Churchtown Landfill Site

Newcastle West

Geophysical Survey

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Confidential Report To:

Limerick County Council
Environment Section
County Hall
Dooradoyle
Co. Limerick

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Issued by:

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Subsurface Geophysical Investigations

EXECUTIVE SUMMARY

1. Minerex Geophysics Ltd. (MGX) carried out a geophysical survey in 2012 consisting of EM31 Ground Conductivity, 2D-Resistivity and seismic refraction for the Tier 2 preliminary Site investigation of the historic Churchtown Landfill Site in Newcastle West, Co. Limerick.
2. The main objectives of the survey were to determine ground conditions in general, the extent, depth, volume and nature of the waste, information on the capping and possible leachate from the site.
3. In June 2013 a seismic survey consisting of 8 short profiles was added in the east of the landfill area in some residential gardens. The aim was to define the landfill boundary as precisely as possible.
4. This report also includes the data from four 2D-Resistivity Profiles that were done in 2007 by BRG Ltd.
5. The draft report in 2012 made some recommendations that were carried out by the client and the results are included in this final report.
6. The boundary of the landfill is well defined when taking all the previous GI, geophysics and historical maps into account. The area within the boundary (Black and magenta line on Map 3) is 1.86 ha.
7. The base of the landfill and floor of the former quarry are at a level of 63 – 65 mOD. Given the ground elevations of 68 – 78 m on the landfill the thickness of the waste body is 5 – 15m. Using the area of 1.86 ha and an average thickness of 10 m there would be a volume of 186000 m^3.
8. There is no evidence of an engineered capping layer though a general trend of higher resistivities at the surface indicates more granular gravelly material and stone or rock fill at the surface. This may provide some capping function.
9. Resistivity data shows that it is likely that some leachate occurs into the rock below the landfill.

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List of Tables, Maps and Figures:

1. INTRODUCTION

1.1 Background

Minerex Geophysics Ltd. (MGX) carried out a geophysical survey for the Tier 2 preliminary site investigation for the historic Churchtown Landfill Site in Newcastle West, Co. Limerick. The survey consisted of EM31 Ground Conductivity, 2D-Resistivity and seismic refraction (p-wave). The survey is part of the ground investigation for the landfill. The survey was commissioned by Limerick County Council. Other work items like trial pits, slit trenches and sampling were done by Limerick Co. Co. in February 2012 at the same time as the geophysical survey. In June 2013 a seismic refraction survey was added to determine the landfill boundary in the residential gardens to the east of the site. Four 2D-Resistivity Profiles done in 2007 were also added to this report.

1.2 Objectives

The main objectives of the first geophysical survey in 2012 were set out by the client in the tender:

- Identify the extent of the former landfill site and quarry
- Provide information on the depth and nature of the waste body
- Quantify the volume of the waste
- Provide information on the depth and extent of the capping layer
- Look for evidence for leachate migration from the site

The detailed objective of the seismic survey in June 2013 was:

- Identify the landfill boundary precisely in the gardens to the east

1.3 Site Description

The landfill site is situated in a former limestone quarry and has a size of approx. 2 ha. A topographical survey was carried out in 2007 and is used as a background map in the maps of this report. The elevations on the site range from 68 to 78 mOD. The site slopes from NE to SW. The surrounding topography generally slopes from East to West. Some parts of the site are overgrown. The site is described in detail in the Tier 1 – Landfill Risk Assessment report.

1.4 Geology

The bedrock geological map of the Shannon Estuary (GSI, 1999) indicates that the survey area is underlain by the Waulsortian limestone formation, described as massive unbedded lime-mudstone. These limestones are typically very clean and liable to karstification.

The Tier 1 and Tier 2 reports detail the site investigations carried out at the Churchtown Landfill 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 maps of the site and the digital version was used as the background map in this report. Elevations were surveyed on site and were incorporated into the data for the vertical sections. The system used in this report is Irish transverse Mercator (ITM).

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 for the geophysical survey consisted of EM31 Ground Conductivity, 2D-Resistivity and Seismic Refraction Profiles. The survey locations are indicated on Map 1. There are four 2D-Resistivity profiles and eight seismic refraction profiles. The geophysical survey parameters for the profile are listed in Table 1.

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: Data Acquisition Parameters for Geophysical Profiles

Profile Name	**Electrode/Geophone Interval/m**	**Number of Electrodes/Geophones**	**Profile Length/m**
R1 - R4	3	64	189
S1 – S8	3	24	69

2.2 EM31 Ground Conductivity

The EM31 ground conductivity survey was carried out on lines over the landfill and the surrounding area to the west and north where clearance was made or previously available. Along each line a reading of ground conductivity was taken every second while walking along. The locations (small crosses on Map 2) 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. Landfill waste and leachate have higher conductivities than most geological materials and can be located within the depth range of the meter. When looking for clay, silt and water infill within rock occurring at relatively shallow depth the EM31 can find anomalous rock zones with a vertical extent of approx. 3m. The measurements are disturbed by metal and other conductive objects within the range of the instrument and therefore no geological interpretations can be made in the vicinity of such man-made objects. Either readings were not taken near sources of interference in the first place or notes were taken by the operator in order to account for these in the interpretation.

2.3 2D-Resistivity

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 materials.

2D-Resistivity profiles with electrode spacing of 3m were surveyed at the locations shown on Map 1. The readings were taken with a Tigre Resistivity Meter and Imager Cables.

2.4 Seismic Refraction

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.

The seismic survey consisted of p-wave seismic refraction profiling. Each of the profiles consisted of 24 geophones with 3 m spacing, resulting in lengths of up to 69m per profile. The recording equipment consisted of a 24 Channel DMT Summit 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.

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 are present or where layers dip with more than 20 degrees angle the accuracy becomes much less. In loose and soft ground like a landfill the seismic energy gets heavily attenuated and usually on 3 – 6 m depth penetration is possible.

2.5 Site Work 2012

The data acquisition was carried out on the 13th and 14th of February 2012. 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 TRIMBLE RTK-GPS to accuracy < 0.02m.

2.6 Site Work 2013

The data acquisition for the 2013 seismic refraction survey was carried out on the 25th June 2013. The geophone spacing used was 1 m in order to resolve the seismic velocity of the shallow subsurface with high resolution. Otherwise the seismic refraction method was done as described above. There were 8 seismic refraction profiles done named S11 – S18 and they are indicated on the location maps.

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 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.

Low conductivities would indicate either shallow bedrock or dry sandy and gravelly overburden while higher conductivities would indicate deeper bedrock and clay-rich overburden. Very high or very low conductivities indicate interference from manmade metal objects or occur over the waste body.

Middle range values (15 – 25 mS/m) indicate gravelly clay outside the landfill in the field to the west or areas where the waste is relatively thin close to that field boundary in the west (and inside the landfill area).

The high values (> 25 mS/m) are concentrated over the highest part of the landfill where they indicate the largest thickness of the waste and leachate within the waste. The transition from high to low values can be seen on the property without a building between the R521 and the landfill. The gradient in the readings indicates the landfill boundary.

A line of high readings occurs in the field to the west close to the road. There is no visible obvious reason for these high readings that must be caused by subsurface metal. The subsequent site investigation showed that this is a buried power cable.

3.2 2D-Resistivity Profiles

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 < 2.1%. The resulting models were colour contoured with the same scale for all profiles and they are displayed as cross sections (Figure 1a and 1b).

The resistivities cover a wide range of values. The high values at depth indicate clean limestone bedrock while low values indicate the presence of the landfill waste body. The lowest values within the landfill are most likely caused by a combination of waste material and water within the landfill body.

The resistivities at depth are generally quite high which is consistent with the clean (non-argillaceous) limestone rock type. It confirms that the undisturbed rock is a clean limestone, which means it has no or very low shale or mud content. The high resistivities indicate that the limestone is liable to karstification but does not have to be karstified.

3.3 Seismic Refraction Data 2012

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 5 layers were used in the individual 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. 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 1a and 1b). The seismic velocities obtained within the layers are annotated on the sections.

S1 and S8 were done outside the landfill to model the normal geological ground conditions in a down gradient direction. S2, S6 and S7 were done to cross the boundary of the waste body and determine the edge of the former rock quarry. S4 and S5 are over the lower part of the landfill to see if the bottom can be reached. S3 is entirely within the landfill waste body.

S1 and S8 indicate that the succession of ground layers is quite normal going from soft topsoil over firm to stiff gravelly clay and weathered bedrock to strong rock. The layer 4 (Figures 1a and 1b) is a typical transition layer between overburden and strong bedrock and can contain weathered rock but also very consolidated overburden. Notable is a thickening of the overburden and weathered rock layer on S8 (at 60-100m on R8) which is also the lowest point of the ground across the road from the westernmost point of the landfill.

S2, S6 and S7 show the lateral change between landfill waste body and the natural geology quite well and the modelling could prove the edge of the former rock quarry well. The large difference of seismic velocities across the boundary causes a good contrast and the first breaks in the seismic shot records allow an excellent locating of the former quarry edge.

S3 is at the thickest part of the landfill and it is not possible to make any deduction about the depth of the landfill. This was to be expected because of the strong attenuation of the seismic signal in the loose waste body. Some variations of the seismic velocity within the waste body could be modelled and improved the model accuracy. This shows that the waste has a quite narrow band of seismic velocities (0.25 to 0.5 km/s).

S4 and S5 still do not show the base of the landfill although it is thinner than at S3. S5 allows some estimation about the depth to the limestone which is significant close to the site entrance. It shows that the former quarry floor was located deeper than the current site entrance (also found in the slit trenches). S4 shows a curious change from normal condition in the waste body as there is an area with high seismic velocities (modelled with 3 km/s). This is likely an area of backfilled very compact and hard stones or rocks though it could be also an area of rock that was not excavated in the former quarry. It is noted that the highest resistivities within the landfill occur at this location.

3.4 Interpretation

Abbreviated trial pit and well logs are shown on the sections where ground investigation points are close to the geophysical profiles. For a full description of the logs the report should be used.

Table 2 summarises the interpretation. The interpretation follows the seismic layers and then is extrapolated along the resistivity sections. The interpretation has been made from all available information including the well logs and trial pits. The base of the landfill which is the old quarry floor has been interpreted from the boreholes and the resistivities as no seismic profile has reached the base.

The interpretations are drawn on Figures 2a and 2b. Layers are indicated by the hatch pattern. The magenta dashed line on R 2 and R3 indicates the water table within the landfill as indicated by the sudden increase in resistivities around this level.

Table 2: Summary of Results and Interpretation

Layer	**General Seismic Velocity Range (km/sec)**	**General Resistivity Range (Ohmm)**	**Compaction/Strength/ Rock Quality**	**Interpretation**
1	0.25 – 0.3	< 160	Soft/Loose	Overburden (Soil or Topsoil)
2	0.25 – 0.5	< 320	Loose/soft	Waste - Landfill
3	0.7 – 1.5	< 240	Firm to stiff	Overburden (Clay)
4	2.1	< 480	Weathered or hard	Weathered Rock or Overburden (Clay)
5	3.5 – 4.3	> 240	Strong	Strong Limestone
-	-	< 60	-	Possible Leachate outside Landfill Waste Body
On S4	3.0	> 320	-	Solid Object/Layer within Landfill

Map 3 summarises some of the interpretations made in this report.

3.5 Seismic Refraction Interpretation 2013

The seismic modelling with ray tracing and interpretation was aimed at defining the landfill boundary as precisely as possible. The layers and velocity ranges used previously on this project were used as far as possible, with some modifications visible on the legend of Figure 3. The results and interpretation of profiles S11 – S18 are displayed on Figure 3.

The 8 seismic profiles (S11 – S18) show quite varying results in term of ground model and background geology. The boundary between waste body natural ground is not always sharp and seismic velocities are quote similar at a shallow depth inside and outside the fill.

Profile 18 shows a 'normal' ground layering with rock at depth and no indication for waste and landfill material. There is no landfill material in this back garden.

Profiles 15 – 17 show the boundary by the drop in the faster velocity layers to the west where they are replaced by lower velocity layers representing the landfill. Profile 11 shows the same pattern where the landfill occurs just at the western profile end.

Profiles 12 – 14 show an opposed pattern where the ground gets less compacted and possibly more gas-rich towards the east. Therefore the boundary was placed at the eastern zone where the velocity get less. On Profile 14 the landfill boundary is outside the profile and taken from the previous survey.

Overall confidence about the landfill boundary location is good at profiles 11 and 15 – 17. On profiles 12 and 13 the confidence is less. There is no landfill under profile 18, and along profile 14 and the old profile S2 the boundary is most eastward.

The boundary may not always be 'sharp' with some mixing of landfill and overburden material likely. The boundaries as displayed here show a 'best fit' solution and are useful for the estimation of size and extent of the landfill.

3.6 2D-Resistivity Interpretation 2007

The resistivity profiles carried out in 2007 have been re-processed with elevations and the same inversion and display parameters as in the 2012 survey. The results are similar as in the 2012 survey. The older profiles have been displayed in Figure 1c and are interpreted in Figure 2c.

4. CONCLUSIONS

This chapter summarises the conclusion based on the objectives and topics investigated.

Lateral extent of waste and boundary

The boundary of the landfill is well defined when taking all the previous GI, geophysics and historical maps into account. The edge of the former quarry has been found at S2, S6, and S7 and twice on R1. R1 runs over the edge of the landfill at an oblique angel therefore the boundary appears less focuses than elsewhere. The boundary has been also modelled on S11 – S17 while S18 is outside the landfill. It also shows on the northern end of R3-2007.

The boundary has been drawn on Map 3 as a black line and for S11 – S17 as a magenta line. The area within the boundary is 1.86 ha.

Volume of waste

The base of the landfill and floor of the former quarry are at a level of 63 – 65 mOD. Given the ground elevations of 68 – 78 m on the landfill the thickness of the waste body is 5 – 15m. Towards the field in the west it is likely that the thickness will decrease to 0m as the EM31 values approach the background values. Using the area of 1.86 ha and an average thickness of 10 m there would be a volume of 186000 m^3.

Nature of waste

In this report the whole landfill body was addressed as waste though it is known from the trial pits and slit trenches that there are significant volumes of made ground consisting of clay and sand/gravel with little or no waste material within the landfill. There is no indication in the resistivities or other physical parameters that allow a distinction between these materials. The waste body as described throughout this report is determined by the low resistivities of the waste that is spreading through solution as leachate and therefore equalises the resistivities.

