Appendix 2

Priority Geotechnical Reports




SI Report

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LONGFORD LANDFILLS

CARTRON BIG

GROUND INVESTIGATION

REPORT No. P18159_CB_Rp_D01

Priority Geotechnical Ltd.

REPORT CONTROL SHEET

Client						
Engineer Representative	Fehily Timoney					
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A) Introduction

A.1) Scope of Works

Priority Geotechnical Ltd. was instructed by Fehily Timoney to undertake an indirect geophysical investigation in conjunction with a direct intrusive ground investigation at Cartron Big Landfill, Longford, Co. Longford.

The direct intrusive works consisted of boreholes, trial pit excavations and in-situ permeability determination of ground conditions. The geophysical survey consisted of seismic refraction and electrical resistivity surveying in accordance with BS5930 and BS7022 and the Geological Society Engineering Group Working Party Report on Engineering Geophysics. The site and geophysical survey locations are shown in Figure A.1 below.

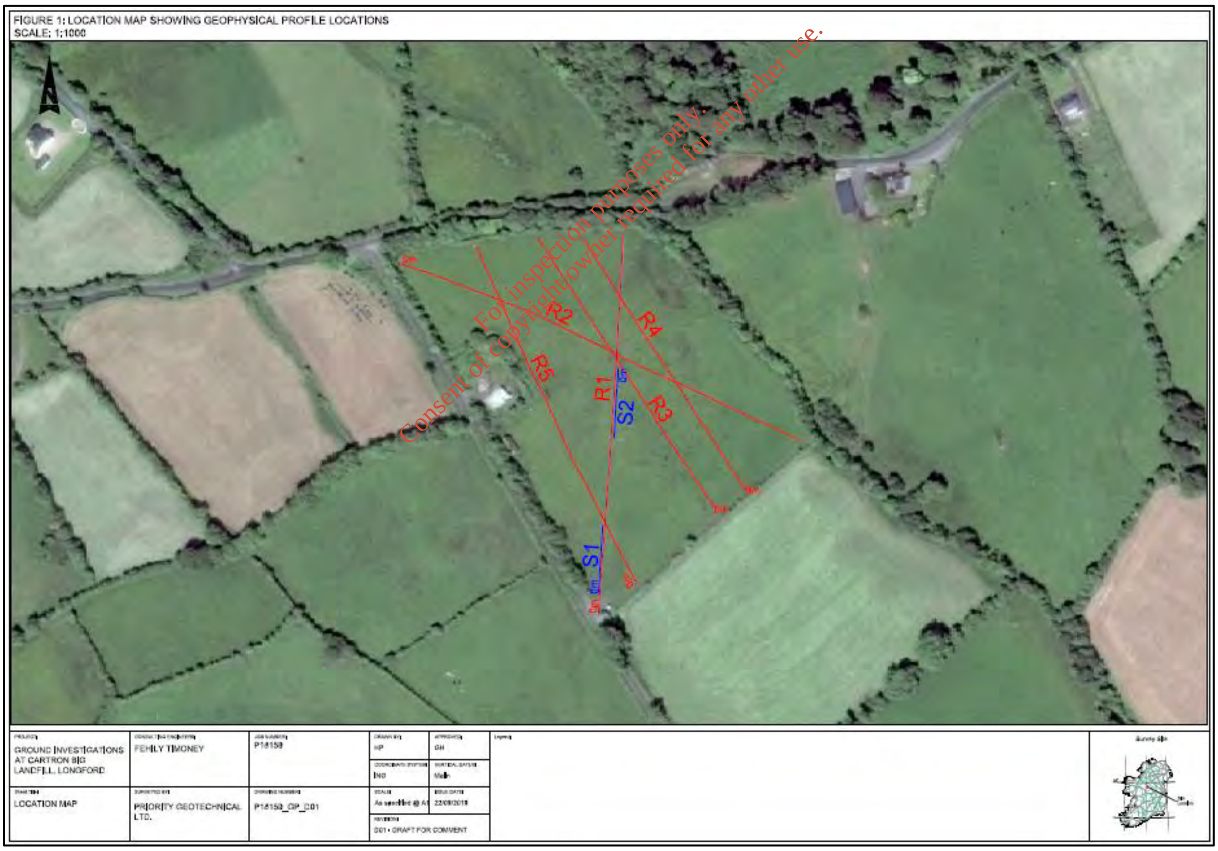

Figure A.1 Background map showing survey location.

