MINOR SUITE INDICATOR PARAMETERS

Method		AQ2	AQ2	AQ2	ICPMS	ICPMS	Titralab		5-Day
Method Number		EW003	EW015	EW015	EM130	EM130	EW139	EW138	EW001
Parameter		Ammonia	Cl	SO4	K	Na	Cond	pH	BOD
Units		mg/l N	mg/l	mg/l	mg/l	mg/l	us/cm	pH Units	mg/l
Limit of Detection		0.007	2.6	1.0	0.2	0.5	25-1999	0.3	1
Date Testing Initiated		29/03	31/03		26/03		24/03		25/03
ELS Ref	**Client Ref**								
16621-1	TP 9	8.50	33.6	24.7	83.7	45.3	954	7.3	164
16621-2	TP 10	0.010	33.5	<10.0 Note 3	6.6	14.6	735	7.2	<2

NOTES

1 Sub-contract analysis denoted by *

2 ND = Concentration was below the limit of detection

3 LOD raised,due to potential sample interference(sample contained a high level of solids)

ELS LTD INAB ACCREDITATION SCHEDULE SUMMARY SHEET

Miscellaneous (P,G,W,S)
Ammonia/Ammonium 0.007-1mg/l N EW003
Chloride 2.6-250 mg/l EW015
Flouride 0.1 - 2 mg/l EW137
COD 8-1500 mg/l EW094
Nitrate 0.12-50 mg/l N EW034
Nitrite 0.013-1 mg/l N EW035
pH 4 – 10 pH Units EW138
Phosphate 0.009-1 mg/l P EW007
Alkalinity 10-1000mg/l EW062
TOC 0.25-100mg/l EW123
BOD 1-1300mg/l EW001
Total Nitrogen 1-100mg/l N EW140
Total Phosphorous 0.01-40 mg/l P EW143

Miscellaneous (P,G,S)
Bromate 1 to 50ug/l BRO3 (EW137)
Colour 2.5-50mg/l PtCCo (EW021)
Conductivity 25-6000 us/cm EW139
Dissolved Oxygen 1 to 10 mg/l (EW043)
Sulphate 1-250mg/l SO4(EW016)
Suspended Solids 5-1000mg/l (EW013)
Total Dissolved Solids 1-1000mg/l (EW046)
Total Hardness 3-330mg/l CaCO3 (EM099)
Total Oxidised Nitrogen 0.138-51mg/l N (EW051)

Metals EM130 (P,G,S)
Aluminium 5.0 – 500 µg/l
Antimony 0.1 – 10µg/l
Arsenic 0.2 - 20µg/l
Barium 1.0 - 100µg/l
Boron 0.02 – 2mg/l
Cadmium 0.1 – 10µg/l
Calcium 1.0 – 100mg/l
Chromium 1.0 - 100µg/l
Cobalt 1.0 - 100µg/l
Copper 3 - 4000µg/l
Iron 5.0 - 500µg/l
Lead 0.3 - 30µg/l
Magnesium 0.3 – 20mg/l
Manganese 1.0 - 100µg/l
Mercury 0.02 - 2µg/l
Molybdenum 1.0 - 100µg/l
Nickel 0.5 - 50µg/l
Potassium 0.2 – 20mg/l
Selenium 0.2 - 20µg/l
Sodium 0.5 – 50mg/l
Strontium 1.0 - 100µg/l
Tin 1.0 - 100µg/l
Vanadium 1.0 - 100µg/l
Zinc 1.0 - 100µg/l

SI439 Potable Water VOCs & THM EO025 (P,G,S)
Benzene 0.1-35 µg/l
1.2-Dichloroethane 0.1-35 µg/l
Tetrachloroethene 0.1-35 µg/l
Trichloroethene 0.1-35 µg/l
Chloroform 1.0-150 µg/l
Bromoform 1.0-35 µg/l
Dibromochloromethane 1.0-35 µg/l
Bromodichloromethane 2.0-35 µg/l

Other VOC's EO025 (P,G,S)
Bromomethane 0.5 - 35 µg/l
Ethyl Ether/Diethyl Ether0.5 - 35 µg/l
11 Dichloroethene0.5 - 35 µg/l
Iodomethane/Mehyl Iodide 0.5 - 35 µg/l
Carbon Disulphide 0.5 - 35 µg/l
Allyl Chloride0.5 - 35 µg/l
Methylene Chloride/DCM 5.0 - 35 µg/l
2-Propenenitrile/Acrylonitrile 2.0 - 35 µg/l
Chlormethyl Cyanide 0.5 - 35 µg/l
Hexachlorobutadiene0.5 - 35 µg/l
Trans-1,2 Dichloroethene0.5 - 35 µg/l
MtBE0.5 - 35 µg/l
11 Dichloroethane0.5 - 35 µg/l
22 Dichloropropane0.5 - 35 µg/l
Cis-12 Dichloroethene0.5 - 35 µg/l
Methyl Acrylate5.0 - 35 µg/l
Bromochloromethane0.5 - 35 µg/l
Tetrahydrofuran5.0 - 35 µg/l
111 Trichloroethane0.5 - 35 µg/l
1-Chlorobutane0.5 - 35 µg/l
Carbon Tetrachloride0.5 - 35 µg/l
11 Dichloropropene0.5 - 35 µg/l
12 Dichloropropane0.5 - 35 µg/l
Dibromomethane0.5 - 35 µg/l
Methyl Methacrylate0.5 - 35 µg/l
13 Dichloropropene, cis2.0 - 35 µg/l
MIBK/4 Methyl 2 Pentanone 2.0 - 35 µg/l
Toluene0.5 - 35 µg/l
13 Dichloropropene,trans2.0 - 35 µg/l
Ethyl Methacrylate2.0 - 35 µg/l
112 Trichloroethane0.5 - 35 µg/l
13 Dichloropropane0.5 - 35 µg/l
2 Hexanone1.0 - 35 µg/l
12 Dibromoethane0.5 - 35 µg/l
Chlorobenzene0.5 - 35 µg/l
1112 Tetrachloroethane2.0 - 35 µg/l
Ethyl Benzene0.5 - 35 µg/l
m & p Xylene0.5 - 35 µg/l
O Xylene0.5 - 35 µg/l
Stryene2.0 - 35 µg/l
Isopropyl Benzene0.5 - 35 µg/l
Bromobenzene0.5 - 35 µg/l
1122 Tetrachloroethane0.5 - 35 µg/l
123 Trichloropropane2.0 - 35 µg/l
Propyl Benzene0.5 - 35 µg/l
2-Chlorotoluene0.5 - 35 µg/l
4 Chlorotoluene0.5 - 35 µg/l
135 Trimenthylbenzene0.5 - 35 µg/l
Tert Butyl Benzene0.5 - 35 µg/l
124 Trimethlbenzene0.5 - 35 µg/l
Sec Butyl Benzene0.5 - 35 µg/l
13 Dichlorobenzene0.5 - 35 µg/l
P Isopropyltoluene0.5 - 35 µg/l
14 Dichlorobenzene0.5 - 35 µg/l
12 Dichlorobenzene0.5 - 35 µg/l
N Butyl Benzene0.5 - 35 µg/l
Hexachloroethane5.0 - 35 µg/l
12 Dibromo 3Chloropropane 2.0 - 35 µg/l
124 Trichlorobenzene0.5 - 35 µg/l
123 Trichlorobenzene0.5 - 35 µg/l

PAH EO129 (P,G,S)
Range 0.01 - 0.2 µg/l
Acenaphthene
Benzo (a) Anthracene
Benzo (a) Pyrene
Benzo (b) Fluoranthene
Benzo (ghi) Perylene
Benzo (k) Fluoranthene
Chrysene
Dibenzo (ah) Anthracene
Fluoranthene
Fluorene
Indeno (123-cd) Pyrene
Phenanthrene
Pyrene

Acid Herbicides (P,G,S)
Range 0.01 - 0.2 µg/l
2,4,5-T H
2,4-D H
2,4-DB H
MCPA H
Picloram H

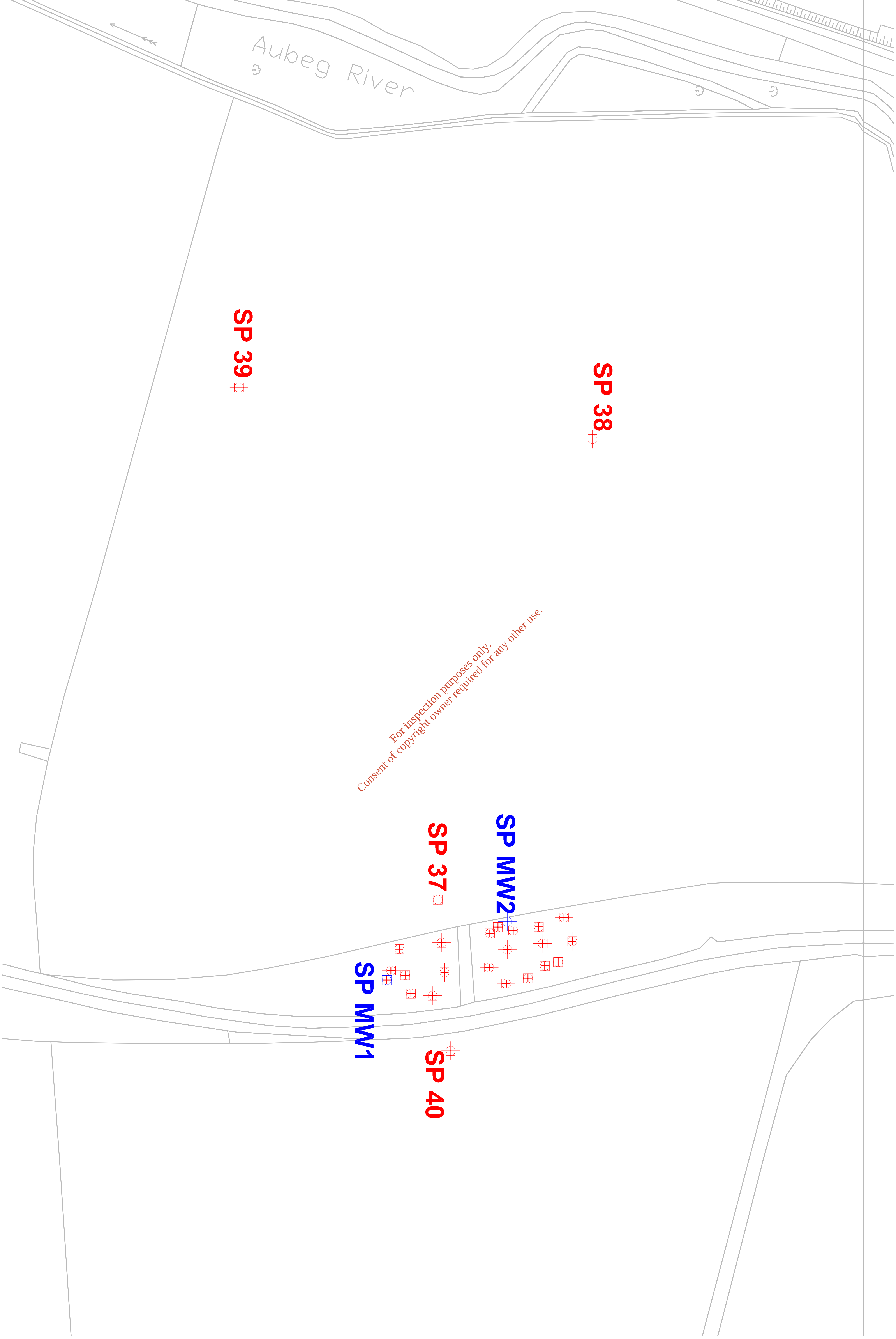
Organophosphorus Pesticides(P,G,S)
Range 0.01 - 0.2 µg/l
Famphur OP
Methyl Parathion OP
Parathion OP
Thionazin OP

Organochlorine Pesticides (P,G,S)
Range 0.01 - 0.2 µg/l
Aldrin
BHC Alpha isomer OC
BHC Beta isomer OC
BHC Delta isomer OC
Dieldrin OC
Endosulphan Alpha isomer OC
Endosulphan Beta isomer OC
Endosulphan Sulphate OC
Endrin OC
Heptachlor Epoxide OC
Heptachlor OC
Lindane OC
P,P' DDE OC
P,P'-DDD OC
P,P'-DDT OC

