APPENDIX 2

GEOPHYSICAL SURVEY

VERDE REF	20476

St. Mary's Park, Limerick City
Illegal Landfill

Geophysical Survey

Report Status: Final

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Confidential Report To:

Verde Environmental Consultants
Galway Office
Block 7
Galway Technology Park
Parkmore, Galway

Report submitted by :
Minerex Geophysics Limited

Unit F4, Maynooth Business Campus
Maynooth, Co. Kildare
Ireland
Tel.: 01-6510030
Fax.: 01-6510033
Email: info@mgx.ie

Issued by:

Hartmut Krahn (Senior Geophysicist)

Tony Lombard M.Sc. (Geophysicist)

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 investigation of an illegal landfill at St. Mary's Park, Limerick City.
2. The main objectives of the survey were to determine ground conditions, delineate the landfill, and determine the depth to bedrock, thickness of the waste body and characteristics of the underlying soils.
3. The ground conductivity survey outlines areas of mainly domestic waste, high metal concentration and possible leachate into the marshy ground to the East.
4. The survey resistivity and seismic survey delineated five layers that represent waste at the top and rock at the bottom of the profile sections.
5. Trial Pitting confirmed the basic underlying ground model interpreted from the survey.

CONTENTS

List of Tables, Maps and Figures:

1. INTRODUCTION

1.1 Background

Minerex Geophysics Ltd. (MGX) carried out a geophysical survey for the investigation of an illegal landfill at St. Mary's Park in Limerick City. The survey consisted of acquiring EM31 Ground Conductivity, 2D Resistivity and seismic refraction datasets. The survey was commissioned by Verde Environmental Consultants acting on behalf of Limerick County Council.

An illegal landfill was created to the east of the boundary of St. Mary's Park by tipping of household and other waste onto public land. The landfill is a long thin strip of land beside the estate. The geophysical survey is a part of a larger ground investigation for this project.

1.2 Objectives

The main objectives of the geophysical survey were:

- To determine the ground conditions under the site
- The delineate the horizontal and vertical extent of the waste body
- To check for possible leachate plumes
- To determine the depth to rock and overburden thickness
- To determine the type of overburden and rock
- To detect lateral changes within the geological layers

1.3 Site Description

The site is best seen on the topographical survey map (Map 1). The site area is covered by the topographical survey that indicates the ground surface contour lines and other items. The floodplain of King's Island lies to the east of the illegal landfill and has a ground surface elevation of around 2.0m mOD. St-Mary's estate lies to the west and the elevation around the houses is generally over 3.0 m. An access track runs from the gate in the north to a bulbous shaped raised area in the south. The total distance where waste can be seen scattered around the access track has a length of approx. 600m.

1.4 Geology

The bedrock geological map of the Shannon Estuary (GSI, 1999) indicates that the site is underlain by the Visean Limestone formation which consists of undifferentiated limestones and calcareous shale.

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 were used as the background map in this report. Elevations were taken from the supplied map.

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 using EM31 Ground Conductivity measurements that were followed by five targeted 2D-Resistivity and Seismic Refraction Profiles.

2.2 EM31 Ground Conductivity

The EM31 ground conductivity survey was carried out on lines nominally 10 m apart. Along each line a reading of ground conductivity was taken every second, thereby resulting in a survey grid of nominally 10m x 1 m. Because of the rough ground and overgrown waste in some areas the distances varied. The locations were measured with a 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 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. 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. The instrument does however indicate high metal concentrations by very high or negative conductivities and by negative Inphase values.

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 of the earth system which can be used for office based digital processing. The generated model resistivity values and their spatial distribution can then be related to typical values for different geological materials.

The 2D-Resistivity profiles were done with 93m length per profile at five locations shown on Map 1. The set-up used 32 electrodes with a spacing of 3m. The readings were taken with a Tigre Resistivity Meter and Imager Cables.

2D-Resistivity has proven zones of anomalous rock/karstified rock with lateral extents of 5 m and more.

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 69m per profile. The recording equipment consisted of an ES-3000 seismograph with 10 Hz vertical geophones. The seismic energy source consisted of a hammer and plate. A zero delay trigger was used to start the recording. At least 7 shot points per p-wave profile were used.

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% angle the accuracy becomes much less.

2.5 Site Work

The data acquisition was carried out on the 8th and 10th of June 2011 in fair weather conditions. Health and safety standards were adhered to at all times.

The survey locations and background map are on Map 1.

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 and Inphase 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 contours lines are overlaid over the location and base maps and the values are visible from the colour scale.

The ground conductivities are indicated on Map 2 and the Inphase values are visible on Map 3.