A.2) Objectives

The objectives were to provide information on the following:

- Lateral and vertical variations in overburden and bedrock type and thickness along the surveyed profiles.
- Extent and thickness of landfill material across along the surveyed profiles.

A.3) Site Topography

Site topography consists of a mostly flat grassy field with areas of rough ground. The perimeter of the site is comprised of densely vegetated ditches on the west, north and east sides of the site, while a metal fence with some vegetation makes up the southern perimeter. Man-made features in the site include several small dilapidated buildings and several metal poles protruding from the ground surface. The site is flanked by roads to the west and north.

A.4) Coordinate System and Datum

All coordinates are given in Irish Transverse Mercator (ITM). All elevations are given in metres Ordnance Datum Malin (OD Malin). The locations are shown on the exploratory layout plans presented in **APPENDIX B.**

Location	Easting	Northing	Ground Level (mOD)	Final Depth (m bgl)	Date Start (ddmmyyyy)
CB-GW01	617323.7	775740.5	66.97	25.00	12/09/2018
CB-GW02	617446.7	775846.6	65.13	7.50	13/09/2018
CB-GW03	617271	775980.9	63.06	4.00	27/09/2018
CB-LG01	617323.8	775901.6	64.4	8.50	04/09/2018
CB-LG02	617279.5	775880.3	64.93	6.00	04/09/2018
CB-SA01	617341.9	775813.7	65.45	0.35	01/08/2018
CB-SA02	617391.5	775838.5	64.8	0.35	01/08/2018
CB-SA03	617324.7	775954.3	63.27	0.50	01/08/2018
CB-SA04	617235.3	775939.8	64.21	0.40	01/08/2018
CB-TP01	617335.7	775780.1	66.24	4.50	31/07/2018
CB-TP02	617366.1	775802.1	65.52	3.50	31/07/2018
CB-TP03	617408.7	775851.9	64.39	1.80	31/07/2018
CB-TP04	617371.8	775915.7	63.63	1.80	31/07/2018
CB-TP05	617333.1	775889.7	64.38	2.10	31/07/2018
CB-TP06	617292.6	775861.5	65.06	1.30	01/08/2018
CB-TP07	617288.4	775924	64.37	3.00	01/08/2018
CB-TP08	617339.8	775959.1	63.01	0.90	01/08/2018

Location	Easting	Northing	Ground Level (mOD)	Final Depth (m bgl)	Date Start (ddmmyyyy)
CB-TP09	617266.9	775969	63.63	1.35	01/08/2018
CB-TP10	617234.1	775947.8	64.08	3.00	01/08/2018
CB-TP11	617211.9	775939.9	63.56	1.50	01/08/2018
CB-TP12	617269	775827.7	64.97	1.10	01/08/2018
CB-TP13	617288.5	775801.4	65.45	2.80	01/08/2018
CB-TP14	617239.5	775976.7	63.02	1.40	01/08/2018
CB-TP15	617276.6	775980	63.15	1.60	01/08/2018

A.5) Acronyms

bgl – below ground level

ERT – Electrical Resistivity Tomography

ITM – Irish Transverse Mercator

OD Malin – metres above Ordnance Datum Malin

PGL – Priority Geotechnical Ltd.

SRP – Seismic Refraction Profiling

A.6) Site Geology

According to the GSI 100k Geology Map (see Fig. A.2) the survey area is underlain by a formation of Argillaceous Limestones, shown in lavender colour. To the southwest of the survey area lies the Ballysteen Formation, described as fossiliferous and argillaceous limestones with shale and shown in cyan colour. These two formations are divided by a northwest-southeast fault. Northeast of the site lies a formation of Mudbank Limestones, shown in a lilac colour.

