APPENDIX 9

AGL18018 REPORT ON THE PHASE 1 & PHASE 2
GEOPHYSICAL INVESTIGATION
AT BARNAGEERAGH COVE LANDFILL, CO. DUBLIN
FOR
MULROY ENVIRONMENTAL
9th FEBRUARY, 2018

AGL18018_01

REPORT ON THE PHASE 1 & PHASE 2 GEOPHYSICAL INVESTIGATION AT BARNAGEERAGH COVE LANDFILL, CO. DUBLIN FOR MULROY ENVIRONMENTAL

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09TH FEBRUARY 2018

PRIVATE AND CONFIDENTIAL

THE FINDINGS OF THIS REPORT ARE THE RESULT OF A GEOPHYSICAL SURVEY USING NON-INVASIVE SURVEY TECHNIQUES CARRIED OUT AT THE GROUND SURFACE. INTERPRETATIONS CONTAINED IN THIS REPORT ARE DERIVED FROM A KNOWLEDGE OF THE GROUND CONDITIONS, THE GEOPHYSICAL RESPONSES OF GROUND MATERIALS AND THE EXPERIENCE OF THE AUTHOR. APEX GEOSERVICES LTD. HAS PREPARED THIS REPORT IN LINE WITH BEST CURRENT PRACTICE AND WITH ALL REASONABLE SKILL, CARE AND DILIGENCE IN CONSIDERATION OF THE LIMITS IMPOSED BY THE SURVEY TECHNIQUES USED AND THE RESOURCES DEVOTED TO IT BY AGREEMENT WITH THE CLIENT. THE INTERPRETATIVE BASIS OF THE CONCLUSIONS CONTAINED IN THIS REPORT SHOULD BE TAKEN INTO ACCOUNT IN ANY FUTURE USE OF THIS REPORT.

PROJECT NUMBER	AGL18018		
AUTHOR	CHECKED	REPORT STATUS	DATE
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1. EXECUTIVE SUMMARY

APEX Geoservices Limited was requested by Mulroy Environmental to carry out a geophysical investigation at the site of Barnageeragh Cove Landfill in Skerries, Co. Dublin. The site which measures c. 1.45Ha. is being redeveloped as a residential scheme.

The objectives of the investigation are to aid in determination of the extent of the waste body, the thickness of the waste, the presence of anomalous features, a volume calculation and proposed locations of sampling points.

The geophysical investigation was conducted on the 24th November 2017 and 29th January 2018 and consisted of EM31 Ground Conductivity mapping, Electrical Resistivity Tomography (ERT), Seismic Refraction surveying and Multi-Channel Analysis of Surface Waves (MASW) across accessible parts of the site.

The site is characterised by the presence of a layer of gravelly silty sand capping (c 0.3 – 5.5m thick) over a sequence of waste fill material. In parts of the northeast and northwest of the site no significant waste is interpreted.

Type 1 waste occurs at the upper level and consists of material with low organic and / or metal content and is C&D mixed with some municipal waste, in places this layer will contain sandy gravelly silt / clay mixed with minor waste. This type of waste is c. 2.0 – 7.0m thick and correlates with similar material on client trial pits.

Type 2 waste consists of municipal waste with high organic and / or metallic content. This material is generally present as a deeper layer of waste and is only present across a limited part of the site. This type of waste covers approximately 0.30Ha. and is c. 1.0 – 9.0m thick. Based on an average thickness of 7.0m this gives an approximate volume of 21,000m^3.

Beneath the waste bodies gravelly silty sand, boulders and possible completely weathered rock are present. The data does not indicate the presence of significant leachate beneath the waste.

These soil layers overlie bedrock of sandstone / siltstone. The depth to the top of the bedrock varies across the site from c. 5.6 – 13.8m BGL.

A trial pit and a borehole are recommended to target the main area of potentially thick organic **Type 2** waste and possible interference from a nearby foundation

The findings of the geophysical investigation should be reviewed following finalisation of intrusive investigations.

2. INTRODUCTION

APEX Geoservices Limited was requested by Mulroy Environmental to carry out a geophysical investigation at the site of Barnageeragh Cove Landfill in Skerries, Co. Dublin. The purpose of the investigation is to assess the nature of a historical landfill on site as the area is being redeveloped as a residential scheme.

A previous phase 1 geophysical investigation was conducted on the 24th November 2017 and is covered in AGL17283 Report on the geophysical investigation at Barnageeragh Cove Landfill, Co. Dublin. This investigation consisted of EM31 ground conductivity mapping, electrical resistivity tomography (ERT) and seismic refraction surveying across accessible parts of the site.

A phase 2 investigation was conducted on the 29th January 2018 and consisted of electrical resistivity tomography (ERT) surveying in the northwest of the site.

This report covers phase 1 and phase 2 of the investigation.

2.1 Survey Objectives

The objective of the investigation is to aid in determination of:

- The extent of the waste body,
- The thickness of the waste body and presence of any anomalous features,
- A volume calculation,
- Proposed location of sampling points.

2.2 Site Background & Topography

Barnageeragh Landfill site is within the grounds of a residential development in Skerries, Co. Dublin and is bounded to the south by a railway line. The area under investigation covers c. 1.45Ha and consists of open ground, areas of hardcore, spoil heaps, metal fences, a works compound and ferric litter. The topography ranges from c. 15.8 – 25.6m OD.

The site location is shown in Fig. 2.1.

Fig 2.1: Location map (site marked in red).

Soils and Bedrock

The Teagasc soils map for the site primarily describes the soil as sandstone and shale sands and gravel (Fig. 2.2).

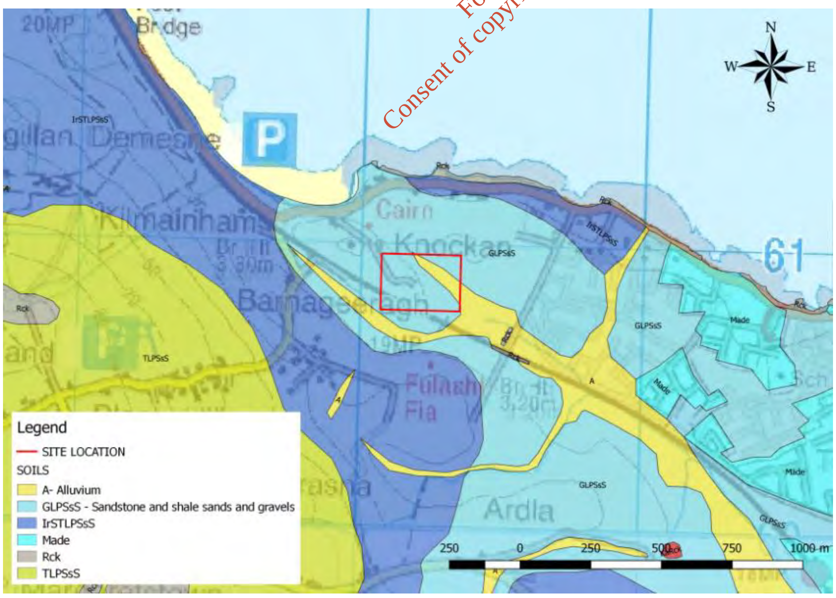

Fig 2.2: The Teagasc soils map (site outlined in red).

The GSI bedrock geology map (Fig. 2.3) shows the area under investigation is located within the Skerries Formation which is described as laminated blue – grey siltstone and sandstone. A series of north – south oriented faults lie to the east and west of the site.

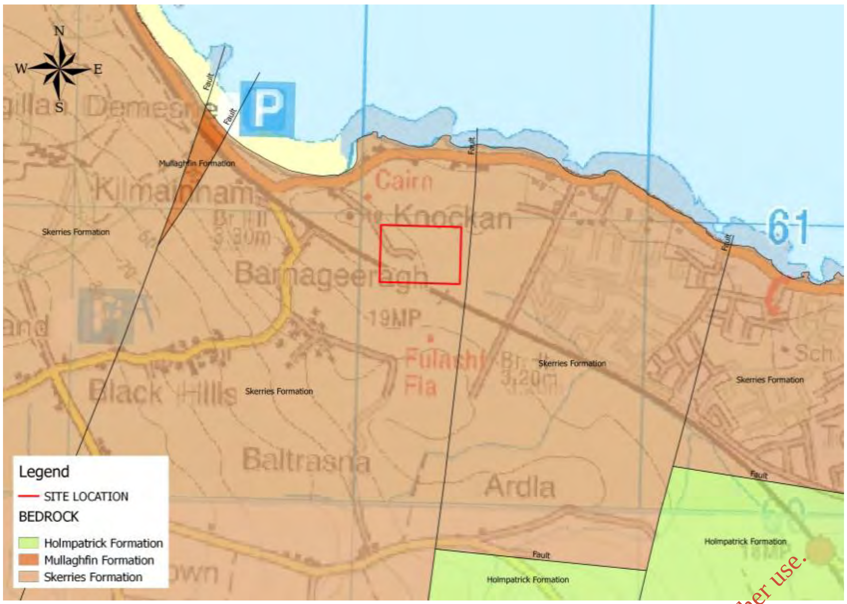

Fig 2.3: The GSI bedrock map (site outlined in red).

2.2.2 Groundwater vulnerability and aquifer classification

The area under investigation lies within an area of high groundwater vulnerability (Fig. 2.4). Bedrock within the site has been classified as bedrock which is a poor aquifer (Fig. 2.5).

