Appendix D

Old Leighlin

Co. Carlow

Geophysical Survey

Report Status: Final

MGX Project Number: 6917

MGX File Ref: 6617f-005.doc

2nd September 2022

Confidential Report To:

Hydo-Environmental Services
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Minerex Geophysics Limited

Subsurface Geophysical Investigations

EXECUTIVE SUMMARY

1. Minerex Geophysics Ltd. (MGX) carried out a geophysical survey consisting of 2D Resistivity (ERT) in an area near Old Leighlin, Co. Carlow to determine its viability as a quarry for Kilkenny Limestone.
2. The survey was carried out across the tree filled fields, grass fields and a laneway leading from the road to the fields.
3. The main objectives of the survey were to determine ground conditions under the survey area, to determine the depth to rock and the overburden thickness and to establish the different rock types underlaying the area.
4. The online bedrock geological map of Ireland (GSI, 2022) indicates a complex geology in the area with various rock formations close to the survey area as well as unconformities and faults in the general area.
5. The resistivities are very varied with the main geological changes occurring from west to east across the area.
6. Along the very west of the survey area there is likely a fault zone close to the bottom of the steep hill.
7. The zone to the east of the fault zone and under the ground surface is interpreted as mudstone or overburden. This layer is 5 – 25m thick.
8. The mudstone/overburden layer is underlain by a shale or weathered muddy limestone layer which gives way to a muddy limestone layer towards the east. The muddy limestone is likely the Clogrenan formation and the top of this layer is at a depth of 5-10m from the field south of the existing quarry to the lane, 16m deep in the east of the fields and becomes deeper to the west.
9. The contact between the muddy limestone and a clean limestone occurs at 285m along line R1/R5 along the laneway and 280m along line R7 north of the lane and is shown on the map.
10. Boreholes were carried out across the area and match with the results in this report in relation to the variations in the depth to rock, the faulting in the west and the changes in rock types from west to east.

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1. INTRODUCTION

1.1 Background

Minerex Geophysics Ltd. (MGX) carried out a geophysical survey at a green field site at Old Leighlin, Co. Carlow. The survey consisted of 2D-Resistivity measurements along agreed lines within the fields and along the laneway leading to them. The survey was commissioned by Hydro-Environmental Services.

The role of geophysics as a non-destructive fast method is to provide a geological interpretation over a wide area to complement direct ground investigations at specific locations. The direct ground investigation results can be used to improve the initial geophysical results and interpretation.

The survey was aimed at determining the depth and quality of rock as well as determining the rock type and any variation within the rock across the survey area with the intention of carrying out quarrying within the fields.

1.2 Objectives

The main objectives of the geophysical survey were:

- To determine the ground conditions under the area
- To determine the depth to rock and the overburden thickness
- To determine the type of rock
- To detect lateral changes within the geological layers
- To determine the presence of possible faults and fracture zones

1.3 Site Description

The survey area is located in the townland of Bannagagole, 1.5km south of the village of Old Leighlin. The fields were accessible along a lane from the L3036 in the east. The north of the site is bounded by an existing quarry. The filed to the south of the quarry was a grass field accessible from a gate along the road. The field in the NW of the site was planted with young conifer trees. The rest of the site was accessible from a laneway which ran W-E through the site. There is a derelict house half way along the land to the south and a derelict farm yard and buildings on the west end of the lane. The area is relatively flat but there is a steep rise in elevations immediately west of the fields. The southern survey area is densely planted with young coniferous trees which required brashing to allow the survey to take place. Surveying was carried out along the laneway as well as the fields.

1.4 Geology

The online bedrock geological map of Ireland (GSI, 2022) indicates that the survey area is underlain by the Clogrenan Formation, described as cherty, muddy, calcarenitic limestone. The Ballyadams formation, described as crinoidal wackestone/packstone limestone.

There is shallow rock noted close to the northwest along corner and a fault running the western edge of the area with Luggacurren Shale Formation, described as mudstone and shale with chert and limestone to the west.

The overburden is described as till derived from sandstone and 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 description of soil and rock follows Eurocode (2007) and BSI (2015) standards. The terms are defined in the standards and the physical parameters are related from experience. This geophysical survey has been acquired, processed, interpreted and reported in accordance with these guidelines.

The client provided maps of the area and the digital version was used as the background map in this report. Elevations were surveyed on site and are used in the vertical sections.

The interpretative nature and the non-invasive survey methods must be taken into account when considering the results of this survey and Minerex Geophysics Limited, while using appropriate practice to execute, interpret and present the data, give no guarantees in relation to the existing subsurface.

2. GEOPHYSICAL SURVEY

2.1 Methodology

The methodology consisted of using 2D-Resistivity lines spread throughout the survey area. The lines were proposed to achieve good coverage of the area while dealing with the difficult access throughout the fields due to the dense tree coverage.

The survey locations are indicated on Map 1. The lines and parameters are tabulated in Table 1 below.

Table 1: Geophysical Survey Locations and Acquisition Parameters

Resistivity Line	**Electrode Spacing/m**	**Number of Electrodes**	**Line Length/m**
R1	5	64	315
R2	5	57	280
R3	5	57	280
R4	5	53	260
R5	5	32	155
R6	5	51	250
R7	5	32	155
R8	5	32	155
SUM			**1,850**

2.2 2D-Resistivity (ERT)

2D-Resistivity lines were surveyed with electrode spacing of 5m, up to 64 electrodes per set-up and a maximum length of 315m per set-up. The readings were taken with a Tigre Resistivity Meter, Imager Cables, stainless steel electrodes and a laptop with ImagerPro acquisition software.

During 2D-Resistivity surveying, data is acquired in the form of linear arrays using a suite of metal electrodes. A current is induced into the ground via a pair of electrodes whilst 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 line. 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.

The penetration depth of a resistivity set-up increases towards the centre where it reaches an approx. value of 1/6th of the array length.

2.3 Site Work

The data acquisition for lines R1 – R6 was carried out on the 13th and 14th of June 2022. A second visit took place on the 21st and 22nd of July 2022 when R7 and R8 were carried out. The weather conditions were fair throughout the acquisition period. Health and safety standards were adhered to at all times. The locations and elevations were surveyed with a Carlson NR3 RTK-GPS to accuracy < 0.05m.

3. RESULTS AND INTERPRETATION

The interpretation of geophysical data was executed utilizing the known response of geophysical measurements, typical physical parameters for subsurface features that may underlay the area, and the experience of the authors.

Ground investigation results were provided after the survey and the abbreviated borehole logs are indicated on the sections. The overburden was described mainly as clay with some boulders and cobbles noted in some places. The rock was generally divided into a grey dolomitic limestone and a dark blue bioclastic limestone. The small size of a borehole only represents a very small volume of ground while the geophysical survey on the other end of the scale averages over a large volume of ground.

3.1 2D-Resistivity (ERT)

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 resistivities from the recorded apparent resistivity values. Three variations of the least squares method are available and for this project the Jacobian Matrix was recalculated for the first three iterations, then a Quasi-Newton approximation was used for subsequent iterations. Each dataset was inverted using seven iterations resulting in a typical RMS error of <3.0%. The resulting models were colour contoured with the same resistivity scale for all lines and they are displayed as cross sections (Figure 1a-1c).

Resistivities are characteristic for certain overburden and rock types. If there is a high content of clay minerals (which are electrically conductive) then the overburden resistivity will be lower than as if there is a high content of clastic grains like sand or gravel. The purer the clay and the lower the sand and gravel content, the lower the resistivity. Water content in overburden layers can influence the resistivities, but generally clay content has a more dominating effect.

Within bedrock types like clean limestone, sandstone or granite high resistivities indicate a fresh, strong, unweathered rock. As the weathering in the rock increases the resistivity gets lower because of weathering products, remineralisation of rock and infill of cracks, faults and voids with clay and water. Weathering within rock is typically indicated by lower resistivity values in the cross sections.

The resistivities cover a range typical for materials from clay rich overburden (low resistivities) to fresh unweathered bedrock (high resistivities). The ranges have been taken into the consideration for the interpretation. Low resistivity values (<250 Ohmm) typically indicate overburden with high clay content or mudstone. Medium values (250 to 700 Ohmm) indicate a shale bedrock or weathering within a higher resistivity rock type such as a muddy limestone. High resistivities (700-2000 Ohmm) indicate bedrock types like a muddy limestone. Very high resistivities, found along the lane, close to the L3036 in the east are interpreted as a clean limestone.

3.2 Interpretation of Resistivity

Table 2 summarises the interpretation. Interpreted cross sections are shown in Figure 2a-2c. The interpretation has been made solely from the resistivity survey results.

Table 2: Summary of Interpretation

Layer	General Resistivity Range (Ohmm)	Interpretation
A	>250 (Near Surface)	Overburden
B	>250 (at depth)	Overburden or Mudstone
C	250 - 700	Shale or weathered muddy Limestone
D	700 - 2000	Muddy Limestone
E	>2000	Clean Limestone
F	Varied	Fault zone

Lines R1 and R5 run west to east across the survey area, along the lane and show all the layers interpreted across the area.