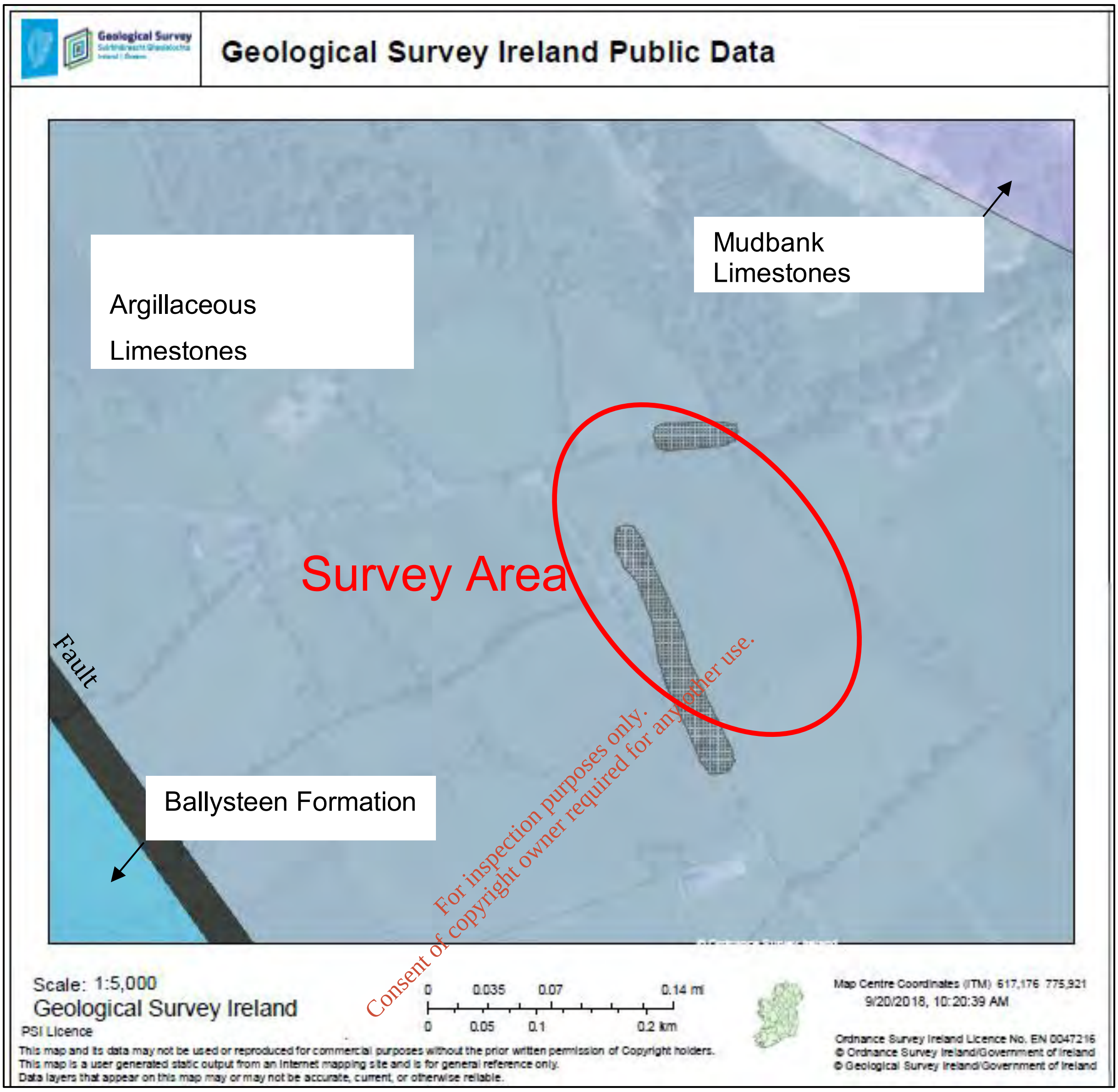

Figure A.2: GSI 100k Bedrock Geology Map of the site.