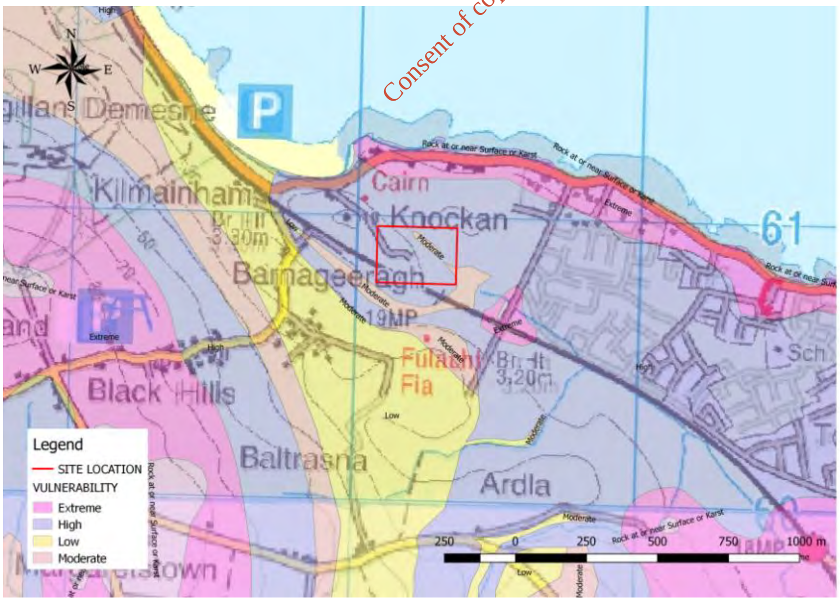

Fig 2.4: The GSI vulnerability map (site outlined in red).

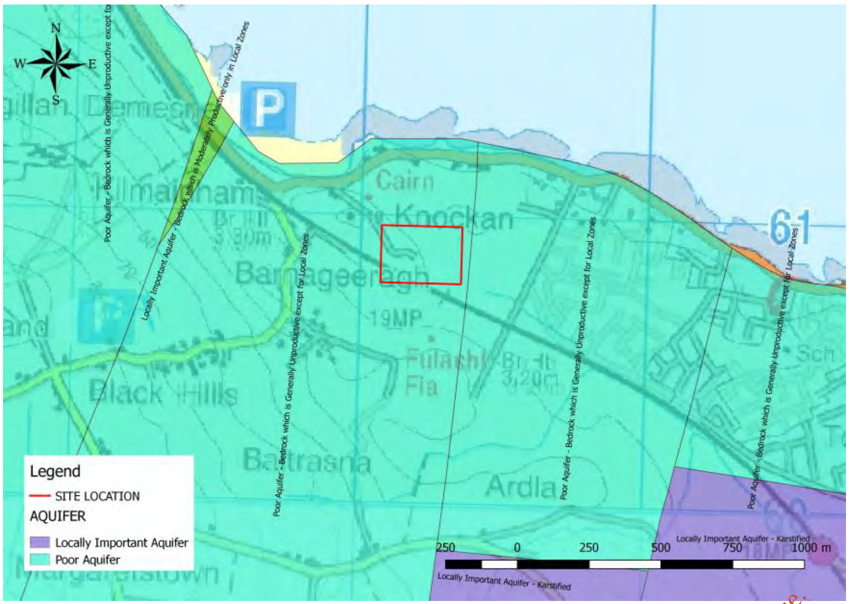

Fig 2.5: The GSI aquifer map (site outlined in red).

2.2.3 Historical Data

The historical 6 inch map shows no outcrop in the immediate vicinity of the site but does show outcrop to the west and to the north along the coastline.

Fig 2.6: The historical 6inch map (site outlined in red).

2.2.4 Direct Investigation Data

A suite of direct investigation information was supplied by the client for incorporation into this report.

Forty eight trial pits were acquired across the area under investigation and in areas to the north and northwest. These trial pits were divided into four main categories by the client, pits where domestic waste was found, pits where C&D waste was found, pits where inert subsoil was found and pits where indigenous soil was found. A number of the pits show a thin layer of sandy gravelly silt/clay or gravelly silty sand over waste material, others show waste very close to the surface. Forty five of the trial pits record 'no evidence of VOC / Hydrocarbon contamination' while three record 'potential hydrocarbon odour'. The trial pits describe layers of sandy gravelly silt/clay or gravelly silty sand mixed with domestic waste and C&D type waste including brick, blocks, timber, pipes and rebar over variable depth, including to termination depth which ranges 2.2 – 4.6m below ground level (BGL).

Thirteen borehole datasets across the site describe natural soils of sandy gravelly silt/clay and fill material consisting of sandy gravelly silt/clay mixed with waste over silty gravelly sand and boulders. Waste is recorded to depths of 10.6m BGL. Borehole BH06 terminates in made ground of gravelly sandy silt / clay with waste of plastic and glass at 8.1m BGL. Where bedrock is encountered it is recorded as weathered – competent siltstone / sandstone at depths of 4.5 – 10.5m BGL.

2.3 Survey Rationale

The following techniques have been employed to achieve the objectives of the investigation:

- Electromagnetic EM31 ground conductivity mapping has been carried out across the site in order to map the extent of the fill and variations in the fill, and also to screen for any leachate plumes and obtain background values for the soils and rock.

- Electrical Resistivity Tomography (ERT) has been carried out across the site to investigate variations in the thickness and extent of the fill material and leachate, as well as to investigate the overburden and bedrock geology.

- Seismic refraction was carried out at selected locations. The results of the seismic survey have been used to outline the fill/soil boundary.

- Multi-Channel Analysis of Surface Waves (MASW) was carried out on the seismic refraction profiles. The results of the MASW have been used to indicate base of waste material. The MASW method is used to estimate shear-wave (S-wave) velocities in the ground material to indicate possible soft zones. Soil / fill material with an S-wave velocity of <175 m/s is generally classified as soft/loose.

As with all geophysical methods the results are based on indirect readings of the subsurface properties. The effectiveness of the proposed approach will be affected by variations in the ground properties. By combining a number of techniques it is possible to provide a higher quality interpretation and reduce any ambiguities which may otherwise exist. Further information on the detailed methodology of each geophysical method employed in this investigation is given in **APPENDIX B: DETAILED METHODOLOGY**.

3. RESULTS

The phase 1 investigation was carried out on the 24th of November 2017 and involved the collection of 299 EM conductivity data points, 4 no. ERT profiles (1 x 180m, 2 x 96m and 1 x 78m), 2 no. seismic refraction profiles (2 x 46m) and 2 no. 1D MASW soundings across the site.

The phase 2 investigation was carried out on the 29th of January 2018 and involved the collection of 4 no. ERT profiles (1 x 96m, 2 x 102m and 1 x 120m)

3.1 EM31 Electromagnetic Conductivity Mapping

The EM ground conductivity results are indicative of the bulk conductivity of the ground materials from 0-6.0m BGL. Drawing AGL17283_02 shows the contoured conductivity results with values in the range 4 – 58 mS/m (milli Siemens/meter).

The recorded EM Inphase values were contoured and plotted on Drawing AGL7283_03. The inphase value is sensitive to the presence of metal objects. Large variations in the inphase values reflect the presence of surface or subsurface metal.

The ground conductivity values have been interpreted in conjunction with the inphase, ERT, borehole and trial pit data as follows:

Conductivity (mS/m)	***Interpretation***
4-16	Natural Ground
16-28	Extent of C&D Waste & some municipal waste of lower organic or metallic content Or Waste mixed with sandy gravelly SILT / CLAY
28-58	Extent of Municipal Waste with high organic & or metallic content

Table 1: Conductivity values and corresponding interpretation.

3.2 ERT

The resistivity values ranged from 5 - 3802 Ohm-m. Typical resistivities of Irish overburden deposits range from 20 Ohm-m for pure clay to around 3000 Ohm-m for clean dry gravel, with the resistivity generally increasing as the sand/gravel content increases. Silty clay typically has values in the range 30-50 Ohm-m and silty gravelly clay typically has resistivity values in the range 50-100 Ohm-m. (An exception is the Irish Sea Till which occurs along the east coast of Wicklow and Wexford and which has resistivity values as low as 10 Ohm-m).

Deposits of predominantly organic waste such as those occurring in municipal landfills typically have resistivities in the range 5-30 Ohm-m. Inert C & D waste such as concrete, brick and mixed stone and clay will have resistivities similar to gravelly material (50-500 Ohm-m).

The resistivity of combined organic and inert material will depend on the percentage of organic material present. If sufficient organic content and moisture is present for connecting electrical conductivity pathways throughout the C & D material then resistivities would be expected to be similar to the range for municipal waste. If the organic waste only occurs in isolated lenses and pockets above the watertable then resistivities would be expected to be similar to the lower end of the range for C & D waste.

The resistivity data has been interpreted on the following basis:

	Resistivity (Ohm-m)	***Interpretation***
Waste	<30	Municipal Waste with high organic & or metallic content
	30-60	C&D Waste & some municipal waste of lower organic or metallic content or Waste mixed with sandy gravelly SILT / CLAY
Natural Ground	60 - 145	Gravelly Silty SAND
	145 - 668	Gravelly Silty SAND & BOULDERS / Completely Weathered ROCK
	145 - 280	Weathered SANDSTONE / SILTSTONE
	280- 3800	SANDSTONE / SILTSTONE

The ERT results have been used for interpretation in conjunction with the EM ground conductivity, seismic refraction and MASW datasets and the borehole and trial pit data.