Low conductivities would indicate either shallow bedrock or sandy and gravely overburden while higher conductivities would indicate deeper bedrock, zones of clay mineral rich bedrock and clay-rich overburden. High conductivities can also derive from leachate or buried domestic waste. Very high or negative conductivities indicate the presence of man-made metal objects. High interference typically occurs along field boundaries and fences.

Inphase values for natural geological layers are typically close to zero. In the presents of metal the Inphase values take on higher positive or negative readings. Therefore the Inphase value can be used like a metal indicator.

Map 2 shows the ground conductivities that cover a large range of values typical for landfill and wate situations. High values over 50 mS/m along the western edges, especially in the North-west, are due to interference from buildings and fences. Rapidly changing values, from 50 mS/m to negative values, indicate the presence of waste and metal within the waste. Medium values of 20 – 40 mS/m indicate the typical geological background of the floodplain to the east of the build-up and made ground area. Negative values generally stretching along and beside the access track indicate a larger amount of metal within the domestic waste.

Map 3 shows the Inphase values in ppt (Parts per thousand). The values act like a metal indicator and where the values turn to very negative values a larger amount of metal can be expected in the subsurface.

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 but 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 five iterations resulting in a typical RMS error of < 3.0%. The resulting models were colour contoured with the same scale for all profiles and they are displayed as cross sections (Figure 1a).

The lowest resistivities occur over the elevated ground on Profiles R1 to R3 (< 20 Ohmm). These low resistivities (comparable to the high conductivities) indicate the domestic waste. Slightly higher resistivities occur at the elevated ground on R4 and R5 (> 40 Ohmm) and this indicates that the nature of the made ground changes to building waste type deposits that contain a high proportion of boulders, sand and gravel. Therefore a distinction between thicker domestic waste and building waste has been made in the interpretation.

Towards the east (floodplain) where natural geological layers are present below the ground surface the resistivities range between 20 and 60 Ohmm. This would indicate clay and silt rich saturated overburden.

The resistivities increase with depth to values of several 100 Ohmm which indicated the presence of rock. The resistivities indicate a shale/limestone rock type in accordance with the bedrock geological map.

3.3 Seismic Refraction Data

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 6 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 supplied elevation data, first break picking, tomographic inversion, travel-time computation via ray-tracing and velocity modelling. Residual deviations of typically 0.6 to 1.5 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 seismic velocities obtained within the layers are annotated on the sections.

Seismic velocities cover a large range from 0.2 to 3.0 km/s. The lowest velocities correspond to made ground and topsoil. The top three layers have been assigned an interpretation of domestic waste with 0.2 km/s seismic velocity (which is most loose), soft/loose overburden (0.3 km/s) and building waste (0.4 km/s).

Below these layers the natural overburden is more compacted with depth. Layer 5 is seen as a transitional layer between overburden and bedrock with highly compacted overburden and weathered broken rock. Below this layer the rock has a good quality and is a strong bedrock.

3.4 Combined Interpretation

Table 1 summarises the interpretation. The compaction/strength/rock quality has been estimated from the seismic velocity.

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 layers outside the seismic profiles.

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/rock quality with depth.

Table 1: Summary of Results and Interpretation

Layer	General Seismic Velocity Range (km/sec)	General Resistivity Range (Ohmm)	Compaction/ Strength/ Rock Quality	Interpretation
1	0.2	< 20	Soft/Loose	Made Ground (Predominantly Domestic Waste)
2	0.4	> 40	Loose/soft	Made Ground (Predominantly Building Waste)
3	0.3	20 – 40	Soft/loose	Overburden (predominantly Clay/Silt)
4	0.8-0.9	>20	Firm-stiff/Dense	Overburden (Predominantly Clay/Silt)
5	1.8-1.9	>30	Very stiff/very dense Poor rock	Overburden and weathered rock
6	3.0	>100	Strong rock	Rock (Shale and Limestone)

Map 4 indicates a summary interpretation for the area investigated. The area outlining made ground and domestic waste is enclosed in a red line. This includes made ground of the access track and land that has been raised probably at a stage when the estate was build.

The areas marked by magenta hatching indicate the thickest domestic and other waste as interpreted from the conductivity and resistivity data. The thickness of domestic waste is expected to be in the order of 0.5 to 1.0m.

Areas marked in blue indicate on interpreted high metal content and this fact can be considered for the remediation of the landfill.

The highest conductivities and lowest resistivities outside the waste area occur in the floodplain to the east of R3 and R4 (orange hatching). This could be either due to leachate or to higher clay content in the overburden.