Capping layer

There is a general trend of higher resistivities at the surface (dry waste) with lower resistivities (saturated waste) near the top. At the very top resistivities change mainly between > 80 Ohmm (green) to < 80 Ohmm (yellow – brown). Higher values indicate more granular gravelly material and stone or rock fill while lower values represent clay and waste material.

Deepest part of landfill and possible leachate vertical below landfill

New and old resistivity profiles for the site indicate lower resistivities stretching deeper than the expected final depth of the landfill (as defined from previous boreholes). This area is centred on the highest part of the landfill and mapped on Map 3. The reason is most likely that there is leachate into the subsurface vertically downwards into the rock below the landfill.

Underground Power Cable

An anomaly found by EM31 in the field to the west was identified as an underground power cable coming from the overhead power line and running west to a residential property.

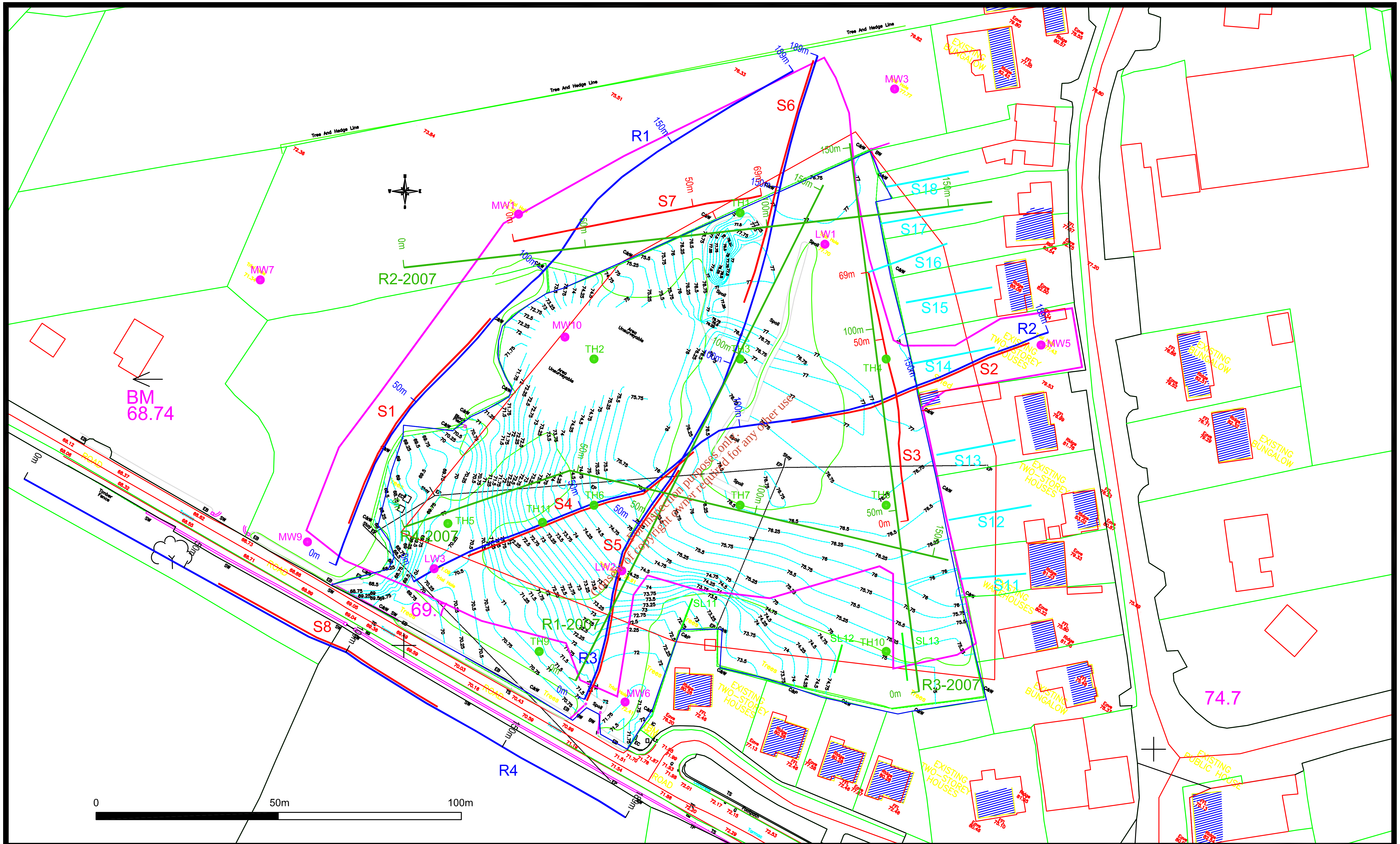
5. REFERENCES

1. **GSEG 2002.** Geophysics in Engineering Investigations. Geological Society Engineering Geology Special Publication 19, London, 2002.

2. **GSI, 1996.** Geology of Tipperary. Geological Survey of Ireland 1996.

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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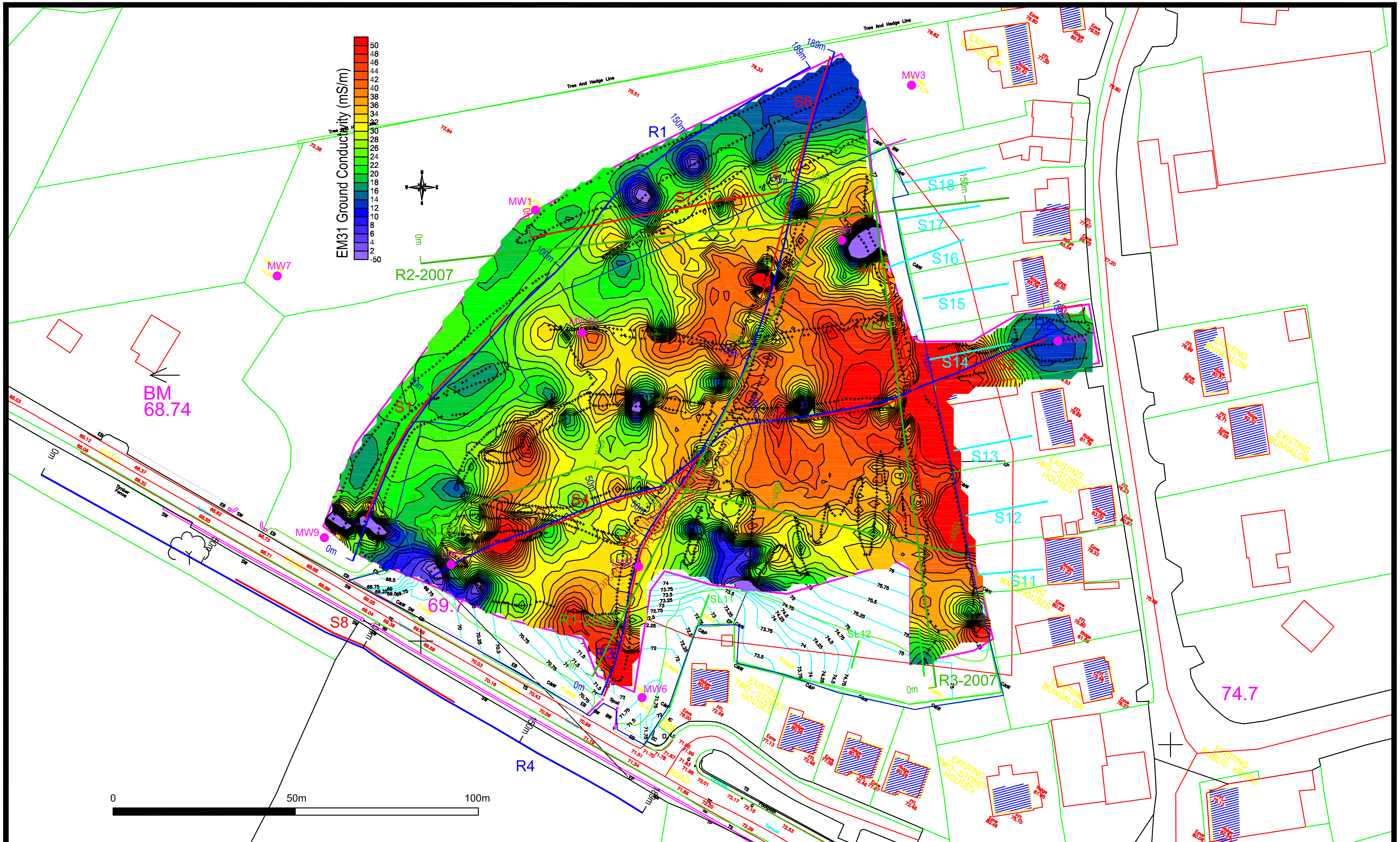
CLIENT	Limerick County Council
PROJECT	Churchtown Landfill, Newcastle W. Geophysical Survey
TITLE	Map 1: Geophysical Survey Location Map

SCALE:	1:1000 @ A3
PROJECT:	5611
DRAWN:	DA
DATE:	06/09/2013
MGX FILE:	5611f_Maps.dwg
STATUS:	Final

LEGEND:

- 2D-Resistivity Profile (2012)
- Seismic Refraction Profile (2012)
- 2D-Resistivity Profile (2007)
- Seismic Refraction Profile (2013)
- Trial Holes (Feb 2012)
- Wells (2007)
- EM31 Survey Area



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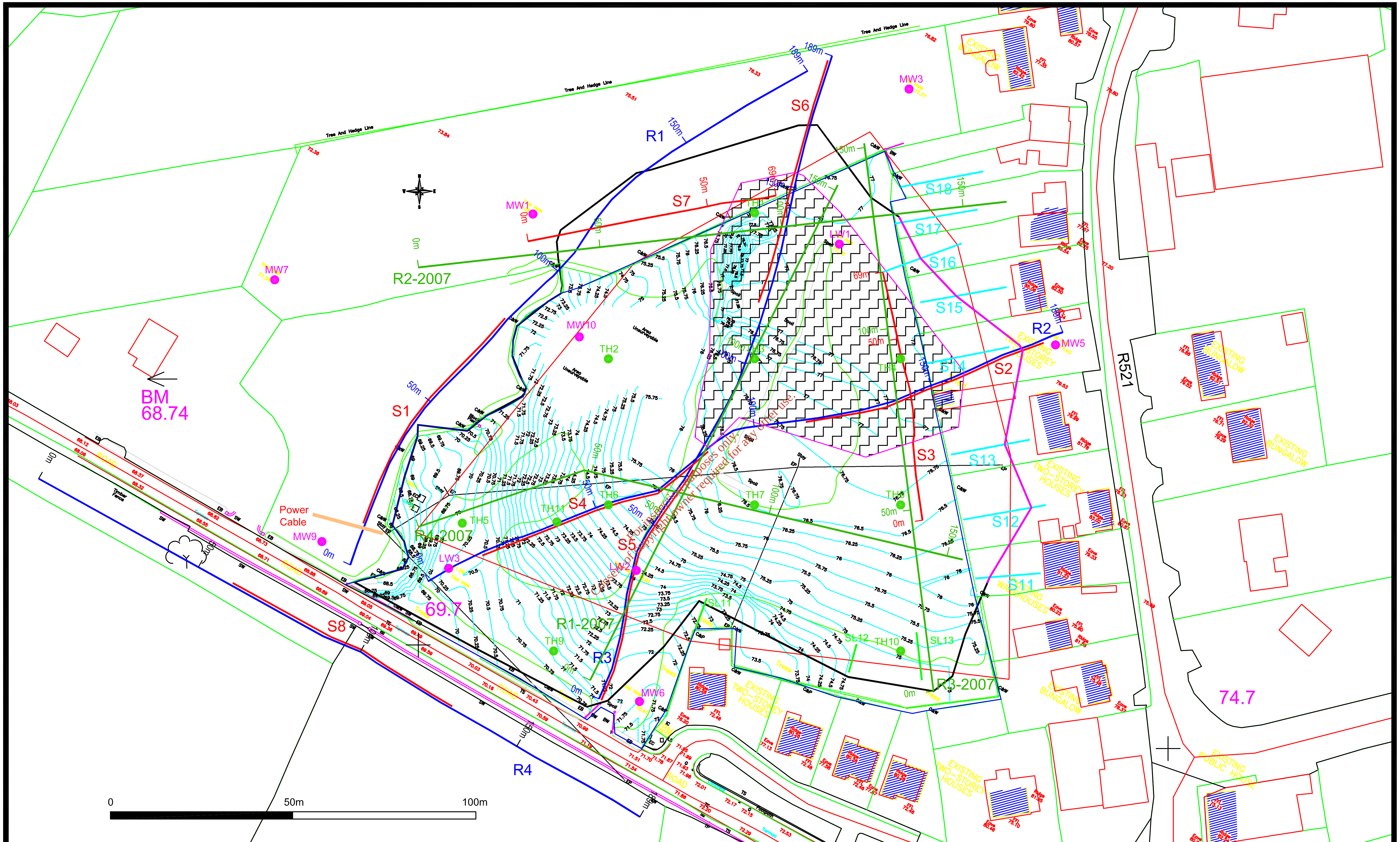
CLIENT	Limerick County Council
PROJECT	Churchtown Landfill, Newcastle W. Geophysical Survey
TITLE	Map 2: EM31 Ground Conductivity Contour Map

SCALE:	1:1000 @ A3
PROJECT:	5611
DRAWN:	DA
DATE:	06/09/2013
MGX FILE:	5611f_Maps.dwg
STATUS:	Final

LEGEND:

The map shows the EM31 ground conductivity contours mS/m. The lowest (magenta) readings occur when the instrument is close over metal. The low (blue) conductivities indicate relatively shallow limestone outside the landfill body. The middle range (green) values indicate gravelly clay outside the landfill or the part of the landfill body with relatively low thickness of waste. The high (red) values indicate the thickest waste body and the highest amount of leachate within the landfill waste body. Red values can also indicate the influence of metal, either above ground (like fences) or below ground (metal waste within the landfill).