3.3 Seismic refraction profiling

Two seismic refraction spreads were recorded across the site (S1-S2). The seismic refraction data has been generally interpreted on the following basis:

Layer	***Average P-Wave Seismic Velocity (m/s)***	***Interpretation***	***Stiffness/Rock Quality***
1	254 - 500	Waste	Soft / Loose
2	500 - 1000	Waste / Natural soil	Firm / Medium Dense
3	1000 - 1800	Waste / Natural soil	Stiff / Dense
4	1800 - 2400	Natural soil / Weathered Rock	Very Stiff / Very Dense or Poor – Fair
5	2400 - 4725	Slightly Weathered – Fresh SANDSTONE/SILTSTONE	Good

3.4 MASW

Two 1D MASW soundings (M1-M2) were recorded across the site. Each sounding was positioned at the centre of the associated seismic refraction profile. The shear wave (Vs) velocity values for the site range from 104-344 m/s, over a depth range of c. 0-.8 – 15.3m BGL. Shear wave velocities of <175m/s are indicative of soft / loose ground conditions typical of unconsolidated waste deposits. Sounding M1 shows soft/loose material to 4m bgl and sounding M2 soft/loose material to 9m bgl.

The shear wave velocities are shown below in Fig. 3.1.

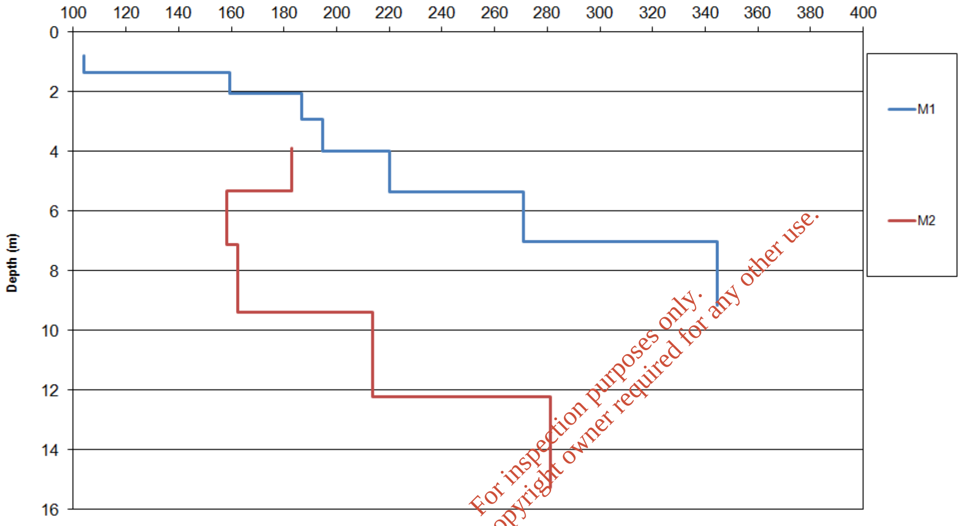

Fig.3.1. Shear-wave velocity plots.

A summary of Shear wave velocity and soil cohesion is shown in Fig. 3.2.

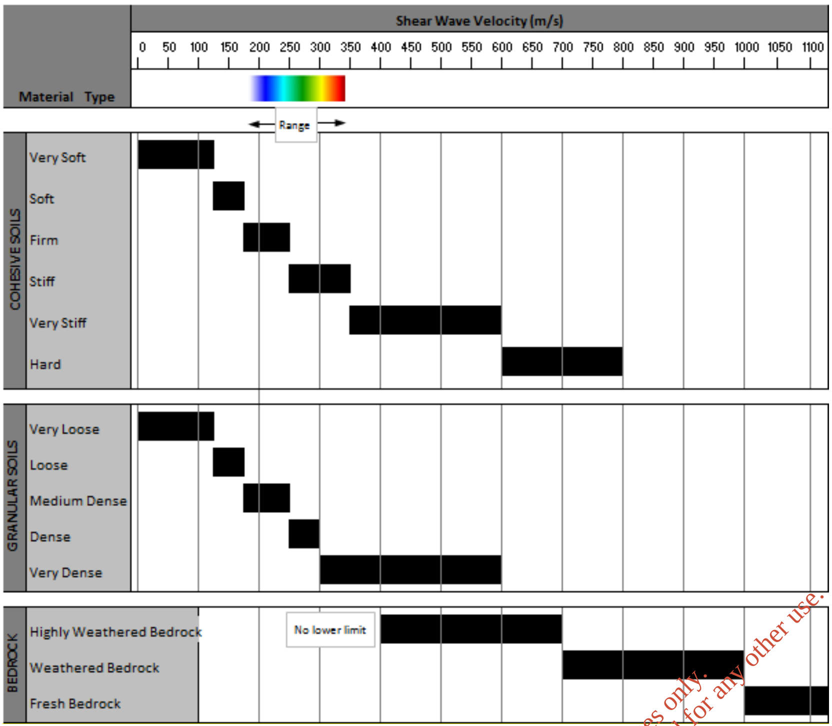

Fig.3.2. Shear-wave velocity and corresponding soil cohesion.

3.5 Interpretation

The integrated interpretation of the geophysical results with client borehole and trial pit data is presented below. Interpreted ERT profiles are presented in Drawing No.s AGL17283_04 to _07. While the investigation data generally correlates well with the trial pit data small discrepancies may occur as many of the trial pits are offsets from the geophysical profiles.

The site is characterised by the presence of a layer of gravelly silty sand capping (c 0.3 – 5.5m thick) over a sequence of fill material. In parts of the northeast and northwest of the site no significant waste is interpreted.

Two main types of waste body are interpreted across the area under investigation.

Type 1 waste consists of material with low organic and / or metal content and is C&D waste mixed with some municipal waste. In places this layer will contain sandy gravelly silt / clay mixed with minor waste. This type of waste is present at a shallow level, and in places at the surface, across central parts of the site and is not interpreted in the southeast corner, the northeast and the far northwest of the site. This layer of waste correlates with similar material on the client trial pits. The level of waste and mixed clay in this layer will be variable such as on ERT profile R3 where gravelly silt / clay is dominant and trial pits indicate a low level of sporadic wood fragments only.

Type 2 waste consists of municipal waste with high organic and / or metallic content. This material is generally present as a deeper layer of waste and is only present across a limited part of the site. This material type is present on a number of ERT profiles, R1, R4, R5, R6, R7 and R8. Between distance 32 – 52m on profile R6 low model resistivity values may also be due to interference from a nearby foundation.This type of waste covers approximately 0.30Ha. and is c. 1.0 – 9.0m thick. Based on an average thickness of 7.0m this gives an approximate volume of 21,000m^3. This material type is defined by low resistivity values of < 30 Ohm-m and high conductivity values of 28 – 58 mS/m.

Beneath the waste bodies resistivity values of 60 – 145 Ohm-m and 145 – 668 Ohm-m indicate gravelly silty sand, boulders and possible completely weathered rock. This range of resistivity values does not indicate the presence of significant leachate beneath the waste.

These soil layers overlie bedrock of sandstone / siltstone. The depth to the top of the bedrock varies across the site from c. 5.6 – 13.8m BGL.

A summary interpretation map of the site is not displayed as access for the EM ground conductivity survey was limited due to the presence of the site compound and plant (see Drawing No. AGL17283_01).

4. RECOMMENDATIONS

A trial pit and a borehole are recommended to target an area of potential waste or interference from a foundation and potentially thick organic **Type 2** waste respectively

Proposed Borehole	*ING Easting*	*ING Northing*	*Target*	*Target Depth (m)*
PTP01	323199	260863	Area of organic waste / interferance	5
PBH01	323204	260811	Area of organic waste	12

5. REFERENCES

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Teagasc website:
http://gis.teagasc.ie/soils/downloads.php

6. APPENDIX A: DRAWINGS

The information derived from the geophysical investigation as well as correlation with the available direct investigation is presented in the following drawings:

AGL17283_01
Fig.1 Geophysical Investigation Locations Scale 1:1000 @A4

AGL17283_02
Fig.1 EM Ground Conductivity Map Scale 1:1000 @A4

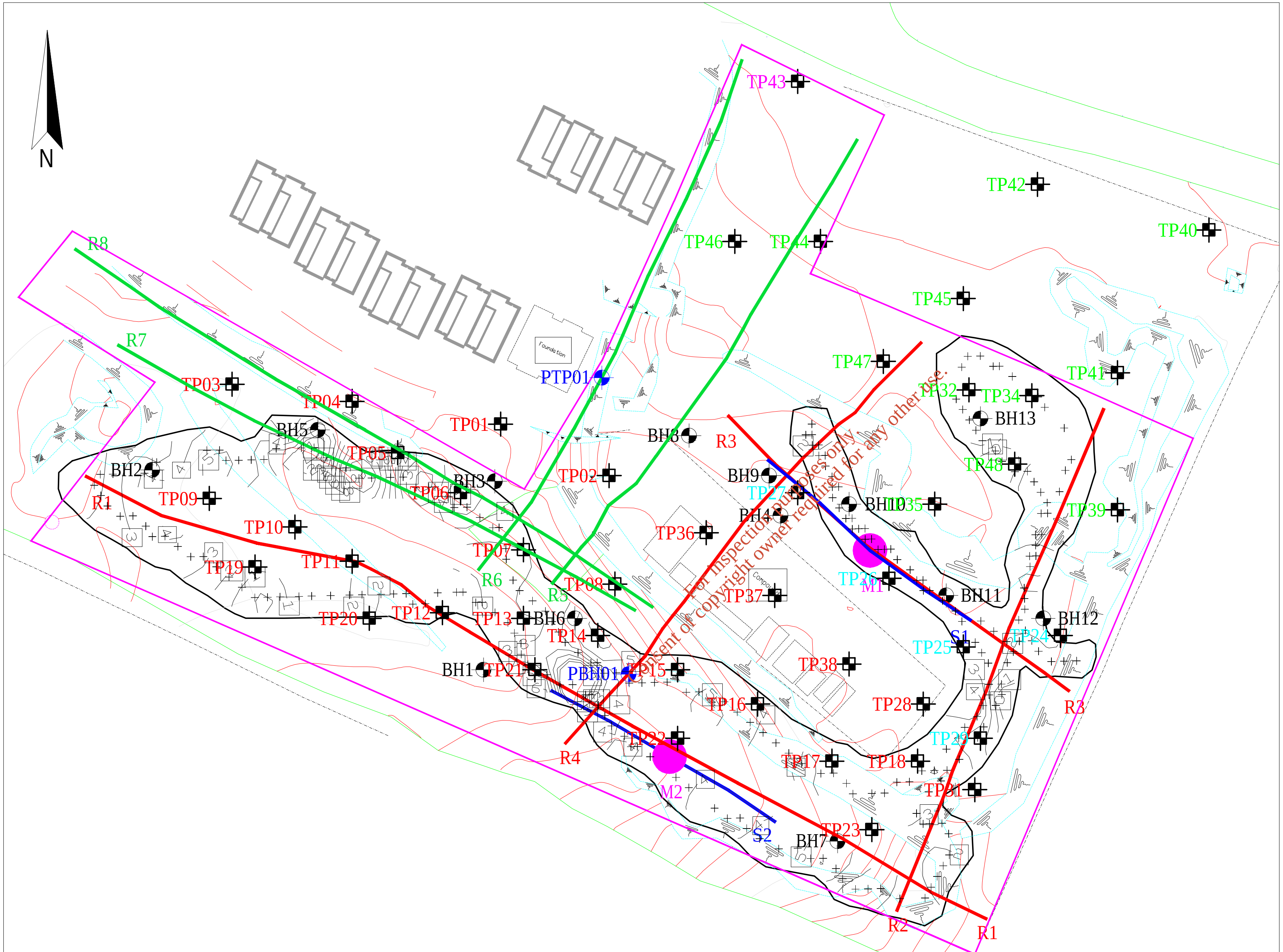
AGL17283_03
Fig.1 EM Inphase Map Scale 1:1000 @A4

