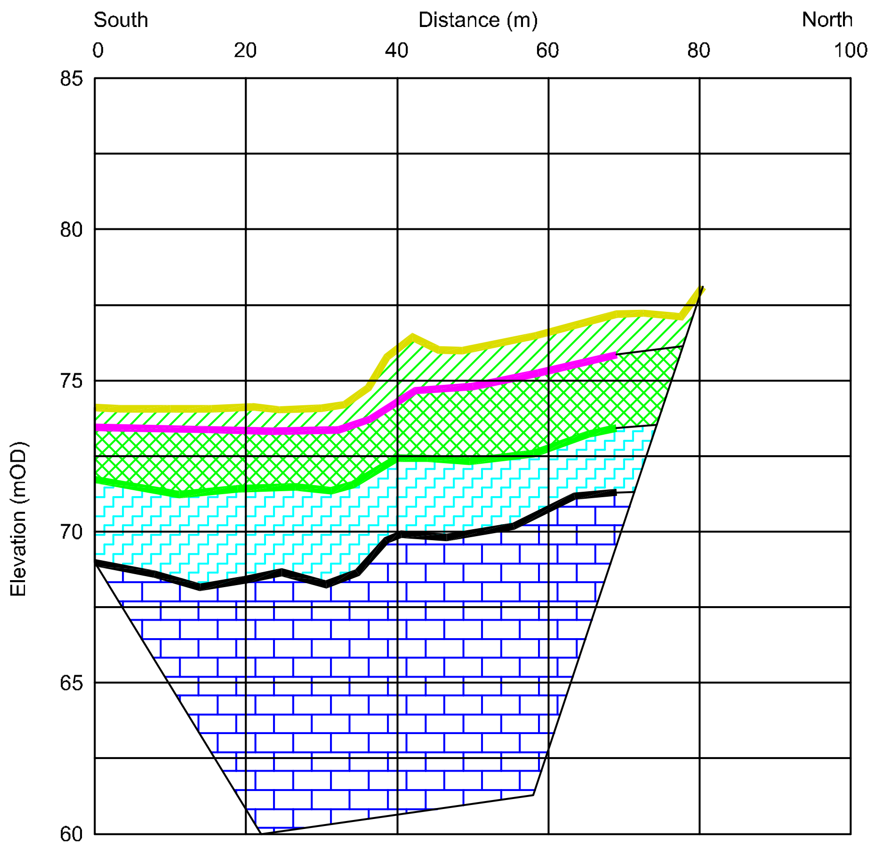
2D-Resistivity Profile R1 and Seismic Refraction Profile S1 Model



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



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



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PROJECT	New Inn Historic Landfill Geophysical Survey	PROJECT:	6499
		DRAWN:	JC
		DATE:	22/05/2020
TITLE	Figure 2: Interpretation of Geophysical Survey	MGX FILE:	6499d_New_MapsFigs.dwg
		STATUS:	Draft

LEGEND: Interpretation:

- 1a Waste (Mainly D/I)
- 1b Topsoil with little or no Waste
- 2a Overburden with Leachate
- 2b Overburden
- 3 Compact Overburden or Weathered Limestone
- 4 Limestone