According to the Quaternary Soils Map (see Fig. A.3) most of the study area is underlain by “Till derived from cherts”, shown in yellow. The other major sediment in the area is described as “Till derived from Lower Palaeozoic Sandstones and Shales”, shown in a pink colour. To the northwest of the area is “Alluvium”, shown in orange colour.

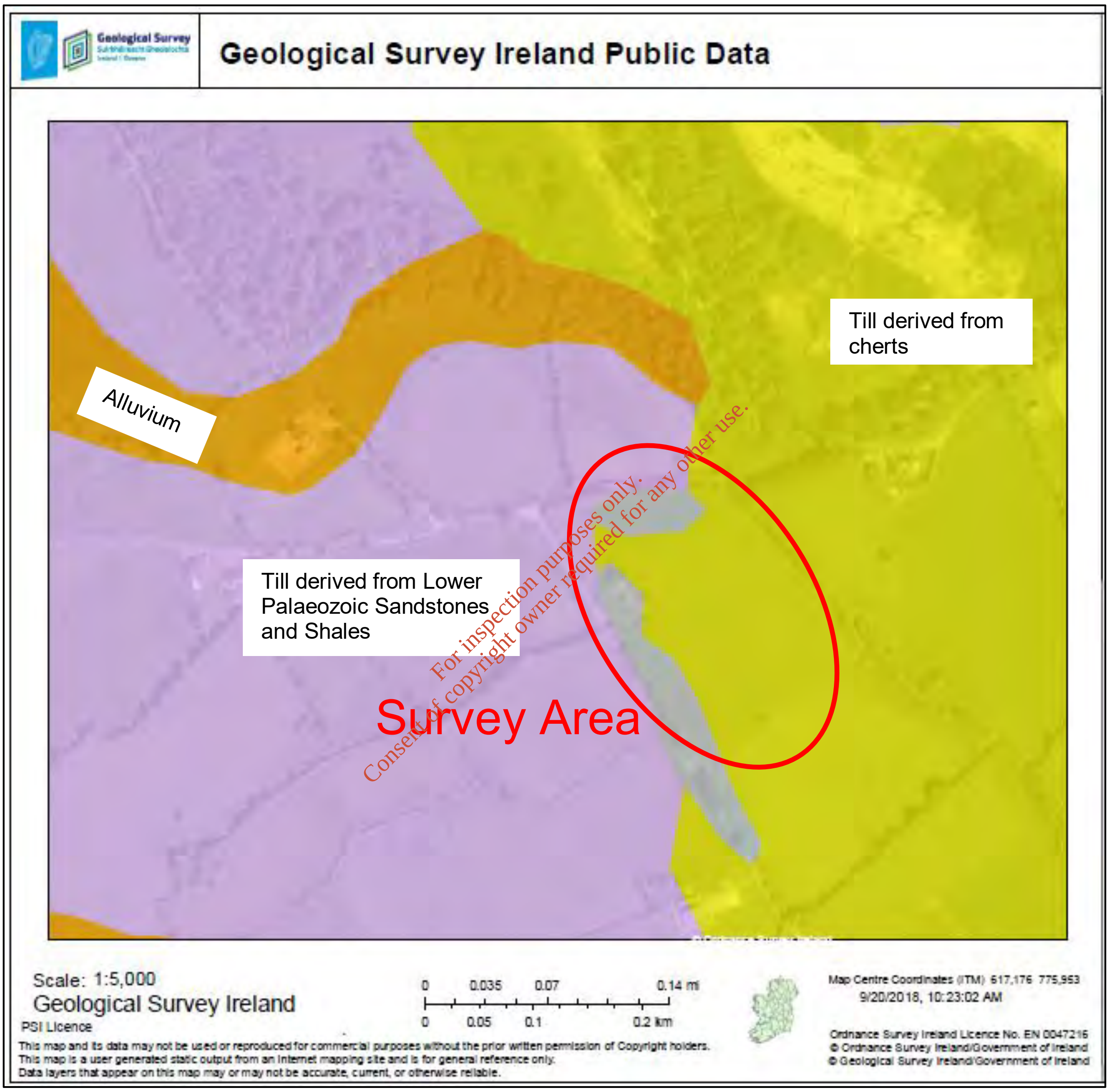

Figure A.3: Quaternary Sediments Map of the site.