Notes

Appendix 5

VELVETSTOWN SITE SURVEY


Aubeg River
SP 39
SP 38
SP 37
SP MW2
SP MW1
SP 40

Appendix 6

GEOPHYSICAL SURVEY

FIGURE 1: Geophysical Survey Locations
Scale 1:1000

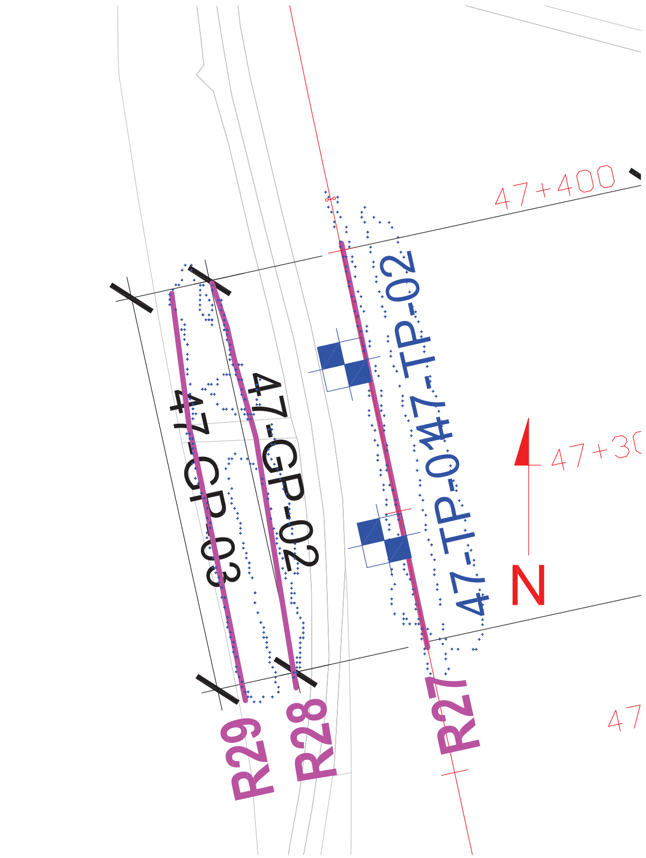


FIGURE 2: EM Conductivity Contours (mS/m)
Scale 1:1000

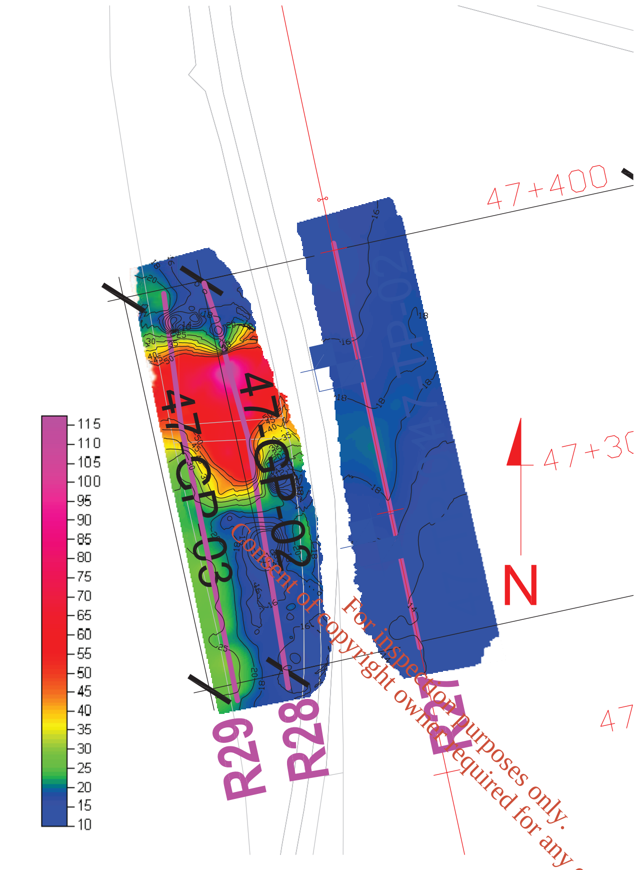


FIGURE 3: Summary Map
Scale 1:1000

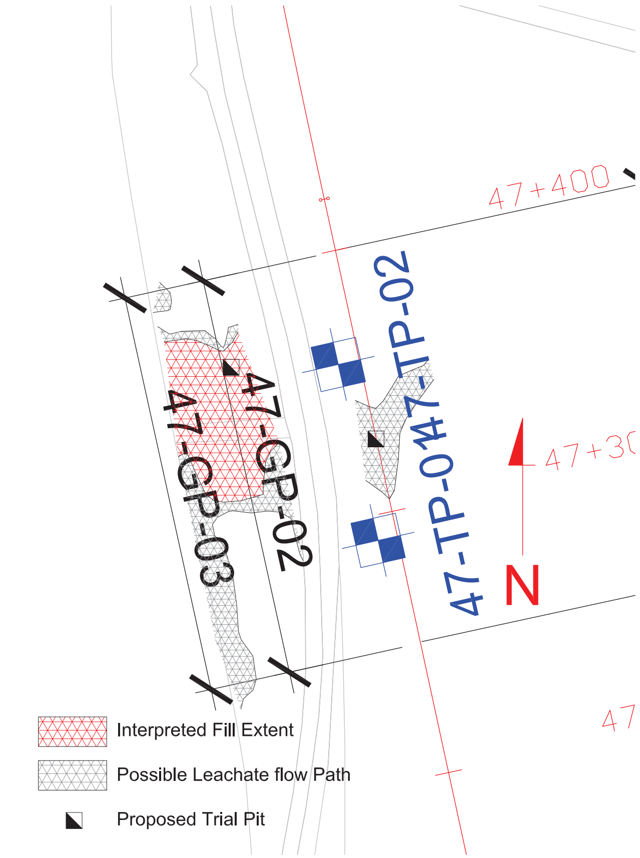
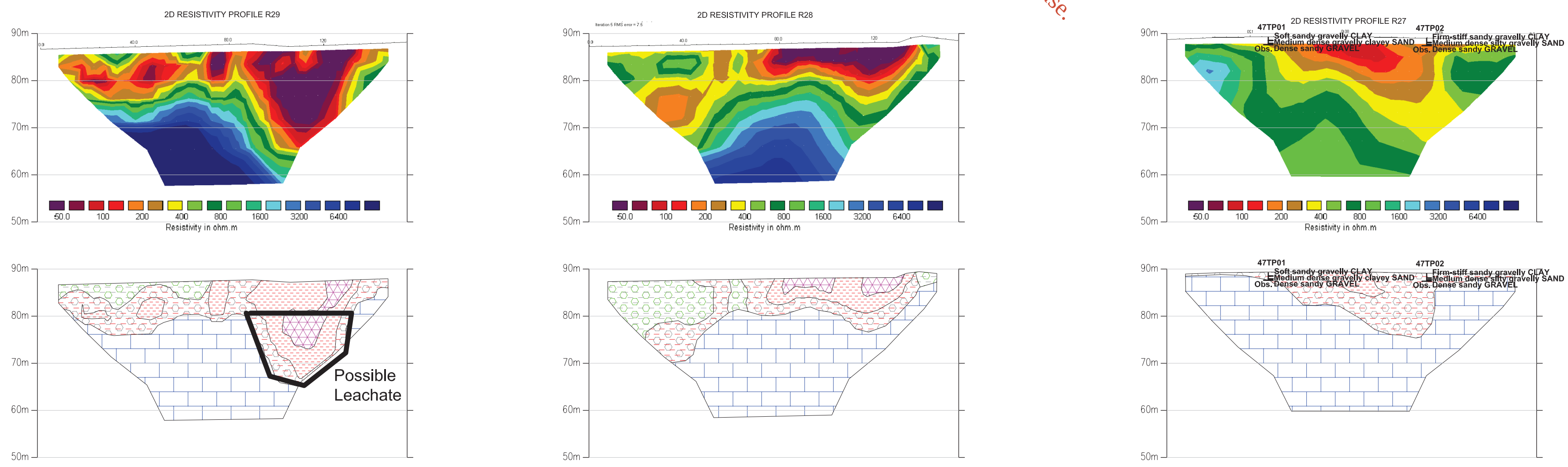
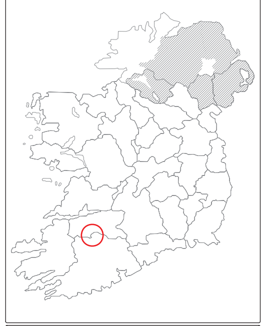


FIGURE 4: Geological Interpretation
Scale 1:1000 (Hz) 1:500 (Vt)



INDEX MAP:



LEGEND:

- R27 2D Resistivity Profile
- EM Conductivity Location
- Possible Organic Fill Material
- CLAY/SILT and/or sandy gravelly CLAY/SILT with possible lenses of Organic Fill Material
- sandy gravelly CLAY/SILT or possible Inert Fill Material
- silty clayey SAND/GRAVEL
- LIMESTONE

NOTES:

TITLE:	GEOPHYSICAL SURVEY
PROJECT:	M20 Cork to Limerick
CLIENT:	ARUP
DRAWING:	Ch 47+250 to 47+400
DRAWING NUMBER:	9046_07
SCALE:	Horz 1:1000 (Vert 1:500)
DATE:	18th September 2009
DRAWN:	YOC
CHECKED:	

REVISION:	DATE:	DRAWN:	CHECKED:
V2			

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AGL10017_01

REPORT ON THE

GEOPHYSICAL SURVEY

FOR THE

M20 CORK TO LIMERICK

MOTORWAY SCHEME,

PRELIMINARY GROUND INVESTIGATION

FOR

IGSL

ON BEHALF OF

ARUP & WYG-EPTISA

19TH FEBRUARY 2010

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	AGL10017		
AUTHOR	**CHECKED**	**REPORT STATUS**	**DATE**
EURGEOL YVONNE O'CONNELL P.GEO., M.SC (GEOPHYSICS)	EURGEOL PETER O'CONNOR P.GEO., M.SC (GEOPHYSICS), DIP. EIA MGT.	V.01	19TH FEBRUARY 2010

TABLE OF CONTENTS

1. INTRODUCTION

APEX Geoservices Ltd. was requested by IGSL Ltd., on behalf of ARUP and WYG-Eptisa, to carry out a geophysical survey as part of the preliminary ground investigation contract for the M20 Cork to Limerick Motorway Scheme.

1.1 Survey Objectives

The objectives of the survey as set out in the specification are to measure the following:

1. Depth to rockhead
2. Seismic velocity of rock
3. Geophysical anomalies indicative of karst.

1.3 Survey Description

The following geophysical techniques were requested in the specification:

- P-wave Seismic Refraction profiles to map overburden thickness, depth to bedrock and to investigate the characteristics of the superficial and rock strata including overburden stiffness, bedrock quality and excavatability.

- S-wave velocity data using the Multi-channel Analysis of Surface Waves (MASW) method to provide Vs shear wave velocity and Gmax small strain shear modulus values.

- 2D Resistivity in to investigate variations in overburden type and thickness, variations in depth to bedrock, variations in bedrock lithology and to identify karstified zones within the limestone bedrock.

- Electromagnetic conductivity mapping to map lateral variations in overburden type & thickness.

1.2 Survey Locations

Use of the above geophysical techniques was requested at four locations specified by the client as follows:

Start Chainage	End Chainage	Survey Length	Resistivity	Seismics	EM
34500	34600		650		650
44300	46000	1700	1700	1700	
47250	47400	150	750		450
49500	50900	1400	1400	1400	

1.4 Site Background

The Geological Survey of Ireland 1:100,000 Bedrock Map Series for the area (GSI, Online Geological Map) indicates that the four survey locations are underlain by Hazelwood, Copstown & Caherduggan limestone Formation and Kiltorcan Formation sandstones and mudstones. The geology at each survey location will be discussed in more detail in Part 2 of this report.

The Geological Survey of Ireland Teagasc subsoils map indicates that the four survey locations are underlain by shale and sandstone till (Namurian) and by sandstone till (Devonian). The subsoils at each survey location will be discussed in more detail in Part 2 of this report.

Rotary core, borehole and trial pit logs have been provided by the client to assist in the interpretation of the geophysical data and have been included on the interpreted sections on Drawings 10017_01 to 10017_05. The site investigation information at each survey location will be discussed in more detail in Part 2 of this report.

2. INTERPRETED RESULTS

2.1 Ch. 34+500 to 34+600

2D resistivity profiling and EM conductivity mapping was recorded east of ch.34+500 to 34+600 (Drawing 10017_01) to investigate the presence of an area of landfill.

The geological map indicates that the survey area is underlain by Hazelwood Formation comprising massive muddy limestone. The Teagasc subsoils map indicates that the soil type across the survey is shale and sandstone till (Namurian). Karstified rock outcrop/subcrop is mapped through the centre of the survey area (Drawing 10017_01, Figure 1).

The EM31 conductivity contoured values have been contoured on Drawing 10017_01, Figure 2. The conductivity values ranged from 10-89 milliSiemens/metre (mS/m) and have been interpreted in conjunction with the 2D resistivity data on the following basis:

Conductivity (mS/m)	**Interpretation of 0-6m Below Ground Level**
10	Rock at or near surface
11-20	Predominantly till or shallow rock in upper 6m
>20	Probable Waste Material deposited on Surface

Five 2D Resistivity profiles were recorded across the survey area (Drawing 10017_01, Figures 1 and 4). The resistivity data have been interpreted as follows:

Resistivity (Ohm-m)	**Interpretation**
50-200	Sandy gravelly SILT/CLAY
200-500	Clayey SAND/GRAVEL
275-9000	LIMESTONE

Typical resistivities of Irish overburden deposits as experienced by the author 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.

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 data does not indicate the presence of fill material across the survey area. The anomalous values in the conductivity data are therefore indicative of waste material/refuse deposited on the surface (Drawing 10017_07, Figure 3).

2.2 Ch. 44+300 to 46+000

Both 2D resistivity profiling and seismic refraction profiling were recorded along this cut section (Drawing 10017_01 & Drawing 10017_02).

The geological map for the area indicates that this section is underlain by Copstown Formation well bedded muddy limestone from ch. 44+300 to 44+460, by Hazelwood Formation comprising massive muddy limestone from ch. 44+460 to 44+750, by Caherduggan Formation comprising crinoidal limestone and chert from ch. 44+750 to 45+035 and by Hazelwood Formation comprising massive muddy limestone from ch. 45+035 to 46+000. The Teagasc subsoils map indicates that the soil type across this section is shale and sandstone till (Namurian). Rock outcrop/subcrop is mapped approx. 175m to the west of ch.45+300.

The seismic data indicate three subsurface velocity layers which have been interpreted in conjunction with resistivity data and boreholes 44-BH-03 and 45-BH-01 as follows:

Layer	Velocity (m/s)	Average Velocity (m/sec)	Resistivity (ohm-m)	Thickness Range (m)	Average Thickness (m)	Interpretation	Estimated Stiffness/ Rock Quality	Excavatability/ Rippability
1	138-547	222	50 - 200	0.4 – 1.8	1.0	Sandy gravelly SILT/CLAY	Soft to firm	Diggable
			200-400			Clayey SAND/GRAVEL	Loose to Medium Dense	
2	276-666	472	50 - 200	0.8 - 2.8	1.8	Sandy gravelly SILT/CLAY	Firm	Diggable
			200-400			Clayey SAND/GRAVEL	Medium Dense	
			400-800			Highly weathered LIMESTONE	Poor	Rippable
3	400-2132	1015	50-200	0.3 – 9.0	4.0	Sandy gravelly SILT/CLAY	Firm to Stiff	Diggable
			200-400			Clayey SAND/GRAVEL	Medium Dense to Dense	
			400-800			Moderately to Slightly weathered LIMESTONE	Fair-Good	Heavy ripping/ Break/ blast
4	2164-5068	3258	800-9000			Slightly weathered to Fresh LIMESTONE	Good/Very good	Break/ blast

Layer 1 has an average velocity of 222 m/s and has been interpreted as indicating soft to firm sandy gravelly silt/clay and/or loose to medium dense clayey sand/gravel. This layer has been interpreted as ranging in thickness from 0.4 to 1.8 m with an average thickness of 1 m.

Layer 2 has only been interpreted from ch.44+300 to 44+700. The velocities for this layer range from 276 to 666 m/s with an average velocity of 472 m/s. This layer has been interpreted as indicating firm sandy gravelly silt/clay and/or medium dense clayey sand/gravel. Highly weathered rippable limestone has been interpreted where resistivities are >400 Ohm-m. This layer has been interpreted up to 2.8m thick with an average thickness of 1.8m.

Layer 3 velocities range from 400 to 2132 m/s with an average velocity of 1015 m/s. This layer has been interpreted as indicating firm to stiff sandy gravelly silt/clay or medium dense to dense clayey sand/gravel. Moderately to slightly weathered limestone has been interpreted where resistivities are >400 Ohm-m. This layer has been interpreted up to 9m thick with an average thickness of 4 m.

Layer 4 has been interpreted as indicating slightly weathered to fresh limestone bedrock with an average velocity of 3258 m/s.

The MASW signal achieved penetration from 4m to 15m bgl. The measured shear wave velocities (Vs) range from 112 to 968 m/s and the derived G_{max} values range from 25 to 2529 MPa (Appendix II).

Low resistivities from ch. 44+350 to 44+750m have been interpreted as indicating possible karstification. This zone has been highlighted on Drawing 10017_02. The GSI geology map indicates that a fault runs through this area. These low resistivities may also be indicative of a fault zone and/or a change in bedrock lithology to a more argillaceous limestone. A localised grid of microgravity surveying together with some follow-up orthogonal resistivity profiling should be considered to delineate the extent of the possible karst zone across the motorway corridor followed by targeted rotary coring.