AGL17283_04
Fig.1 ERT Profiles R1 & R3 Results & Interpretation Scale 1:1000 @A4

AGL17283_05
Fig.1 ERT Profiles R4 & R2 Results & Interpretation Scale 1:1000 @A4

FIGURE 1: GEOPHYSICAL INVESTIGATION LOCATIONS

SCALE 1:1000



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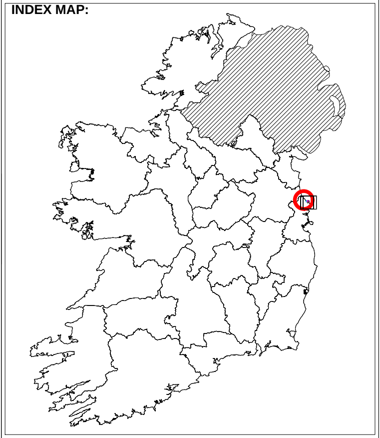
INDEX MAP:



LEGEND:

- Site Boundary
- Phase 1 EM conductivity station
- R1 — Phase 1 2D Electrical Resistivity (ERT)
- R5 — Phase 2 2D Electrical Resistivity (ERT)
- S1 — Phase 1 Seismic Refraction Spread
- M1 — Phase 1 MASW Sounding
- PBH1 / PTP01 — Proposed Trial Pit/Borehole location
- TP04 — Client Trial Pit - Domestic Waste
- TP43 — Client Trial Pit - C&D Waste
- TP24 — Client Trial Pit - Inert Soil
- TP39 — Client Trial Pit - Natural Soil

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PROJECT:	BARNAGEERAGH COVE LANDFILL, DUBLIN GEOPHYSICAL INVESTIGATION
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DRAWING NO:	AGL18018_01
SCALE:	AS INDICATED @ A4
DATE:	8th February 2018

Version:	Date:	Drawn By:	Checked:
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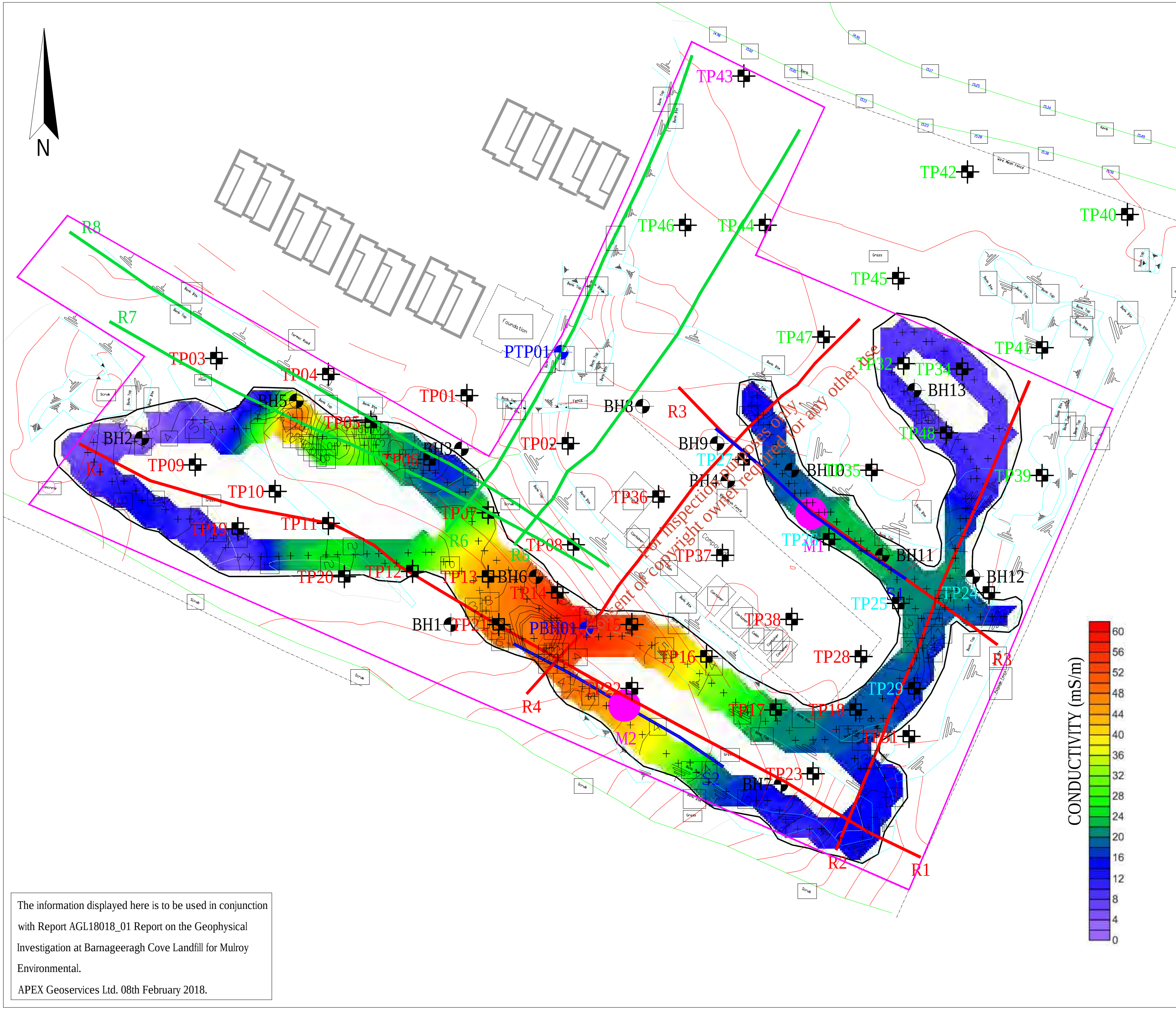
FIGURE 1: EM GROUND CONDUCTIVITY MAP

SCALE 1:1000



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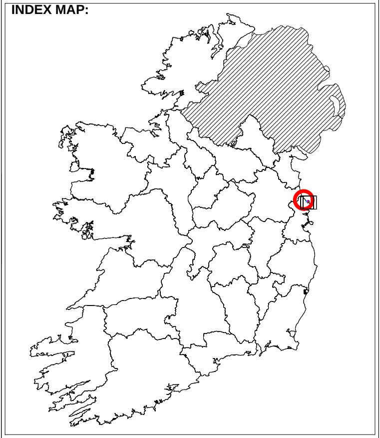
INDEX MAP:



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DRAWING NO:	AGL18018_02
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DATE:	8th February 2018