All above mapping is available for free viewing on the Geological Survey of Ireland website at *https://www.gsi.ie/en-ie/Pages/default.aspx.*

B) Intrusive, direct investigation fieldworks

This direct investigation fieldworks were undertaken between the 31st July and the 27th September, 2018 under the supervision of PGL, Engineering Geologist(s) in accordance with Eurocode 7- Geotechnical Design Part 2, ground investigation and testing (BS EN 1997-2: 2007) and the relevant British Standards (BS 5930 (2015) Code of Practice for Site Investigation and BS 1377, Method of Tests for Soil for Civil Engineering Purposes, *in situ* Tests Parts 1 to 9). Details of the plant and equipment used are detailed on the relevant exploratory records, attached herein.

B.1.i) Boreholes

Five (5) number rotary boreholes were bored to depths 4.0m below existing ground level (bgl) to 25.0m bgl using PGL's Deltabase 520 rotary rig. The records are presented in **APPENDIX A**.

Location	Depth (m bgl)	Date (dd/mm/yyyy)
CB-GW01	25.0	12/09/2018
CB-GW02	7.5	13/09/2018
CB-GW03	4.0	27/09/2018
CB-LG01	8.5	04/09/2018
CB-LG02	6.0	04/09/2018

B.1.ii) Trial Pits

A total of fifteen (15) Trial Pit excavations were dug to a depth 0.9m bgl to 4.5m bgl using a 13t tracked excavator. Trial pits terminated for a variety of reasons as outlined on the exploratory logs included in **APPENDIX A**.

Location	Final Depth (m, bgl)	Date Start (dd/mm/yyyy)
CB-TP01	4.5	31/07/2018
CB-TP02	3.5	31/07/2018
CB-TP03	1.8	31/07/2018
CB-TP04	1.8	31/07/2018
CB-TP05	2.1	31/07/2018
CB-TP06	1.3	01/08/2018
CB-TP07	3.0	01/08/2018
CB-TP08	0.9	01/08/2018
CB-TP09	1.35	01/08/2018
CB-TP10	3.0	01/08/2018

Location	Final Depth (m, bgl)	Date Start (dd/mm/yyyy)
CB-TP11	1.5	01/08/2018
CB-TP12	1.1	01/08/2018
CB-TP13	2.8	01/08/2018
CB-TP14	1.4	01/08/2018
CB-TP15	1.6	01/01/2018

B.1.iii) Soakaway Pits

Four (4) soakaway pits were excavated to depths 0.35m bgl to 0.5m bgl using a 13t tracked excavator. The exploratory logs are presented in **APPENDIX A** of this report.

Location	Depth (m bgl)	Date (dd/mm/yyyy)
CB–SA01	0.35	01/08/2018
CB-SA02	0.35	01/08/2018
CB–SA03	0.50	01/08/2018
CB–SA04	0.40	01/08/2018

B.2) In-Situ Testing

Four (4) number infiltration tests were carried out in general accordance with the BRE Digest 365, 2007 Soakaway Design Standards. Single (1) and double (2) cycles of infiltration/ drainage was undertaken. Soakaway pits failed to drain in full over the test durations 60mins to 120mins. The data from the testing was presented accompanying the relevant exploratory soakaway pit records in **APPENDIX A**.

B.3) Lab Testing

Under the scope of works no laboratory testing was required.