Other low resistivity zones occur from ch. 45+320 to 45+420m, from ch. 45+555 to 45+570m, from ch. 45+595 to 45+665m, from ch. 45+816 to 45+830m, from ch. 45+855 to 45+890m and from ch. 45+940 to 45+960m and have been interpreted as indicating possible karstification. These zones have been highlighted on Drawings 10017_02 and 10017_03. Slight surface depressions were noted in the vicinity of the zone at ch. 45+940 to 45+960m. Localised grids of microgravity surveying together with some follow-up orthogonal resistivity profiling should be considered to delineate the extent of all the possible karst zones across the motorway corridor followed by targeted rotary coring.

2.3 Ch. 47+250 to 47+400

2D resistivity profiling and EM conductivity mapping was recorded along this fill section (Drawing 10017_04) to investigate the presence of an area of landfill.

The geological map for the area indicates that this section is underlain by Hazelwood Formation comprising massive muddy limestone. The Teagasc subsoils map indicates that the soil type is sandstone till (Devonian). Rock outcrop/subcrop is mapped in the centre of the site. This outcrop/subcrop has not been identified as karstified on the Teagasc subsoils map.

The EM31 conductivity contoured values have been contoured on Drawing 10017_04, Figure 2. The conductivity values ranged from 10-115 milliSiemens/metre (mS/m) and have been interpreted in conjunction with the 2D resistivity data on the following basis:

Conductivity (mS/m)	**Interpretation of 0-6m Below Ground Level**
10-18	Predominantly till or shallow rock in upper 6m
18-30	Till with possible leachate
30-115	Probable Fill Material

Five 2D Resistivity profiles were recorded parallel to the proposed route, between ch. 47+250 to 47+400 (Drawing 10017_04, Figures 1 and 4). Profiles R27, R28 & R29 were recorded in June 2009 and Profiles R63 and R64 were recorded in January 2010

The resistivity data have been interpreted in conjunction with the conductivity data as follows:

Resistivity (Ohm-m)	**Interpretation**
< 30	Possible Organic Fill Material
30-100	SILT/CLAY and/or sandy gravelly SILT/CLAY with possible lenses of Organic Fill Material
100-275	Sandy gravelly SILT/CLAY or possible Inert Fill Material
275-500	Silty clayey SAND/GRAVEL
275-9000	LIMESTONE

Typical resistivities of Irish overburden deposits as experienced by the author 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.

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 to 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 combined conductivity and resistivity data indicates the presence of fill material in the common ground to the west of the proposed route (Drawing 10017_07 Figure 3).

2D resistivity Profile 28 indicates that the fill is between 3 and 7m thick. 2D resistivity Profile 29 suggests the fill may be up from 12 to 19m deep though this is likely to be <12m of fill with probable leachate into the underlying rock. Profiles R63 and R64 were recorded in the second field west of the existing road to investigate the extent of fill material to the west. The profiles could not be carried out nearer to R29 due to the presence of a metal cattle crush. Neither profile indicates resistivity values indicative of landfill material as seen on profiles R29 & R28.

A seismic spread should be considered to confirm depth to rock underlying the fill material. The GSI Teagasc soils map for the area indicates rock outcrop/subcrop through the centre of the survey area. There was no evidence of outcrop at the time of surveying, though some places were overgrown. This may be a backfilled small-scale rock quarry.

The conductivity and resistivity data suggests that there may be some fill along the route centerline (2D Resistivity Profile 27) though it is likely that this is leachate.

Two trial pits are recommended at the locations indicated on Drawing 10017_07 Figure 3 to investigate the probable fill material to the west and the absence of fill (but possible leachate) to the east.

2.4 Ch. 49+500 to 50+900

Both 2D resistivity profiling and seismic refraction profiling were recorded along this cut section (Drawing 10017_05).

The geological map for the area indicates that this section is underlain by Kiltorcan Formation comprising yellow and red sandstone and green mudstone. The Teagasc subsoils map indicates that the soil type across this section is sandstone till (Devonian). The subsoils map indicates rock outcrop/subcrop from ch.50+700 to 50+800.

The seismic data indicate three subsurface velocity layers which have been interpreted in conjunction with resistivity data and boreholes 49-BH-02, 50-BH-01, 50-BH-02 and 50-RC-02 as follows:

Layer	Velocity (m/s)	Average Velocity (m/sec)	Resistivity (ohm-m)	Thickness Range (m)	Average Thickness (m)	Interpretation	Estimated Stiffness/ Rock Quality	Excavatability/ Rippability
1	2220-606	321	50 - 200	0.5-1.8	1.1	Sandy gravelly SILT/CLAY	Soft to firm	Diggable
			200-400			Clayey SAND/GRAVEL	Loose to Medium Dense	
2	526-1641	977	50 - 200	1.3-6.4	3.5	Sandy gravelly SILT/CLAY	Firm to stiff	Diggable
			200-400			Clayey SAND/GRAVEL	Medium Dense to Dense	
	533-1981	1292	200-3200	0.5-7.7	3.2	Highly to Moderately weathered SANDSTONE	Poor-Fair	Heavy ripping
3	2108-2866	2450	50-300			Slightly weathered to Fresh MUDSTONE	Good/Very good	Break/ blast
	2097-3630	2968	300-2500			Slightly weathered to Fresh SANDSTONE		

From ch.49+500 to ch.50+265 the data indicates an upper layer with an average thickness of 1.1m interpreted as comprising soft to firm sandy gravelly clay/silt or loose to medium dense clayey sand/gravel.

This is underlain by a layer with an average thickness of 3.5m interpreted in conjunction with 49-BH-02 and 50-BH-01 as comprising firm to stiff sandy gravelly clay/silt and medium dense to dense clayey sand/gravel. The resistivities and velocities of this layer could also be indicative of highly to moderately weathered mudstone, however the boreholes encountered till. It may be that this layer incorporates sandy gravelly clay/silt and clayey sand/gravel with some moderately weathered mudstone/shale at its base.

A third layer with high velocities (2108-2866m/s) and low resistivities (50-300 Ohm-m) has been interpreted as indicating slightly weathered to fresh mudstone bedrock. The slightly weathered to fresh mudstone bedrock has been interpreted at depths ranging from 1.3 to 6.4m below ground level.

From ch.50+265 to ch.50+900 the data indicates an upper layer with an average thickness of 1.1m which has been interpreted as comprising loose to medium dense clayey sand/gravel.

This is underlain by a layer with an average thickness of 3.2m which has been interpreted in conjunction with 50-BH-02 and 50-RC-02 as comprising highly to moderately weathered sandstone.

A third layer with high velocities (2097-2968m/s) and high resistivities (300-2500 Ohm-m) has been interpreted in conjunction with 50-RC-02 as slightly weathered to fresh sandstone bedrock. The slightly weathered to fresh bedrock has been interpreted at depths ranging from 0.5 to 7.7m below ground level.

The average velocity of the mudstone bedrock (2450m/s) is significantly lower than the average velocity of the sandstone bedrock (2968m/s).

The MASW signal achieved penetration from 12.5m to 25m bgl. The measured shear wave velocities (Vs) range from 305 to 1703 m/s and the derived G_{max} values range from 186 to 7832 MPa (Appendix II).

The proposed cut level requires excavation of Layer 2 from ch. 49+555 to 50+876 and excavation of Layer 3 from ch. 49+615 to 50+865. A maximum cut of 19.5m is required at ch. 50+525m with a maximum slightly weathered to fresh rock cut of 16.1m at ch. 50+500m.

3. RECOMMENDATIONS

The following recommendations have been made:

Start Chainage	End Chainage	Recommendations
44300	46000	Localised grids of microgravity surveying together with some follow-up orthogonal resistivity profiling should be considered from 44+350 to 44+750m, ch. 45+320 to 45+420m, from ch. 45+555 to 45+570m, from ch. 45+595 to 45+665m, from ch. 45+816 to 45+830m, from ch. 45+855 to 45+890m and from ch. 45+940 to 45+960m to delineate the extent of the karst zones across the motorway corridor followed by targeted rotary coring.
47250	47400	Two trial pits are recommended at the locations indicated on Drawing 10017_04 Figure 3 to investigate the probable fill material to the west and the absence of fill (but possible leachate) to the east.

Where bedrock excavation is proposed a detailed assessment of excavatability should be carried out combining the results of the geophysical survey, rotary core drilling, strength testing, and trial excavation pits using a high powered excavator. A more detailed discussion of velocity and excavatability is contained in Appendix III.

The normal mitigation measures applying to construction over karstic limestone, such as sealed drainage, and foundations capable of spanning voids that may migrate to the surface, should be incorporated into the design.

A surface water management plan is advised to avoid activation of karst features which may alter surface drainage.

The interpretation of the geophysical data should be reviewed on receipt of the completed rotary core, borehole and trial pit logs.

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APPENDIX I GEOPHYSICAL METHODLOGY

M1. **Methods Used**

1.1 2D-Resistivity Profiling

1.2 Seismic Refraction Profiling

1.3 EM31 Conductivity Mapping

M2. **Equipment Used**

2.1 2D-Resistivity Profiling

2.2 Seismic Refraction Profiling

2.3 EM31 Conductivity Mapping

M3. **Field Procedure**

3.1 2D-Resistivity Profiling

3.2 Seismic Refraction Profiling

3.3 EM31 Conductivity Mapping

M4. **Data Processing**

4.1 2D-Resistivity Profiling

4.2 Seismic Refraction Profiling

4.3 EM31 Conductivity Mapping

M1. Methods Used

1.1 2D-Resistivity Profiling

The resistivity surveying technique used for the survey makes use of the Wenner resistivity array whereby four electrodes are placed in a line in the ground and a current is passed through the two outer electrodes. The potential difference is measured across the two inner electrodes. The measured potential is divided by the current value to obtain the resistance. The resistivity is determined from the resistance using the following formula: Resistivity = Resistance* 2 * Pi * Spacing.

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 32 to 64 electrodes connected to a resistivity meter, using computer software to control the process of data collection and storage.

1.2 Seismic Refraction Profiling

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. Readings are taken using geophones connected via multi-core cable to a seismograph.

In the MASW method Surface waves (Rayleigh waves) are utilized 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 Multi-channel Analysis of Surface Waves (MASW) was used for this survey (Park et al., 1998, 1999). This 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 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.

1.3 EM31 Conductivity Mapping

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). As the effective penetration of this method is around 6m below ground level the measured conductivity is a function of the different overburden layers and/or rock from 0 to 6m below ground level.

M2. Equipment Used

2.1 2D-Resistivity Profiling

A Campus Tigre with three 32 take-out cables and 96 stainless steel electrodes were used. Equipment was carried in a 4WD. A 2/3 person crew was employed.

2.2 Seismic Refraction Profiling

A Geode 24 channel digital seismograph, 10HZ vertical geophones and a 10 kg hammer were used to provide unambiguous first breaks, with a 24 take-out cable and a trigger geophone. Equipment was carried in a 4WD vehicle with a 2/3 person crew.

2.3 EM31 Conductivity Mapping

The equipment used was a GF Instruments CM31 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.

M3. Field Procedure

3.1 2D-Resistivity Profiling

Twenty profiles were recorded between the 26th January and the 31st February and from the 16th to the 17th February 2010. Resistances were measured for expanding arrays. 2 cycles were recorded to 3% repeatability. Saline solution was added around electrodes in areas of high contact resistance. Local conditions and variations were recorded. QC inversion of each profile was carried out before removal of electrodes.

3.2 Seismic Refraction Profiling

Forty five seismic spreads were recorded between the 26th January and the 31st February 2010. The seismic spreads consisted of 24 collinear geophones at spacings of 3m. Records from up to seven different positions were taken on each spread (2 x off-end, 2 x end, 3 x middle) to ensure optimum coverage of all refractors. Ongoing estimation of refractor velocities was carried out to monitor refractor type and depth.

3.3 EM31 Conductivity Mapping

A total of 804 conductivity readings were recorded on the 17th February 2010. Conductivity and in-phase values were recorded at 3m separations along accessible lines through the survey area. Local conditions and variations were recorded.

M4. Data Processing

4.1 2D-Resistivity Profiling

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 to obtain a 2D-Depth model of the resistivities.

The inverted 2D-Resistivity model and corresponding interpreted geology are displayed on Drawings 10017_01 to 10017_05. The chainage is indicated along the horizontal axis of the profile and the depth below ground level is indicated on the vertical axis.

It is important to note that the data displayed on the 2D-Resistivity profiles is real physical data however interpretation of the geophysical results is required to transform the resistivities directly into geological layers.

4.2 Seismic Refraction Profiling

For the P-wave interpretation, first break picking in digital format was carried out using the FIRSTPIX software program to construct traveltime plots for each spread. Velocity phases were selected from these plots using the GREMIX software program and were used to calculate the thickness of individual velocity units. Topographic data were input. Material types were assigned and estimation made of material properties, cross-referenced to the 2D Resistivity and borehole data. The processed seismic data are displayed on Drawings 10017_01 to 10017_05.

Approximate errors for 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).

For the S-wave interpretation, processing was carried out using the SURFSEIS processing package developed by Kansas Geological Survey (KGS, 2000). SURFSEIS is designed to generate a shear wave velocity profile. SURFSEIS data processing involves three steps:

(i) Preparation of the acquired multichannel record. This involves converting the 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.

The shear wave velocities were then converted into shear modulus values using the formula:

$$G = V_s^2 * \rho / 1000000$$

Where G = Shear Modulus (MPa)
V_s = Shear Wave Velocity (m/s)
ρ = Density (kg/m^3)

Processing parameters were optimized by test processing using varying options in the processing package and also by reference to optimal parameters referred to in the literature.

For the purpose of the calculation in this report a soil density of 2000 kg/m^3 and a rock density of 2700kg/m^3 have been used.