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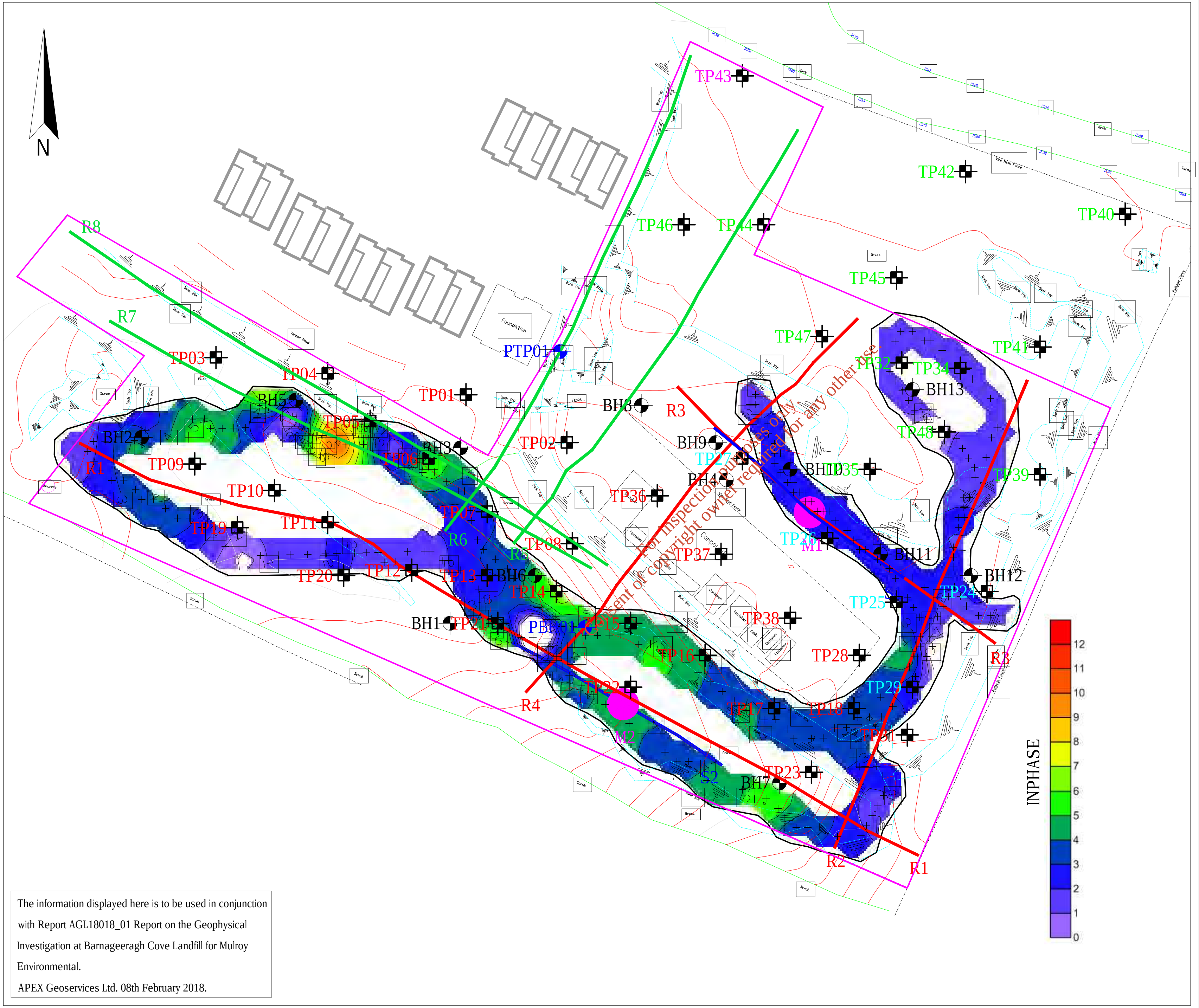
FIGURE 1: EM INPHASE MAP

SCALE 1:1000



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INDEX MAP:

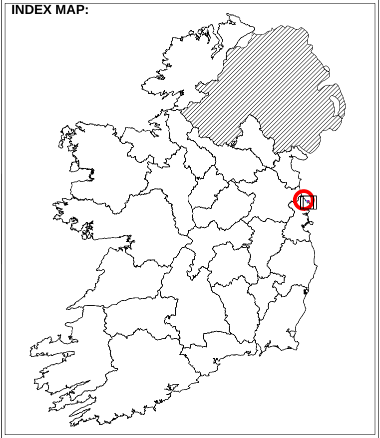

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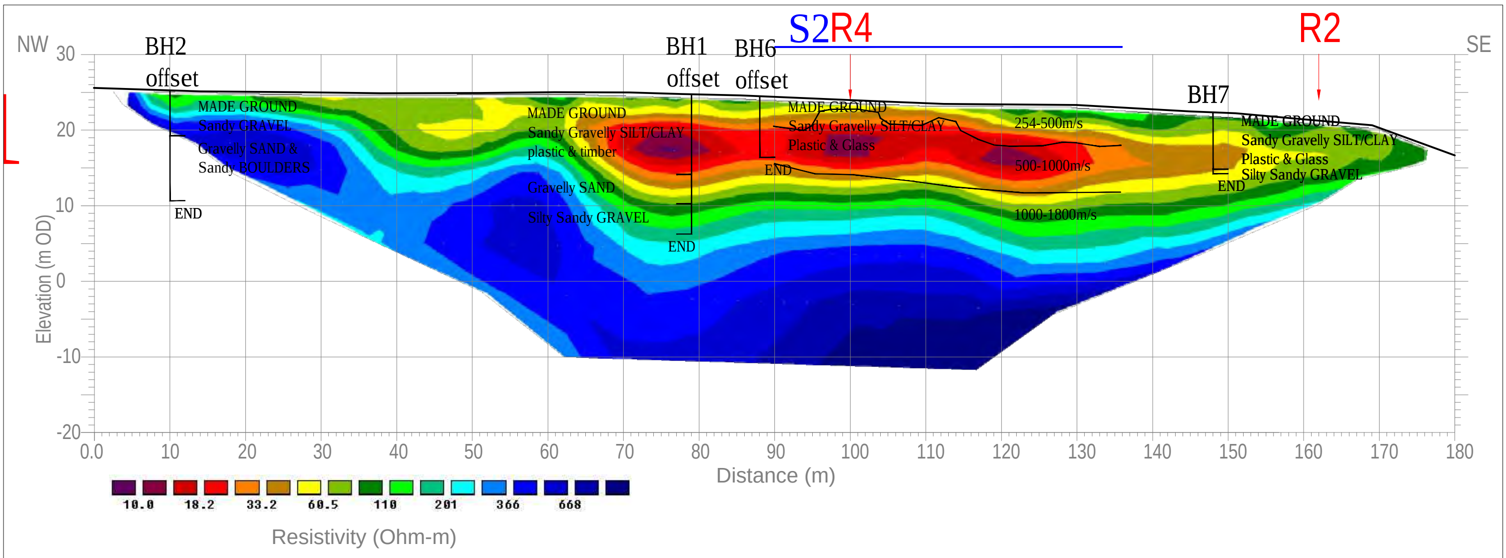
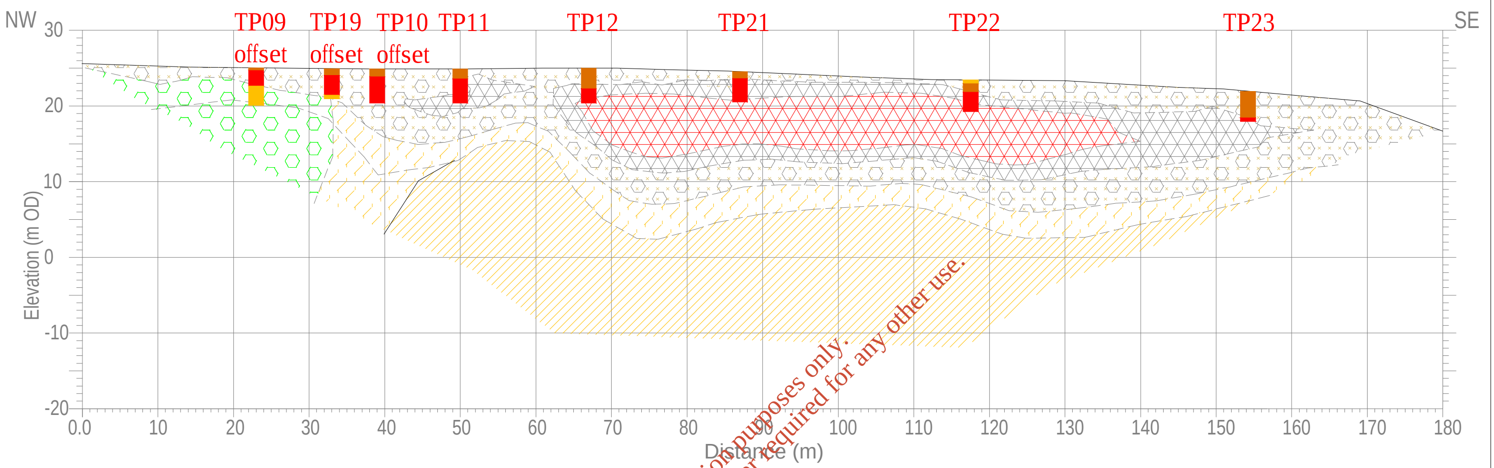
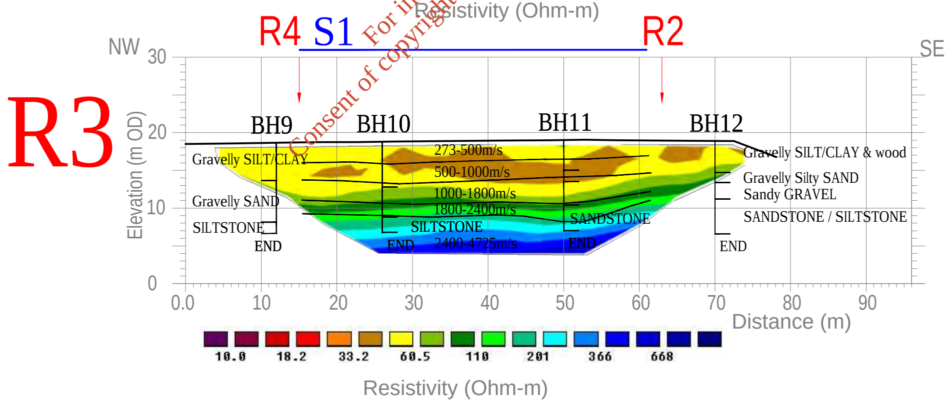
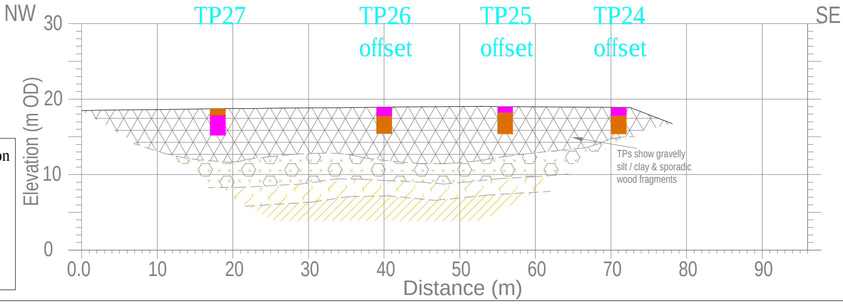
FIGURE 1: ERT PROFILES R1 & R3 RESULTS AND INETRPRETATION