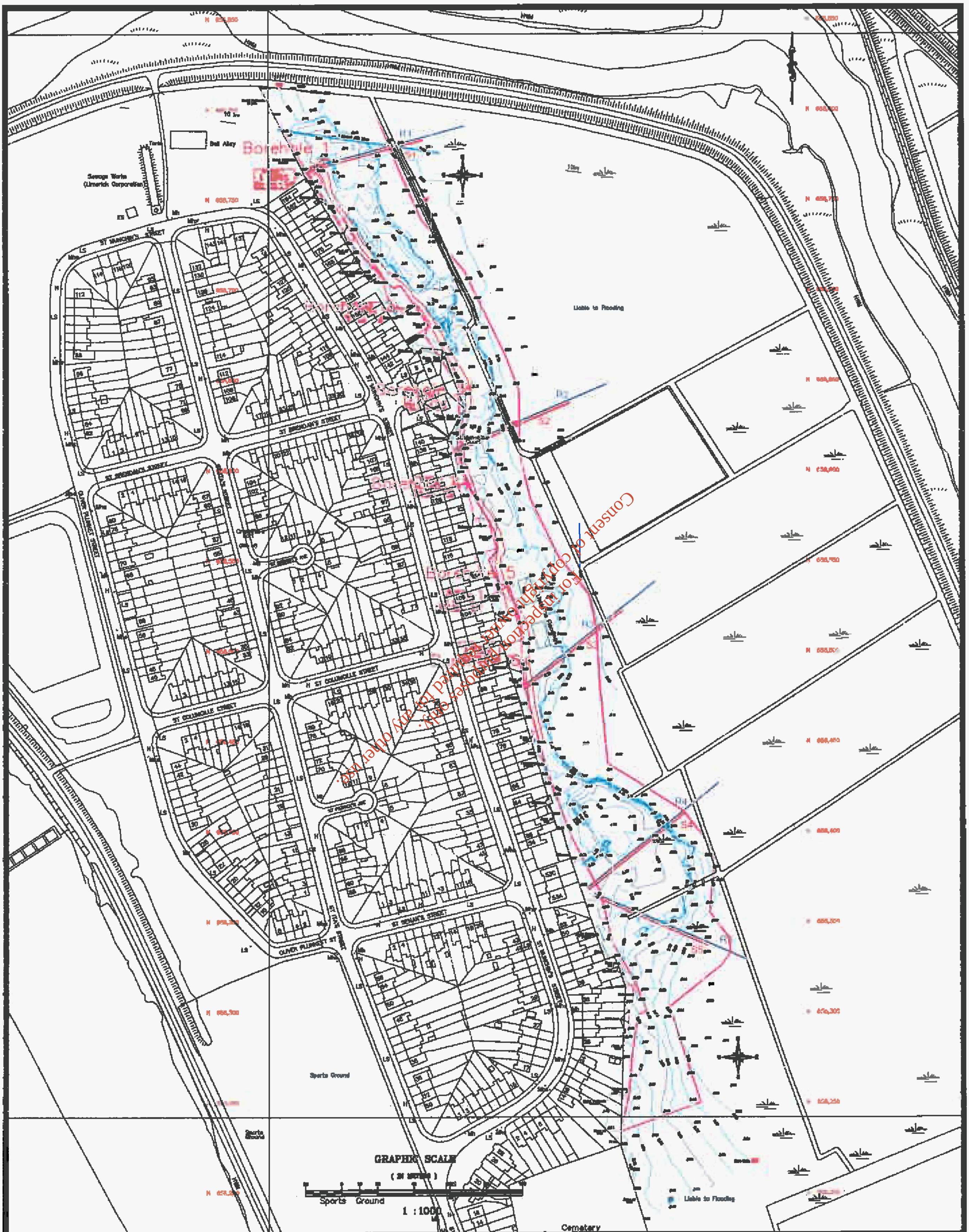
4. CONCLUSIONS AND RECOMMENDATIONS

The following conclusions and recommendations are made:

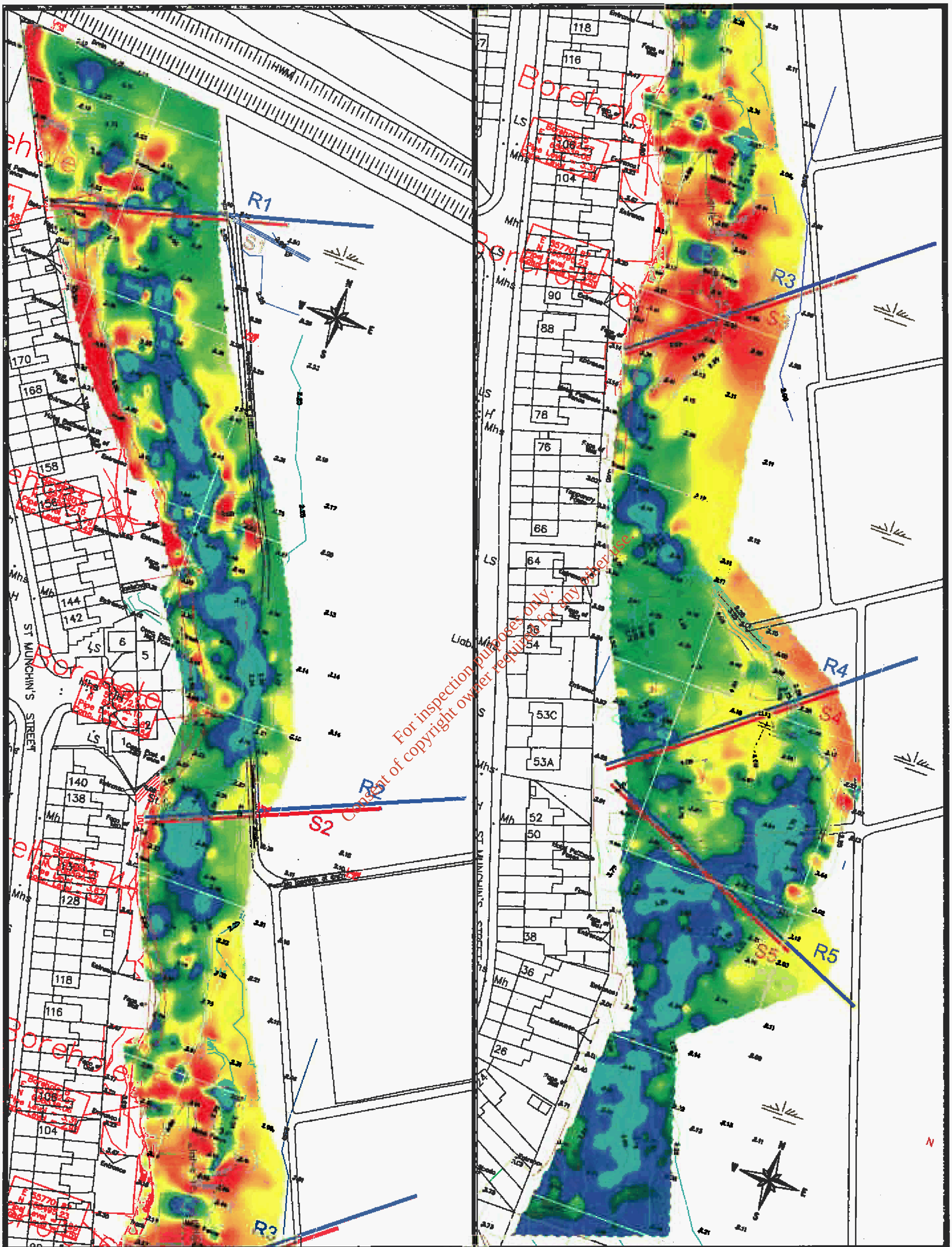
- The geophysical surveys delineated areas with domestic waste, building waste and possible leachate.
- Further sampling after the report confirmed that the geophysical derived interpretation is valid. Some of the waste encountered in the trial pit was described a municipal waste, that stretches into the layer 2 of the interpretation and that is partially decomposed.

5. REFERENCES

1. **GSEG 2002.** Geophysics in Engineering Investigations. Geological Society Engineering Geology Special Publication 19, London, 2002.
2. **GSI, 1999.** Geology of the Shannon Estuary. Geological Survey of Ireland 1999.
3. **Milsom, 1989.** Field Geophysics. John Wiley and Sons.
4. **Reynolds, 1997.** An Introduction to Applied and Environmental Geophysics. John Wiley and Son.



Minerex Geophysics Limited Unit F4, Maynooth Business Campus Maynooth, Co. Kildare Tel. (01) 6510030 Fax. (01) 6510033 Email: info@mgx.ie Web: www.mgx.ie	CLIENT: Verde Environmental Consultants Limerick County Council	SCALE: 1:2000 @ A3	LEGEND:
		PROJECT: 5550	Seismic Refraction Profile
	PROJECT: St. Mary's Park, Limerick City Geophysical Survey	DRAWN: HK	2D-Resistivity Profile
		DATE: 13/06/2011	EM31 Ground Conductivity Survey
	TITLE: Map 1: Location Map of Geophysical Survey	MGX FILE: 5550f_Maps.dwg	
		STATUS: Final	



Minerex
Geophysics Limited
Unit F4, Maynooth Business Campus
Maynooth, Co. Kildare
Tel. (01) 6510030
Fax. (01) 6510033
Email: info@mgx.ie
Web: www.mgx.ie

CLIENT	Verde Environmental Consultants Limerick County Council
PROJECT	St. Mary's Park, Limerick City Geophysical Survey
TITLE	Map 2: EM31 Ground Conductivity Contour Map