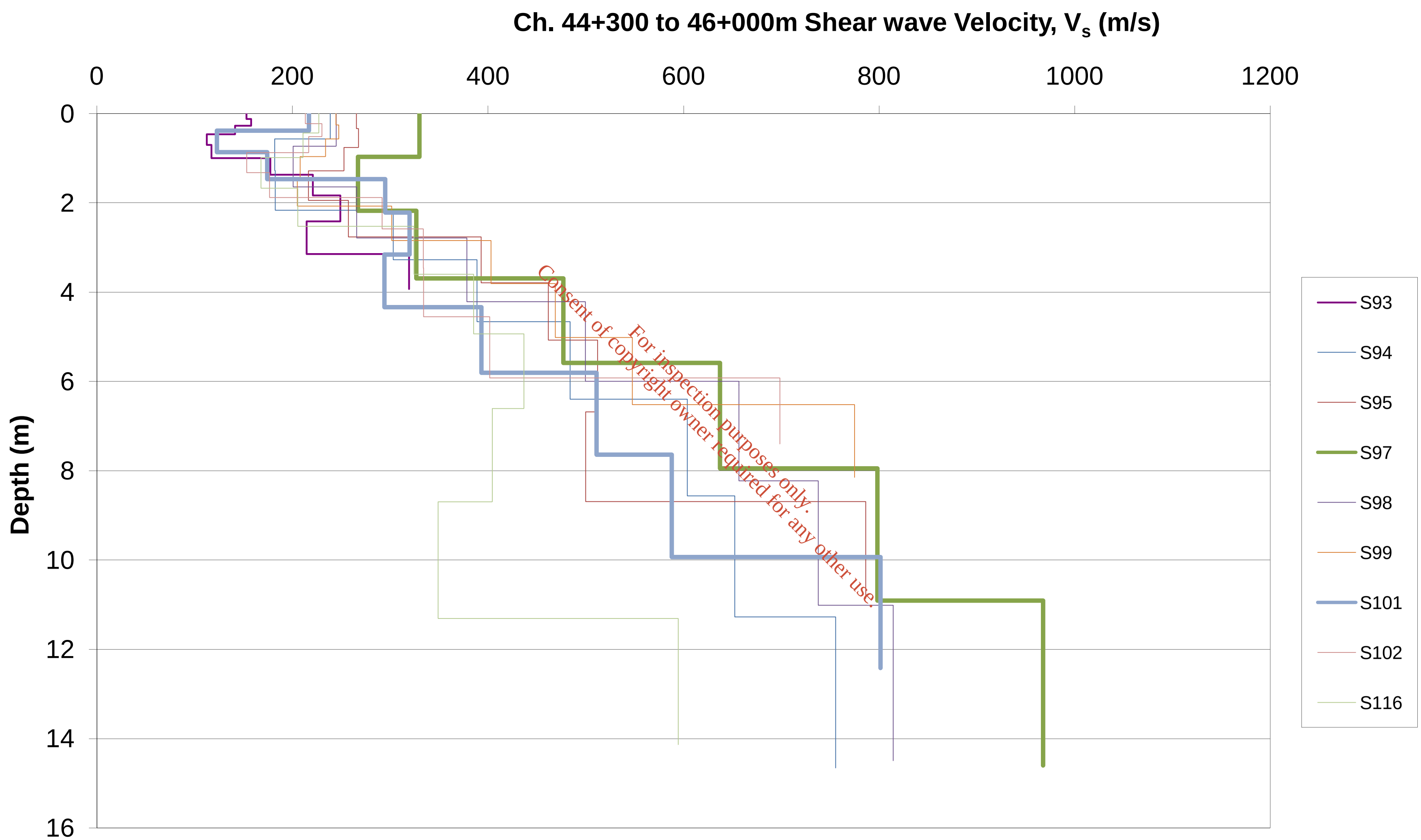
The processed MASW data indicating shear wave velocities and Gmax values are contained in Appendix II.

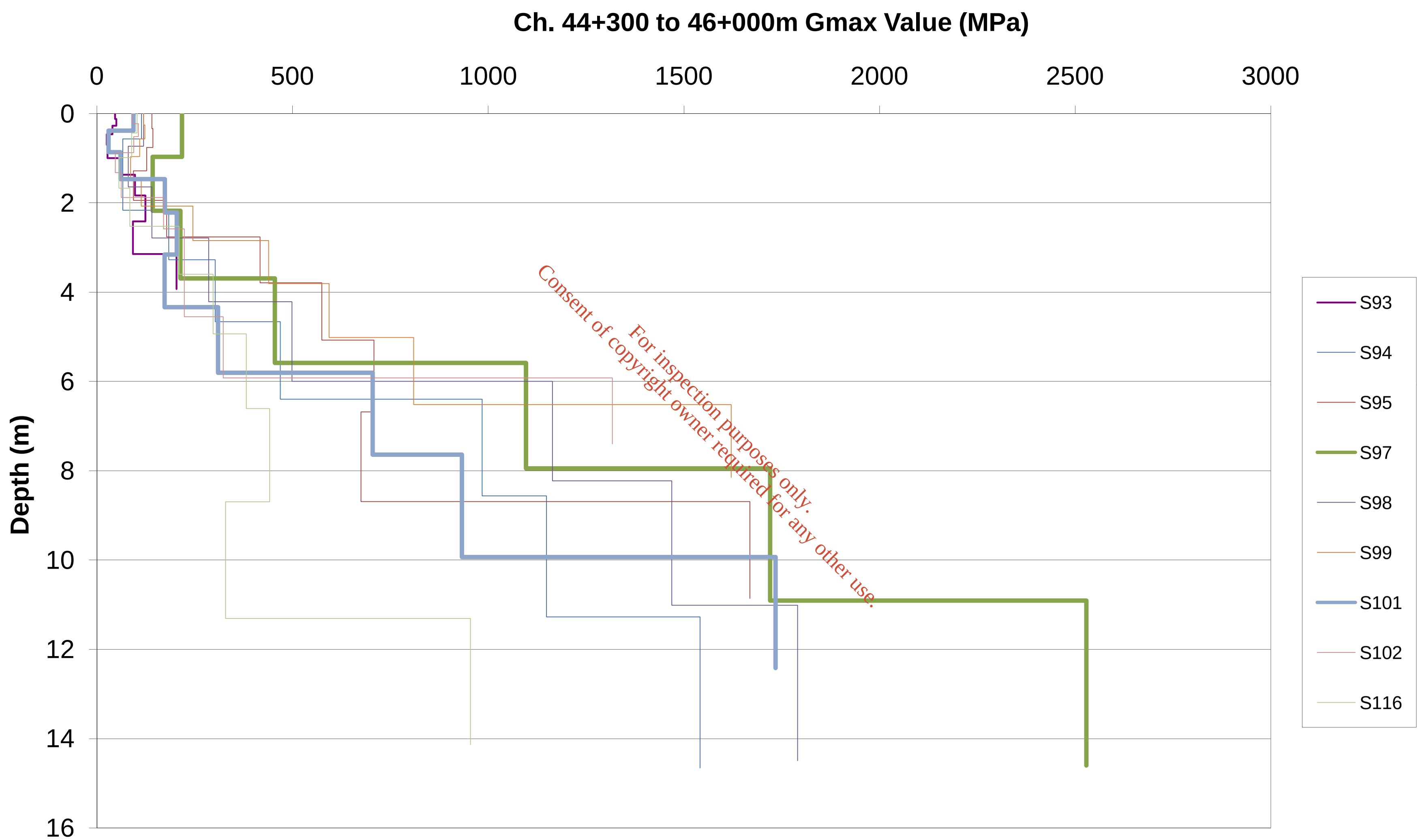
4.3 EM31 Conductivity Mapping

The data were downloaded and plotted using the SURFER contouring software. Assignation of material types was carried out, with cross-reference to other data. A scaled plot of conductivity was prepared (Drawing 10017_01).

APPENDIX II MASW DATA

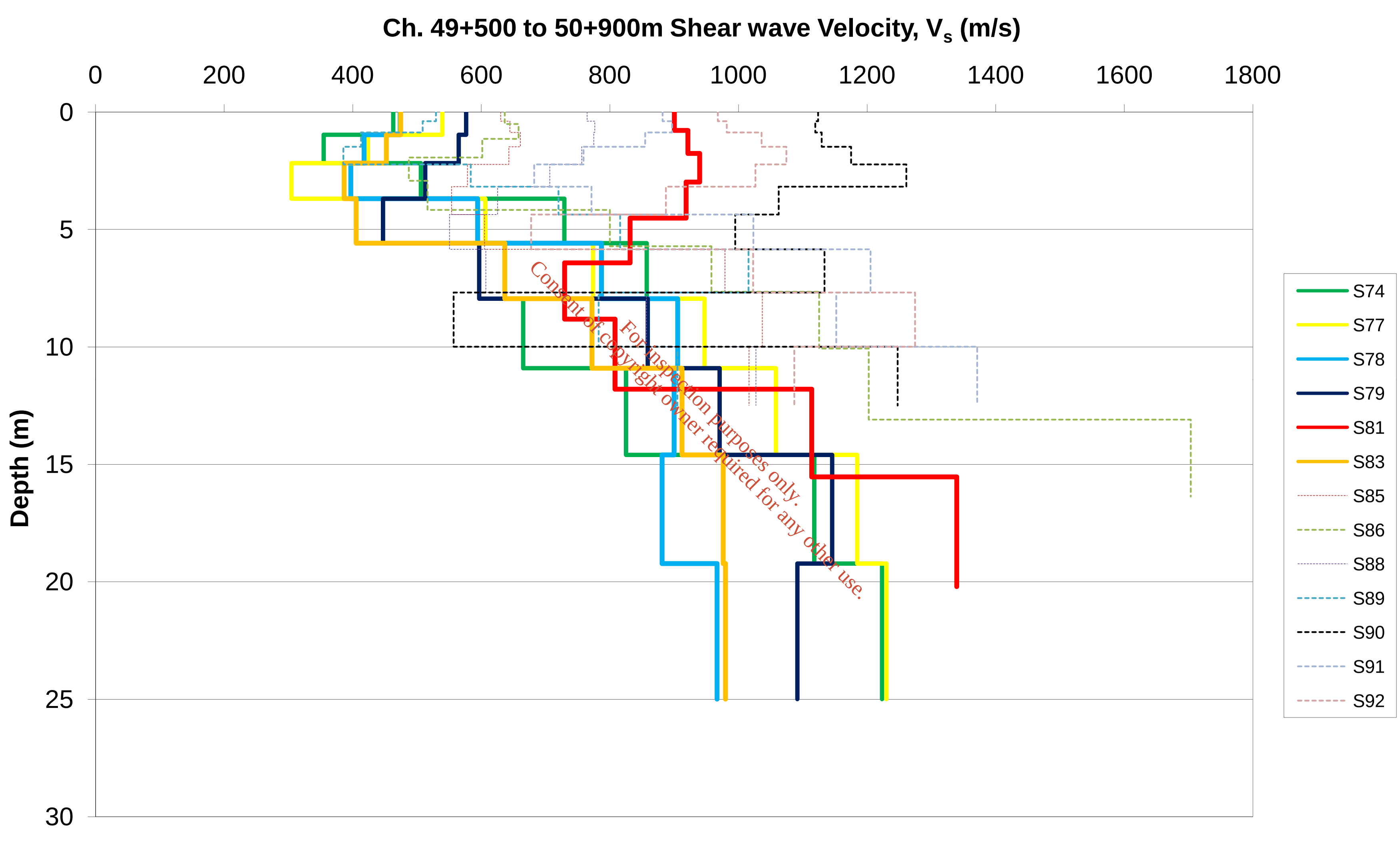
S93			S94			S95			S97			S98			S99			S101			S102			S116		
Depth m	Vs m/s	Gmax MPa	Depth m	Vs m/s	Gmax MPa	Depth m	Vs m/s	Gmax MPa	Depth m	Vs m/s	Gmax MPa	Depth m	Vs m/s	Gmax MPa	Depth m	Vs m/s	Gmax MPa	Depth m	Vs m/s	Gmax MPa	Depth m	Vs m/s	Gmax MPa	Depth m	Vs m/s	Gmax MPa
0	153	47	0.00	239	114	0	265	141	0	330	218	0	245	120	0	245	120	0	217	94	0	213	91	0	227	103
0.122	153	47	0.57	239	114	0.337	265	141	0.969	330	218	0.731	245	120	0.253	245	120	0.385	217	94	0.229	213	91	0.438	227	103
0.122	157.7	50	0.57	182	66	0.337	268	143	0.969	267	143	0.731	201	81	0.253	248	123	0.385	123	30	0.229	230	106	0.438	211	89
0.274	157.7	50	1.28	182	66	0.758	268	143	2.18	267	143	1.644	201	81	0.569	248	123	0.866	123	30	0.516	230	106	0.986	211	89
0.274	141.3	40	1.28	183	67	0.758	253	128	2.18	327	214	1.644	266	141	0.569	234	110	0.866	174	61	0.516	217	94	0.986	168	56
0.464	141.3	40	2.17	183	67	1.284	253	128	3.694	327	214	2.786	266	141	0.964	234	110	1.468	174	61	0.875	217	94	1.671	168	56
0.464	112.4	25	2.17	303	184	1.284	216	94	3.694	477	455	2.786	378	286	0.964	208	86	1.468	295	174	0.875	153	47	1.671	206	85
0.702	112.4	25	3.28	303	184	1.942	216	94	5.586	477	455	4.213	378	286	1.457	208	86	2.22	295	174	1.323	153	47	2.527	206	85
0.702	117.1	27	3.28	389	303	1.942	257	179	5.586	637	1096	4.213	500	499	1.457	205	114	2.22	320	205	1.323	177	63	2.527	324	210
0.999	117.1	27	4.66	389	303	2.764	257	179	7.951	637	1096	5.997	500	499	2.074	205	114	3.16	320	205	1.883	177	63	3.597	324	210
0.999	177.3	63	4.66	484	469	2.764	393	417	7.951	798	1720	5.997	657	1164	2.074	302	246	3.16	294	173	1.883	292	170	3.597	385	297
1.371	177.3	63	6.40	484	469	3.792	393	417	10.908	798	1720	8.227	657	1164	2.845	302	246	4.335	294	173	2.583	292	170	4.934	385	297
1.371	220.8	97	6.40	604	984	3.792	462	575	10.908	968	2529	8.227	738	1470	2.845	403	439	4.335	393	310	2.583	334	223	4.934	437	382
1.836	220.8	97	8.57	604	984	5.076	462	575	14.604	968	2529	11.014	738	1470	3.809	403	439	5.804	393	310	3.458	334	223	6.606	437	382
1.836	248.9	124	8.57	652	1149	5.076	512	708				11.014	814	1791	3.809	469	594	5.804	511	705	3.458	334	223	6.606	404	442
2.417	248.9	124	11.28	652	1149	6.682	512	708				14.498	814	1791	5.014	469	594	7.64	511	705	4.552	334	223	8.696	404	442
2.417	214.5	92	11.28	756	1541	6.682	500	675							5.014	548	810	7.64	588	933	4.552	402	323	8.696	349	329
3.143	214.5	92	14.66	756	1541	8.689	500	675							6.52	548	810	9.935	588	933	5.92	402	323	11.308	349	329
3.143	319.2	204				8.689	786	1669							6.52	775	1621	9.935	801	1734	5.92	698	1317	11.308	595	955
3.929	319.2	204				10.861	786	1669							8.15	775	1621	12.419	801	1734	7.4	698	1317	14.135	595	955