SCALE 1:1000









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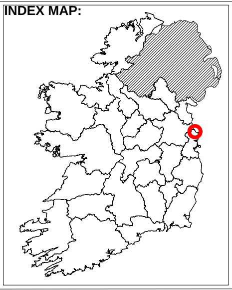
INDEX MAP:



LEGEND:

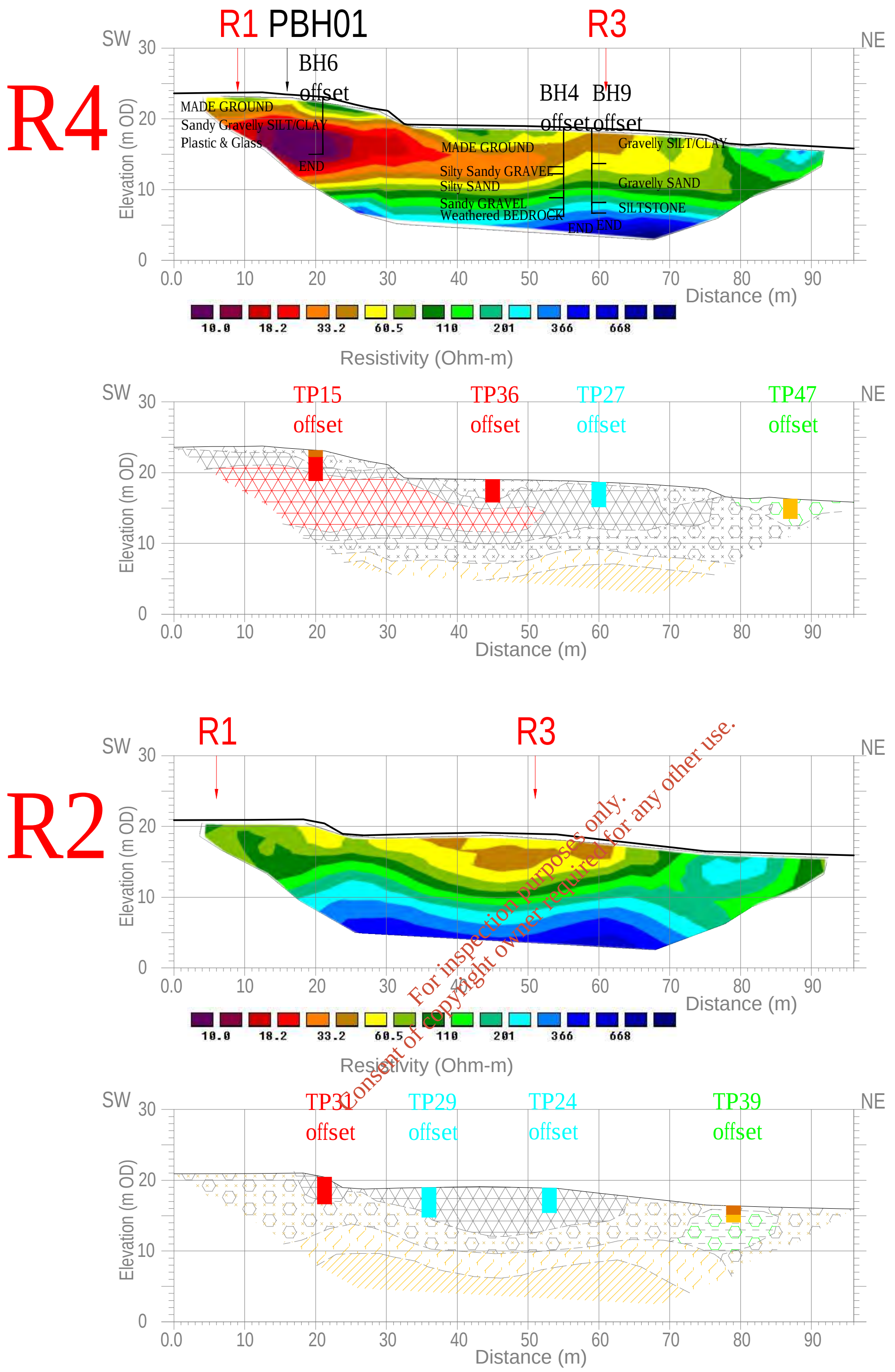
- Capping / Gravelly Silty SAND
- Gravelly Sand/Boulders / Completely Weathered Rock
- Municipal Waste with high organic & or metallic content
- C&D Waste with lower organic & or metallic content or Waste mixed with sandy gravelly SILT/CLAY
- Weathered SILTSTONE / SANDSTONE
- SILTSTONE / SANDSTONE
- Seismic Refraction Layer & Vp velocity (254 - 500m/s)
- TP04 Client Trial Pit - Domestic WASTE
- TP43 Client Trial Pit - C&D WASTE
- TP24 Client Trial Pit - Inert SOIL
- TP39 Client Trial Pit - Natural SOIL
- Silty Gravelly Sand
- Sandy SILT / CLAY
- Domestic WASTE
- C&D WASTE
- Inert SOIL

PROJECT:	BARNAGEERAGH COVE LANDFILL, DUBLIN GEOPHYSICAL INVESTIGATION
CLIENT.:	MULROY ENVIRONMENTAL
DRAWING NO:	AGL18018_04
SCALE:	AS INDICATED @ A4
DATE:	8th February 2018

Version:	Date:	Drawn By:	Checked:
01	08/02/2018	AP	TL

FIGURE 1: ERT PROFILES R4 & R2 AND INETRPRETATION

SCALE 1:1000



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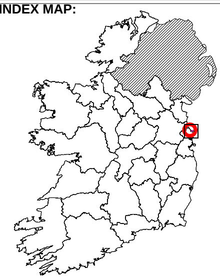
INDEX MAP:



LEGEND:

- Capping / Gravelly Silty SAND
- Gravelly Sand/Boulders / Completely Weathered Rock
- Municipal Waste with high organic & or metallic content
- C&D Waste with lower organic & or metallic content or Waste mixed with sandy gravelly SILT/CLAY
- Weathered SILTSTONE / SANDSTONE
- SILTSTONE / SANDSTONE
- Seismic Refraction Layer & Vp velocity
- TP04 Client Trial Pit - Domestic WASTE
- TP43 Client Trial Pit - C&D WASTE
- TP24 Client Trial Pit - Inert SOIL
- TP39 Client Trial Pit - Natural SOIL
- Silty Gravelly Sand
- Sandy SILT / CLAY
- Domestic WASTE
- C&D WASTE
- Inert SOIL

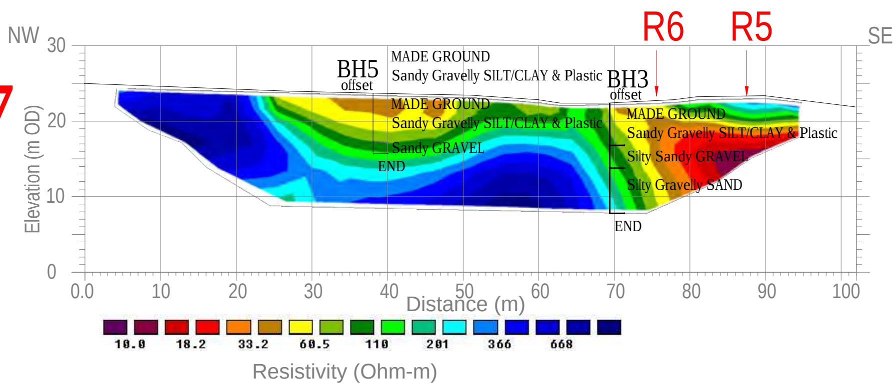
PROJECT:	BARNAGEERAGH COVE LANDFILL, DUBLIN GEOPHYSICAL INVESTIGATION
CLIENT.:	MULROY ENVIRONMENTAL
DRAWING NO:	AGL18018_05
SCALE:	AS INDICATED @ A4
DATE:	8th February 2018

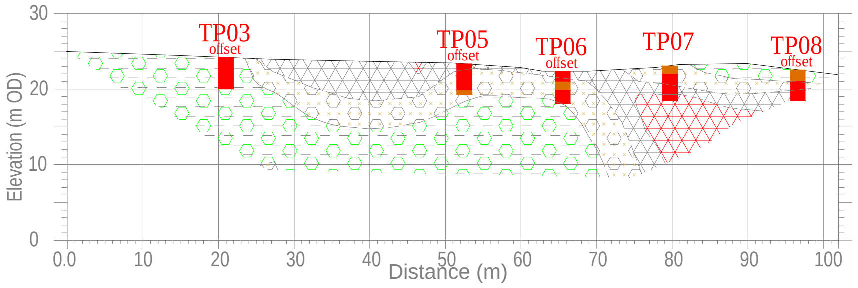
Version:	Date:	Drawn By:	Checked:
01	08/02/2018	AP	TL