B.4) Ground and Groundwater Conditions

The full details of the ground conditions encountered are provided for on the exploratory records accompanying this report. The records provide descriptions, in accordance with BS 5930 (2015) and Eurocode 7, Geotechnical Investigation and Testing, Identification and classification of soils, Part 1, Identification and description (EN ISO 14688-1: 2002),– Identification and Classification of Soil, Part 2: Classification Principles (EN ISO 14688-2:2004) and Identification and Classification of Rock, Part 1: Identification & Description (EN ISO 14689-1:2004) of the materials encountered, in situ testing and details of the samples taken, together with any observations made during the ground investigation.

Groundwater was recorded when encountered during boring over a period of 20 minutes, noting any changes that may occur. Groundwater levels were also monitored at start and end of drilling shifts.

It should be noted that the normal rate of boring may not permit the recording of equilibrium groundwater levels for any one groundwater water strike where casing may exclude low volume flows as the borehole progresses. The normal duration over which a trial excavation remains open may not allow for low volume flow to ingress in cohesive deposits. Groundwater conditions observed in the borings and the excavations, are those appertaining to the period of the investigation. Groundwater levels may be subject to diurnal, seasonal and climatic variations and can also be affected by drainage conditions, tidal variations etc. Five (5) groundwater monitoring installations were constructed upon request of the engineer. The groundwater regime should be assessed from standpipe well installations, where available. A summary of groundwater is presented below.

Location	Depth Strike (m bgl)	Remarks	Standpipe (Y/N)
CB-GW01	-	See shift data.	Y
CB-GW02	4.5	See shift data.	Y
CB-GW03	-	None encountered.	Y
CB-LG01	2.8	See shift data.	Y
CB-LG02	-	None encountered.	Y
CB-SA01	-	None encountered.	N
CB-SA02	-	None encountered.	N
CB-SA03	-	None encountered.	N
CB-SA04	-	None encountered.	N
CB-TP01	2.4	Slow rate of flow.	N

Location	**Depth Strike (m bgl)**	**Remarks**	**Standpipe (Y/N)**
CB-TP02	2.85	2.85m: Steady rate of flow.	N
CB-TP03	1.8	1.80m: Slow rate of flow.	N
CB-TP04	1.0	1.00m Slow rate of flow.	N
CB-TP04	1.7	1.70m: Fast rate of flow.	N
CB-TP05	2.0	2.00m: Fast rate of flow.	N
CB-TP06	1.1	1.10m: Slow flow rate.	N
CB-TP07	2.9	2.90m: Slow flow rate.	N
CB-TP08	0.65	0.65m: Fast flow rate.	N
CB-TP09	1.2	1.20m: Steady flow rate.	N
CB-TP10	2.9	2.90m: Steady flow rate.	N
CB-TP11	-	None encountered.	N
CB-TP12	-	None encountered.	N
CB-TP13	-	None encountered.	N
CB-TP14	-	None encountered.	N
CB-TP15	-	None encountered.	N

Location	**Depth Top (m bgl)**	**Depth Base (m bgl)**	**Diameter (mm)**	**Pipe Type**
CB-GW01	0.00	2.00	90	PLAIN
CB-GW01	2.00	25.00	90	SLOTTED
CB-GW02	0.00	2.00	90	PLAIN
CB-GW02	2.00	7.50	90	SLOTTED
CB-GW03	0.00	3.00	90	PLAIN
CB-GW03	3.00	25.00	90	SLOTTED
CB-LG01	0.00	2.00	50	PLAIN
CB-LG01	2.00	8.20	50	SLOTTED
CB-LG02	0.00	2.00	50	PLAIN
CB-LG02	2.00	5.00	50	SLOTTED

Exploratory holes were backfilled upon instruction from the engineer. Backfill details are shown graphically on the exploratory logs accompanying this factual report.

GRAVEL Backfill to installation/ borehole	ARISINGS Backfill
uPVC slotted pipe	BENTONITE Backfill to installation/

C) Indirect Geophysical Fieldworks; Methodology and Results

C.1) 2D Electrical Resistivity Tomography (ERT)

The geophysical survey comprised of 2D electrical resistivity tomography (ERT) to measure the ground resistivity distribution across the survey area.