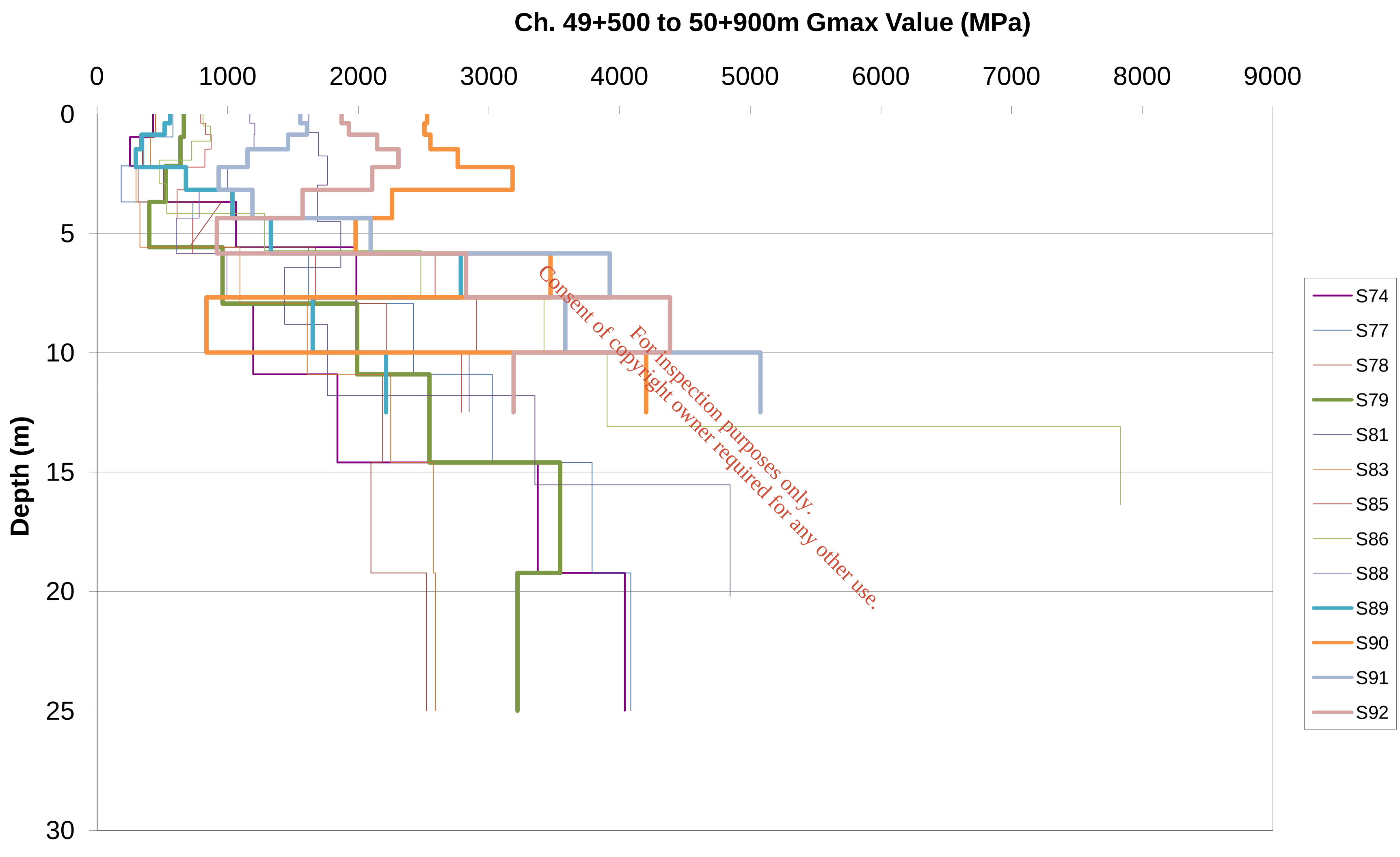

Ch. 44+300 to 46+000m Shear wave Velocity, Vs (m/s)
0
200
400
600
800
1000
1200
Depth (m)
0
2
4
6
8
10
12
14
16
S93
S94
S95
S97
S98
S99
S101
S102
S116


Ch. 44+300 to 46+000m Gmax Value (MPa)
0
500
1000
1500
2000
2500
3000
Depth (m)
0
2
4
6
8
10
12
14
16
S93
S94
S95
S97
S98
S99
S101
S102
S116

S74			S77			S78			S79			S81			S83			S85		
Depth m	Vs m/s	Gmax MPa	Depth m	Vs m/s	Gmax MPa	Depth m	Vs m/s	Gmax MPa	Depth m	Vs m/s	Gmax MPa	Depth m	Vs m/s	Gmax MPa	Depth m	Vs m/s	Gmax MPa	Depth m	Vs m/s	Gmax MPa
0	463	429	0	539	582	0	474	450	0	576	664	0.00	900	1621	0.00	475	451	0.00	630	794
0.969	463	429	0.969	539	582	0.969	474	450	0.969	576	664	0.78	900	1621	0.97	475	451	0.39	630	794
0.969	355	252	0.969	424	359	0.969	418	350	0.969	565	639	0.78	921	1697	0.97	452	409	0.39	644	831
2.18	355	252	2.18	424	359	2.18	418	350	2.18	565	639	1.76	921	1697	2.18	452	409	0.87	644	831
2.18	506	513	2.18	305	186	2.18	397	316	2.18	513	526	1.76	939	1765	2.18	387	299	0.87	661	873
3.694	506	513	3.694	305	186	3.694	397	316	3.694	513	526	2.99	939	1765	3.69	387	299	1.48	661	873
3.694	729	1064	3.694	607	736	3.694	594	954	3.694	447	400	2.99	918	1686	3.69	406	329	1.48	643	826
5.586	729	1064	5.586	607	736	5.586	594	707	5.586	447	400	4.51	918	1686	5.59	406	329	2.24	643	826
5.586	857	1984	5.586	774	1617	5.586	787	1673	5.586	597	962	4.51	831	1866	5.59	637	1094	2.24	579	669
7.951	857	1984	7.951	774	1617	7.951	787	1673	7.951	597	962	6.43	831	1866	7.95	637	1094	3.18	579	669
7.951	665	1194	7.951	947	2422	7.951	905	2214	7.951	859	1992	6.43	729	1437	7.95	772	1611	3.18	554	613
10.908	665	1194	10.908	947	2422	10.908	905	2214	10.908	859	1992	8.82	729	1437	10.91	772	1611	4.36	554	613
10.908	825	1839	10.908	1058	3024	10.908	900	2186	10.908	971	2544	8.82	808	1763	10.91	913	2248	4.36	605	732
14.604	825	1839	14.604	1058	3024	14.604	900	2186	14.604	971	2544	11.80	808	1763	14.60	913	2248	5.84	605	732
14.604	1118	3373	14.604	1185	3789	14.604	881	2097	14.604	1146	3544	11.80	1114	3351	14.60	976	2574	5.84	979	2588
19.224	1118	3373	19.224	1185	3789	19.224	881	2097	19.224	1146	3544	15.54	1114	3351	19.22	976	2574	7.69	979	2588
19.224	1223	4040	19.224	1230	4085	19.224	967	2523	19.224	1092	3218	15.54	1340	4845	19.22	980	2593	7.69	1037	2904
24.999	1223	4040	24.999	1230	4085	24.999	967	2523	24.999	1092	3218	20.20	1340	4845	25.00	980	2593	10.00	1037	2904
24.999	1206	3925	24.999	1303	4582	24.999	1287	4471	24.999	1720	7989	20.20	1970	10478	25.00	1408	5356	10.00	1016	2789
31.249	1206	3925	31.249	1303	4582	31.249	1287	4471	31.249	1720	7989	25.26	1970	10478	31.25	1408	5356	12.50	1016	2789

S86			S88			S89			S90			S91			S92		
Depth m	Vs m/s	Gmax MPa	Depth m	Vs m/s	Gmax MPa	Depth m	Vs m/s	Gmax MPa	Depth m	Vs m/s	Gmax MPa	Depth m	Vs m/s	Gmax MPa	Depth m	Vs m/s	Gmax MPa
0.00	637	811	0.00	765	1170	0.00	529	560	0.00	1124	2527	0.00	882	1556	0.00	968	1873
0.51	637	811	0.39	765	1170	0.39	529	560	0.39	1124	2527	0.39	882	1556	0.39	968	1873
0.51	658	866	0.39	777	1206	0.39	509	518	0.39	1119	2506	0.39	897	1608	0.39	982	1927
1.14	658	866	0.87	777	1206	0.87	509	518	0.87	1119	2506	0.87	897	1608	0.87	982	1927
1.14	602	724	0.87	775	1202	0.87	413	341	0.87	1130	2552	0.87	855	1462	0.87	1036	2146
1.94	602	724	1.48	775	1202	1.48	413	341	1.48	1130	2552	1.48	855	1462	1.48	1036	2146
1.94	488	475	1.48	756	1144	1.48	385	297	1.48	1175	2761	1.48	759	1153	1.48	1074	2309
2.93	488	475	2.24	756	1144	2.24	385	297	2.24	1175	2761	2.24	759	1153	2.24	1074	2309
2.93	517	534	2.24	707	999	2.24	583	681	2.24	1261	3181	2.24	682	931	2.24	1026	2107
4.17	517	534	3.18	707	999	3.18	583	681	3.18	1261	3181	3.18	682	931	3.18	1026	2107
4.17	800	1281	3.18	625	782	3.18	720	1037	3.18	1063	2259	3.18	771	1190	3.18	887	1574
5.72	800	1281	4.36	625	782	4.36	720	1037	4.36	1063	2259	4.36	771	1190	4.36	887	1574
5.72	958	2477	4.36	551	606	4.36	816	1331	4.36	995	1980	4.36	1023	2094	4.36	677	918
7.65	958	2477	5.84	551	606	5.84	816	1331	5.84	995	1980	5.84	1023	2094	5.84	677	918
7.65	1125	3420	5.84	607	995	5.84	1016	2785	5.84	1134	3470	5.84	1206	3924	5.84	1023	2825
10.08	1125	3420	7.69	607	995	7.69	1016	2785	7.69	1134	3470	7.69	1206	3924	7.69	1023	2825
10.08	1202	3904	7.69	857	1983	7.69	782	1653	7.69	557	838	7.69	1152	3584	7.69	1274	4386
13.10	1202	3904	10.00	857	1983	10.00	782	1653	10.00	557	838	10.00	1152	3584	10.00	1274	4386
13.10	1703	7832	10.00	1027	2849	10.00	905	2212	10.00	1248	4203	10.00	1371	5077	10.00	1087	3189
16.38	1703	7832	12.50	1027	2849	12.50	905	2212	12.50	1248	4203	12.50	1371	5077	12.50	1087	3189


Ch. 49+500 to 50+900m Shear wave Velocity, V_s (m/s)
0
200
400
600
800
1000
1200
1400
1600
1800
Depth (m)
0
5
10
15
20
25
30
S74
S77
S78
S79
S81
S83
S85
S86
S88
S89
S90
S91
S92



Ch. 49+500 to 50+900m Gmax Value (MPa)
Depth (m)
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
0
5
10
15
20
25
30
S74
S77
S78
S79
S81
S83
S85
S86
S88
S89
S90
S91
S92

APPENDIX III EXCAVATABILITY RATING

The seismic velocity of a rock formation is related to characteristics of the rock mass which include rock hardness and strength, degree of weathering and discontinuities. Usually the velocity is just one of several parameters used in the assessment of excavatability. The excavatability of a rock formation is favoured by the following factors:

- Open fractures, faults and other planes of weakness of any kind
- Weathering
- Brittleness and crystalline nature
- High degree of stratification or lamination
- Large grain size
- Low compressive strength

Weaver (1975) presented a comprehensive rippability rating chart (Fig.1) in which the p-wave velocity value and the relevant geological factors could be entered and assigned appropriate weightings. The total weighted index was found to correlate very well with actual rippability.

Fig.1 Rippability Rating Chart

Rock class	I	II	III	IV	V
Description	Very good rock	Good rock	Fair rock	Poor rock	Very poor rock
Seismic velocity (m/s)	>2150	2150-1850	1850-1500	1500-1200	1200-450
Rating	26	24	20	12	5
Rock hardness	Extremely hard rock	Very hard rock	Hard rock	Soft rock	Very soft rock
Rating	10	5	2	1	0
Rock weathering	Unweathered	Slightly weathered	Weathered	Highly weathered	Completely weathered
Rating	9	7	5	3	1
Joint spacing (mm)	>3000	3000-1000	1000-300	300-50	<50
Rating	30	25	20	10	5
Joint continuity	Non continuous	Slightly continuous	Continuous- no gouge	Continuous- some gouge	Continuous- with gouge
Rating	5	5	3	0	0
Joint gouge	No separation	Slight separation	Separation <1mm	Gouge <5mm	Gouge >5mm
Rating	5	5	4	3	1
Strike and dip orientation	Very unfavourable	Unfavourable	Slightly unfavourable	Favourable	Very favourable
Rating	15	13	10	5	3
Total rating	100-90	90-70*	70-50	50-25	<25
Rippability assessment	Blasting	Extremely hard ripping and blasting	Very hard ripping	Hard ripping	Easy ripping
Tractor horsepower		770/385	385/270	270/180	180
Tractor kilowatts		575/290	290/200	200/135	135