FIGURE 1: ERT PROFILES R7 & R8 AND INETRPRETATION

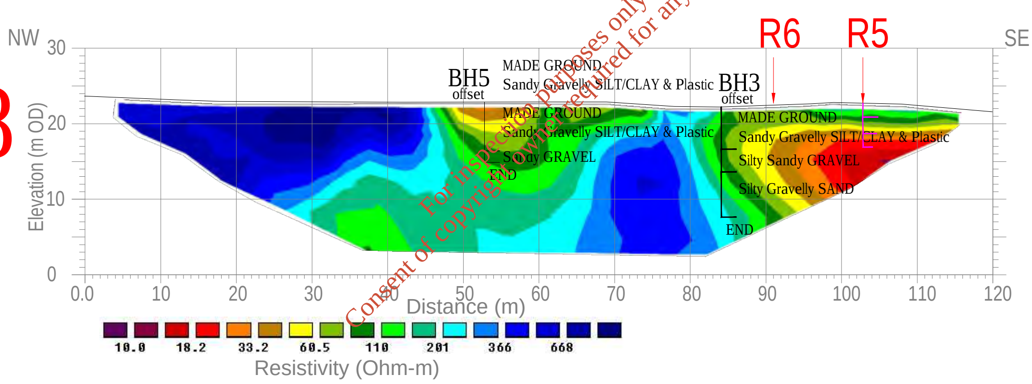
SCALE 1:1000

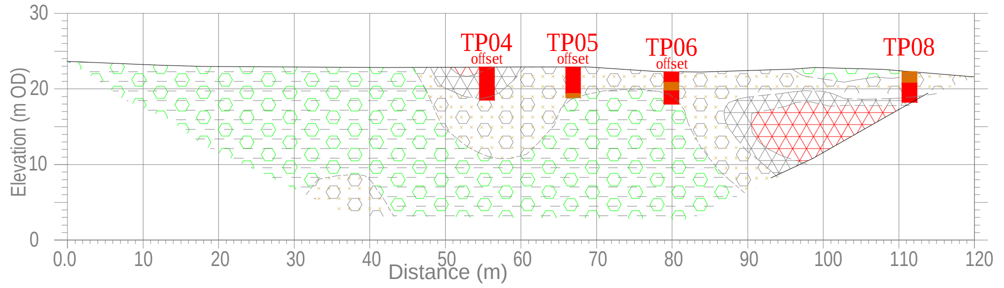
R7





R8





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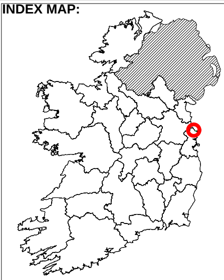

LEGEND:

- Capping / Gravelly Silty SAND
- Gravelly Sand/Boulders / Completely Weathered Rock
- Municipal Waste with high organic & or metallic content
- C&D Waste with lower organic & or metallic content or Waste mixed with sandy gravelly SILT/CLAY
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- SILTSTONE / SANDSTONE
- Seismic Refraction Layer & Vp velocity
- TP04 Client Trial Pit - Domestic WASTE
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- C&D WASTE
- Inert SOIL

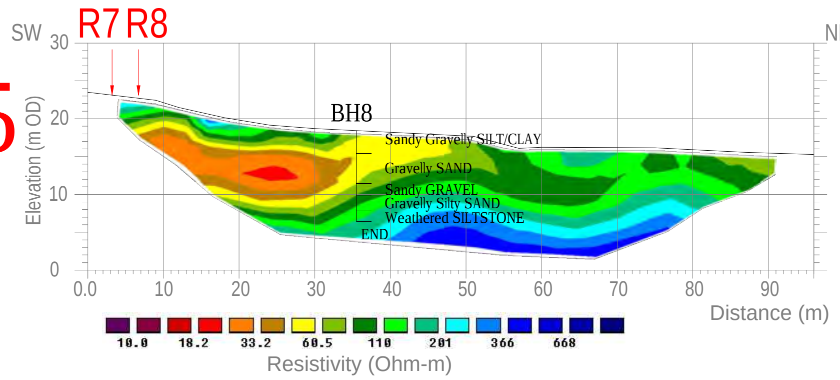
PROJECT:	BARNAGEERAGH COVE LANDFILL, DUBLIN GEOPHYSICAL INVESTIGATION
CLIENT.:	MULROY ENVIRONMENTAL
DRAWING NO:	AGL18018_06
SCALE:	AS INDICATED @ A4
DATE:	8th February 2018

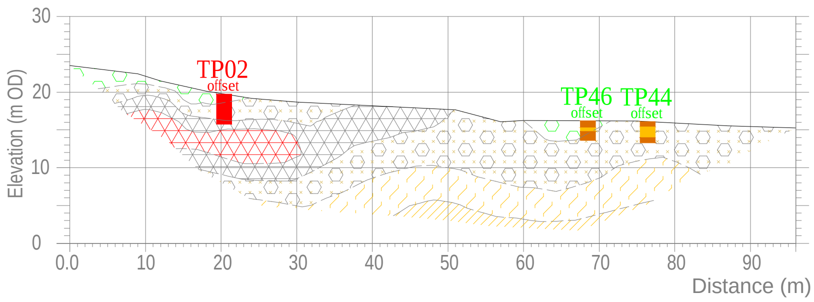
Version:	Date:	Drawn By:	Checked:
01	08/02/2018	AP	TL

FIGURE 1: ERT PROFILES R5 & R6 AND INETRPRETATION

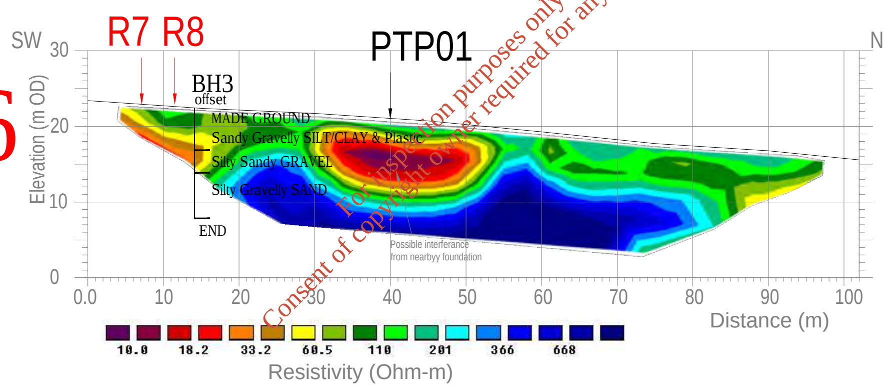
SCALE 1:1000

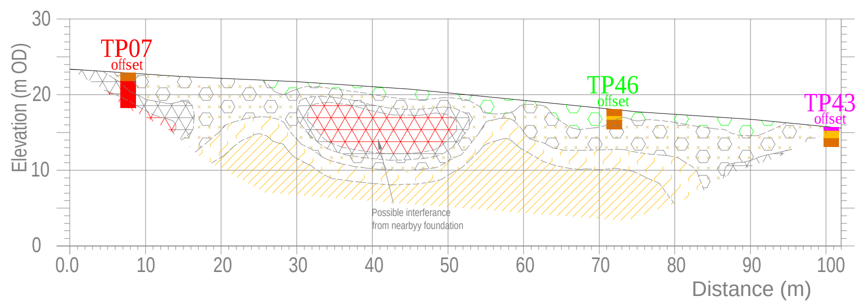
R5





R6





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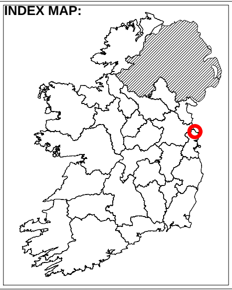
INDEX MAP:



LEGEND:

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- SILTSTONE / SANDSTONE
- Seismic Refraction Layer & Vp velocity
- TP04 Client Trial Pit - Domestic WASTE
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- TP24 Client Trial Pit - Inert SOIL
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- Sandy SILT / CLAY
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- C&D WASTE
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PROJECT:	BARNAGEERAGH COVE LANDFILL, DUBLIN GEOPHYSICAL INVESTIGATION
CLIENT:	MULROY ENVIRONMENTAL
DRAWING NO:	AGL18018_07
SCALE:	AS INDICATED @ A4
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7. APPENDIX B: DETAILED METHODOLOGY

A combination of a number of geophysical techniques was used to provide the high quality interpretation and reduce any ambiguities, which may otherwise exist.

7.1 EM ground conductivity mapping

7.1.1 Principles

This method operates on the principle of inducing currents in conductive substrata and measuring the resultant secondary electro-magnetic field. The strength of this secondary EM field is calibrated to give apparent ground conductivity in milliSiemens/metre (mS/m). Readings over material such as organic waste and peat give high conductivity values while readings over dry materials with low clay mineral content such as gravels, limestone or quartzite give low readings.

The EM31 survey technique determines the apparent conductivity of the ground material from 0-6m bgl depending on the dipole mode used. Depending on the dipole mode used, the measured conductivity is a function of the different overburden layers and/or rock from 0 to 6m below ground level.

7.1.2 Data collection

The EM31 equipment used was a GF CMD-4 conductivity meter equipped with data logger. This instrument features a real time graphic display of the previous 20 measurement points to monitor data quality and results. Conductivity and in-phase values were recorded across the site. Local conditions and variations were recorded.

7.1.3 Data processing

The conductivity and in-phase field readings were downloaded, contoured and plotted using the SURFER 12 program (Golden Software, 2015). Data which was affected by metallic objects was removed. Assignation of material types and possible anomaly sources was carried out, with cross-reference to other data.

7.1.4 Relocation

All data were referenced using a GPS system and all positions are given in Irish National Grid coordinates.

7.2 Electrical Resistivity Tomography (ERT)

Electrical Resistivity Tomography was carried out to provide information on lateral variations in the overburden material as well as on the underlying overburden and bedrock.

7.2.1 Principles

This surveying technique makes use of the Wenner resistivity array. The 2D-resistivity profiling method records a large number of resistivity readings in order to map lateral and vertical changes in material types. The 2D-resistivity profiling method involves the use of 64 electrodes connected to a resistivity meter, using computer software to control the process of data collection and storage.

7.2.2 Data Collection

ERT Profiles were recorded using ABEM Terrameter LS resistivity meter, imaging software, two takeout multicore cables, up to 64 stainless steel electrodes and a 3m electrode spacing. Saline solution was used at the electrode/ground interface in order to gain a good electrical contact required for the technique to work effectively. The recorded data were processed and viewed immediately after survey.