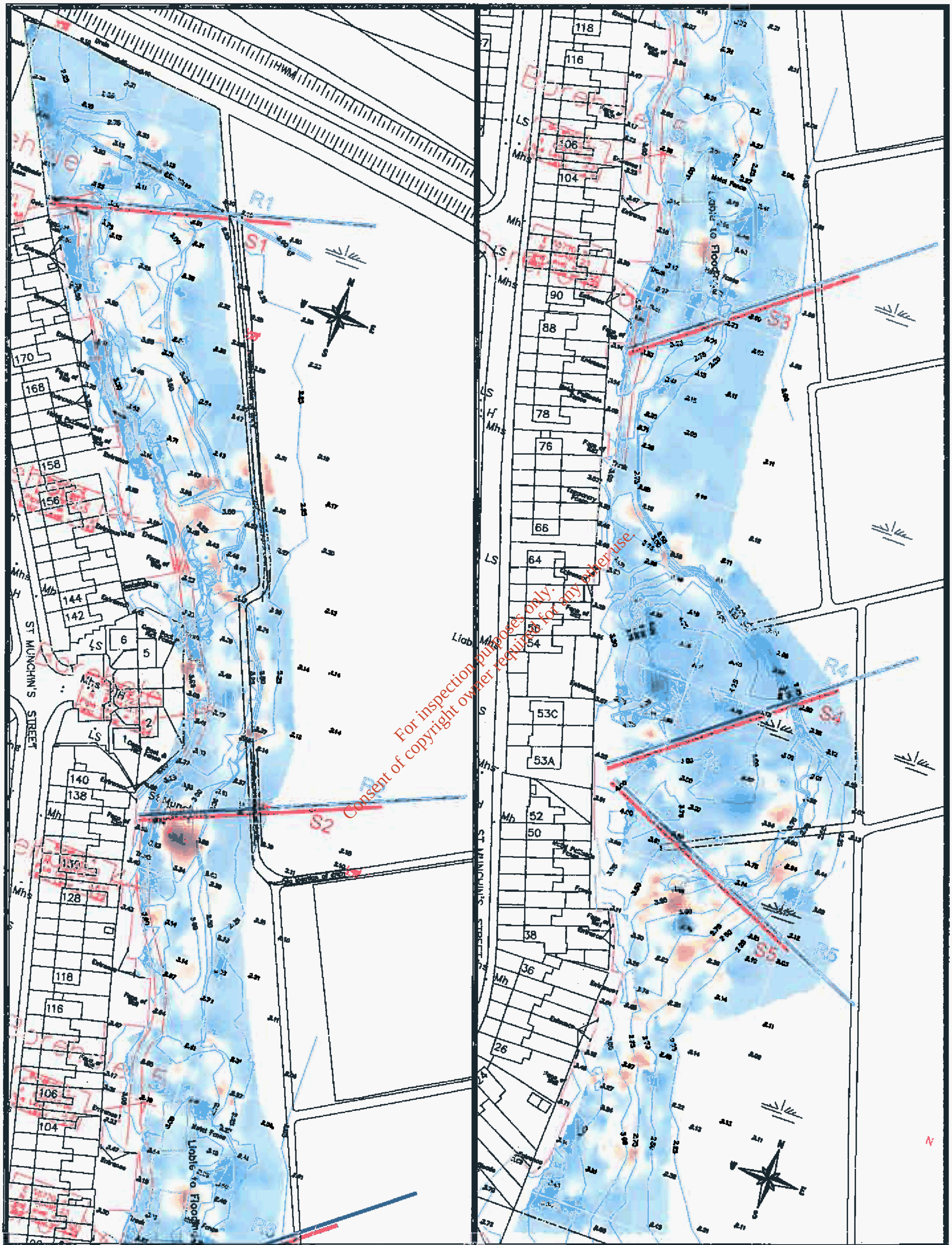
SCALE:	1:2000 @ A3
PROJECT:	5550
DRAWN:	HK
DATE:	13/06/2011
MGX FILE:	5550f_Maps.dwg
STATUS:	Final

LEGEND:

The Colour Contour Map shows the EM31 Ground Conductivity in mS/m

EM31 Ground Conductivity in mS/m

0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36 38 40 42 44 46 48 50



Minerex
Geophysics Limited

Unit F4, Maynooth Business Campus
Maynooth, Co. Kildare
Tel. (01) 6510030
Fax. (01) 6510033
Email: info@mgx.ie
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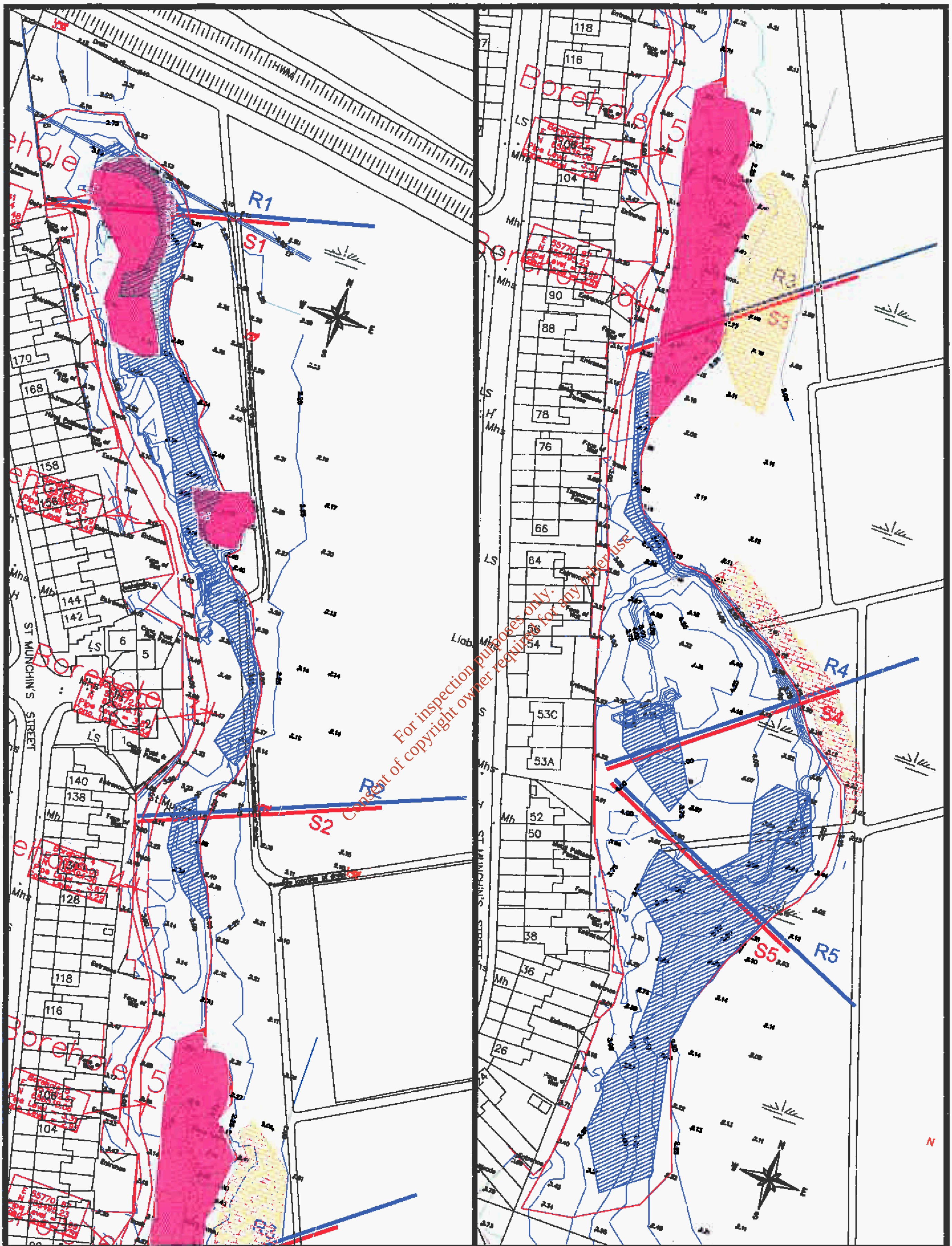
CLIENT	Verde Environmental Consultants Limerick County Council	SCALE:	1:2000 @ A3
PROJECT	St. Mary's Park, Limerick City Geophysical Survey	PROJECT:	5550
		DRAWN:	HK
		DATE:	13/06/2011
TITLE	Map 3: EM31 Inphase Value Contour Map	MGX FILE:	5550f_Maps.dwg
		STATUS:	Final

LEGEND:

The Colour Contour Map shows the EM31 Inphase Values in ppt

EM31 Inphase Value in ppt

-32 -30 -28 -26 -24 -22 -20 -18 -16 -14 -12 -10 -8 -6 -4 -2 0 2 4 6 8 10 12 14 16 18 20 22 24