FIGURE 1: Geophysical Survey Locations
Scale 1:1000

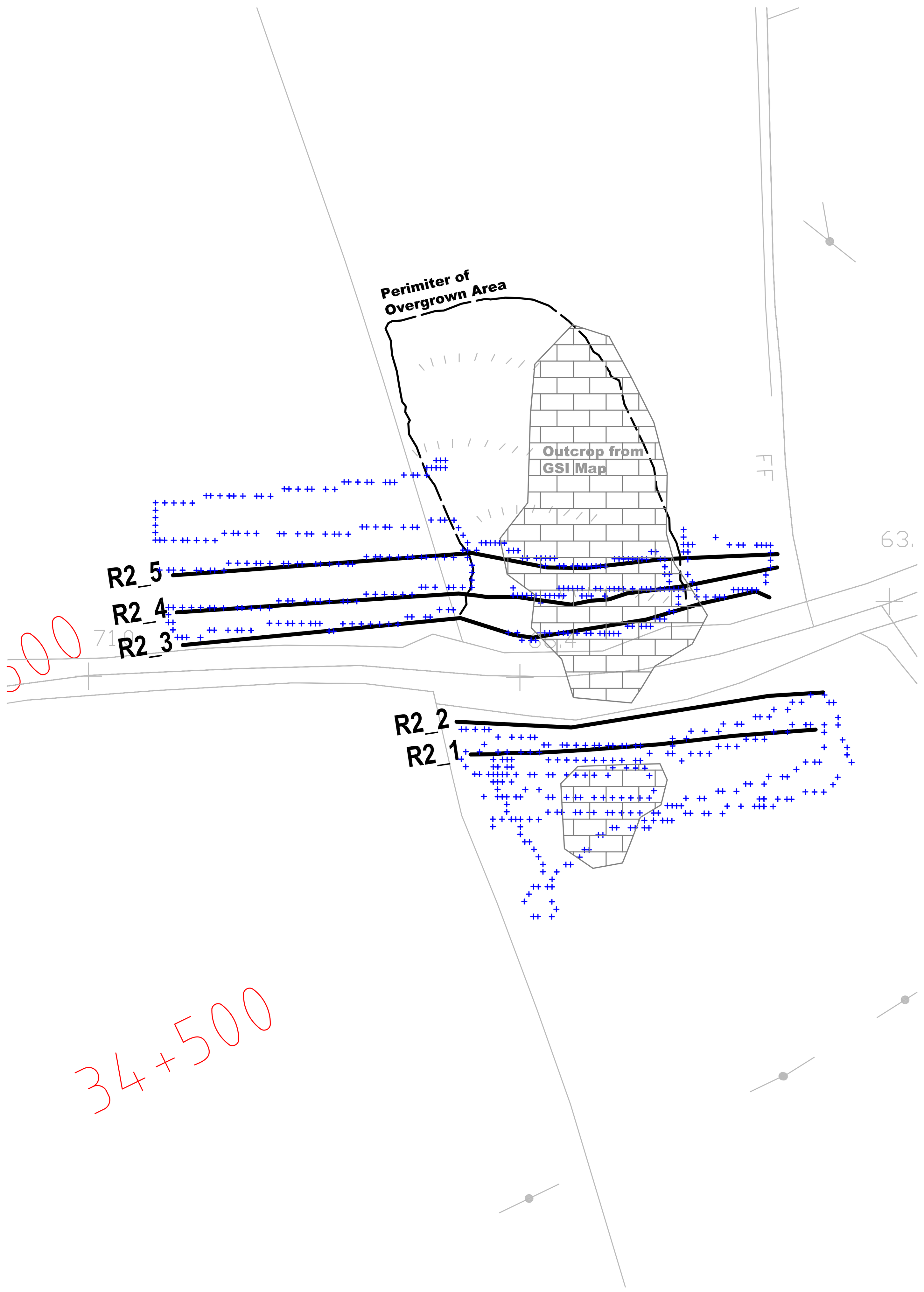


FIGURE 2: EM Conductivity Contours (mS/m)
Scale 1:1000

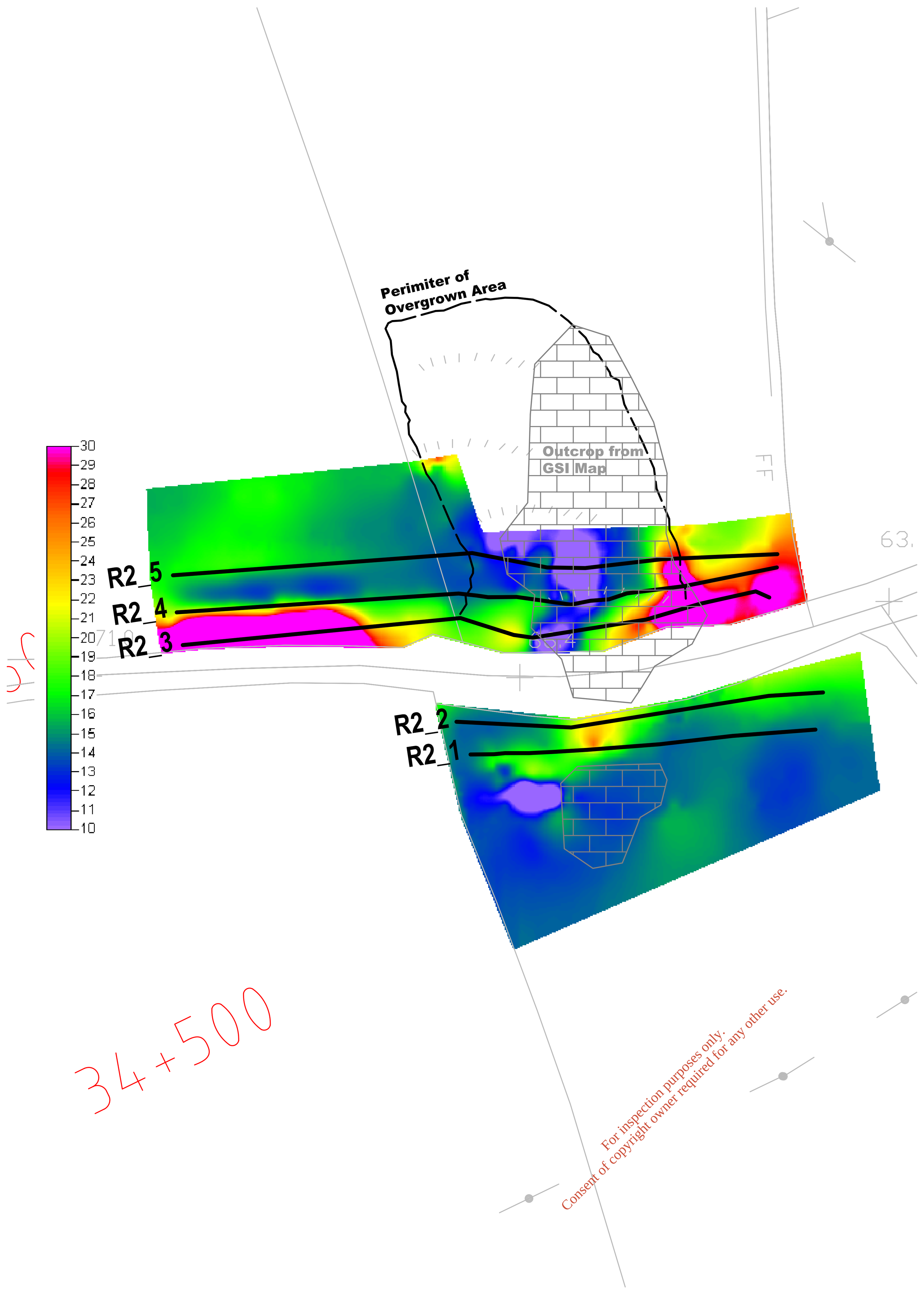


FIGURE 3: Summary Map
Scale 1:1000

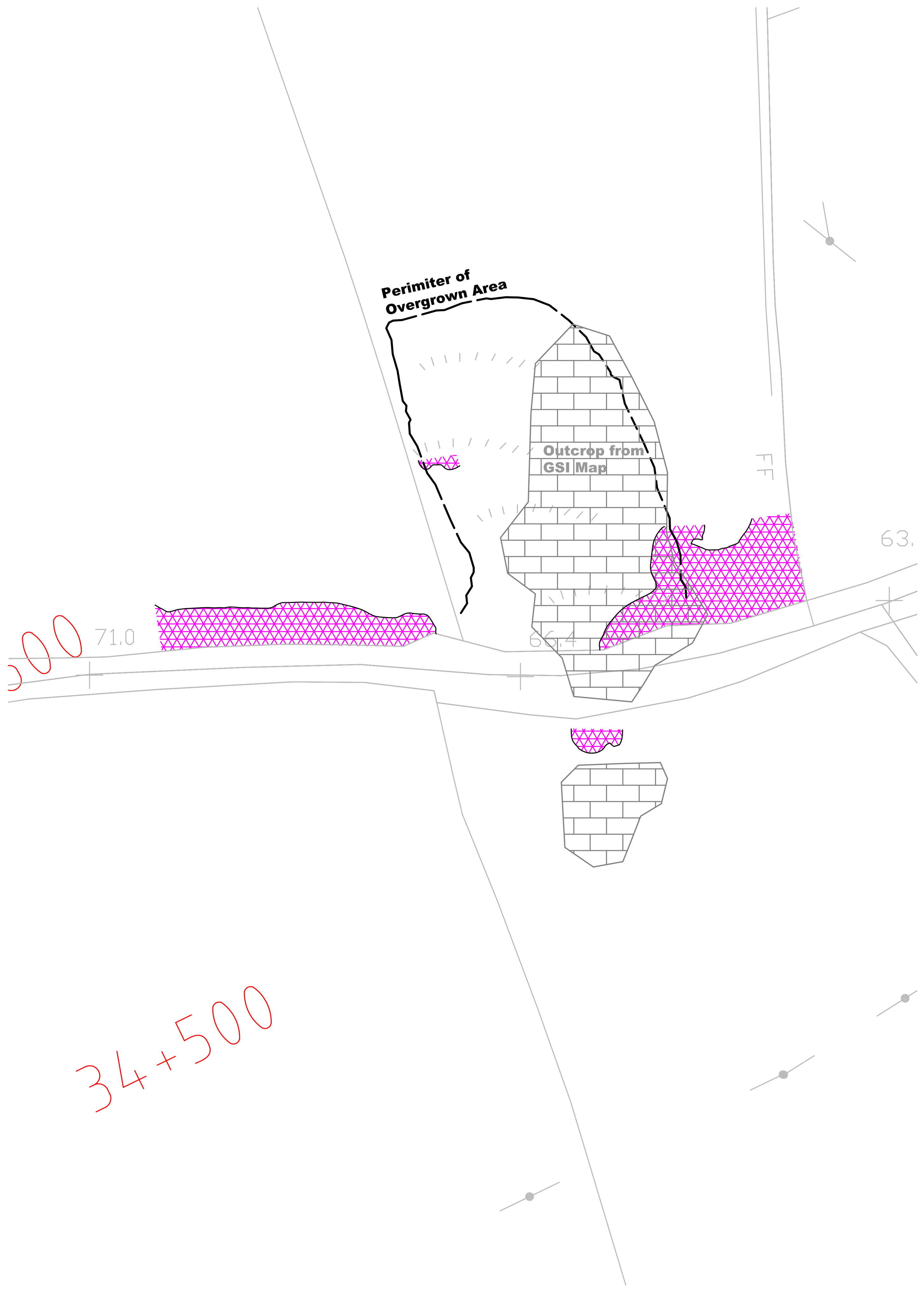
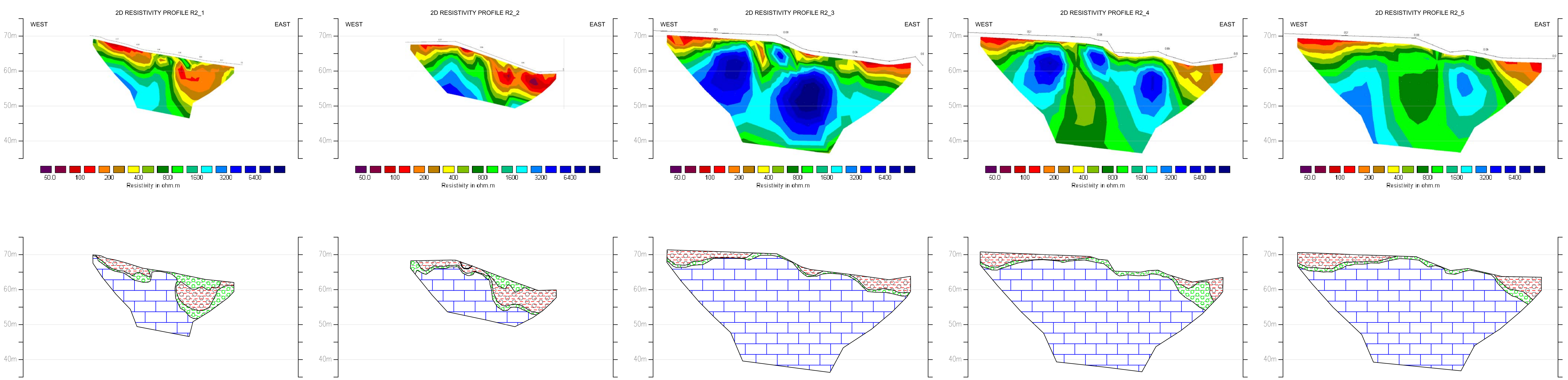


FIGURE 4: Geological Interpretation
Scale Horz. 1:1250 & Vert. x 2



INDEX MAP:

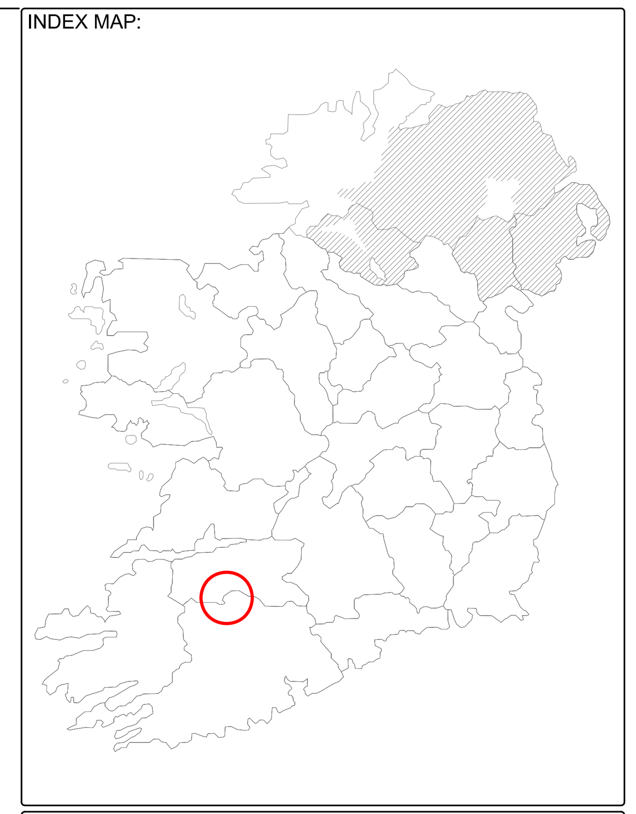


Figure 1 Legend

- R2_1 — 2D Resistivity Profile
- EM Conductivity Location

Figure 3 Legend

- Waste/Refuse on Surface and/or interference from metal gates/fences

Figure 4 Legend

- sandy gravelly CLAY/SILT
- clayey SAND/GRAVEL
- LIMESTONE

NOTES:

TITLE:	GEOPHYSICAL SURVEY
PROJECT:	M20 Cork to Limerick
CLIENT:	WYG
DRAWING:	Ch 34+500
DRAWING NUMBER:	10017_01
SCALE:	As Shown @ A1
DATE:	19th February 2010
DRAWN:	YOC
CHECKED:	

REVISION:	DATE:	DRAWN:	CHECKED:
V1			

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FIGURE 1: Geophysical Survey Locations
Scale 1:2000