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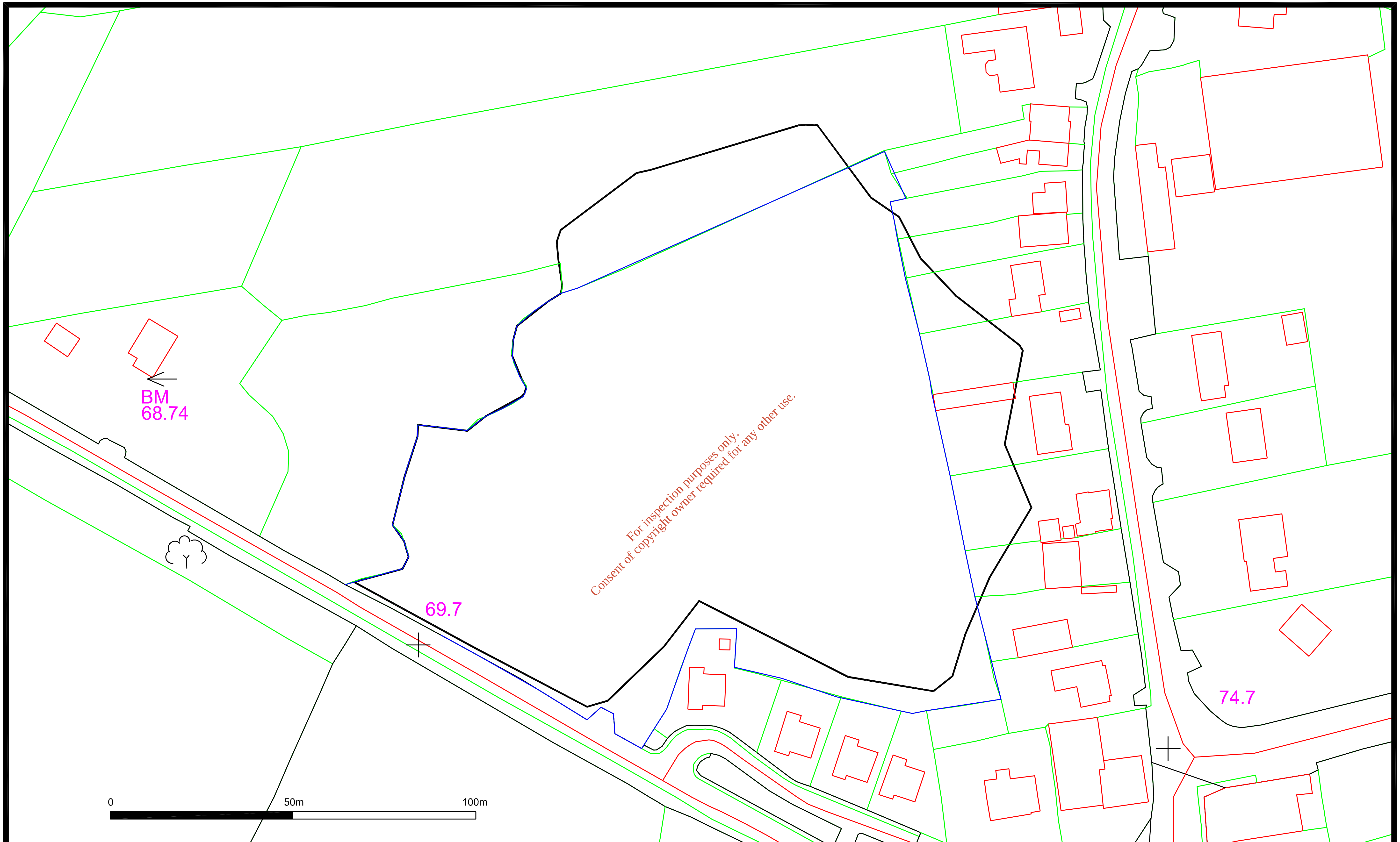
CLIENT	Limerick County Council
PROJECT	Churchtown Landfill, Newcastle W. Geophysical Survey
TITLE	Map 3: Interpretation Map

SCALE:	1:1000 @ A3
PROJECT:	5611
DRAWN:	HK
DATE:	06/09/2013
MGX FILE:	5611f_Maps.dwg
STATUS:	Final

LEGEND:

- Power Cable
- Landfill Boundary (Best Fit)
- Possible Leachate below Landfill
- Landill Boundary from 2013 Seismic Survey (S11 - S18)



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CLIENT	Limerick County Council
PROJECT	Churchtown Landfill, Newcastle W. Geophysical Survey
TITLE	Map 4: Boundaries Map

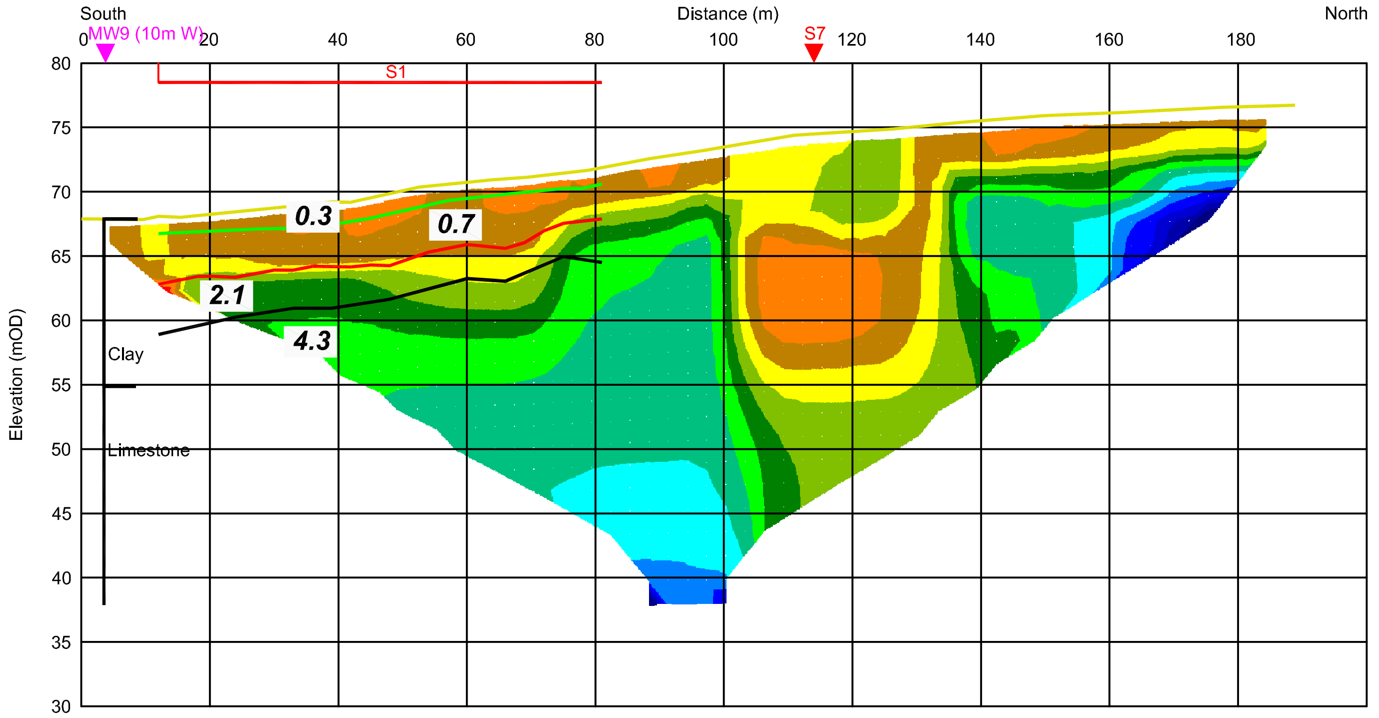
SCALE:	1:1000 @ A3
PROJECT:	5611
DRAWN:	HK
DATE:	06/09/2013
MGX FILE:	5611f_Maps.dwg
STATUS:	Final

LEGEND:

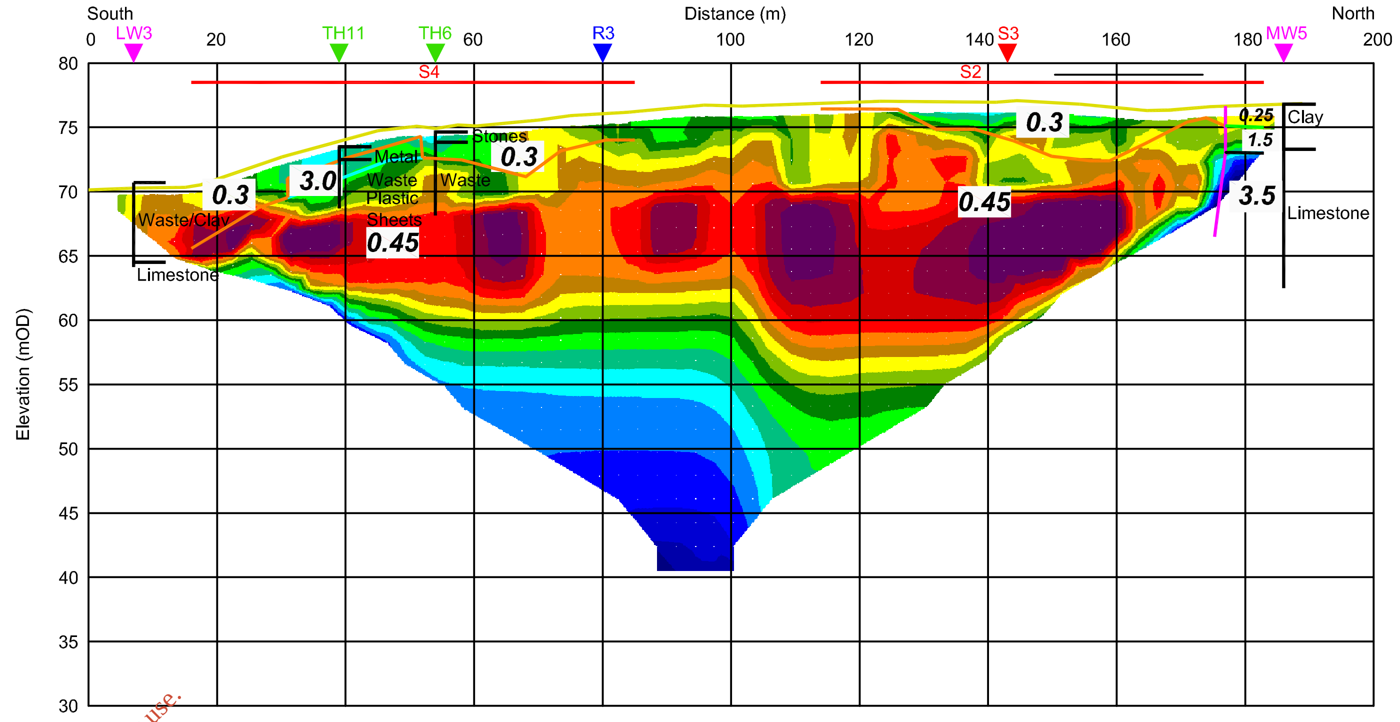
Landfill Waste Boundary (Best Fit)

Site Boundary

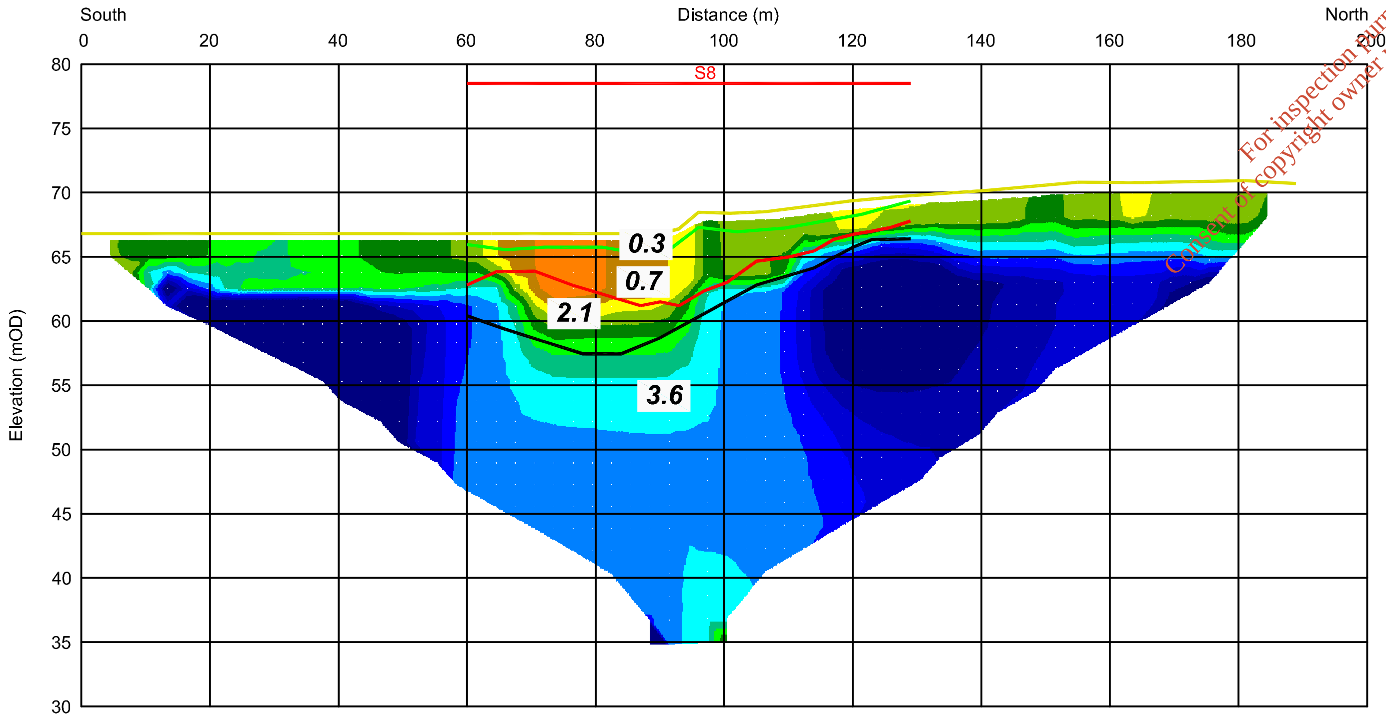
2D-Resistivity Profile R1 and Seismic Refraction Profile S1 Model