The resistivity survey was comprised of three profiles along pre-determined lines as well as two additional profiles, all of which were named R1 through R5. These profiles were collected with an electrode spacing of 3m spacing, and varied in length with R1, R2, R3, R4, and R5 measuring 255m, 295m, 215m, 200m, and 250m respectively. The non-intrusive survey was carried out on 15th and 16th August 2018.

C.1.i) Data Acquisition

Survey data was collected using a 64 channel Tigre Resistivity Meter. The Tigre has a maximum power of 36 watts and maximum current output of 200mA. The receiver incorporates automatic gain steps providing a range of measurements from 0.001ohm to 360kohm.

Multicore resistivity cables with 32 take-outs were used with stainless steel electrodes. Contact resistivities were checked prior to running the survey, to ensure an adequate electrical contact between the ground and the electrodes were made. Electrodes with poor contacts were treated with saline solution and rechecked till an optimum contact resistance were obtained.

The Tigre was connected to a laptop running Imager Pro™ 2006 acquisition software (Campus International Products Ltd., 2006) and subsequently viewed and inverted using Res2DInv software. All data was checked on site and any spurious readings were repeated until satisfactory results were achieved.

C.1.ii) Array Type

The Wenner Alpha Array protocol was utilized during this survey. The Wenner Array uses four equally spaced electrodes. Current is injected through the two outer electrodes and the resulting voltage difference at two inner electrodes. From the current (I) and the voltage (V) an apparent resistivity (p_a) value is calculated.

$$p_a = k\,V/I$$

Where k is the geometric factor which depends on the arrangement of the 4 electrodes. This calculated resistivity value is not the true resistivity of the subsurface but an “apparent” resistivity value, i.e. the resistivity of a homogenous ground which would give the same resistance value for the same electrode arrangement. To determine “true” ground resistivity an inversion of the measured apparent resistivity is undertaken, in this case using Res2DInv software.

The Wenner array is relatively sensitive to vertical changes (i.e. horizontal structures), but relatively poor in detecting horizontal changes (i.e. narrow vertical structures). Among the common array types for ERT profiling the Wenner alpha array has the strongest signal strength (Loke, 2000).

C.1.iii) Data Processing

Survey data was processed using Res2DInv, where the raw files were edited and inverted. The software does this by first dividing the subsurface 2D model into rectangular blocks and then calculates the resistivity of these blocks such that the calculated apparent resistivity measurements of the blocks agree with the measured values from the field survey.

Up to 5 iterations of the inversion of the measured data were carried out for each profile to obtain a 2D pseudosection of the apparent resistivities. The least squares inversion was used to produce an apparent resistivity depth model.

A degree of fit between the measured apparent resistances and the inverted resistances is calculated by the program, allowing an assessment of the degree of confidence of the inverted data. A damping factor can be applied to smooth erroneous data points; however, resolution lessens with an increased damping factor. A moderate damping factor was used during all inversions. All but one (R4) of the ERT dataset inversions resulted in an RMS error of > 10% (R1 = 18.1%, R2 = 13.7%, R3 = 12.9%, R4 = 9.4%, R5 = 35.8%).

Resistivity values in the inverted profiles varied from 7 to c.1575 Ohm-m.

C.2) Seismic Refraction Profiling (SRP)

PGL recorded 2 no. SRP profiles in total across the survey area along the pre-determined lines. SRP profiles are named S1 and S2 and measured 46m in length. The geophone spacing used for this survey was 2m providing p-wave seismic velocities (Vp) for overburden and bedrock materials.

SRP profile S2 was seen to be of poor quality, insufficient for picking of first break Vp arrival times. This has been observed by PGL in areas of landfill material previously. As such the SRP was abandoned in favour of acquisition of additional ERT across the survey area.

Seismic refraction measurements are made by measuring the travel time of direct and refracted acoustic waves as they travel from the surface through one layer to another and back to the surface where their arrival times are recorded. The travel time is a function of the seismic or acoustic velocity and geometry of the subsurface layers of soil and rock.