In the west, Line R2 runs close to the foot of a hill which rises to the west of the fields. Rapidly changing resistivities along this line, generally ranging from 45 – 500Ohmm are interpreted as a fault zone (F).

To the east of this area, up to 170m along lines R1/R5, on the western side of R7 and R8, and the shallower sections of R3, R4 and R6, low resistivities are interpreted as overburden or mudstone (B). The online bedrock geological map of Ireland (GSI, 2022) describes the Luggacurren formation, to the west of an unconformity as mudstone and shale with chert and limestone. This low resistivity area may be related to this formation or it could indicate very deep overburden to depths of 5 – 25m below ground level (bgl). In the east of line R1/R5, R7 and R8, the low resistivities are interpreted as overburden.

Along lines R3 and R6, medium resistivities are interpreted as shale or weathered muddy limestone (C). The depth to the top of this layer is 5-25m across the fields and is shallowest in the west at the start of R6. This layer could be shales from the Luggacurren formation or a layer of weathered limestone related to the Clogrenan Formation. This layer may also be present on the west side of lines R7 and R8.

High resistivities along most of lines R7, R8. At depth along lines R3, R4 and in the centre of lines R1/R5 are interpreted as a muddy limestone (D). This layer is likely the Clogrenan Formation. The depth to the top of this layer is from 16 – 40m bgl but as shallow as 5m along the lane and in the fields to the north.

Very high resistivities in the east of lines R1/R5 close to the L3036 and in the east of line R7 are described as clean limestone (E) and likely indicates the location of the contact between the Clogrenan and Ballyadams Formations.

The boreholes carried out across the site match with the depth to rock interpreted by the geophysics. Within the rock, the progression is generally from a pale grey dolomitic limestone to a blue or dark blue bioclastic limestone. In BH1 in the west the progression in depth is different with changes between the two generalised rock types with depth. This is interpreted as being due to faulting in the area. BHs, 2, 4 & 5 show approx. 14-38m of dolomitised limestone over the bioclastic limestone while BH3 which is farther to the east shows 4m of dolomitised limestone over the dark blue bioclastic limestone. This indicates the dark blue limestone moving to the surface in the east and shows a progression from a fault zone to an area of thick dolomitised limestone to an area of bioclastic limestone in the east. No boreholes were carried out in the clean limestone (Layer E) area farther to the east.

The geophysical differences in the differing rocks described by the boreholes are not strong enough to give clear boundaries in the geophysical interpretation but the general description in this report of changes in the limestone from west to east match with the results from the boreholes.

4. CONCLUSIONS AND RECOMMENDATIONS

The following conclusions and recommendations are made:

- The geophysical surveys carried out near Old Leighlin, Co. Carlow consisted of 2D-Resistivity lines spread across the area consisting of four fields and a lane to identify the depth to rock and different rock types across the area.
- The resistivities generally vary from west to east across the area. There is a fault zone interpreted along the west side of the fields at the foot of the hill to the west.
- Low resistivities to depths of 5 – 40m immediately east of the fault zone are interpreted as overburden or mudstone.
- The medium resistivities below this and to the east of the area are interpreted as shale or weathered muddy limestone and the high resistivities as muddy limestone.
- To the east of the area, close to the L3036 along lines R1/R5 and R7, the very high resistivities indicate a clean limestone. The contact between the clean limestone and muddy limestone is shown as a black line on the map.
- An attempt to relate the various resistivities to the different rock types indicated on the online bedrock geological map of Ireland (GSI, 2022) has been made in Ch3.2 above.
- Boreholes carried out on site give a better indication of the variations in the rock across the site. The geophysics and the boreholes generally match well with each other.

5. REFERENCES

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2. **Eurocode, 2007.** EN 1997-2:2007. Eurocode 7. Part 2 Ground Investigation and Testing 2007
3. **GSEG, 2002.** Geophysics in Engineering Investigations. Geological Society Engineering Geology Special Publication 19, London, 2002
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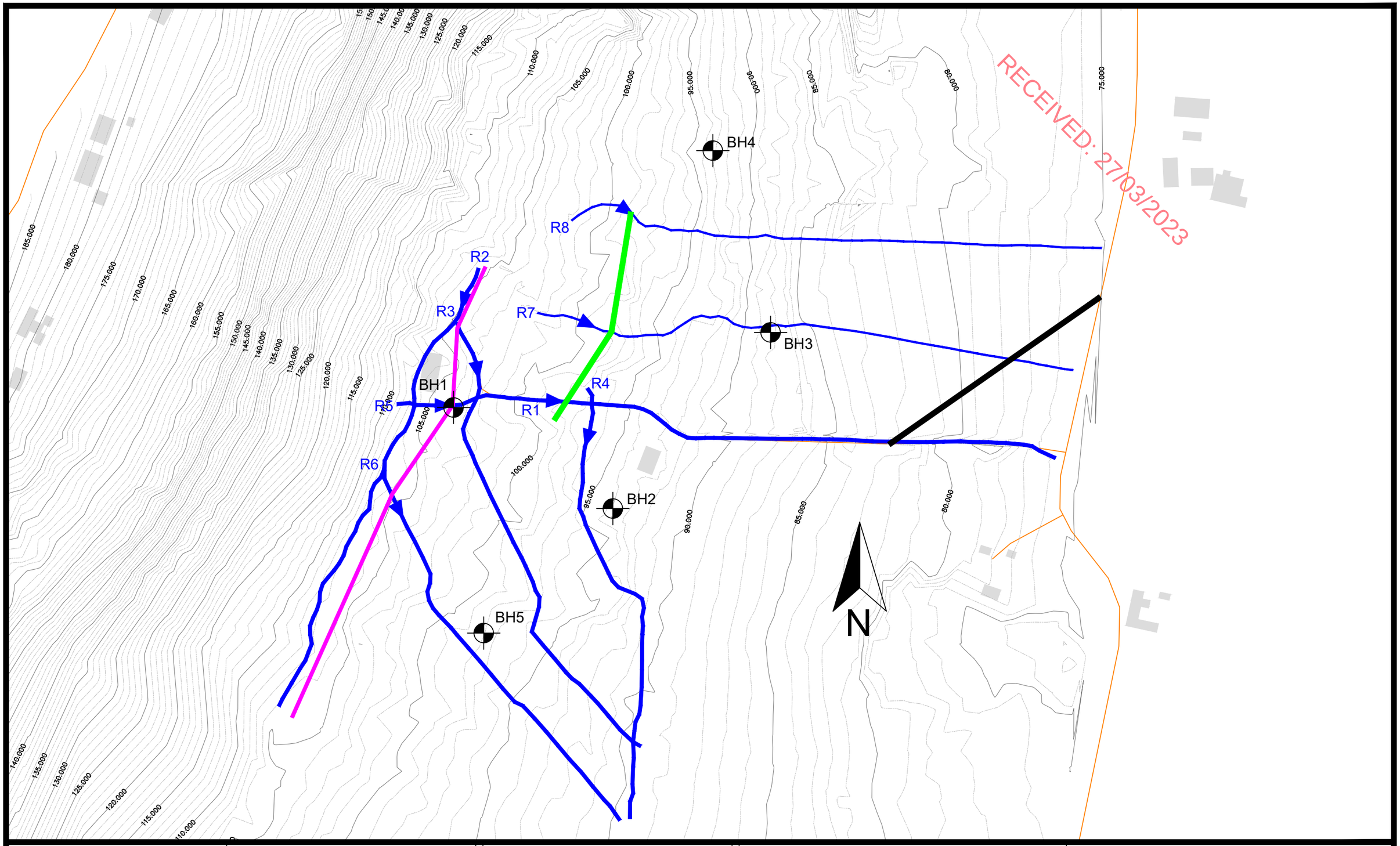
5. **Milsom, 1989.** Field Geophysics. John Wiley and Sons, 1989
6. **Reynolds, 1997.** An Introduction to Applied and Environmental Geophysics. John Wiley and Son, 1997
7. **Weaver, 1975.** Geological Factors significant in the Assessment of Rippability, 1975



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CLIENT	Hydro-Environmental Services
PROJECT	Old Lieghlin, County Carlow Geophysical Survey
TITLE	Map 1: Geophysical Survey Location Map

SCALE:	1:2,000 @ A3
PROJECT:	6617
DRAWN:	JC
DATE:	22/06/2022
MGX FILE:	6617f_Drawings.dwg
STATUS:	Final

Geophysical Survey Locations:

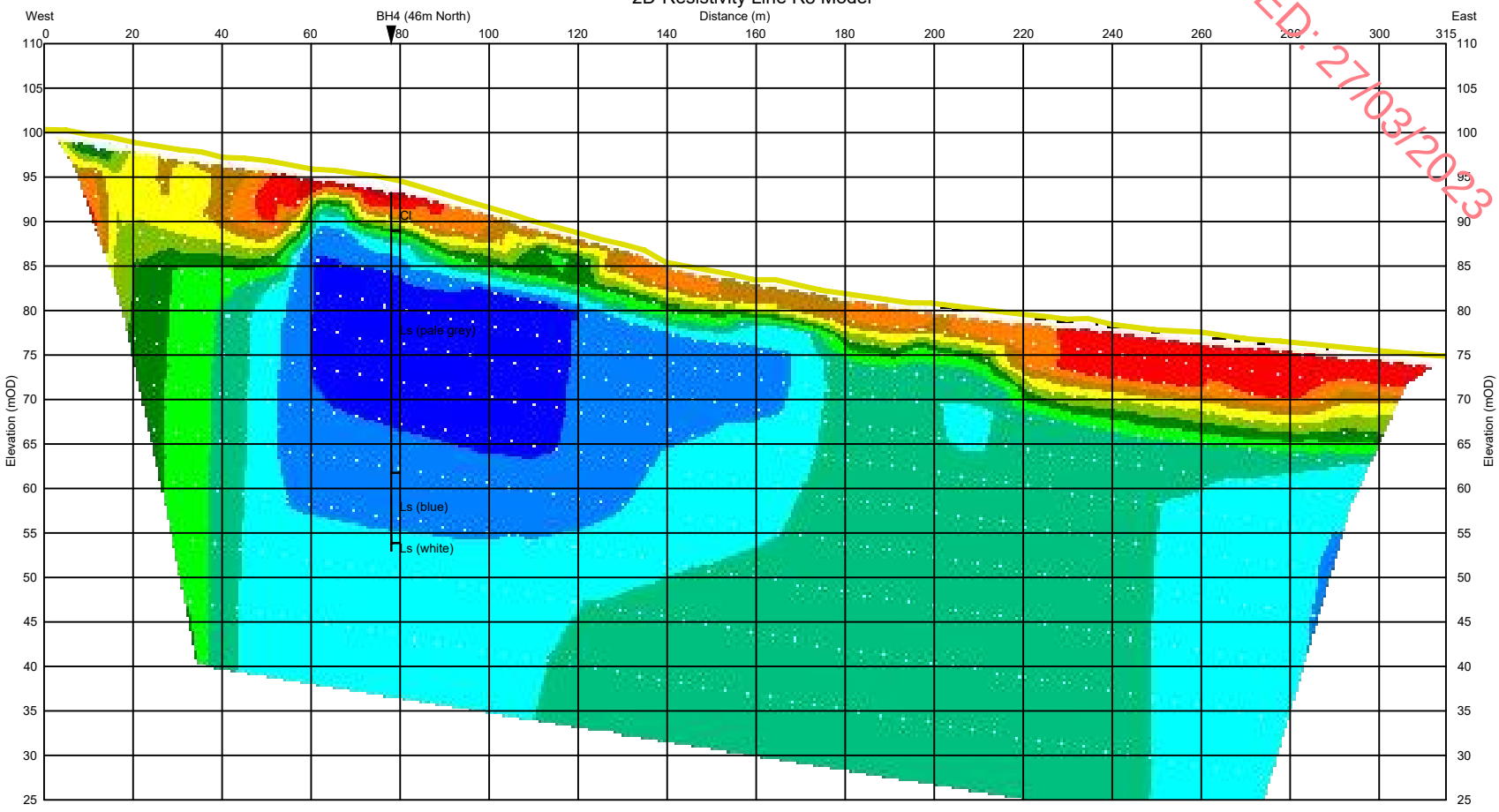
R2	2D-Resistivity Line
	Rock Contact between D & E
	Rock Contact Between C & D
	Fault Zone

Locations are in Irish Transverse Mercator (ITM), Elevations are in mOD (Malin Head)

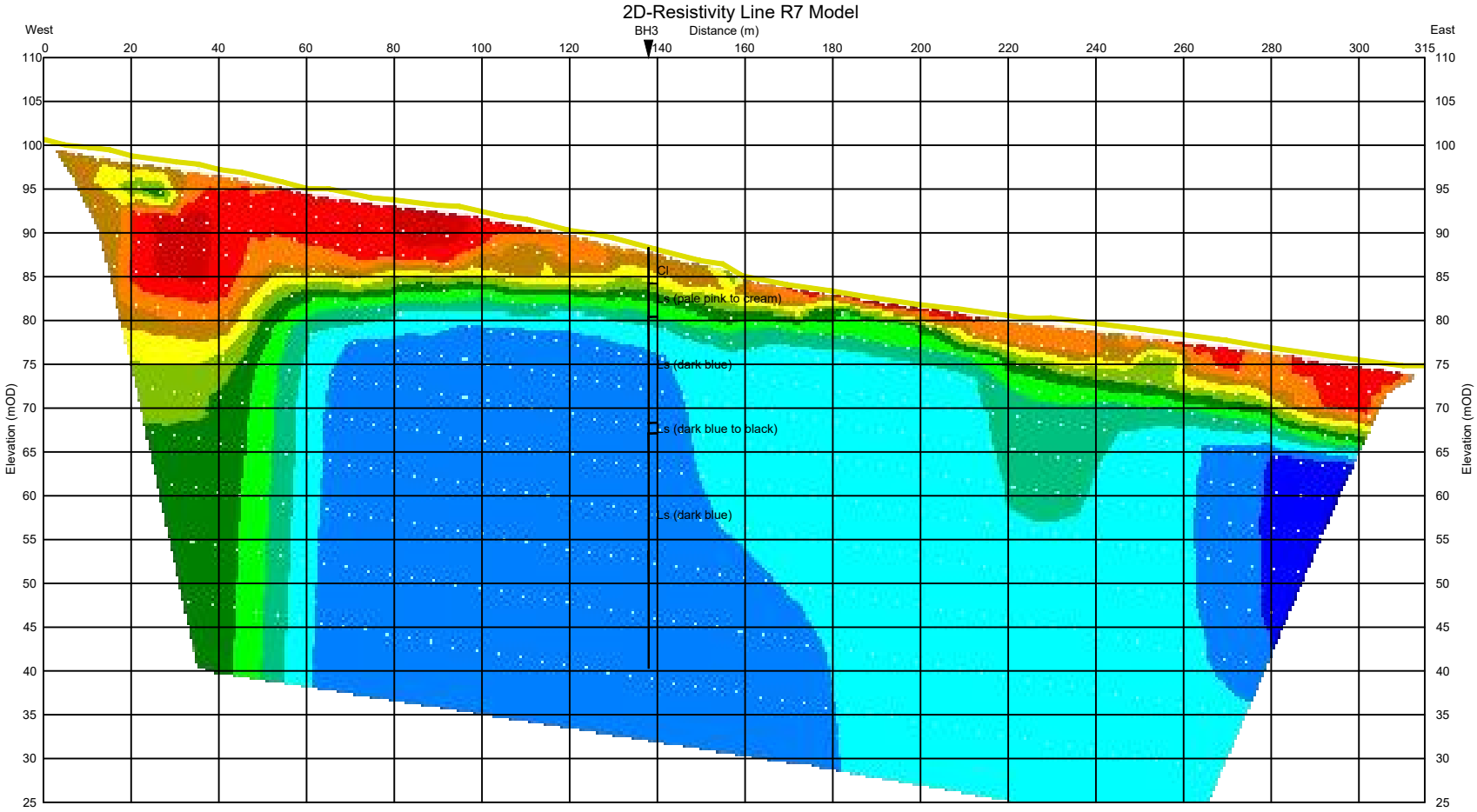
Direct Ground Investigation Locations:

BH1	Borehole

2D-Resistivity Line R8 Model



2D-Resistivity Line R7 Model



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CLIENT	Hydro-Environmental Services
PROJECT	Old Leighlin, County Carlow Geophysical Survey
TITLE	Figure 1a: Models of Geophysical Survey

SCALE:	1:1,500 @ A3, VE x 2
PROJECT:	6617
DRAWN:	JC
DATE:	22/06/2022
MGX FILE:	6617f_Drawings.dwg
STATUS:	Final

2D-Resistivity Model Values:

Resistivities (Ohmm) for 2D-Resistivity Model

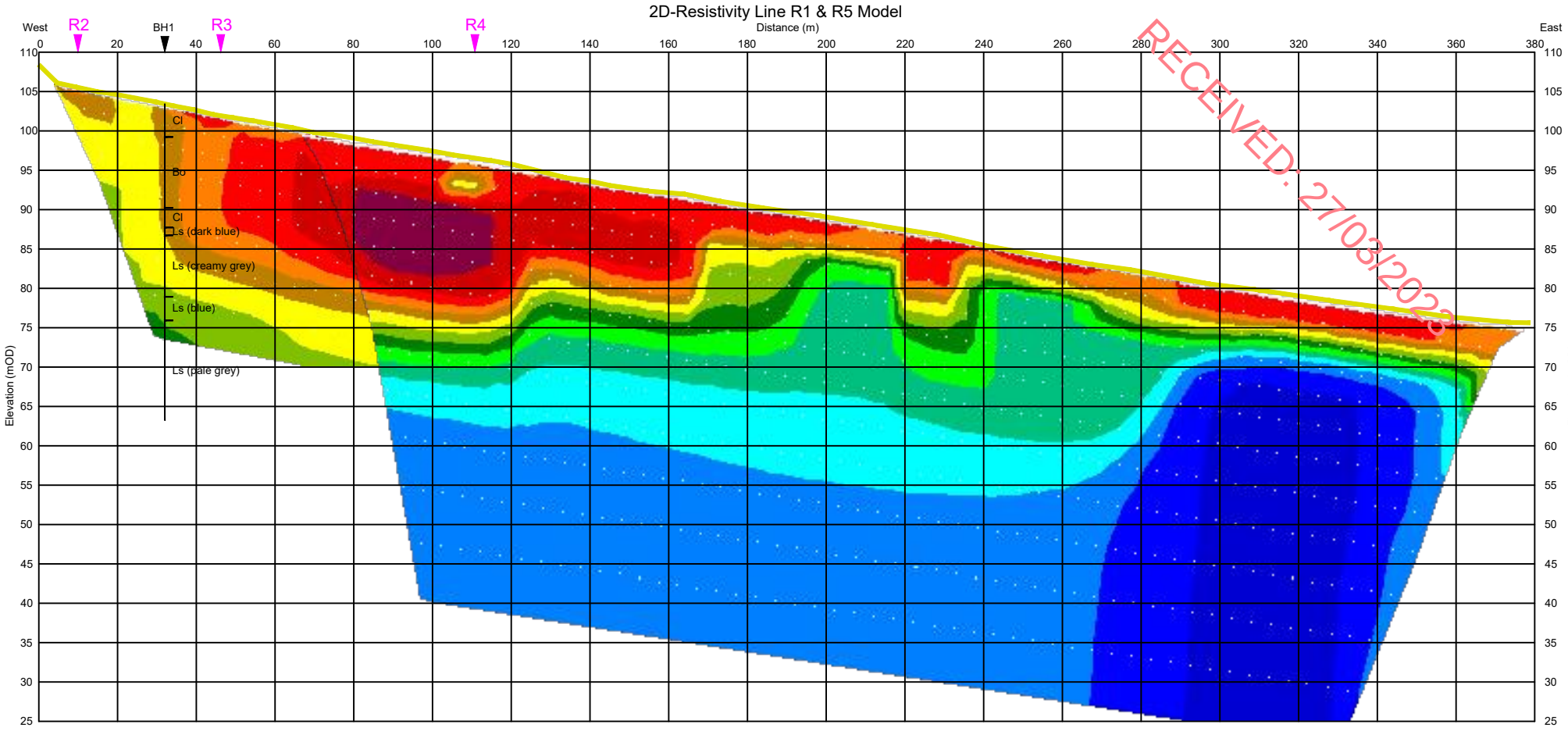
31.3 62.5 125 250 500 1000 2000 4000

Abbreviated GI Logs:

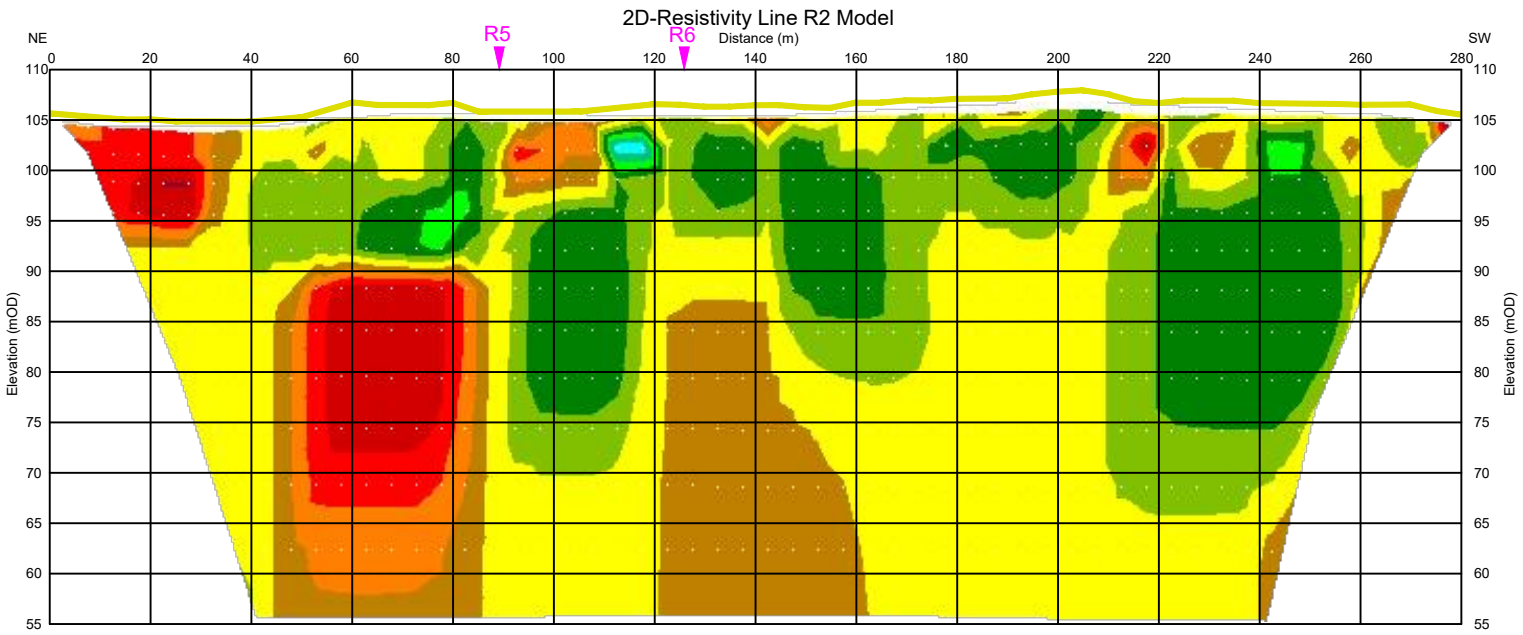
BH01 Borehole Name and Location

Bo	Boulders	Co	Cobbles
Cl	Clay	Ls	Limestone

2D-Resistivity Line R1 & R5 Model



2D-Resistivity Line R2 Model



CLIENT	Hydro-Environmental Services
PROJECT	Old Leighlin, County Carlow Geophysical Survey
TITLE	Figure 1b: Models of Geophysical Survey

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DRAWN:	JC
DATE:	22/06/2022
MGX FILE:	6617f_Drawings.dwg
STATUS:	Final

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2D-Resistivity Model Values:

Resistivities (Ohmm) for 2D-Resistivity Model

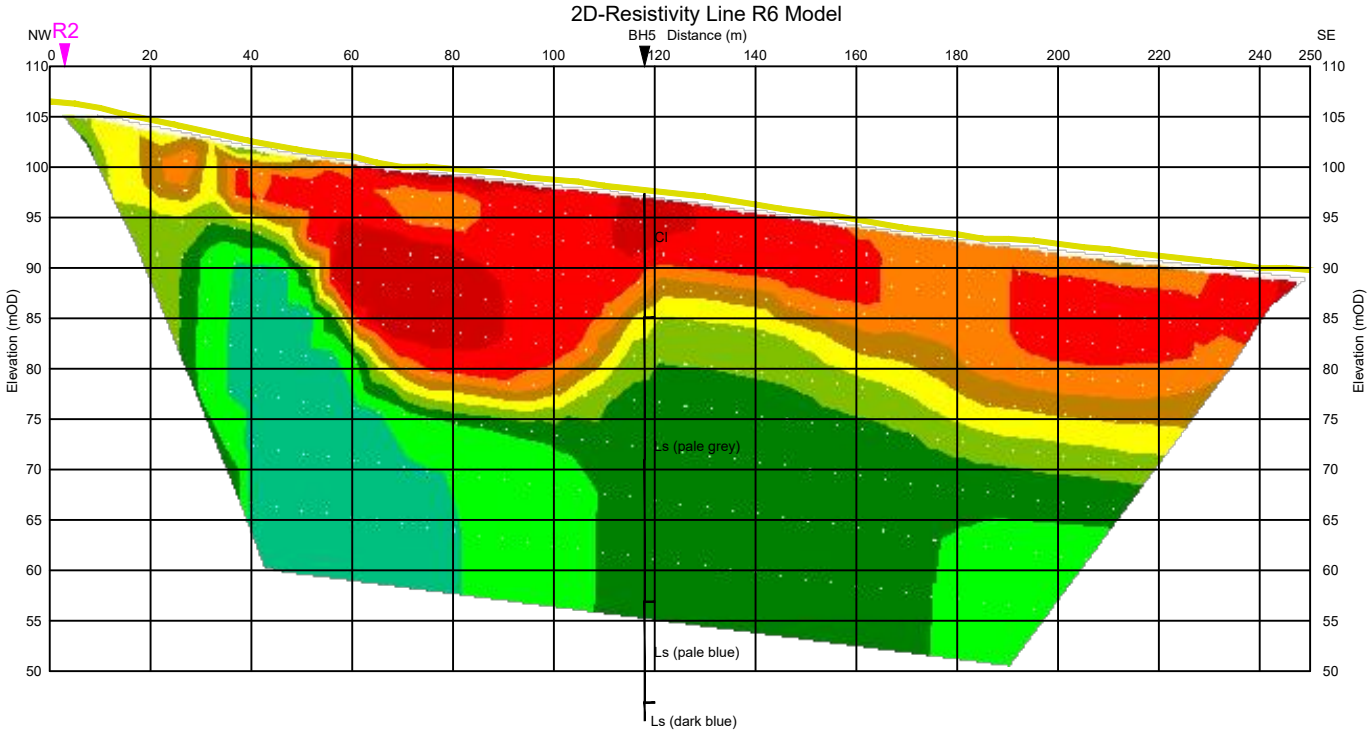
31.3 62.5 125 250 500 1000 2000 4000

Abbreviated GI Logs:

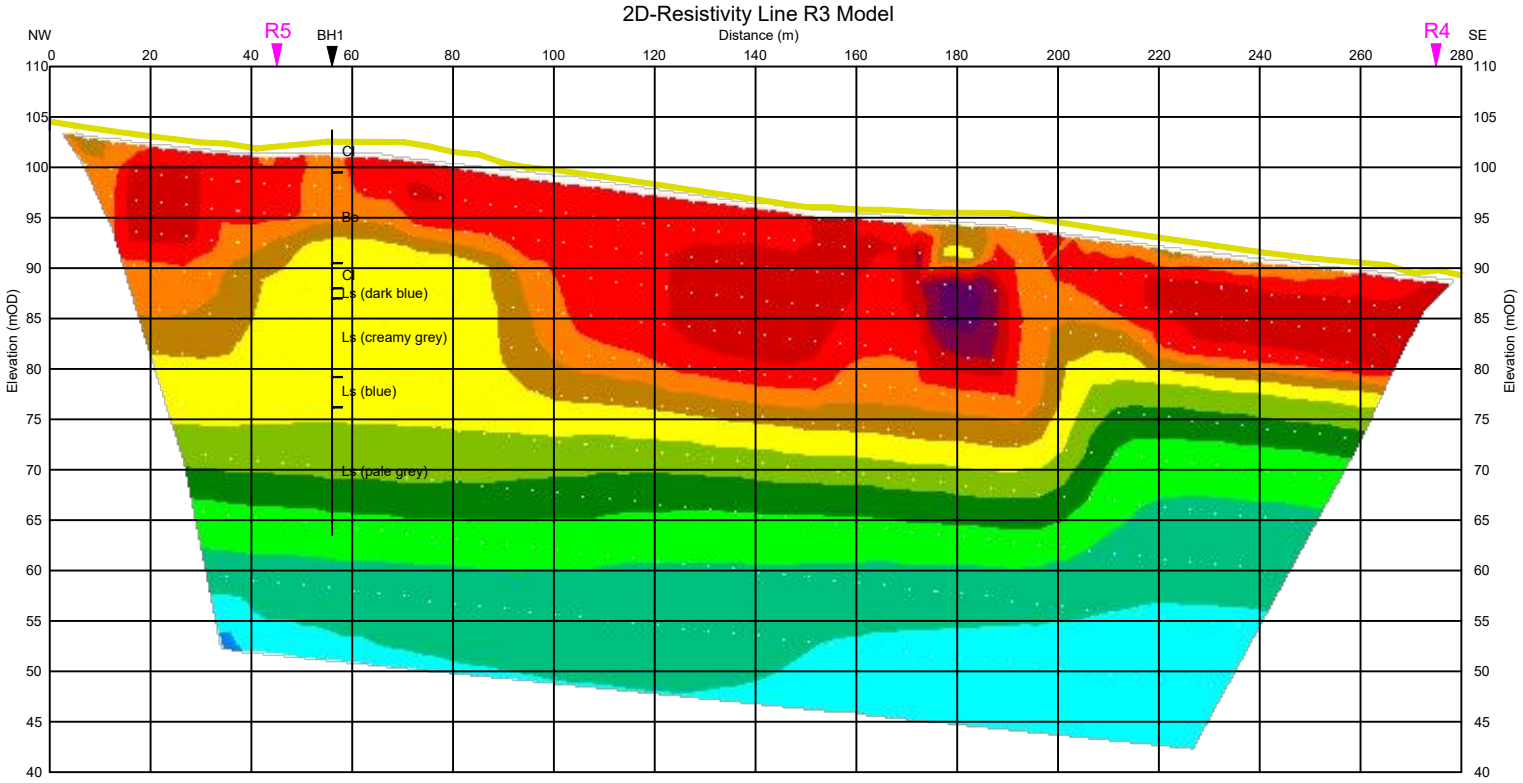
BH01 Borehole Name and Location

Bo	Boulders	Co	Cobbles
Cl	Clay	Ls	Limestone

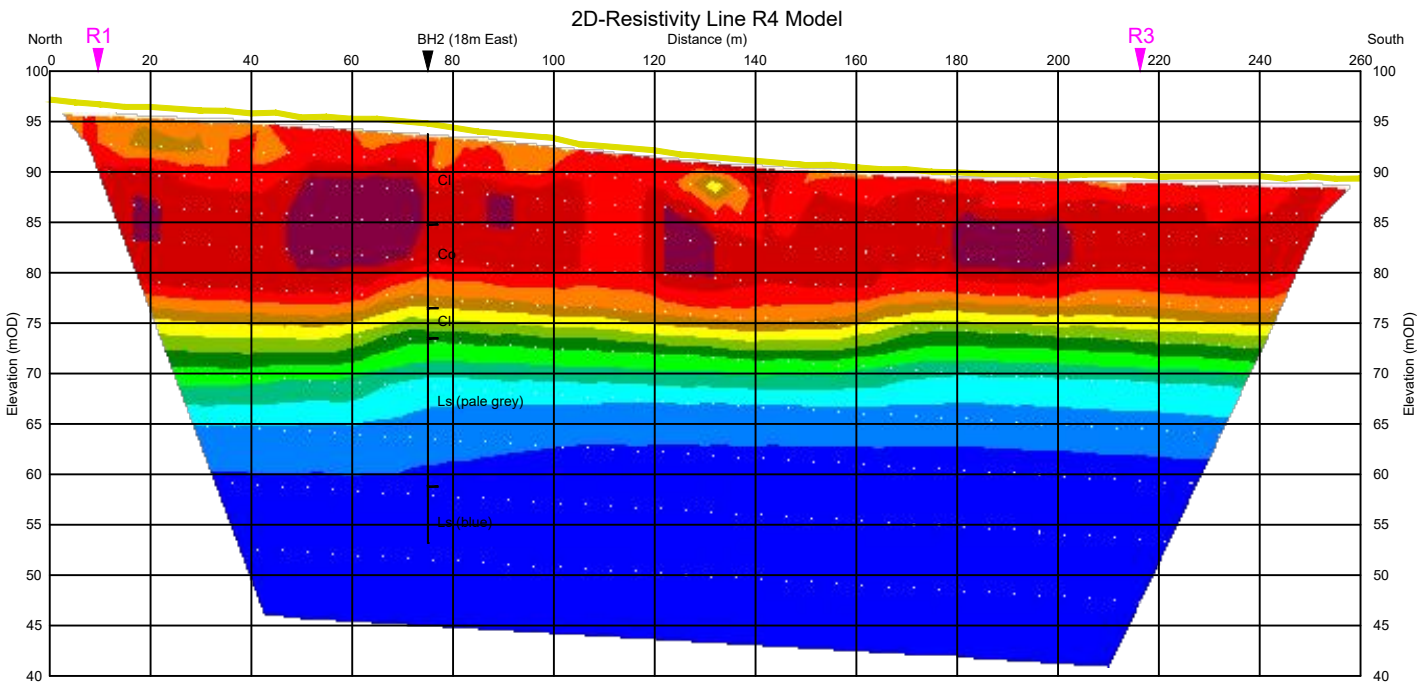
2D-Resistivity Line R6 Model



2D-Resistivity Line R3 Model



2D-Resistivity Line R4 Model



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CLIENT	Hydro-Environmental Services
PROJECT	Old Leighlin, County Carlow Geophysical Survey
TITLE	Figure 1c: Models of Geophysical Survey

SCALE:	1:1,500 @ A3, VE x 2
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DRAWN:	JC
DATE:	22/06/2022
MGX FILE:	6617f_Drawings.dwg
STATUS:	Final

2D-Resistivity Model Values:

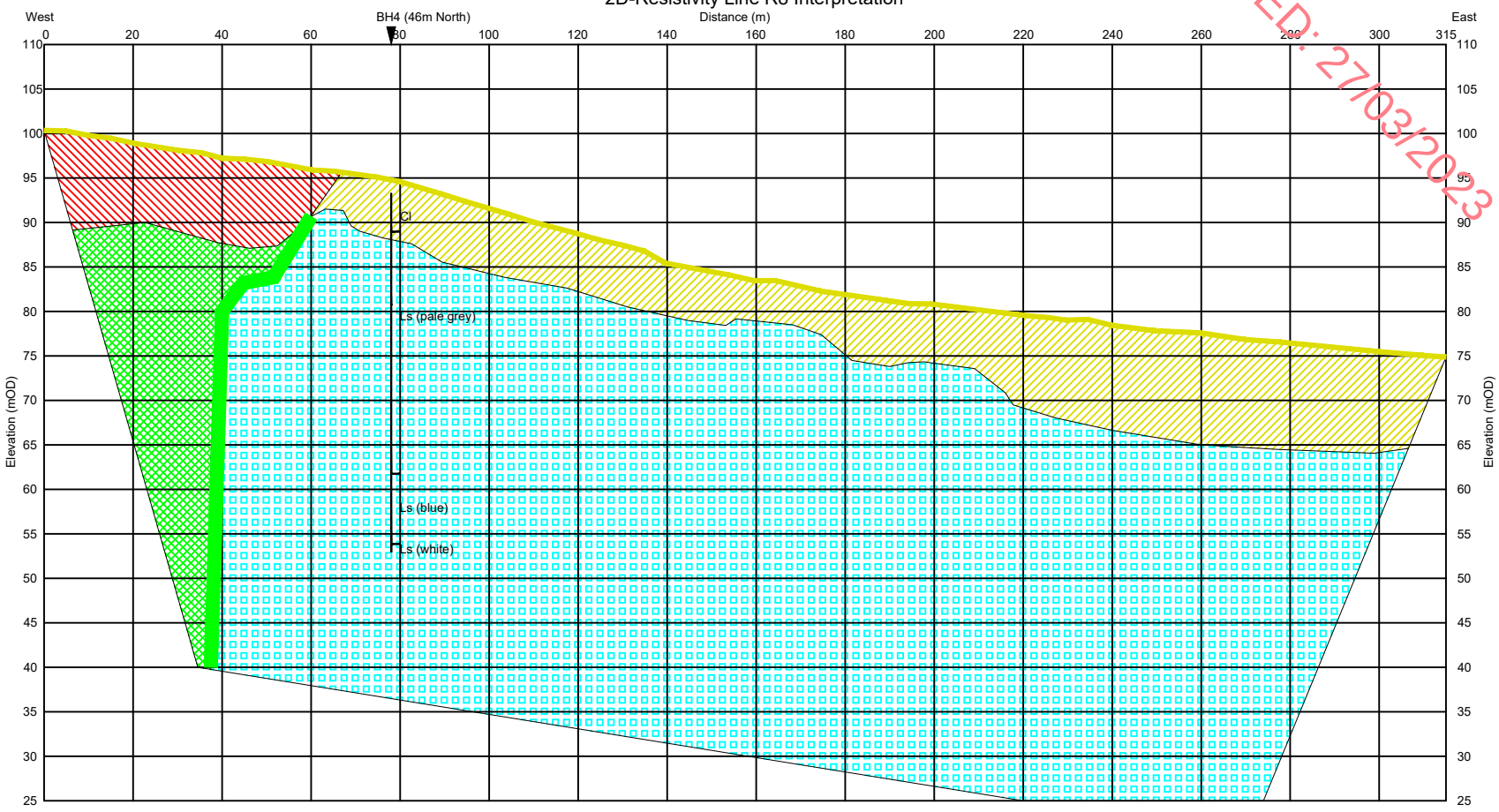
Resistivities (Ohmm) for 2D-Resistivity Model

Abbreviated GI Logs:

BH01 Borehole Name and Location

Bo	Boulders	Co	Cobbles
Cl	Clay	Ls	Limestone

2D-Resistivity Line R8 Interpretation



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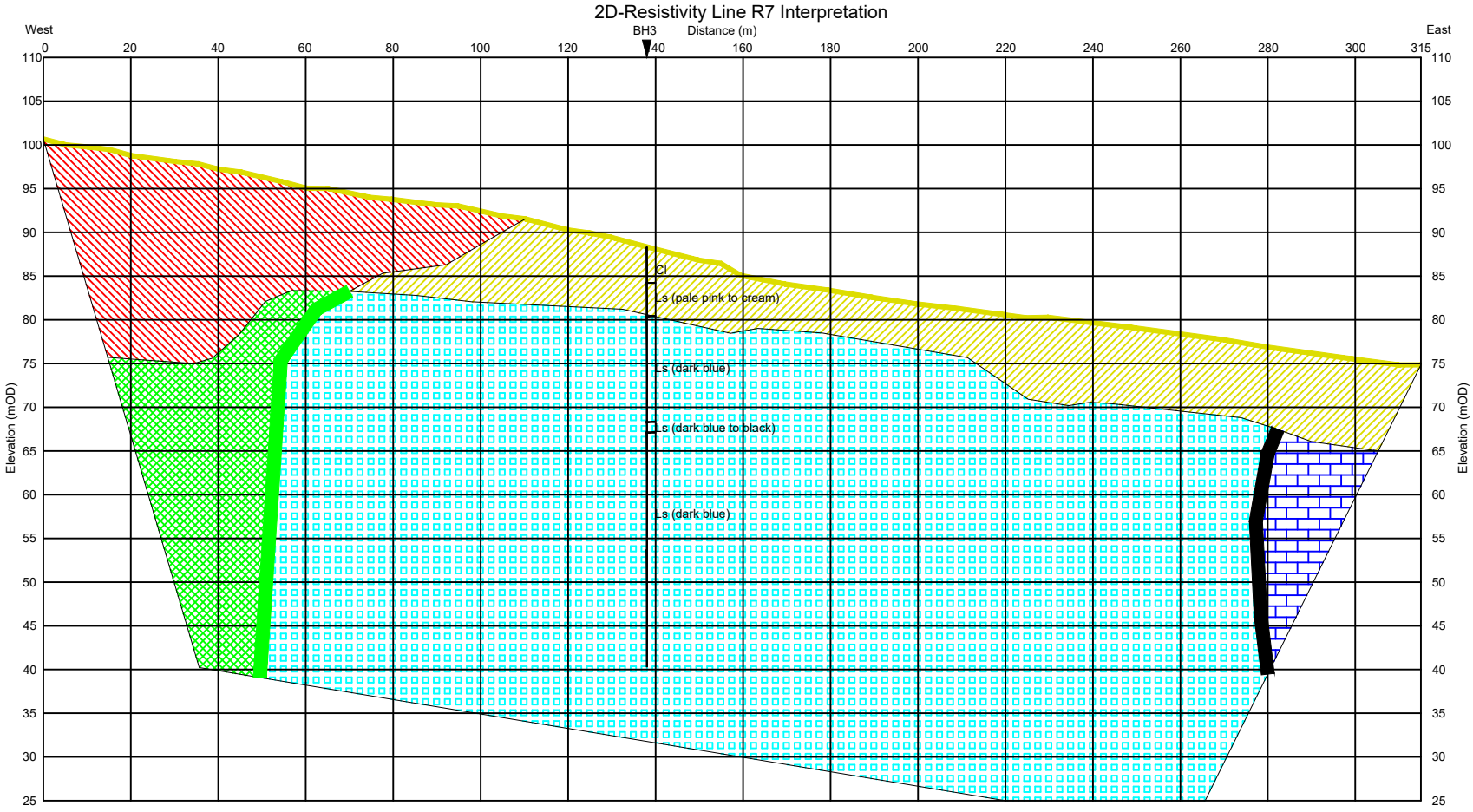

Abbreviated GI Logs:

BH01 Borehole Name and Location

Bo	Boulders	Co	Cobbles
Cl	Clay	Ls	Limestone

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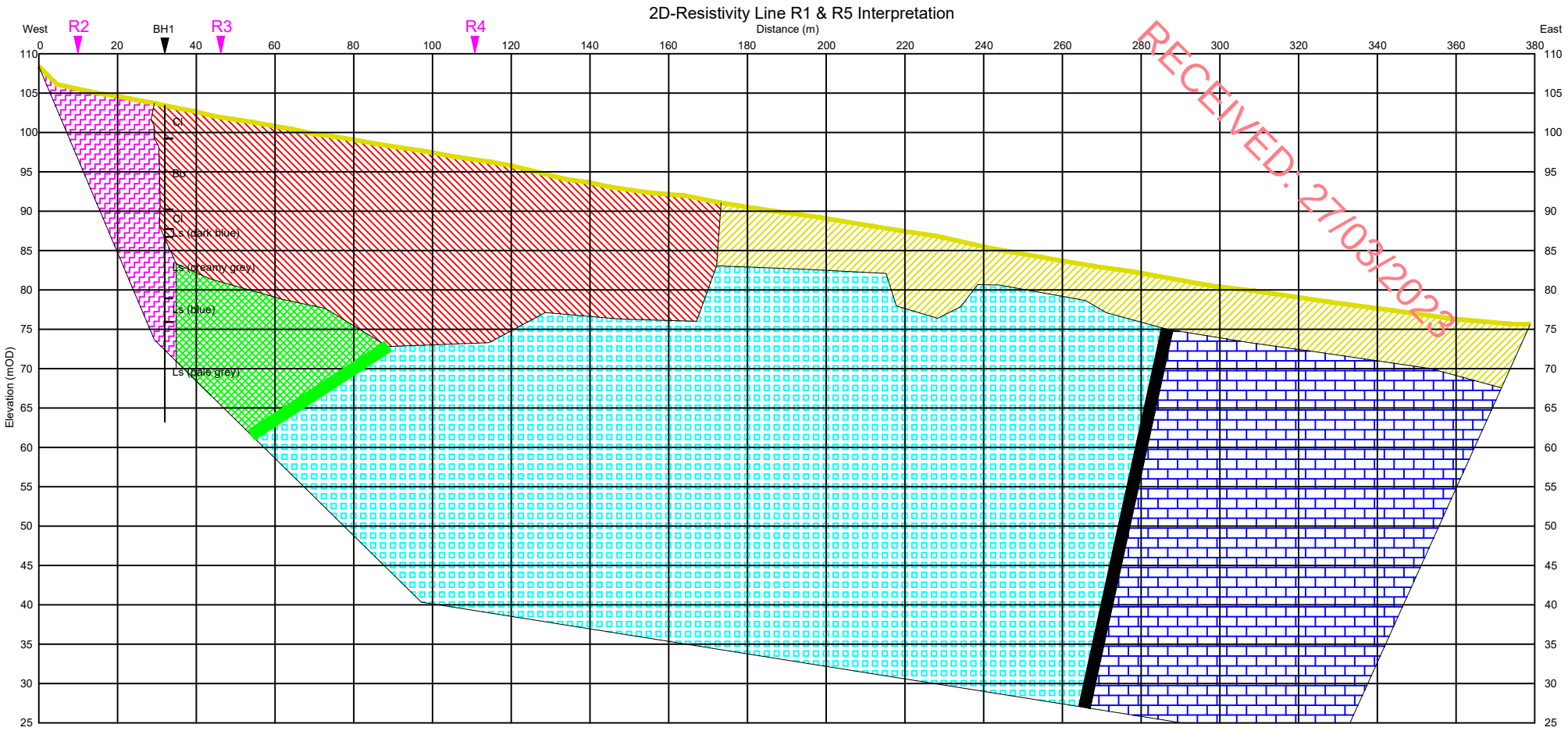
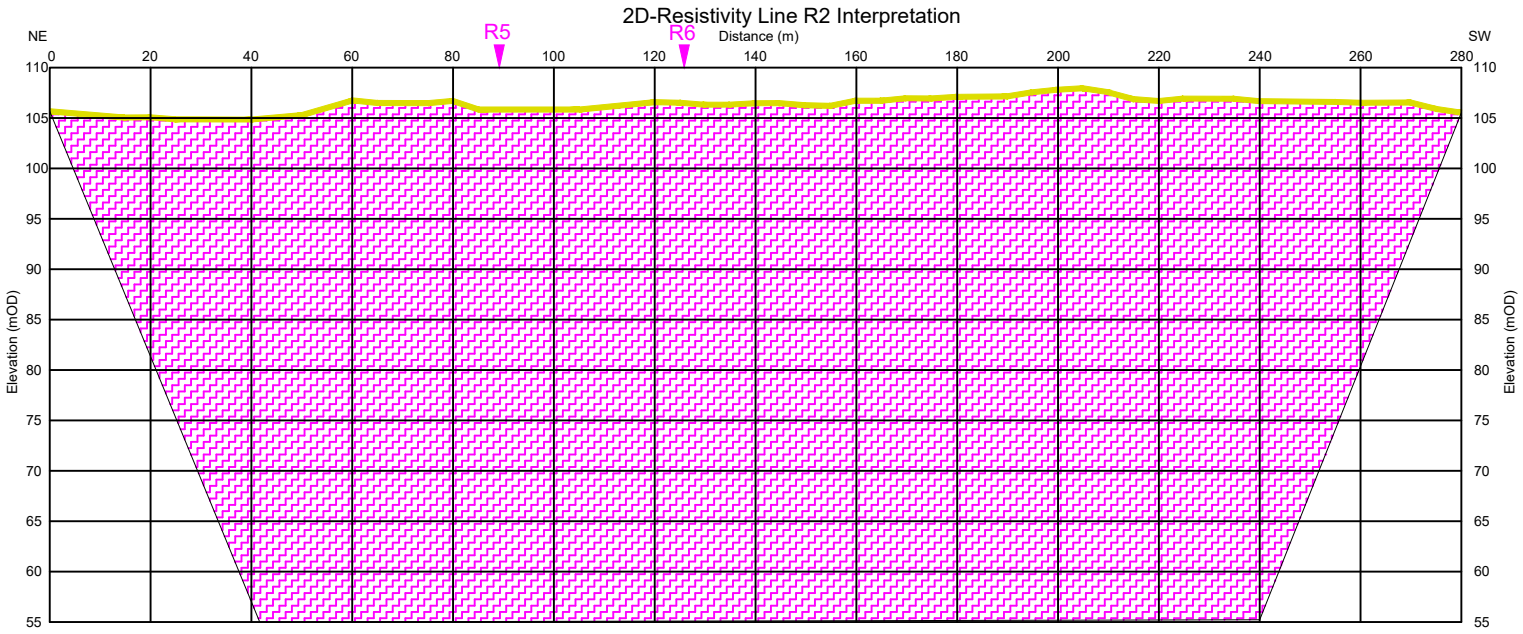
CLIENT	Hydro-Environmental Services
PROJECT	Old Leighlin, County Carlow Geophysical Survey
TITLE	Figure 2a: Interpretation of Geophysical Survey

SCALE:	1:1,500 @ A3, VE x 2
PROJECT:	6617
DRAWN:	JC
DATE:	22/06/2022
MGX FILE:	6617f_Drawings.dwg
STATUS:	Final

Interpretation:

- A Overburden
- B Overburden or Mudstone
- C Shale or weathered muddy Limestone
- D Muddy Limestone
- E Clean Limestone
- F Fault Zone





Abbreviated GI Logs:

BH01	Borehole Name and Location		
Bo	Boulders	Co	Cobbles
Cl	Clay	Ls	Limestone

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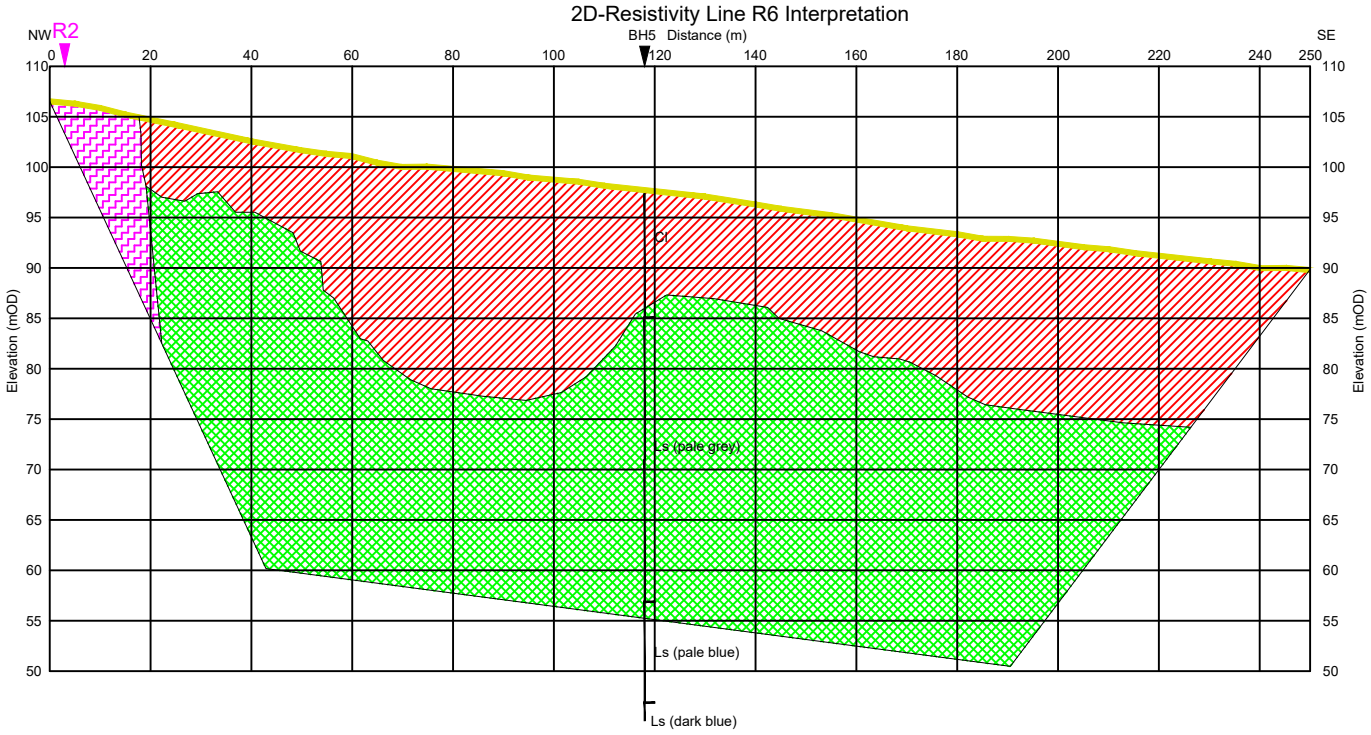
CLIENT	Hydro-Environmental Services
PROJECT	Old Leighlin, County Carlow Geophysical Survey
TITLE	Figure 2b: Interpretation of Geophysical Survey