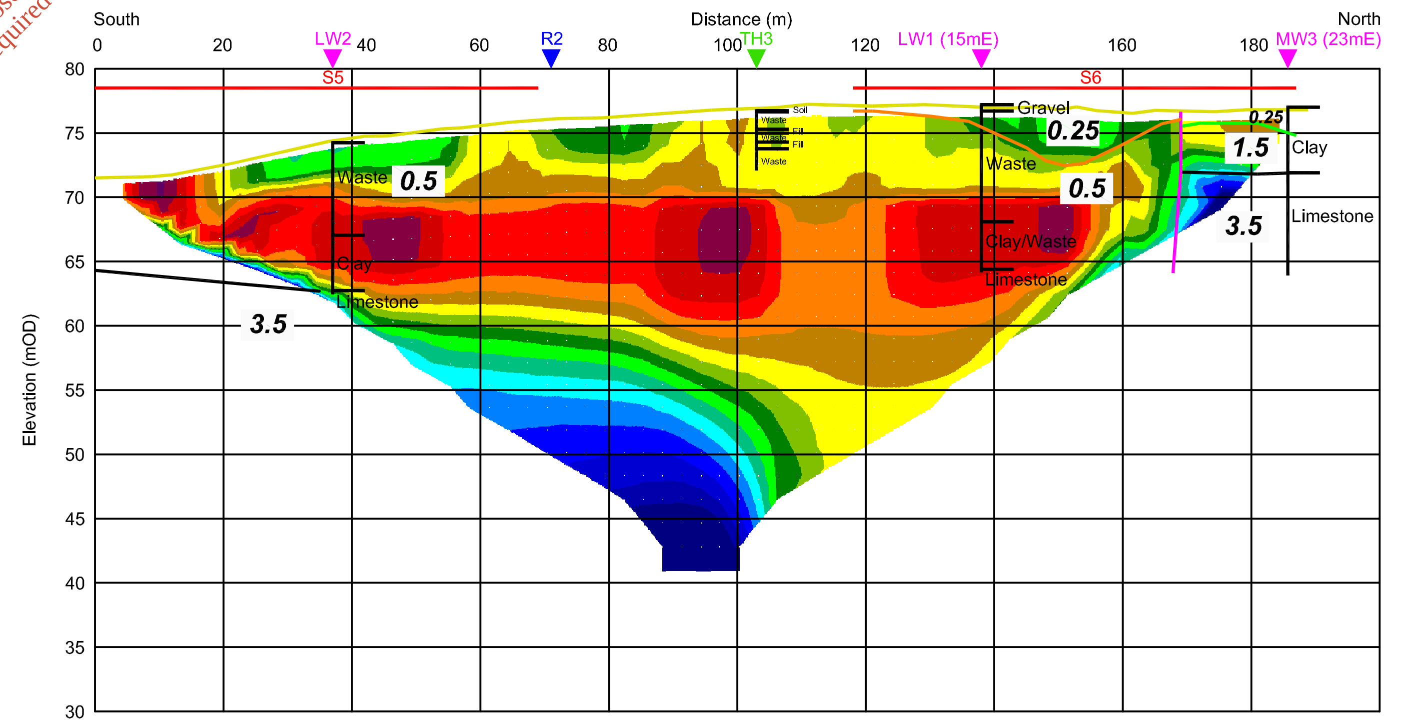
2D-Resistivity Profile R2 and Seismic Refraction Profile S2, S4 Model



2D-Resistivity Profile R4 and Seismic Refraction Profile S8 Model



2D-Resistivity Profile R3 and Seismic Refraction Profile S5, S6 Model



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CLIENT	Limerick County Council
PROJECT	Churchtown Landfill, Newcastle W. Geophysical Survey
TITLE	Figure 1a: Results of Geophysical Survey

SCALE:	NTS, VE x 2
PROJECT:	5711
DRAWN:	DA
DATE:	06/09/2013
MGX FILE:	5711f_Figs.dwg
STATUS:	Final

LEGEND:

Layers from Seismic Refraction Model:

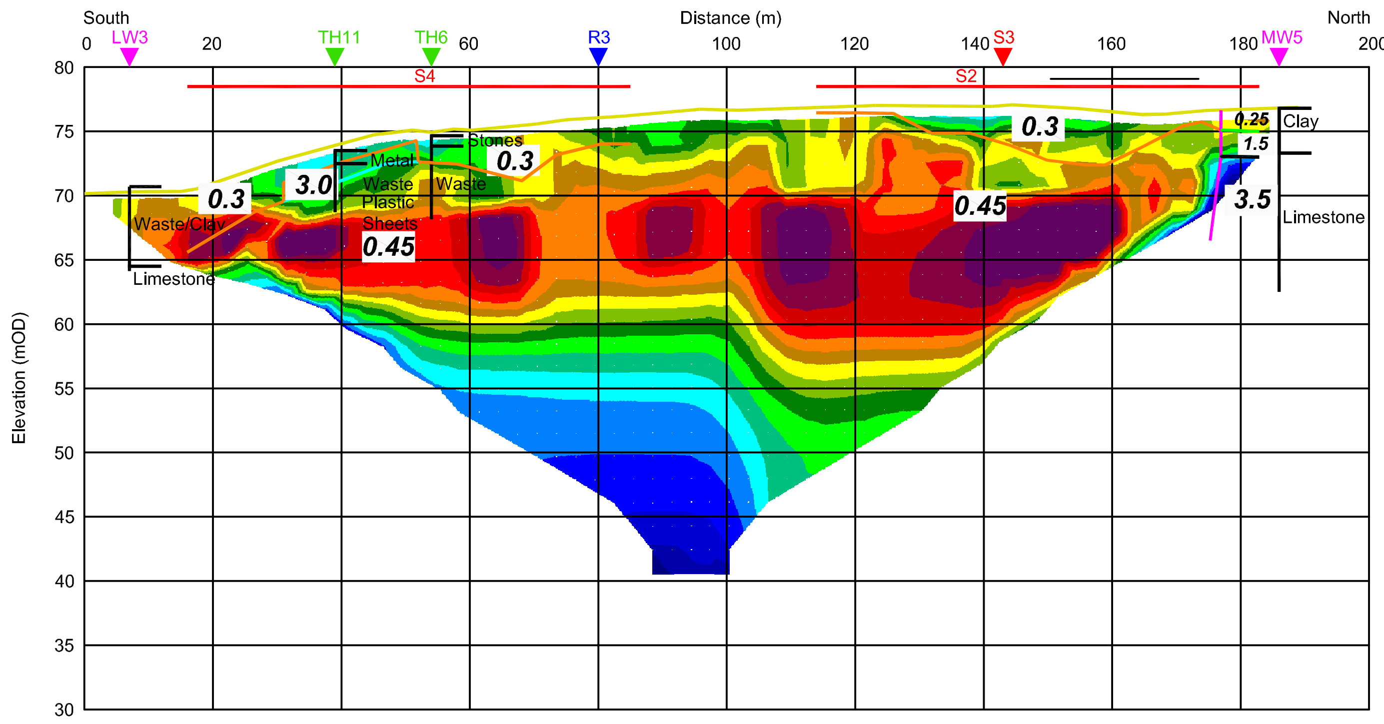
1.5 Seismic Velocity km/s

- Ground Surface
- Layer 2 Intra-Waste Boundary (0.25 - 0.5 km/s)
- Boundary between Waste and geological Layer
- Base of solid Object/Layer within Landfill
- Base of Layer 1 (0.25-0.3 km/s) Soil and Top of Layer 3 Firm to stiff Clay (0.7-1.5 km/s)
- Top of Layer 4 weathered Rock or hard Clay (2.1 km/s)
- Top of Layer 5 Strong Limestone (3.5 - 4.3 km/s)

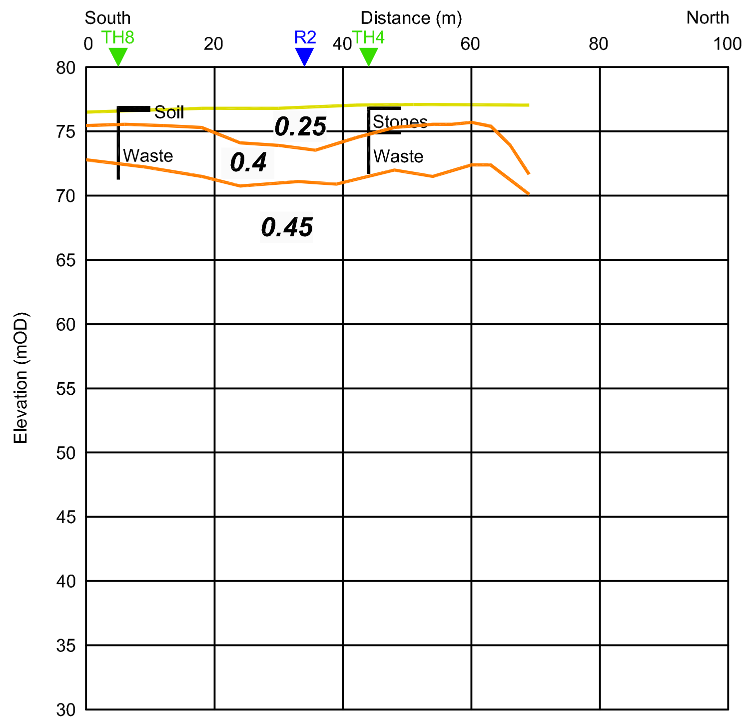
Model Values 2D-Resistivity (Ohmm)

10.0 20.0 40.0 80.0 160 320 640 1280

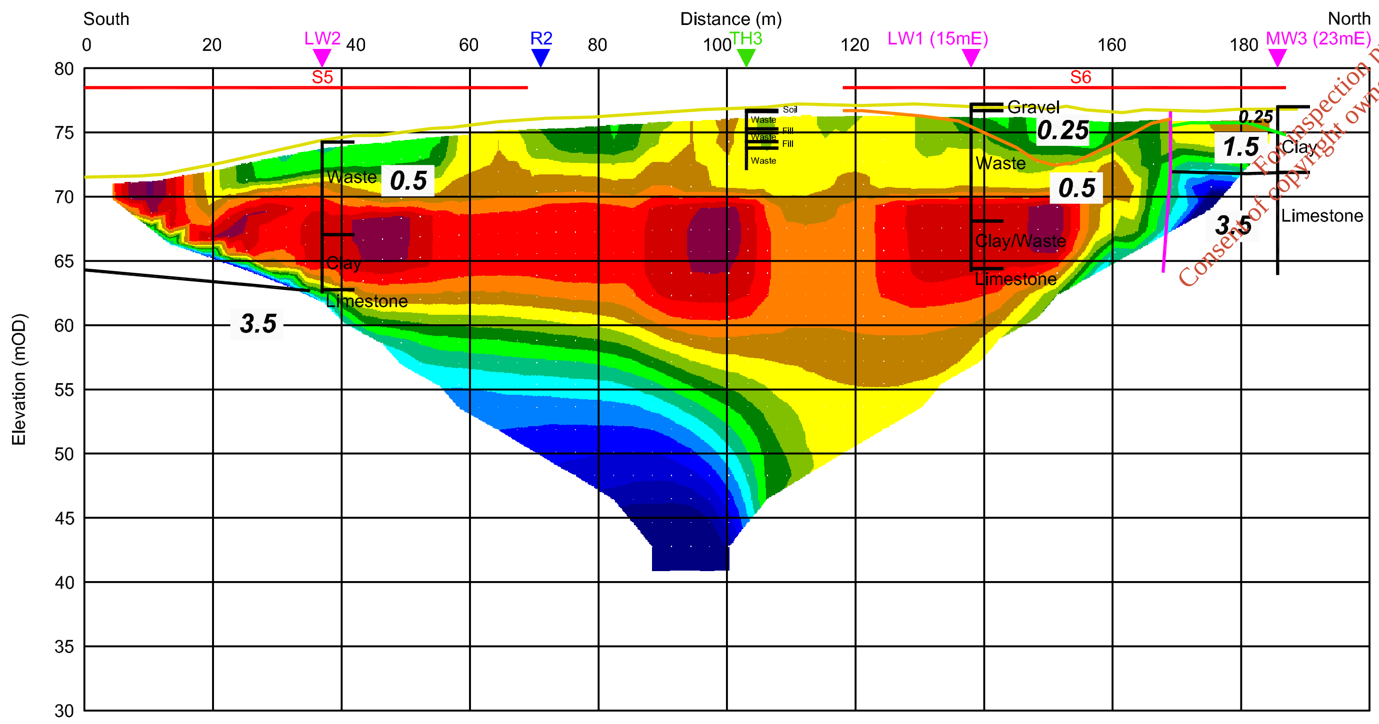
2D-Resistivity Profile R2 and Seismic Refraction Profile S2, S4 Model



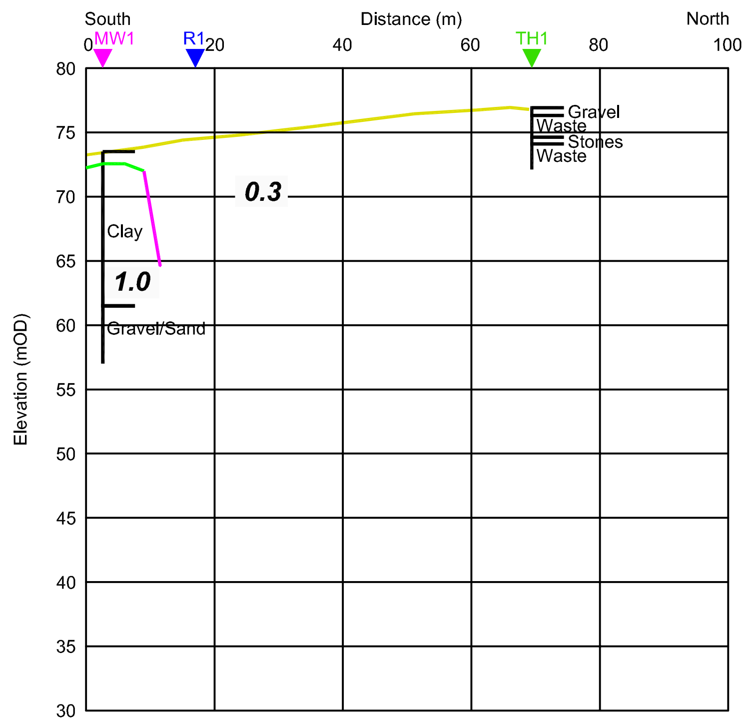
Seismic Refraction Profile S3 Model



2D-Resistivity Profile R3 and Seismic Refraction Profile S5, S6 Model



Seismic Refraction Profile S7 Model



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CLIENT	Limerick County Council
PROJECT	Churchtown Landfill, Newcastle W. Geophysical Survey
TITLE	Figure 1b: Results of Geophysical Survey

SCALE:	NTS, VE x 2
PROJECT:	5711
DRAWN:	DA
DATE:	06/09/2013
MGX FILE:	5711f_Figs.dwg
STATUS:	Final

LEGEND: Layers from Seismic Refraction Model:

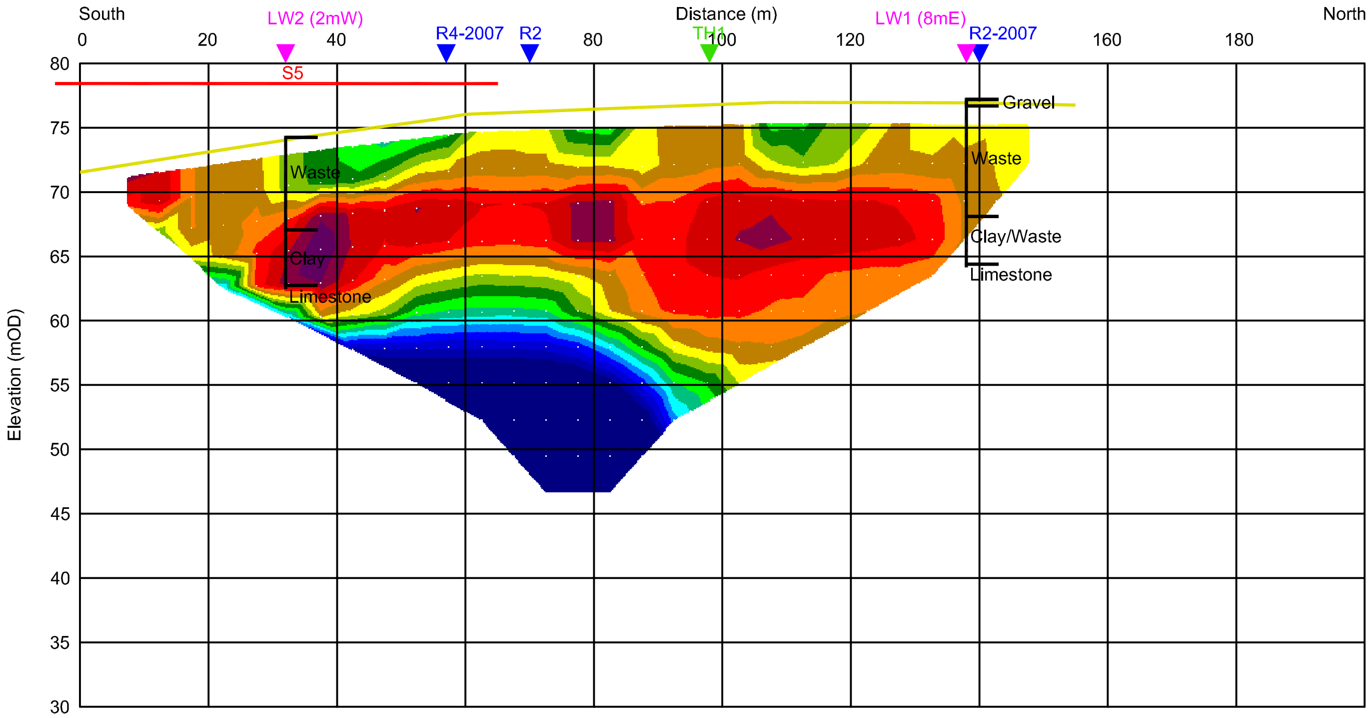
1.5 Seismic Velocity km/s

- Ground Surface
- Layer 2 Intra-Waste Boundary (0.25 - 0.5 km/s)
- Boundary between Waste and geological Layer
- Base of solid Object/Layer within Landfill
- Base of Layer 1 (0.25-0.3 km/s) Soil and Top of Layer 3 Firm to stiff Clay (0.7-1.5 km/s)
- Top of Layer 4 weathered Rock or hard Clay (2.1 km/s)
- Top of Layer 5 Strong Limestone (3.5 - 4.3 km/s)

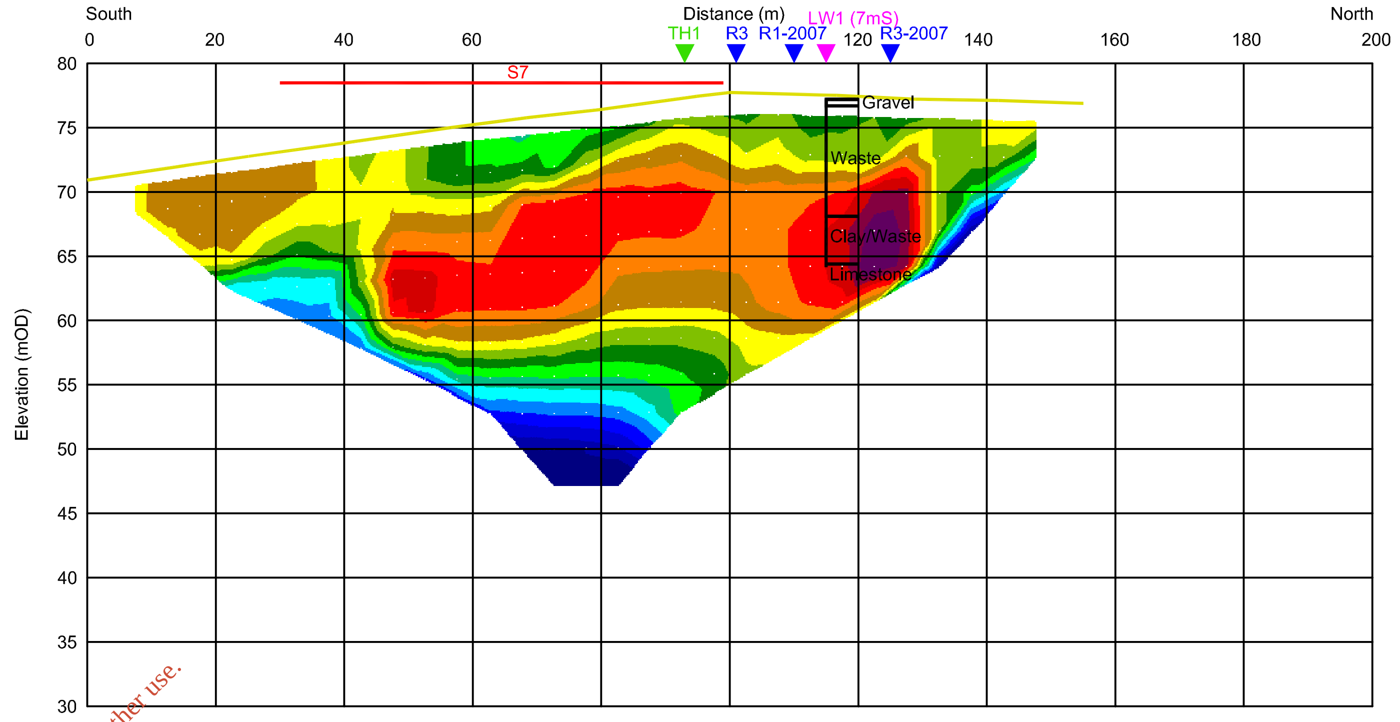
Model Values 2D-Resistivity (Ohmm)

10.0 20.0 40.0 80.0 160 320 640 1280

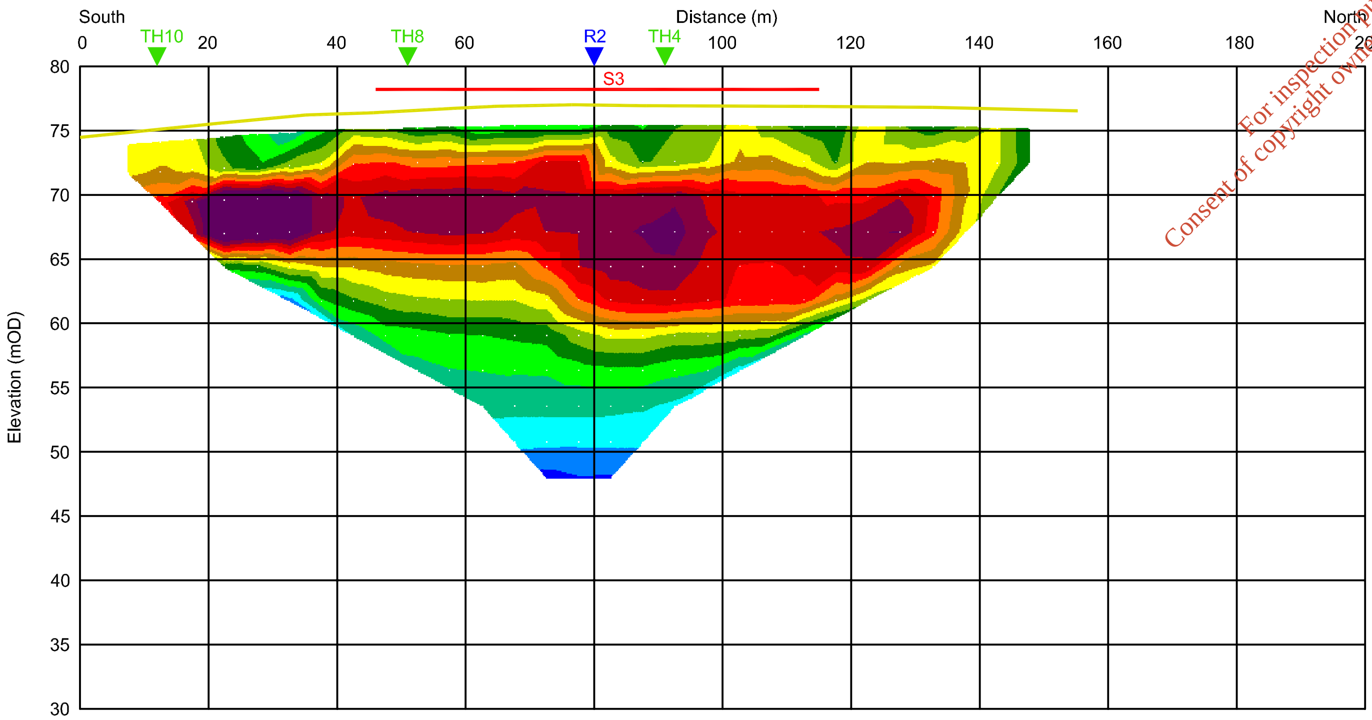
2D-Resistivity Profile R1-2007 Model



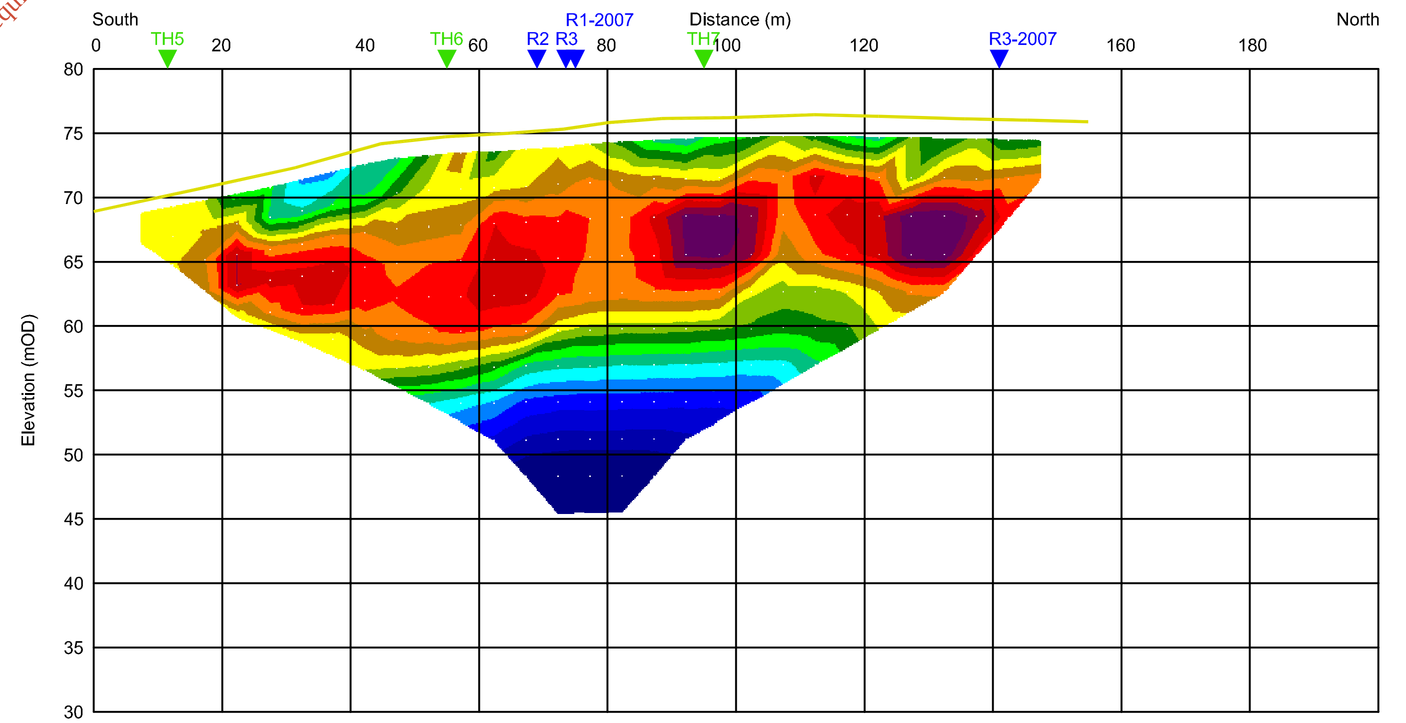
2D-Resistivity Profile R2-2007 Model



2D-Resistivity Profile R3-2007 Model



2D-Resistivity Profile R4-2007 Model



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CLIENT	Limerick County Council
PROJECT	Churchtown Landfill, Newcastle W. Geophysical Survey
TITLE	Figure 1c: Results of Geophysical Survey 2007

SCALE:	NTS, VE x 2
PROJECT:	5711
DRAWN:	DA
DATE:	06/09/2013
MGX FILE:	5711f_Figs.dwg
STATUS:	Final

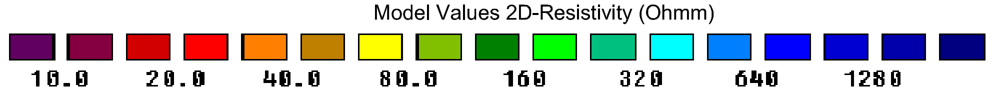
LEGEND:

Layers from Seismic Refraction Model:

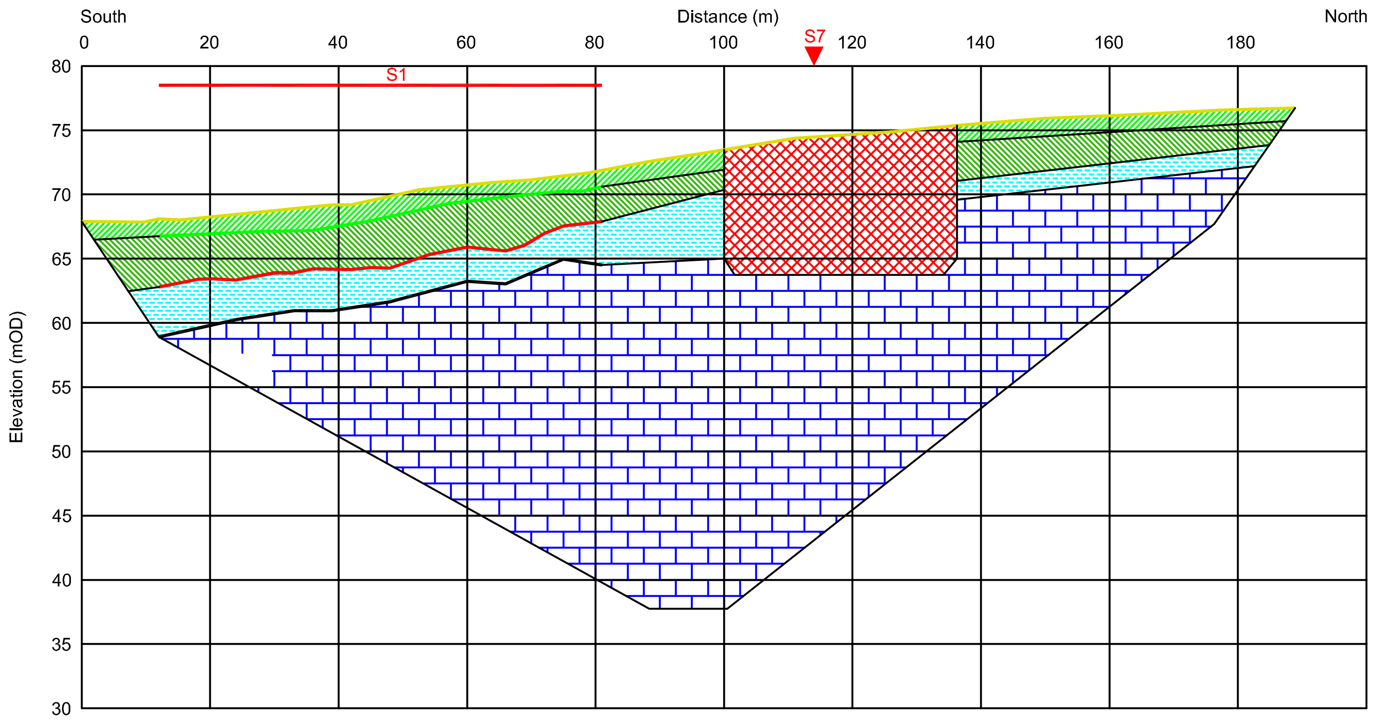
1.5 Seismic Velocity km/s

- Ground Surface
- Layer 2 Intra-Waste Boundary (0.25 - 0.5 km/s)
- Boundary between Waste and geological Layer
- Base of solid Object/Layer within Landfill
- Base of Layer 1 (0.25-0.3 km/s) Soil and Top of Layer 3 Firm to stiff Clay (0.7-1.5 km/s)
- Top of Layer 4 weathered Rock or hard Clay (2.1 km/s)
- Top of Layer 5 Strong Limestone (3.5 - 4.3 km/s)

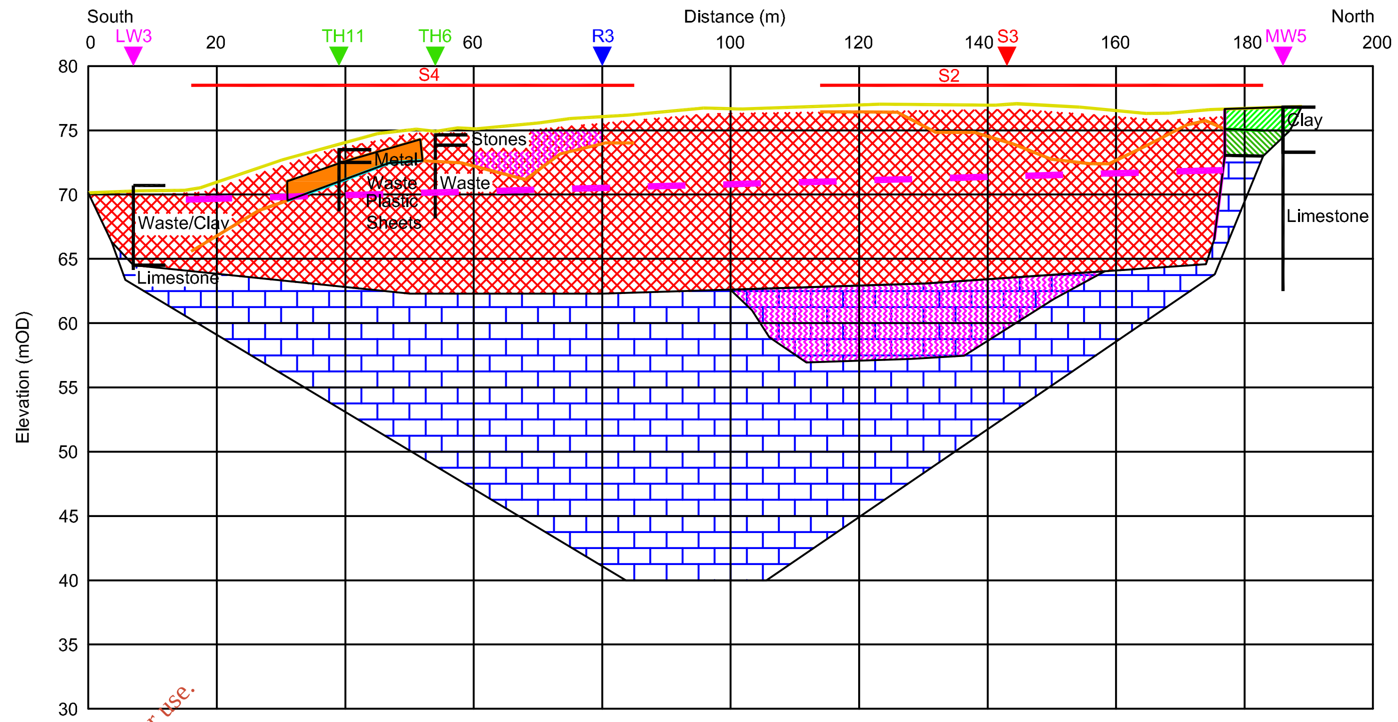
Model Values 2D-Resistivity (Ohmm)



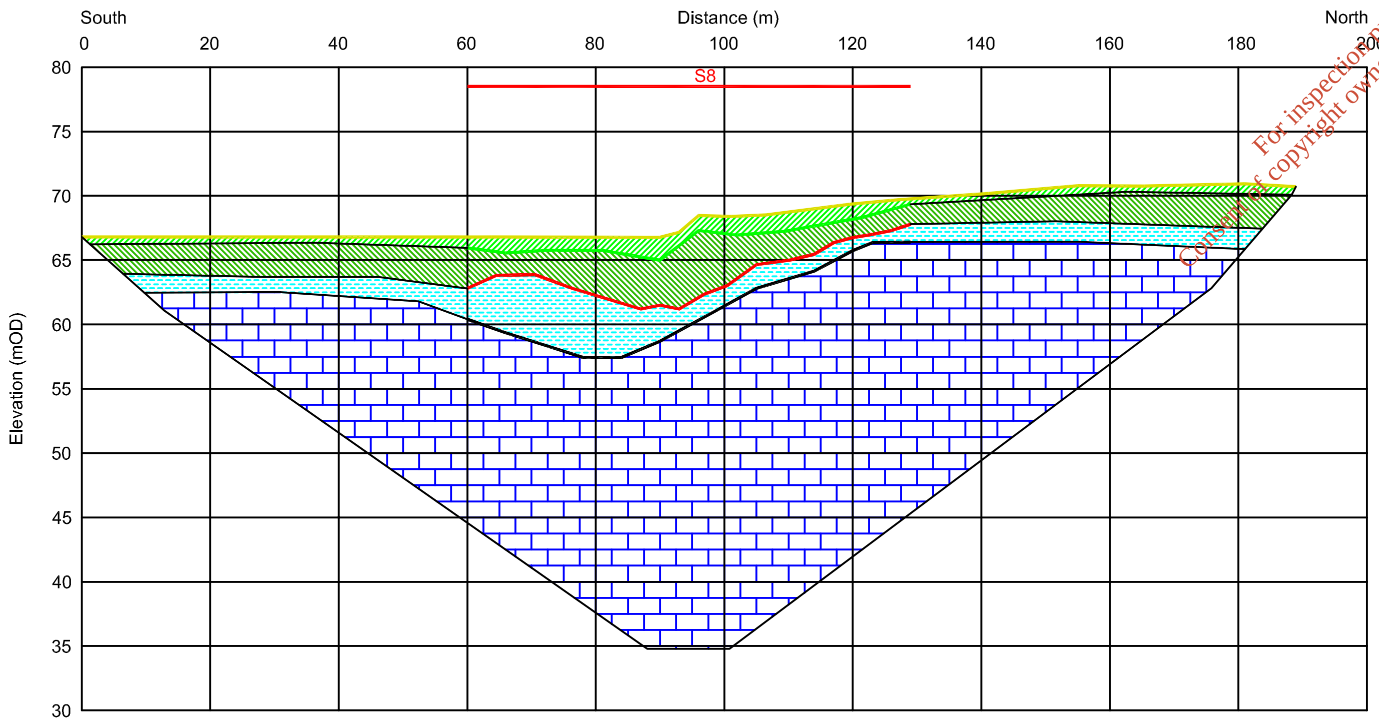
2D-Resistivity Profile R1 and Seismic Refraction Profile S1 Model



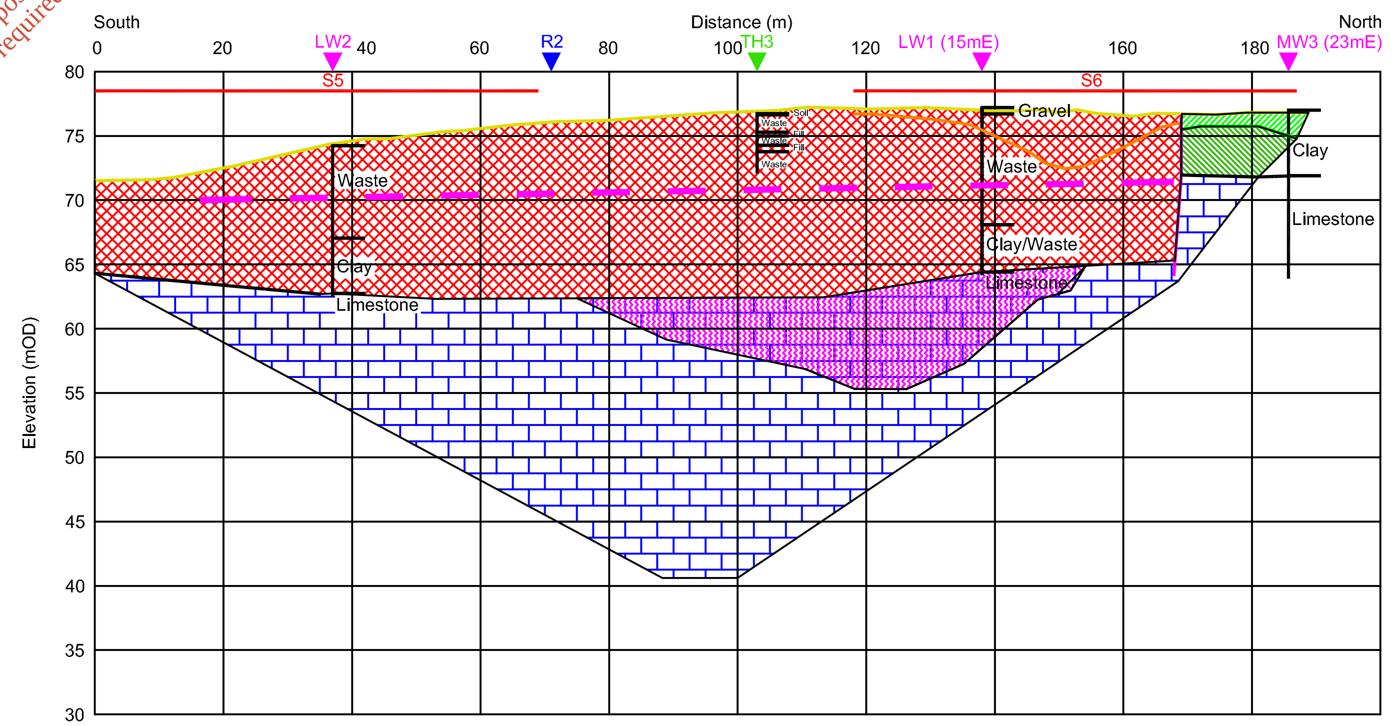
2D-Resistivity Profile R2 and Seismic Refraction Profile S2, S4 Model