7.2.3 Data Processing

The field readings were stored in computer files and inverted using the RES2DINV package (Campus Geophysical Instruments, 1997) with up to 5 iterations of the measured data carried out for each profile to obtain a 2D-Depth model of the resistivities.

The inverted 2D-Resistivity models and corresponding interpreted geology are displayed on the accompanying drawings alongside the processed seismic sections. Distance is indicated along the horizontal axis of the profiles. Profiles have been contoured using the same contour intervals and colour codes.

7.3 Seismic refraction profiling

7.3.1 Principles

This method measures the velocity of refracted seismic waves through the overburden and rock material and allows an assessment of the thickness and quality of the materials present to be made. Stiffer and stronger materials usually have higher seismic velocities while soft, loose or fractured materials have lower velocities.

Seismic profiling measures the p-wave velocity (Vp) of refracted seismic waves through the overburden and rock material and allows an assessment of the thickness and quality of the materials present to be made. Stiffer and stronger materials usually have higher Vp velocities while soft, loose or fractured materials have lower Vp velocities. Readings are taken using geophones connected via multi-core cable to a seismograph.

7.3.2 Data Collection

A Geode high resolution 24 channel digital seismograph, 24 10HZ vertical geophones and a 10 kg hammer were used to provide first break information, with a 24 take-out cable (2m spacing). Equipment was carried was operated by a two-person crew.

Readings are taken using geophones connected via multi-core cable to a seismograph. The depth of resolution of soil/bedrock boundaries is determined by the length of the seismic spread, typically the depth of resolution is about one third the length of the profile.(eg. 69m profile ~23m depth, 46m profile ~ 15m depth)

Shots from seven different positions were taken (2 x off-end, 2 x end, 3 x middle) to ensure optimum coverage of all refractors. All profiles were surveyed to Irish National Grid using a ProXR dGPS system.

7.3.3 Data Processing

The recorded data was processed and interpreted using ray-tracing along with time term inversion and tomographic inversion methods, to acquire depths to boundaries and the P-wave velocities of these layers, using the SeisImager/2D programme from Geometrics.

SeisImager/2D interprets seismic refraction data as a laterally varying layered earth structure. The programme includes three methods for data analysis, time-term inversion, the reciprocal method and tomography.

The tomography method creates an initial velocity model, then traces rays through the model, comparing the calculated and measured traveltimes. The model is then modified and the process repeated to minimise the difference between the calculated and measured times.

Approximate errors for Vp velocities are estimated to be +/- 10%. Errors for the calculated layer thicknesses are of the order of +/-20%. Possible errors due to the "hidden layer" and "velocity inversion" effects may also occur (Soske, 1959).

7.4 Multichannel Analysis of Surface Waves (MASW)

MASW profiling was carried out to provide shear wave velocity profiles with depth.

7.4.1 Principles

The Multi-channel Analysis of Surface Waves (MASW) (Park et al., 1998, 1999) utilizes Surface waves (Rayleigh waves) to determine the elastic properties of the shallow subsurface (<15m). Surface waves carry up to two/thirds of the seismic energy but are usually considered as noise in conventional body wave reflection and refraction seismic surveys.

The penetration depth of surface waves changes with wavelength, i.e. longer wavelengths penetrate deeper. When the elastic properties of near surface materials vary with depth, surface waves then become dispersive, i.e. propagation velocity changes with frequency. The propagation (or phase) velocity is determined by the average elastic property of the medium within the penetration depth. Therefore the dispersive nature of surface waves may be used to investigate changes in elastic properties of the shallow subsurface.

The MASW method employs the multi-channel recording and processing techniques (Sheriff and Geldart, 1982) that have similarities to those used in a seismic reflection survey and which allow better waveform analysis and noise elimination. To produce a shear wave velocity (Vs) profile and a stiffness profile of the subsurface using Surface waves the following basic procedure is followed:

(i)A point source (eg. a sledgehammer) is used to generate vertical ground motions,

(ii)The ground motions are measured using low frequency geophones, which are disposed along a straight line directed toward the source,

(iii)the ground motions are recorded using either a conventional seismograph, oscilloscope or spectrum analyzer,

(iv)a dispersion curve is produced from a spectral analysis of the data showing the variation of Surface wave velocity with wavelength,

(v)the dispersion curve in inverted using a modeling and least squares minimization process to produce a subsurface profile of the variation of Surface wave and shear wave velocity with depth.

7.4.2 Data Collection

A Geode high resolution 24 channel digital seismograph, 24 10HZ vertical geophones and a 10 kg hammer were used, with a 24 take-out cable (2m spacing). Equipment was carried was operated by a two-person crew.

Five 1D MASW profiles were acquired.

7.4.3 Data Processing

MASW processing was carried out using the SURFSEIS processing package developed by Kansas Geological Survey (KGS, 2010). SURFSEIS is designed to generate a shear wave (Vs) velocity profile.

SURFSEIS data processing involves three steps:

(i) Preparation of the acquired multichannel record. This involves converting data file into the processing format.

(ii) Production of a dispersion curve from a spectral analysis of the data showing the variation of Raleigh wave phase velocity with wavelength. Confidence in the dispersion curve can be estimated through a measure of signal to noise ratio (S/N), which is obtained from a coherency analysis. Noise includes both body waves and higher mode surface waves. To obtain an accurate dispersion curve the spectral content and phase velocity characteristics are examined through an overtone analysis of the data.

(iii) Inversion of the dispersion curve is then carried out to produce a subsurface profile of the variation of shear wave velocity with depth.

7.5 Spatial relocation

All the geophysical investigation locations were acquired using Trimble Geo 7X high-accuracy GNSS handheld using the settings listed below. This system allows collecting GPS data with sub-meter accuracy.

Coordinate zone:	ITM (Republic of Ireland)
Datum:	Ordnance
Coordinate units:	Meters
Altitude units:	Meters
Survey altitude reference:	MSL
Geoid model:	Republic of Ireland

8. APPENDIX C: SEISMIC REFRACTION PLATES

For each of the two seismic refraction profiles the tomographic inversions are shown below. The locations of the profiles are shown in **Appendix A: Drawings**.

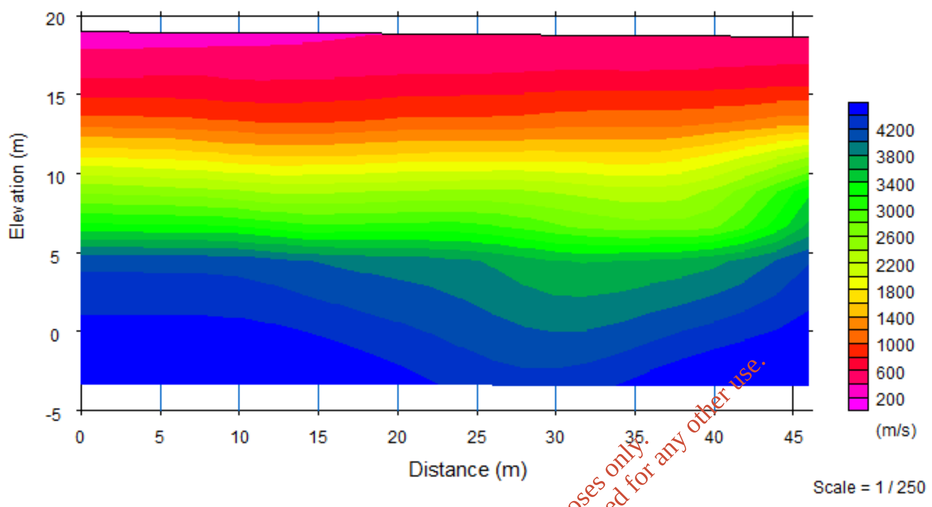

Figure 8.1: Tomographic inversion for seismic refraction spreads S1.

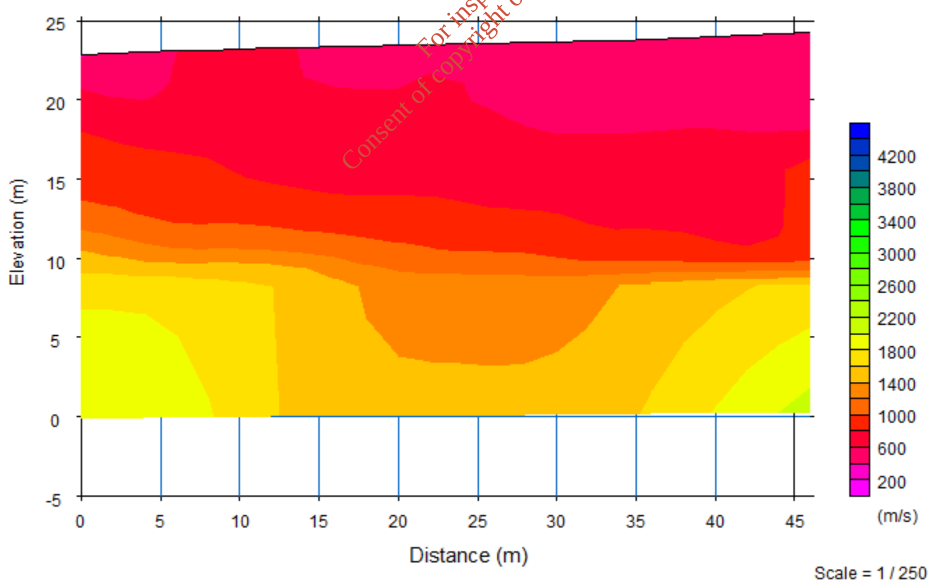

Figure 8.2: Tomographic inversion for seismic refraction spreads S2.