SCALE:	1:1,500 @ A3, VE x 2
PROJECT:	6617
DRAWN:	JC
DATE:	22/06/2022
MGX FILE:	6617f_Drawings.dwg
STATUS:	Final

Interpretation:

- A Overburden
- B Overburden or Mudstone
- C Shale or weathered muddy Limestone
- D Muddy Limestone
- E Clean Limestone
- F Fault Zone

2D-Resistivity Line R6 Interpretation



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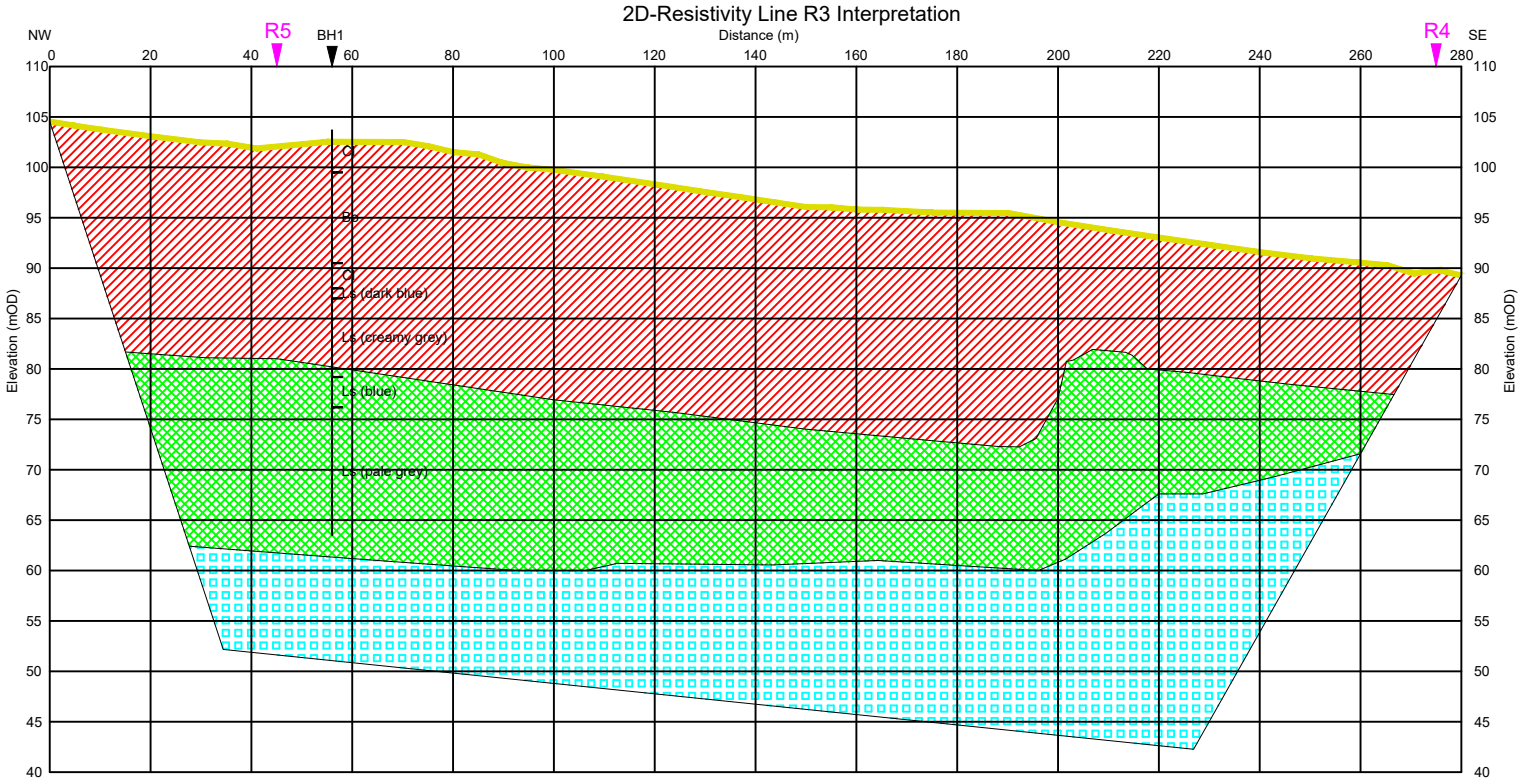

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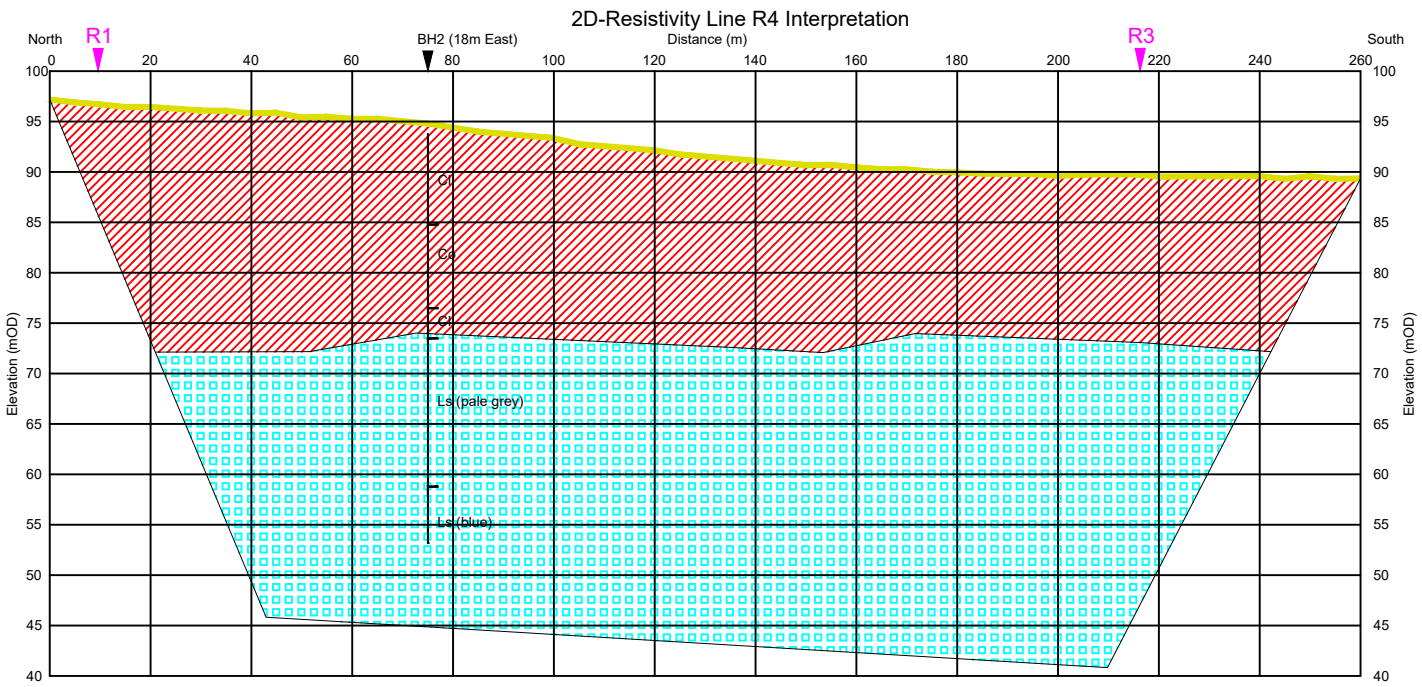

Abbreviated GI Logs:

BH01 Borehole Name and Location

Bo	Boulders	Co	Cobbles
Cl	Clay	Ls	Limestone

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CLIENT	Hydro-Environmental Services
PROJECT	Old Leighlin, County Carlow Geophysical Survey
TITLE	Figure 2c: Interpretation of Geophysical Survey

SCALE:	1:1,500 @ A3, VE x 2
PROJECT:	6617
DRAWN:	JC
DATE:	22/06/2022
MGX FILE:	6617f_Drawings.dwg
STATUS:	Final

Interpretation:

- A Overburden
- B Overburden or Mudstone
- C Shale or weathered muddy Limestone
- D Muddy Limestone
- E Clean Limestone
- F Fault Zone