2D-Resistivity Profile R4 and Seismic Refraction Profile S8 Model



2D-Resistivity Profile R3 and Seismic Refraction Profile S5, S6 Model



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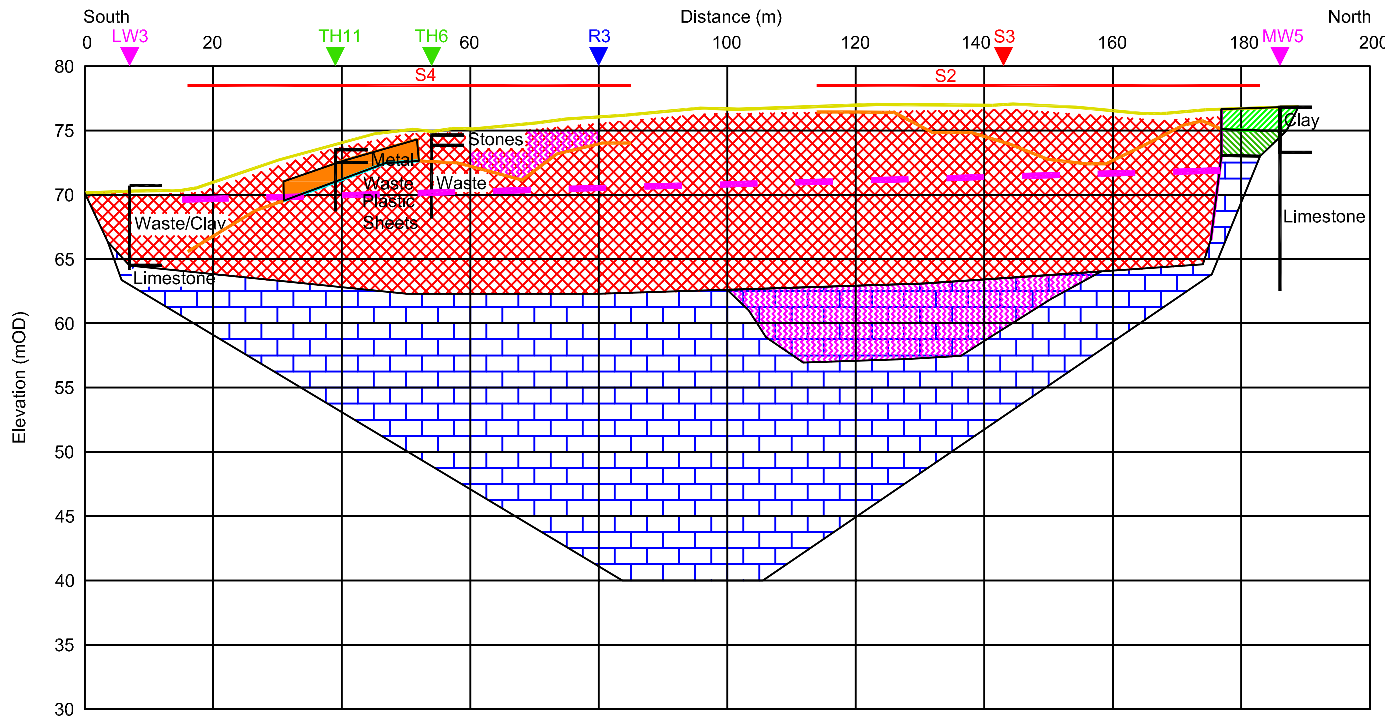
CLIENT	Limerick County Council
PROJECT	Churchtown Landfill, Newcastle W. Geophysical Survey
TITLE	Figure 2a: Interpretation of Geophysical Survey

SCALE:	NTS, VE x 2
PROJECT:	5711
DRAWN:	DA
DATE:	06/09/2013
MGX FILE:	5611f_Figs.dwg
STATUS:	Final

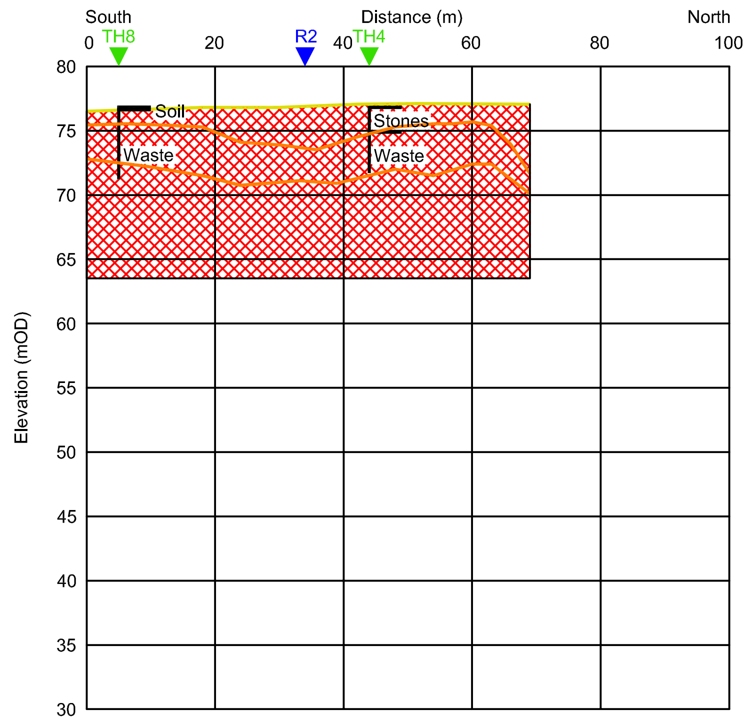
LEGEND: Combined Interpretation:

- 1 Overburden / Soft Soil
- 3 Overburden / Firm - Stiff Clay
- 3 Weathered Rock or Overburden (hard Clay)
- 4 Strong Limestone
- 2 Waste - Landfill
- Solid Object/Layer within Landfill
- Possible Leachate outside Landfill Waste Body
- Approx. Water Level within Landfill

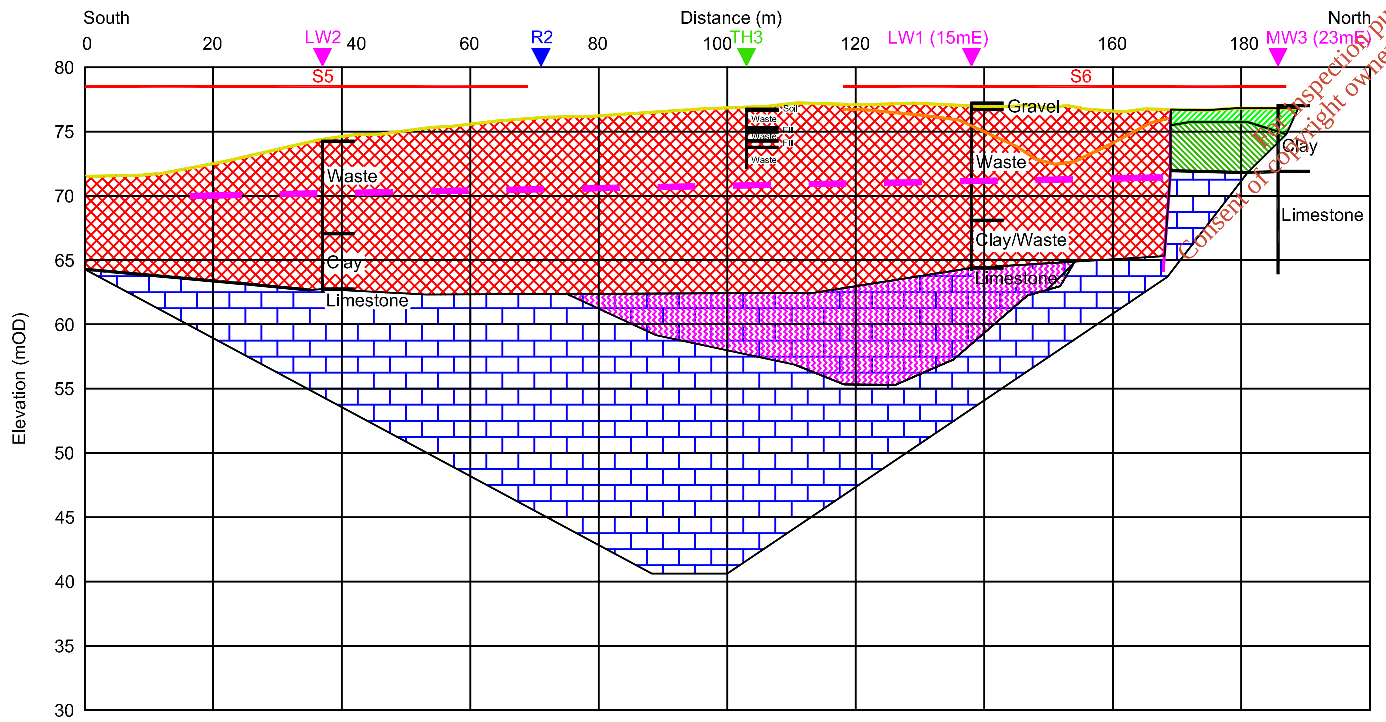
2D-Resistivity Profile R2 and Seismic Refraction Profile S2, S4 Model



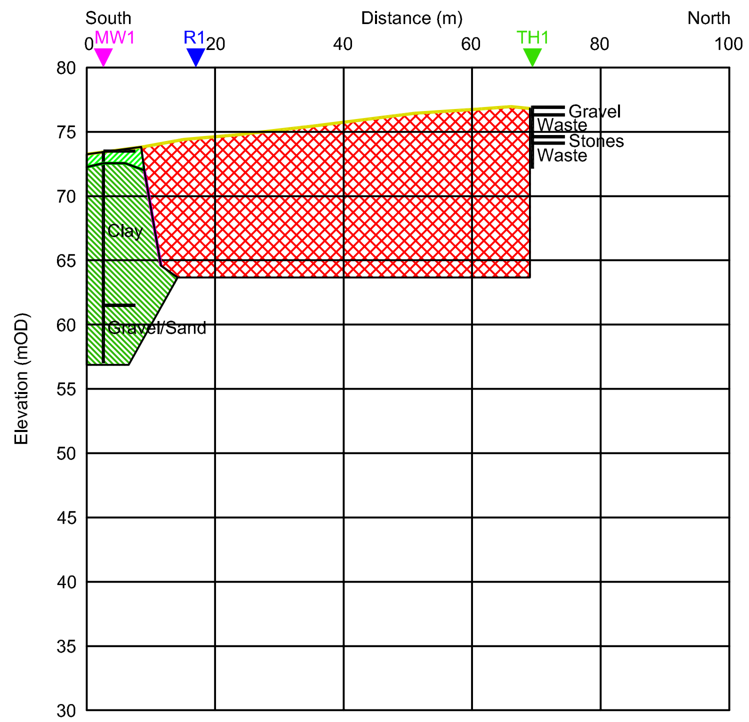
Seismic Refraction Profile S3 Model



2D-Resistivity Profile R3 and Seismic Refraction Profile S5, S6 Model



Seismic Refraction Profile S7 Model



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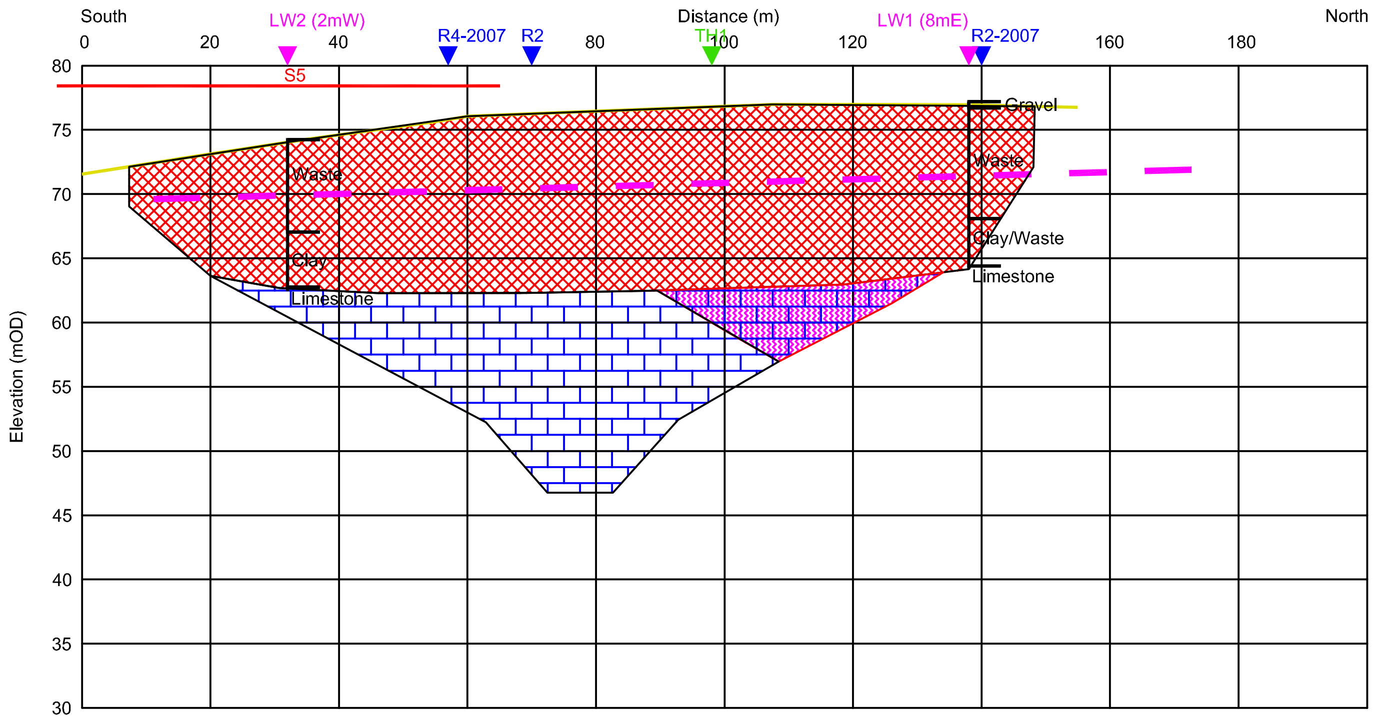
CLIENT	Limerick County Council
PROJECT	Churchtown Landfill, Newcastle W. Geophysical Survey
TITLE	Figure 2b: Interpretation of Geophysical Survey

SCALE:	NTS, VE x 2
PROJECT:	5711
DRAWN:	DA
DATE:	06/09/2013
MGX FILE:	5611f_Figs.dwg
STATUS:	Final