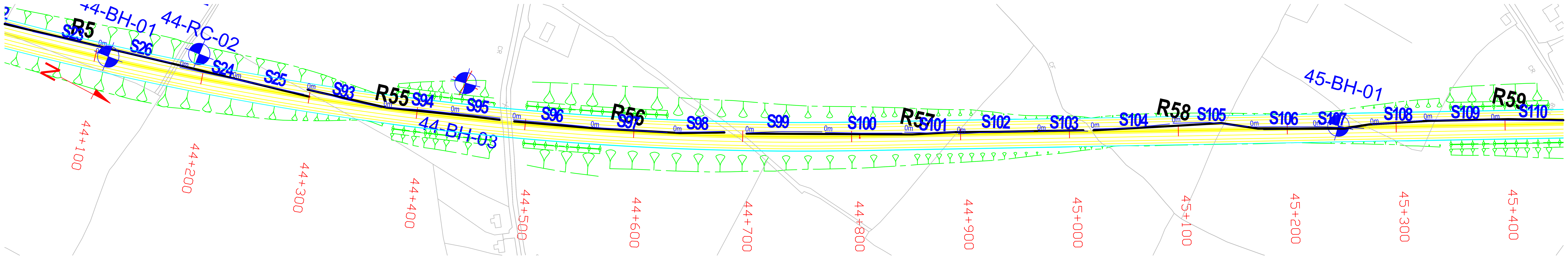


FIGURE 2: 2D Resistivity & Seismic Velocity Profiles
Scale 1:2000

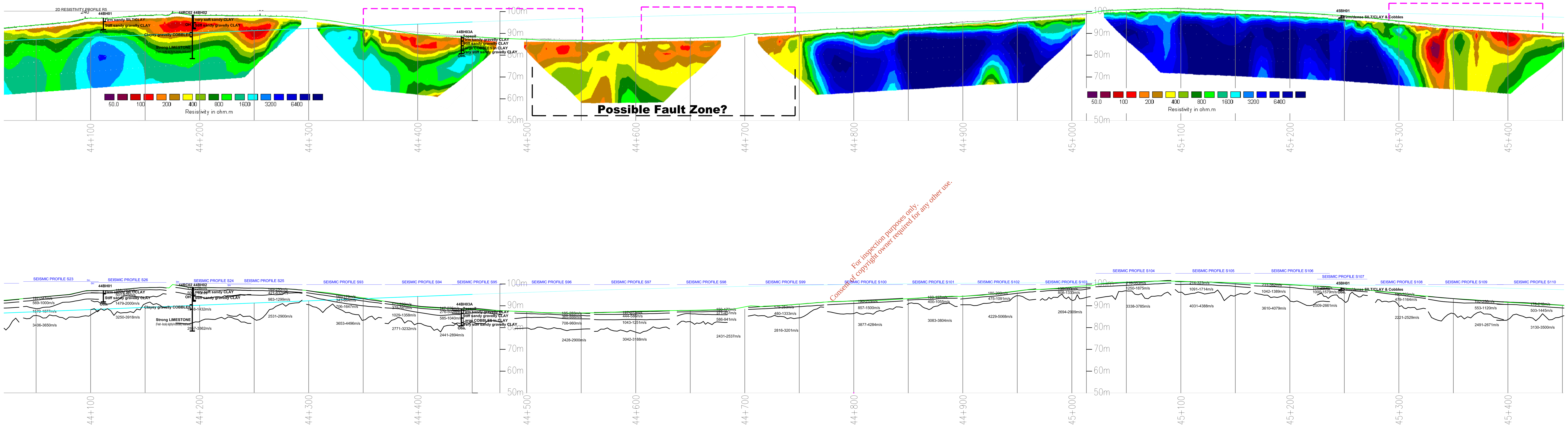
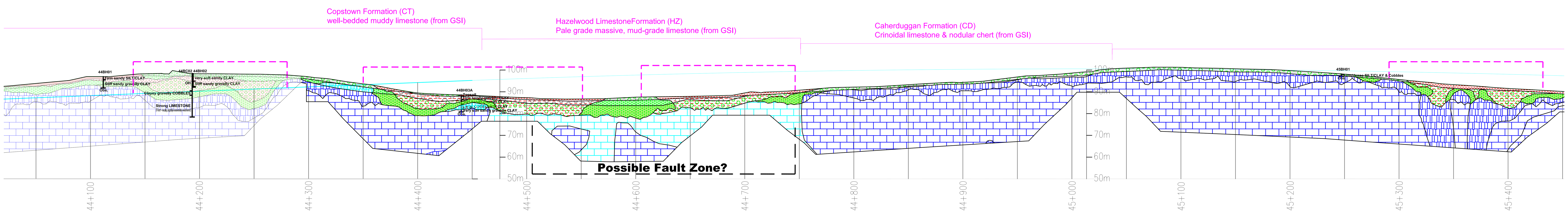
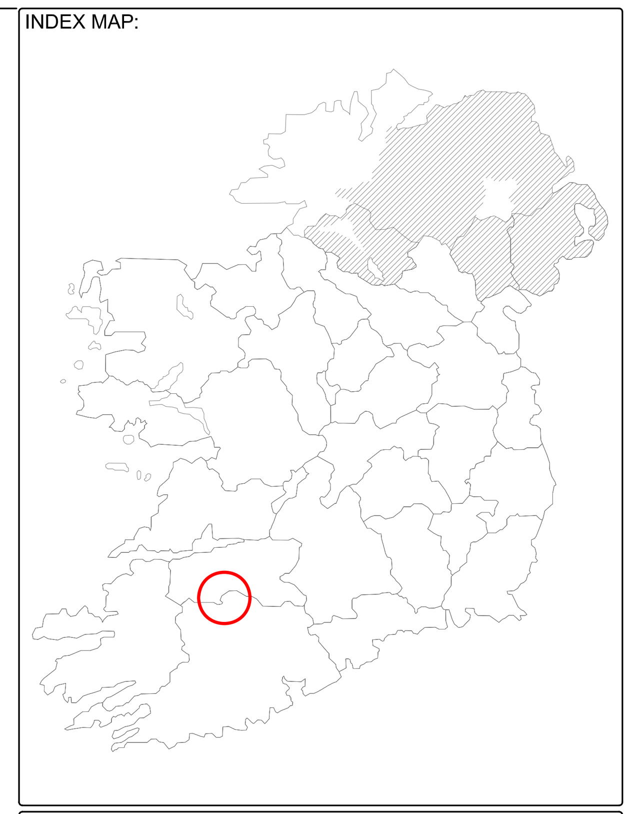


FIGURE 3: Geological Interpretation
Scale 1:2000 (Hz), (Vertical x 2)



INDEX MAP:



LEGEND:

- R6 — 2D Resistivity Profile
- S9 — Seismic Profile
- Soft to firm sandy gravelly CLAY/SILT
- Firm sandy gravelly CLAY/SILT
- Firm to stiff sandy gravelly CLAY/SILT
- Loose to Medium Dense clayey SAND/GRAVEL
- Medium Dense clayey SAND/GRAVEL
- Medium Dense to Dense clayey SAND/GRAVEL
- Highly Weathered LIMESTONE
- Moderately to Slightly Weathered LIMESTONE
- Slightly Weathered to Fresh LIMESTONE
- Possible Argillaceous LIMESTONE
- Borehole Depth to Refusal

NOTES:

TITLE:	GEOPHYSICAL SURVEY
PROJECT:	M20 Cork to Limerick
CLIENT:	WYG
DRAWING:	Ch 44+300 to 46+000
DRAWING NUMBER:	10017_02
SCALE:	Horz 1:2000 (Vert x 2)
DATE:	January 2010
DRAWN:	YOC
CHECKED:	

REVISION:	DATE:	DRAWN:	CHECKED:
-			

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www.apexgeoservices.co.uk

FIGURE 1: Geophysical Survey Locations
Scale 1:2000

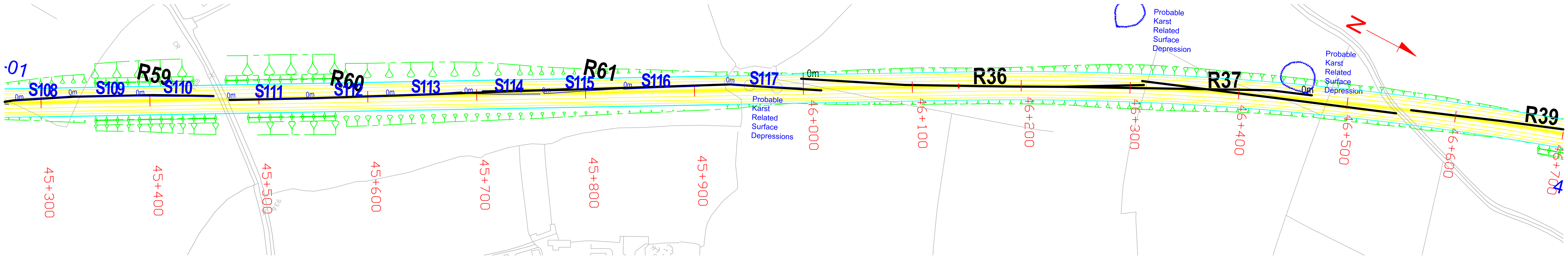


FIGURE 2: 2D Resistivity & Seismic Velocity Profiles
Scale 1:2000

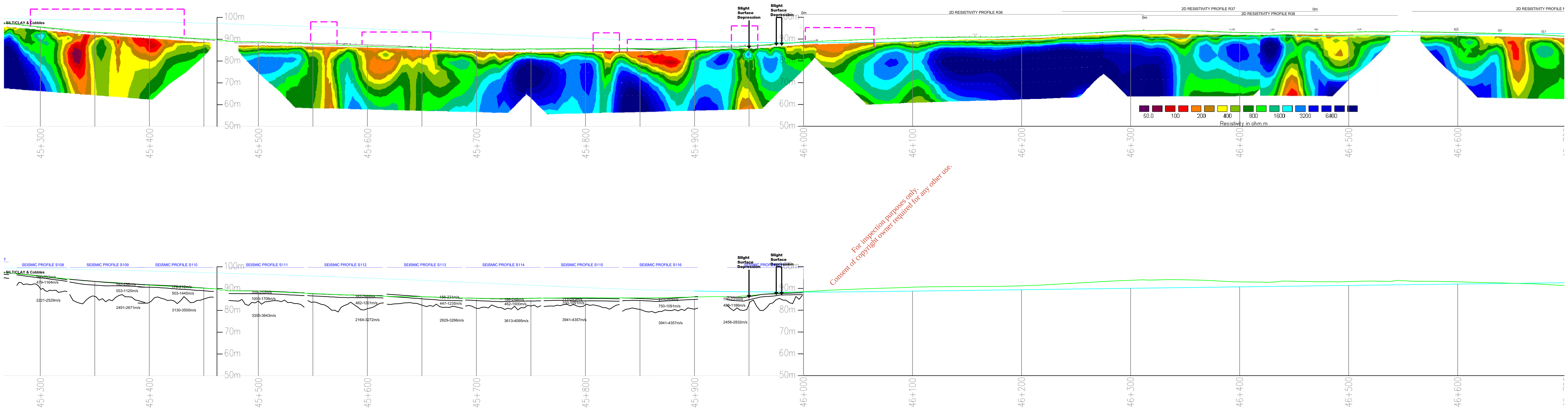
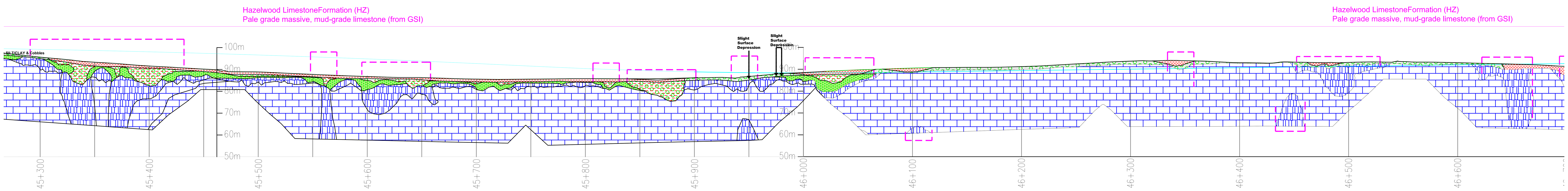
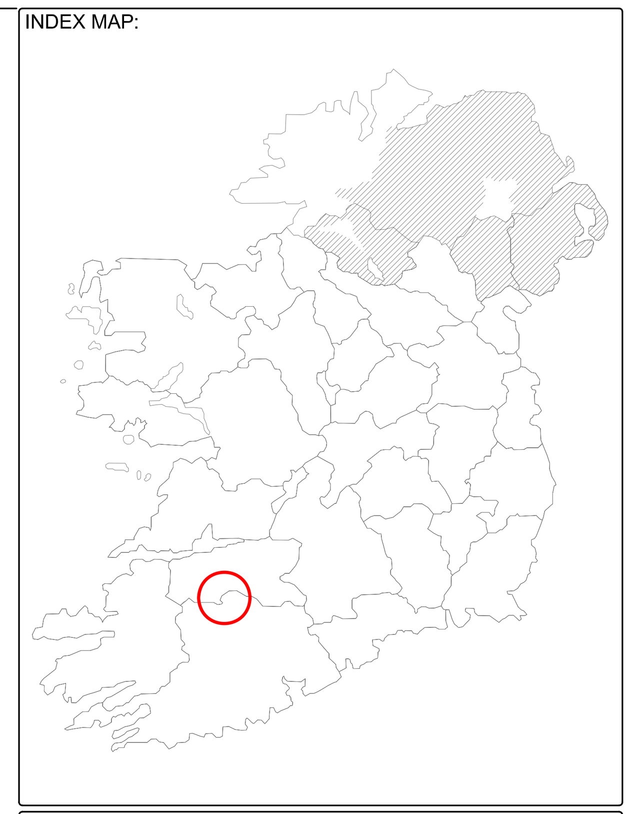


FIGURE 3: Geological Interpretation
Scale 1:2000 (Hz), (Vertical x 2)



INDEX MAP:



LEGEND:
- R6 2D Resistivity Profile
- S9 Seismic Profile
- Soft to firm sandy gravelly CLAY/SILT
- Firm sandy gravelly CLAY/SILT
- Firm to stiff sandy gravelly CLAY/SILT
- Loose to Medium Dense clayey SAND/GRAVEL
- Medium Dense clayey SAND/GRAVEL
- Medium Dense to Dense clayey SAND/GRAVEL
- Highly Weathered LIMESTONE
- Moderately to Slightly Weathered LIMESTONE
- Slightly Weathered to Fresh LIMESTONE
- Possible Argillaceous LIMESTONE
- Borehole Depth to Refusal

NOTES:

TITLE: GEOPHYSICAL SURVEY

PROJECT: M20 Cork to Limerick

CLIENT: WYG

DRAWING: Ch 44+300 to 46+000

DRAWING NUMBER: 10017_03

SCALE: Horz 1:2000 (Vert x 2)

DATE: January 2010

DRAWN: YOC | CHECKED:

REVISION:	DATE:	DRAWN:	CHECKED:
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www.apexgeoservices.co.uk