Modelled seismic velocities (Vp) ranged from 400 to 2500 m/s over two separate layers for the soil and bedrock materials on SRP profile S1. The resulting layer boundaries and seismic velocities are shown as thick dashed lines on cross sections in the attached drawings. The model was developed with average velocities and boundaries moved to minimise the model deviation.

C.2.i) Data Acquisition

A 24-channel Geometrics Geode seismic system was utilized with a 24-channel seismic multicore cable and 4.5Hz geophones. A sledge hammer and a HDPE plate were used as a seismic source. A geophone spacing of 2m was utilised during data acquisition resulting in a profile length of 46m.

Data was recorded using SGOS Seismodule Controller software. A total of 7 shots were undertaken on each seismic line; 2 end-shots, 2 off-shots and 3 mid-shots. To improve signal to noise ratio, individual hammer shots were stacked at each shot location where necessary.

C.2.ii) Data Processing

Data processing was undertaken utilizing Seisimager Seismic 2D software programs. Surveyed topography was input for each seismic spread. First breaks were picked after which a time term inversion was computed using travel-time computation via ray-tracing. Velocity modeling and travel time plots were constructed for each spread. Seismic velocity phases were picked and the thickness of each velocity unit calculated using the intercept-time method.

C.2.iii) Data Interpretation

It should be noted that when layer thicknesses are modelled from the seismic data the areas of greatest coverage (i.e. the centre of the spread) will have the greatest accuracy. At the edges of the spread less ray coverage reduces the accuracy of layer interpretation and thickness calculation.

Approximate errors for velocities are estimated to be +/-10%. Errors for the calculated layer thickness are of the order of +/-15%. Possible errors due to the "hidden layer" and "velocity" effects may also occur (Soske, 1959). Seismic refraction generally determines the depth to horizontal or near horizontal layers where the compaction/strength/rock quality changes. Where low velocity layers are present or where layers dip with more than 20 degrees angle the accuracy becomes less.

C.3) Spatial Relocation

Horizontal control and elevation were provided by a Trimble VRS (Real Time Kinematic/Virtual Reference Station) enabled GPS. Survey Controller software was used to provide high-accuracy, GNSS positioning. All positions are plotted in ITM. Elevations are to OD Malin using geoid model OSGM15.

D) Results and Interpretation

The modelled profiles and geophysical interpretations are shown in APPENDIX A: Drawing No.'s P18159-GP-D02 to P18159-GP-D06. A location map of the surveyed profiles is supplied as Drawing No. P18159-GP-D01.

The ERT was used to interpret the overburden and bedrock composition on all profiles. The ERT has generally interpreted on the following basis;

Resistivity (Ohm-m)	Interpretation
< 10	Landfill Material
> 10 boundaries extending to depth to > 1000	Limestone bedrock

Table C.1: Interpretation based on electrical resistivity

Landfill material was seen to extend to a maximum depth of 10m bgl and was imaged on all ERT profiles as an area of very low resistivity (high conductivity) (<10 Ohm-m) at the surface. The SRP methodology was not capable of penetrating the landfill material likely due to the unconsolidated nature of the material. The ERT profiles mapped the lateral extent of the landfill material with an increase in resistivity close to the surface outside areas of landfill material. ERT profile R3, R4 (to the south) and R5 did not image the lateral extent of the landfill material as it extended across the entire length of the profiles. An area on Drawing No. P18159-GP-D01 was been hatched to give the rough outline of the imaged landfill material.

The bedrock / landfill interface was seen as a gradual increase in depth on all profiles apart from R5 where there was a rapid increase in resistivity below the landfill material. This gradual increase in resistivity may represent landfill leachate penetrating the upper weathered bedrock and thus reducing its resistivity. Bedrock is indicated as argillaceous LIMESTONE in the GSI mapping, resistivity ranges for the bedrock are within the range of bedrock expected for this lithology.

SRP profile S1 gave bedrock Vp velocity of 2500m/s representing a weathered bedrock.