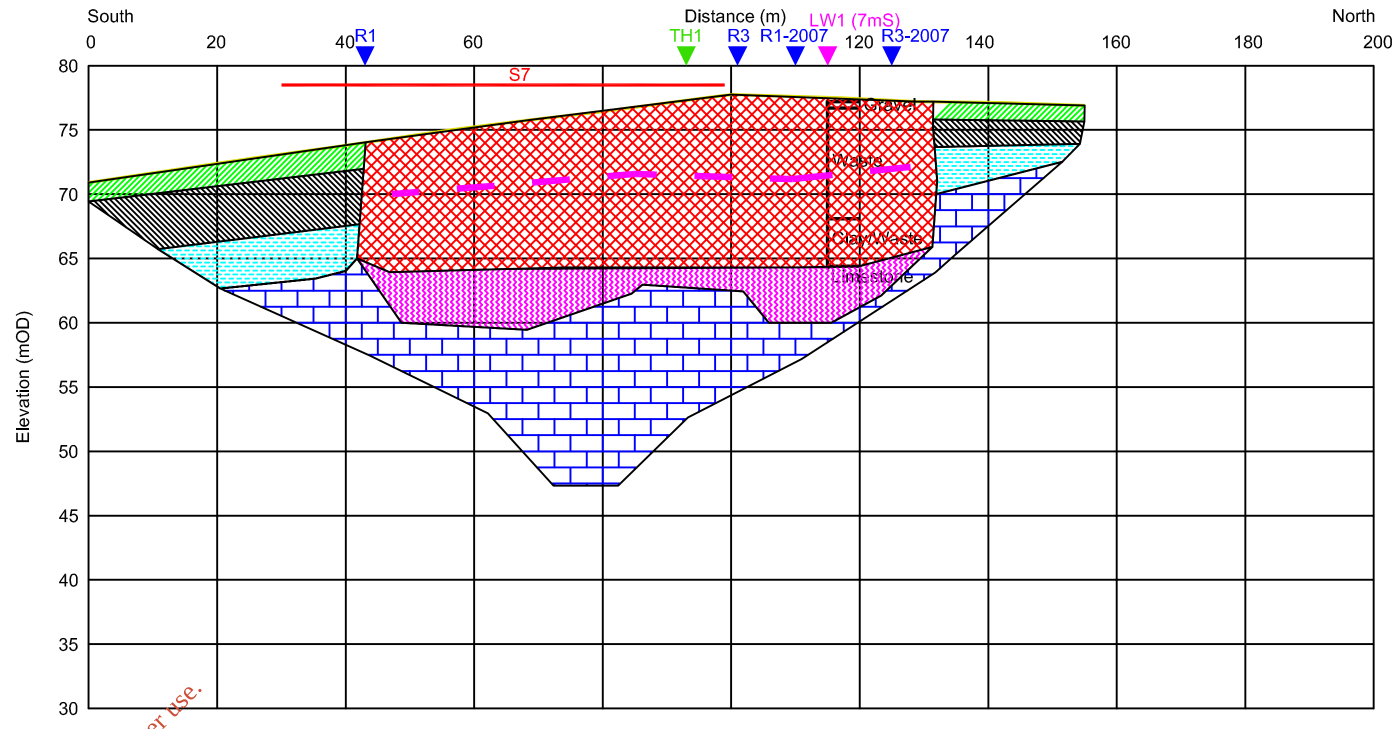
LEGEND: Combined Interpretation:

- 1 Overburden / Soft Soil
- 3 Overburden / Firm - Stiff Clay
- 3 Weathered Rock or Overburden (hard Clay)
- 4 Strong Limestone
- 2 Waste - Landfill
- Solid Object/Layer within Landfill
- Possible Leachate outside Landfill Waste Body
- Approx. Water Level within Landfill

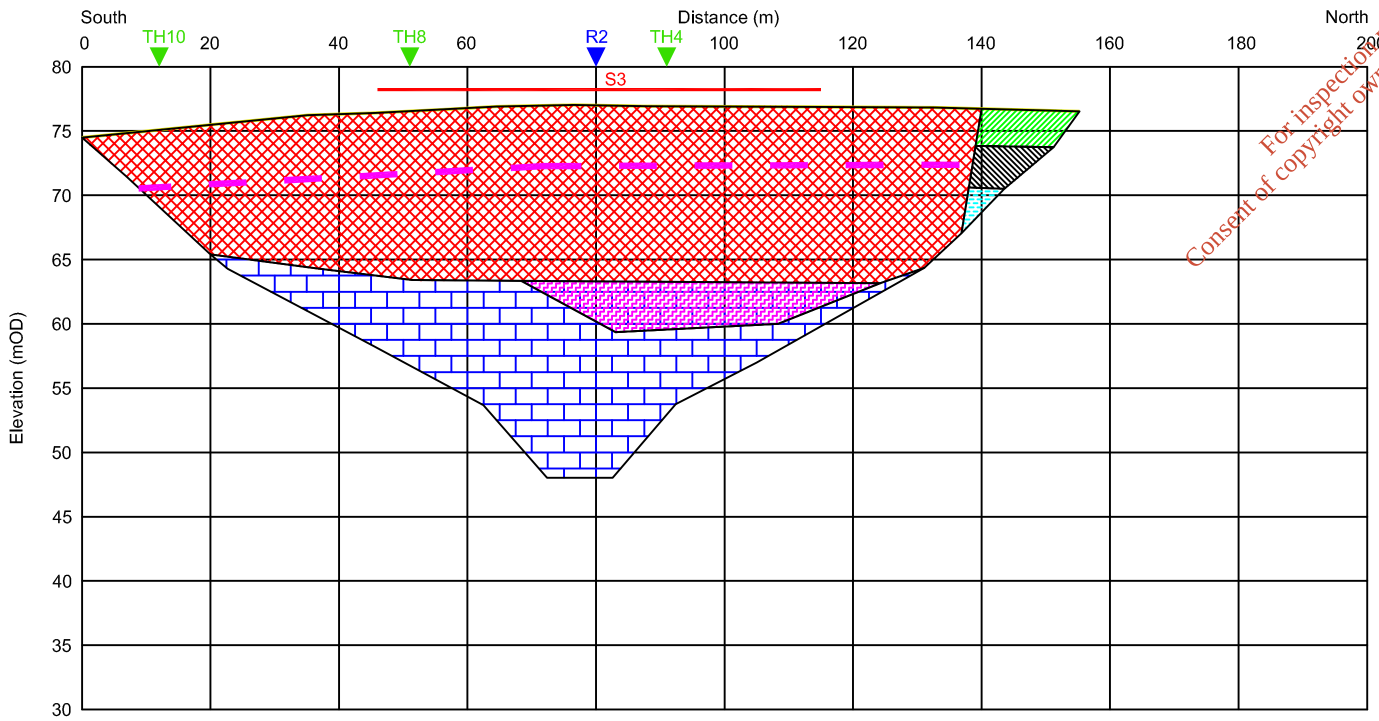
2D-Resistivity Profile R1-2007 Interpretation



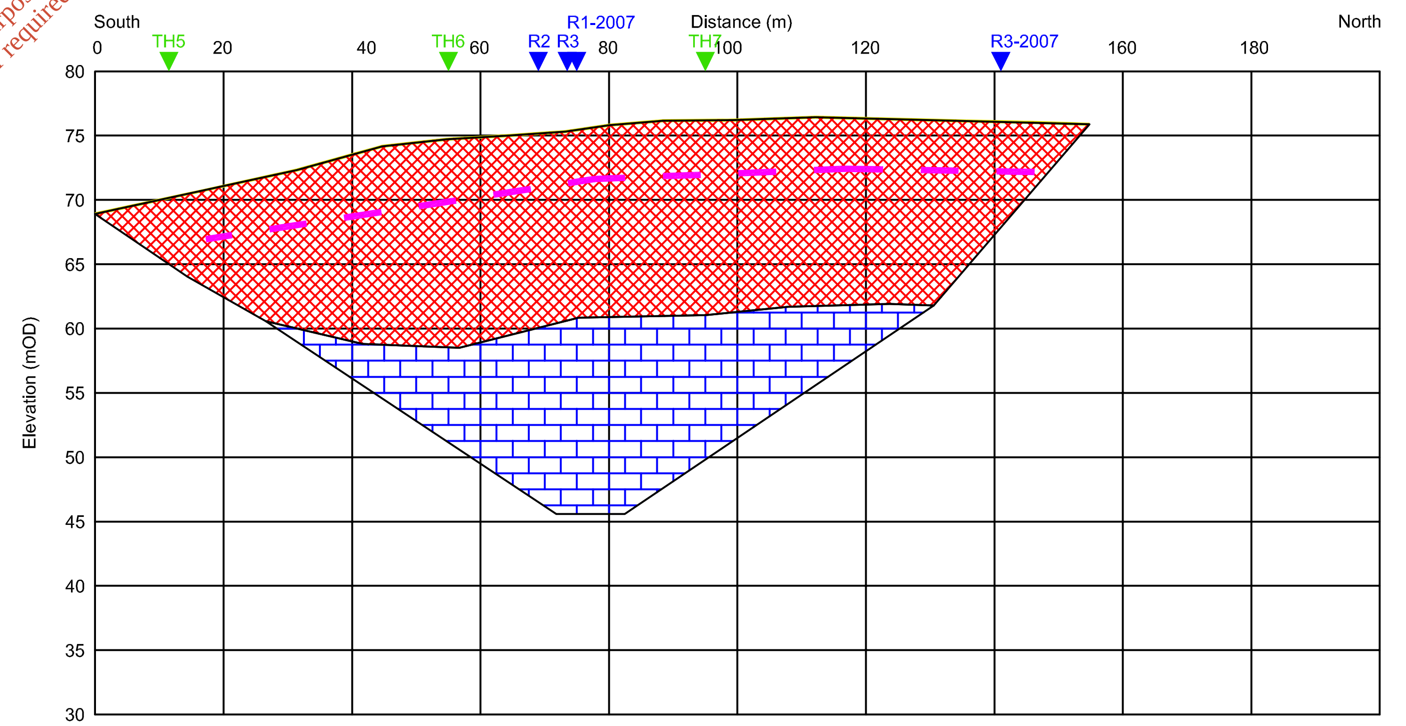
2D-Resistivity Profile R2-2007 Interpretation



2D-Resistivity Profile R3-2007 Interpretation



2D-Resistivity Profile R4-2007 Interpretation



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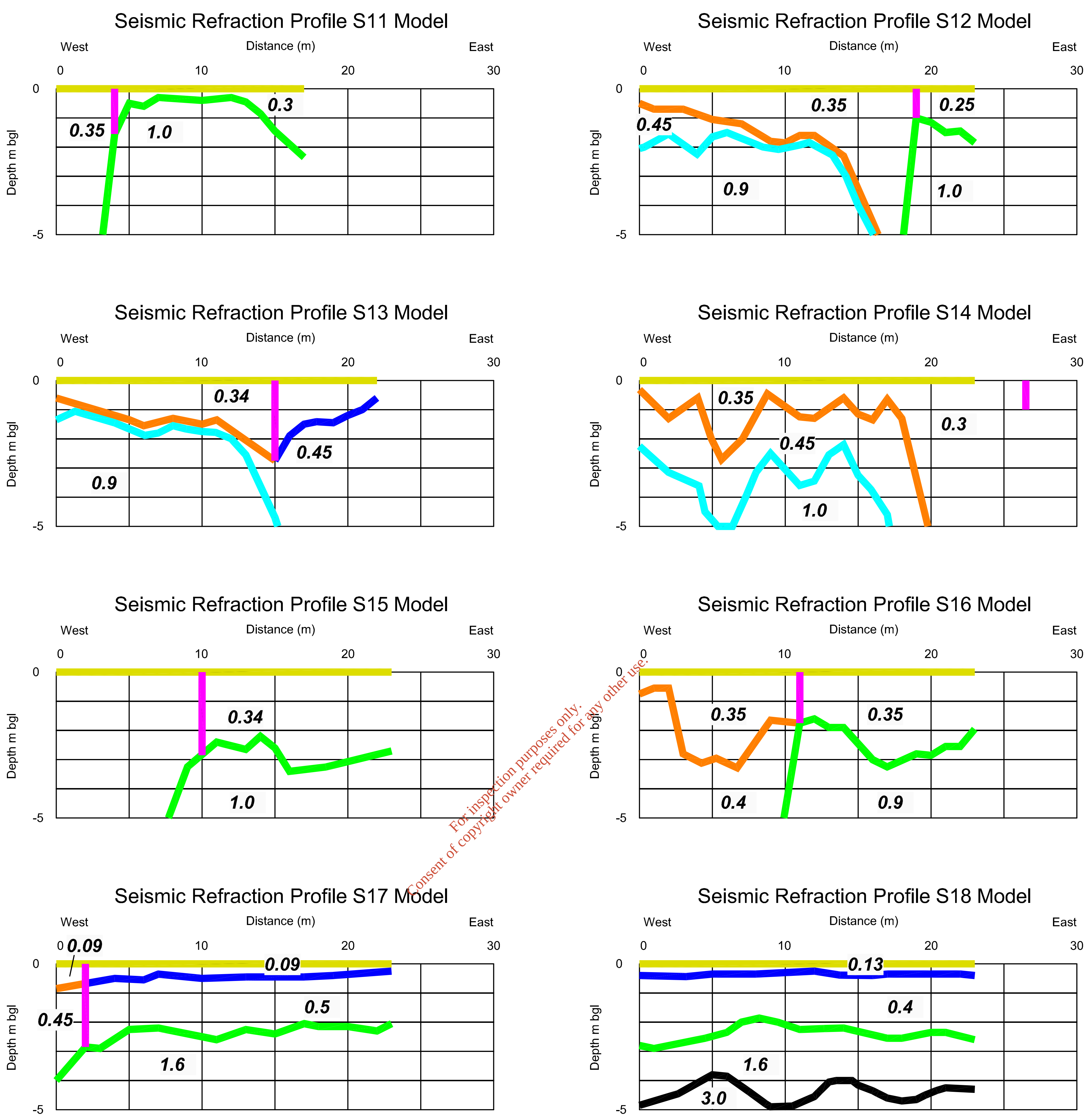
CLIENT	Limerick County Council
PROJECT	Churchtown Landfill, Newcastle W. Geophysical Survey
TITLE	Figure 2c: Interpretation of Geophysical Survey 2007

SCALE:	NTS, VE x 2
PROJECT:	5711
DRAWN:	DA
DATE:	06/09/2013
MGX FILE:	5611f_Figs.dwg
STATUS:	Final

LEGEND: Combined Interpretation:

- 1 Overburden / Soft Soil
- 3 Overburden / Firm - Stiff Clay
- 3 Weathered Rock or Overburden (hard Clay)
- 4 Strong Limestone
- 2 Waste - Landfill
- Solid Object/Layer within Landfill
- Possible Leachate outside Landfill Waste Body
- Approx. Water Level within Landfill



Layers with Interpretation from Seismic Refraction Model:

Within Landfill Boundary

- Ground Surface and Top of Waste (0.09 - 0.35 km/s)
- Layer 2 Intra-Waste Boundary (0.25 - 0.5 km/s)
- Top of more compacted Layer within Landfill (0.9 - 1.0 km/s)
- Boundary between Waste and geological Layer

Outside Landfill Boundary

- Ground Surface and Top of Topsoil Layer1 (0.09 - 0.13)
- Base of Layer 2b (0.4-0.5 km/s) Subsoil
- Top of Layer 3 Firm to stiff Clay (1.0 - 1.6 km/s)
- Top of Layer 5 Strong Limestone (3.5 - 4.3 km/s)

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CLIENT	Limerick County Council
PROJECT	Churchtown Landfill, Newcastle W. Geophysical Survey
TITLE	Figure 3: Results and Interpretation of Geophysical Survey 2013

SCALE:	NTS, VE x 2
PROJECT:	5711
DRAWN:	HK
DATE:	06/09/2013
MGX FILE:	5611f_Figs.dwg
STATUS:	Final

LEGEND:

1.5 Seismic Velocity km/s