Minerex
Geophysics Limited

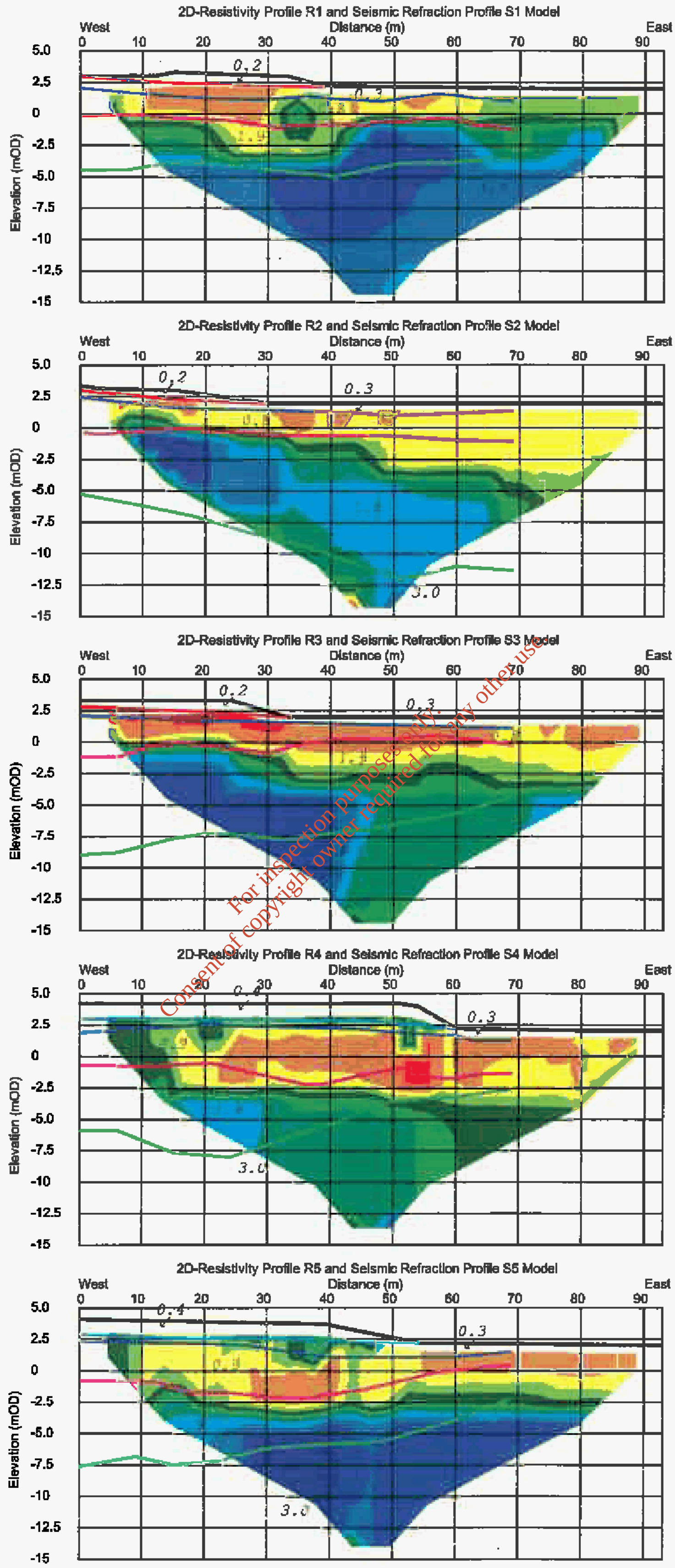
Unit F4, Maynooth Business Campus
Maynooth, Co. Kildare
Tel. (01) 6510030
Fax. (01) 6510033
Email: info@mgx.ie
Web: www.mgx.ie

CLIENT	Verde Environmental Consultants Limerick County Council
PROJECT	St. Mary's Park, Limerick City Geophysical Survey
TITLE	Map 4: Summary Interpretation Map

SCALE:	1:2000 @ A3
PROJECT:	5550
DRAWN:	HK
DATE:	13/06/2011
MGX FILE:	5550f_Maps.dwg
STATUS:	Final

LEGEND:

- Outline of Made Ground/Domestic Waste
- Largest Thickness of Domestic Waste
- High Concentration of Metal in Waste
- Outline of Possible Leachate



Minerex Geophysics Limited
Unit F4, Maynooth Business Campus
Maynooth, Co. Kildare
Tel. (01) 6510030
Fax. (01) 6510033
Email: info@mgx.ie
Web: www.mgx.ie

CLIENT	Verde Environmental Consultants Limerick County Council
PROJECT	St. Mary's Park, Limerick City Geophysical Survey
TITLE	Figure 1: Results of 2D-Resistivity and Seismic Refraction Data

SCALE:	1:750 hor at A3, VE x 2
PROJECT:	5550
DRAWN:	HK
DATE:	13/06/2011
MGX FILE:	5550f_Figs.dwg
STATUS:	Final

LEGEND:

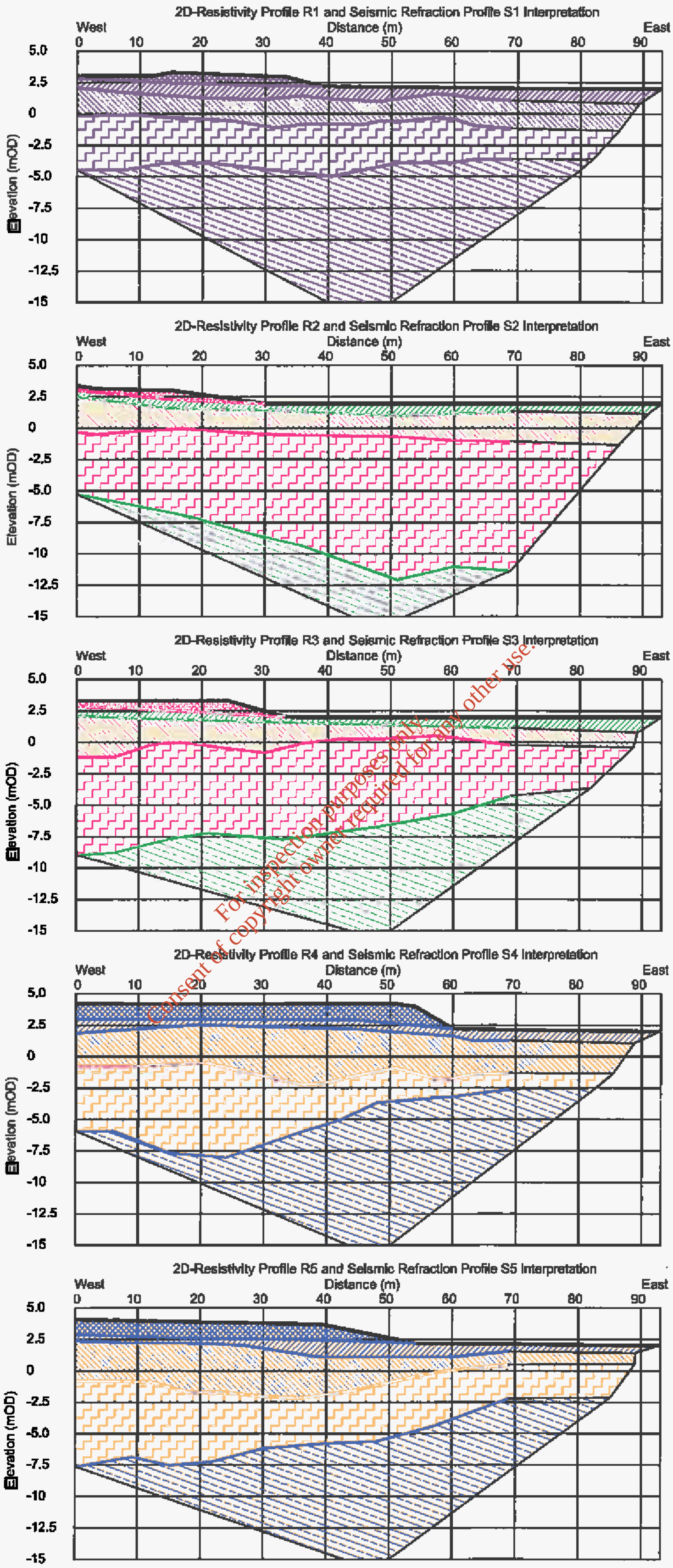
1.9 Seismic Velocity km/s

Layers from Seismic Refraction Model:

- Ground Surface
- Bottom of Layer 1 (0.2 km/s)
- Bottom of Layer 2 (0.4 km/s)
- Bottom of Layer 3 (0.3 km/sec)
- Bottom of Layer 4 (0.8 km/s)
- Bottom of Layer 5 (1.8-1.9 km/s) / Top of Layer 5 (3.0 km/s)

Model Values 2D-Resistivity (Ohm.m)

5.00 10.0 20.0 40.0 80.0 160 320 640



Minerex
Geophysics Limited
Unit F4, Maynooth Business Campus
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Tel. (01) 6510030
Fax. (01) 6510033
Email: info@mgx.ie
Web: www.mgx.ie

CLIENT	Verde Environmental Consultants Limerick County Council	SCALE:	1:750 hor at A3, VE x 2
PROJECT	St. Mary's Park, Limerick City Geophysical Survey	PROJECT:	5550
		DRAWN:	HK
		DATE:	13/06/2011
TITLE	Figure 2: Interpretation of 2D-Resistivity and Seismic Refraction Data	MGX FILE:	5550f_Figs.dwg
		STATUS:	Final

LEGEND:

Combined Interpretation:

- Layer 1 Made Ground (Predominantly Domestic Waste)
- Layer 2 Made Ground (Predominantly Building Waste)
- Layer 3 Soft/Loose Overburden
- Layer 4 Firm-stiff/dense Overburden
- Layer 5 Very stiff/very dense Overburden and weathered Rock
- Layer 6 Strong Rock (Shale and Limestone)