FIGURE 1: Geophysical Survey Locations
Scale 1:1000

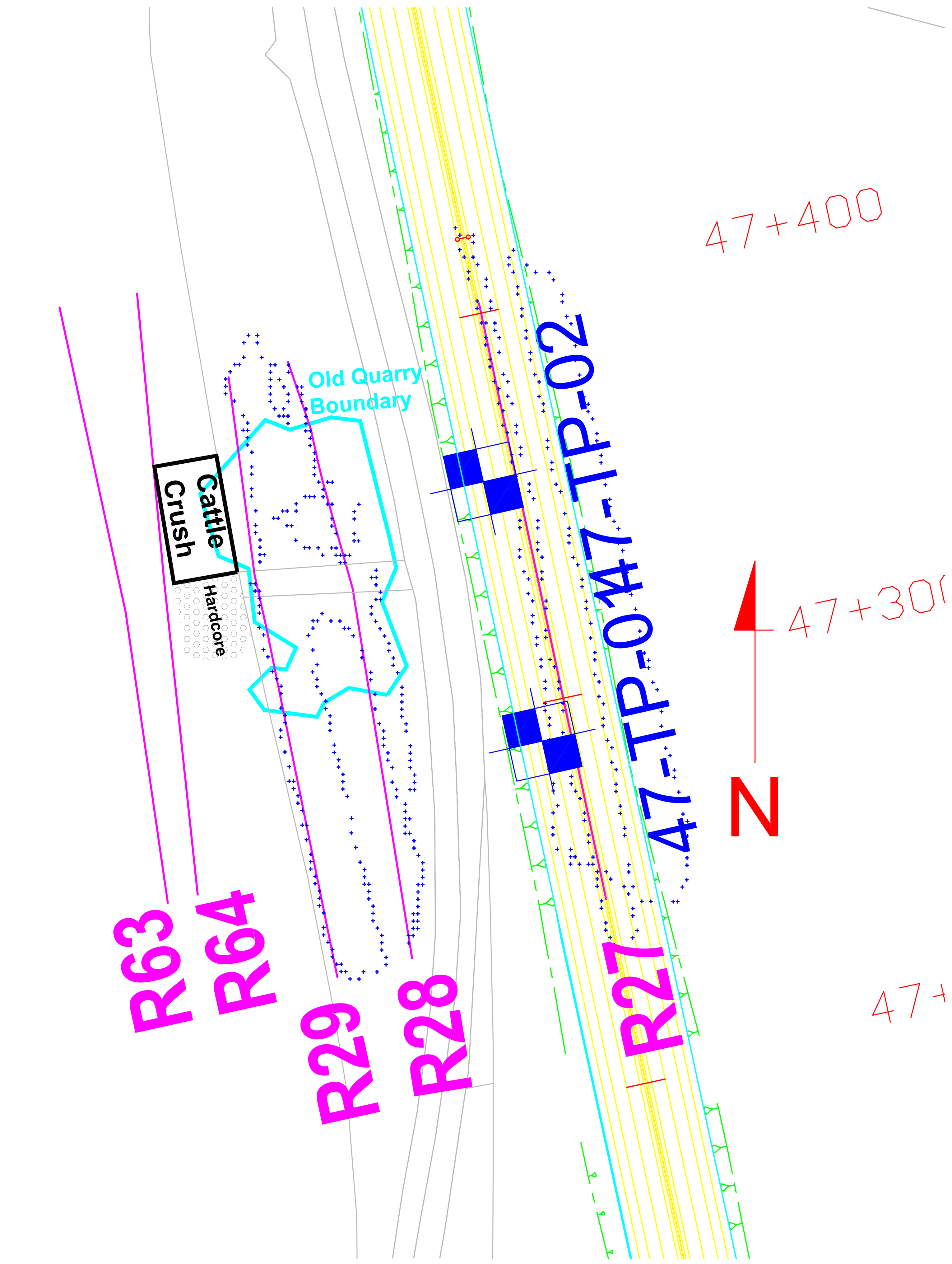


FIGURE 2: EM Conductivity Contours (mS/m)
Scale 1:1000

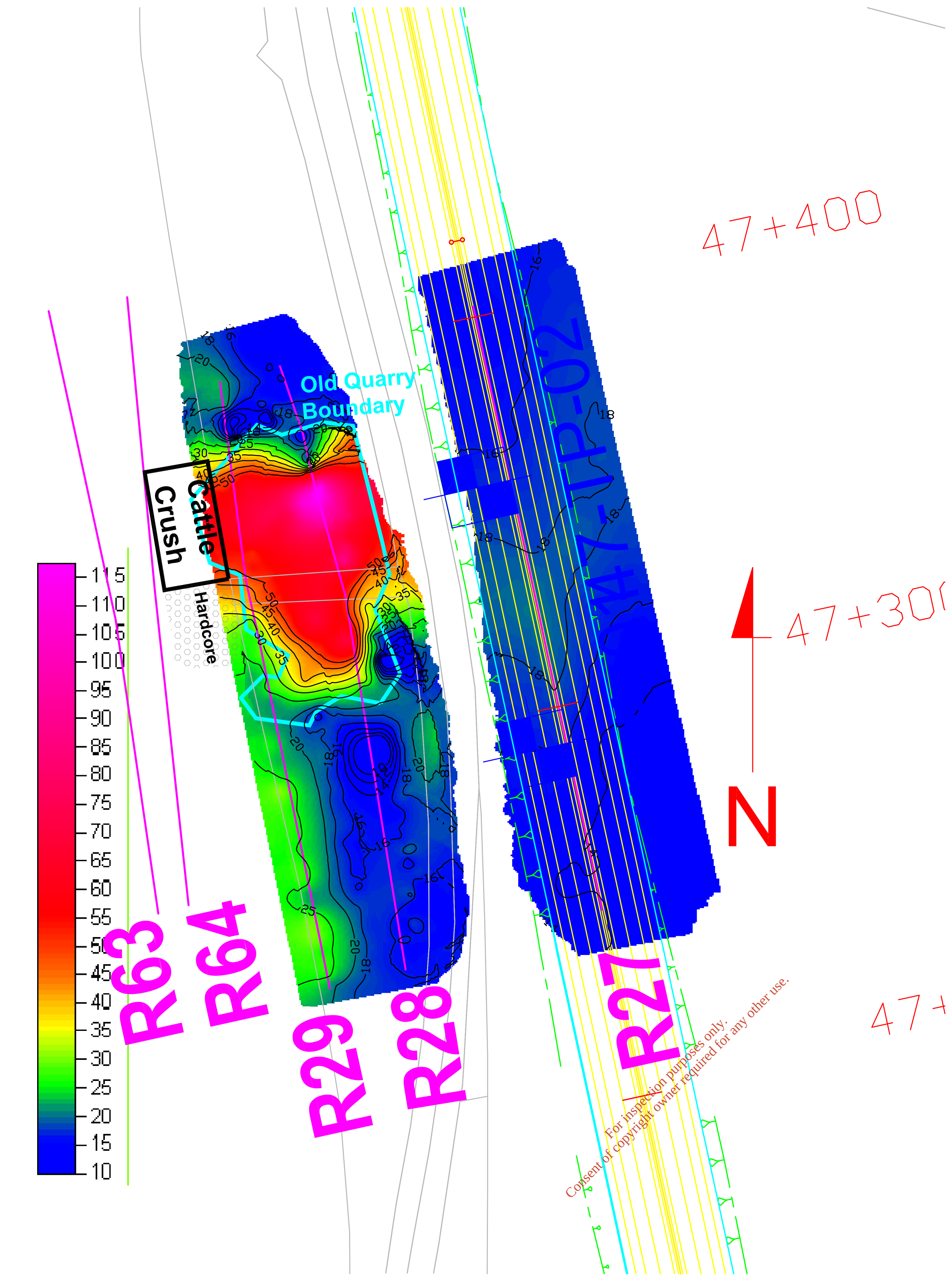


FIGURE 3: Summary Map
Scale 1:1000

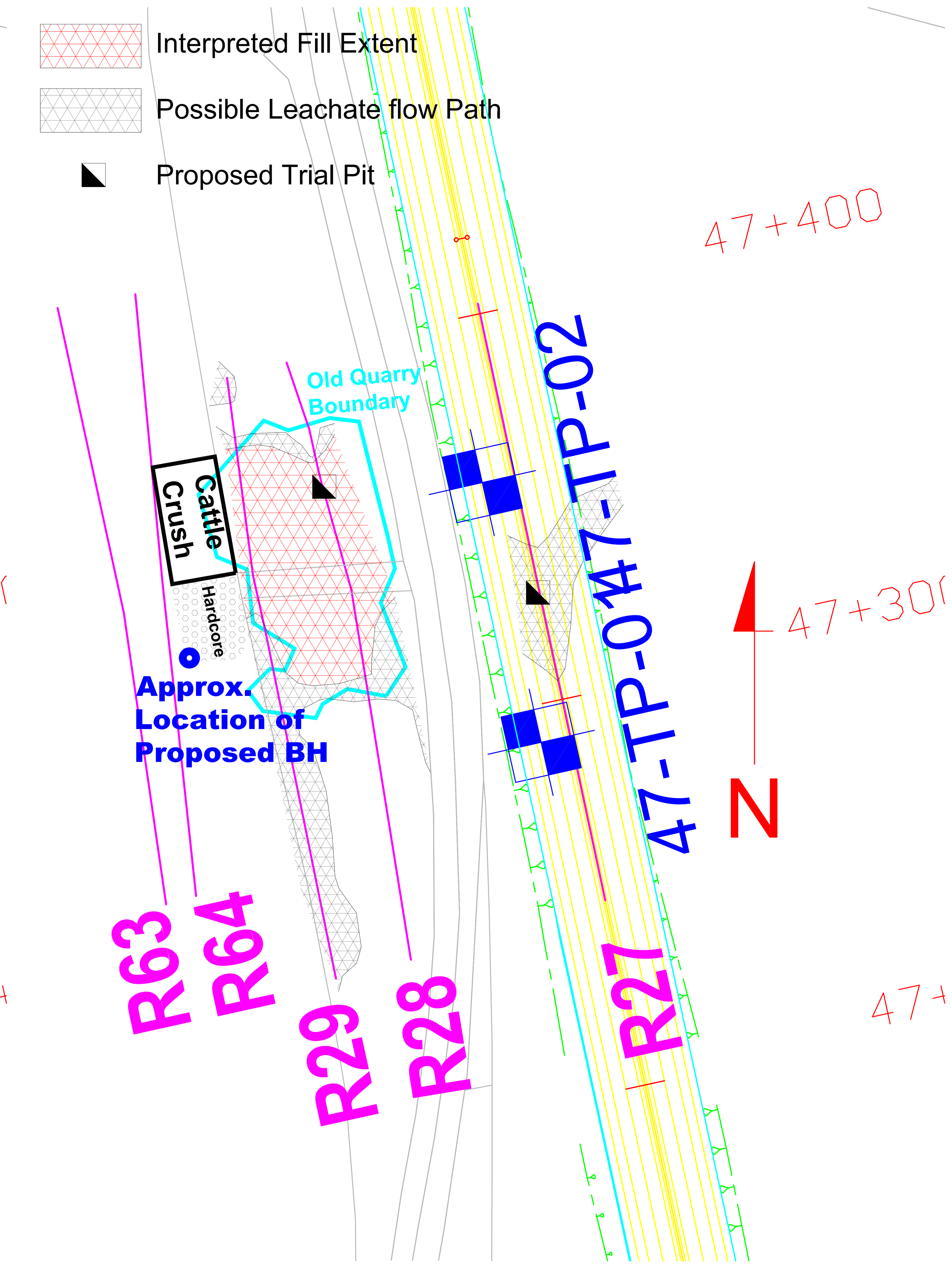
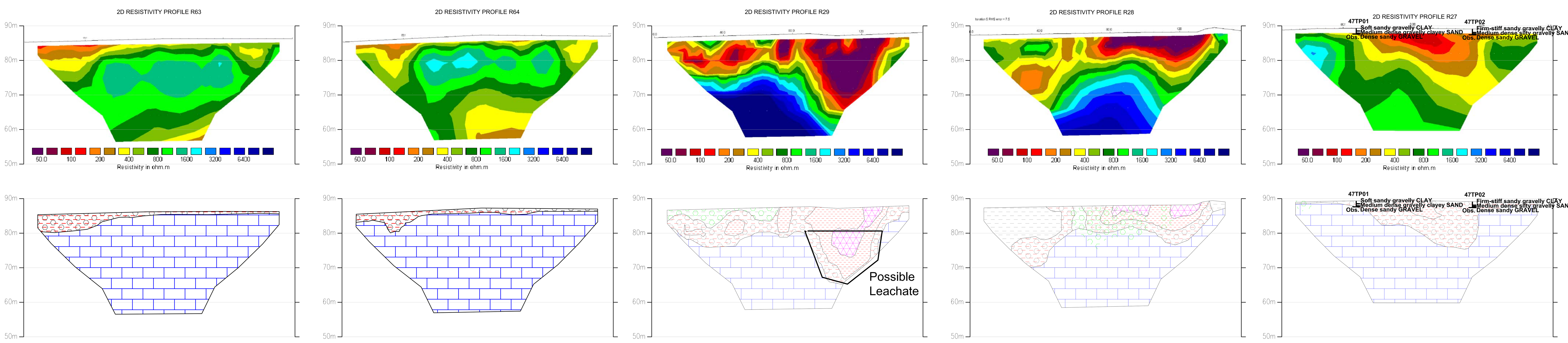
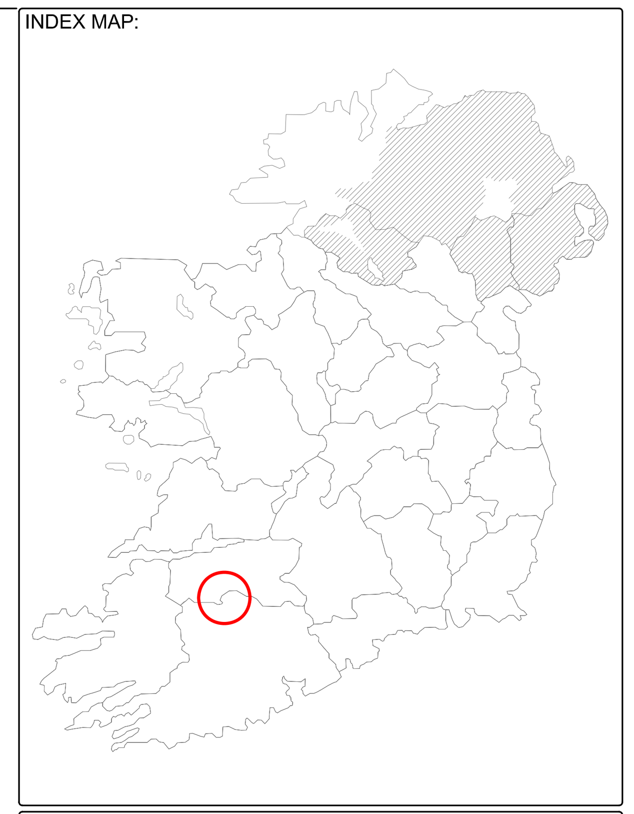


FIGURE 4: Geological Interpretation
Scale Horz. 1:1250 & Vert. x 2



INDEX MAP:



LEGEND:
- R27 2D Resistivity Profile
- EM Conductivity Location
- Possible Organic Fill Material
- CLAY/SILT and/or sandy gravelly CLAY/SILT with possible lenses of Organic Fill Material
- sandy gravelly CLAY/SILT or possible Inert Fill Material
- silty clayey SAND/GRAVEL
- LIMESTONE

NOTES:

TITLE:	GEOPHYSICAL SURVEY
PROJECT:	M20 Cork to Limerick
CLIENT:	WYG
DRAWING:	Ch 47+250 to 47+400
DRAWING NUMBER:	10017_04
SCALE:	As Shown @ A1
DATE:	1st February 2010
DRAWN: YOC	CHECKED:

REVISION:	DATE:	DRAWN:	CHECKED:
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FIGURE 1: Geophysical Survey Locations
Scale 1:2000

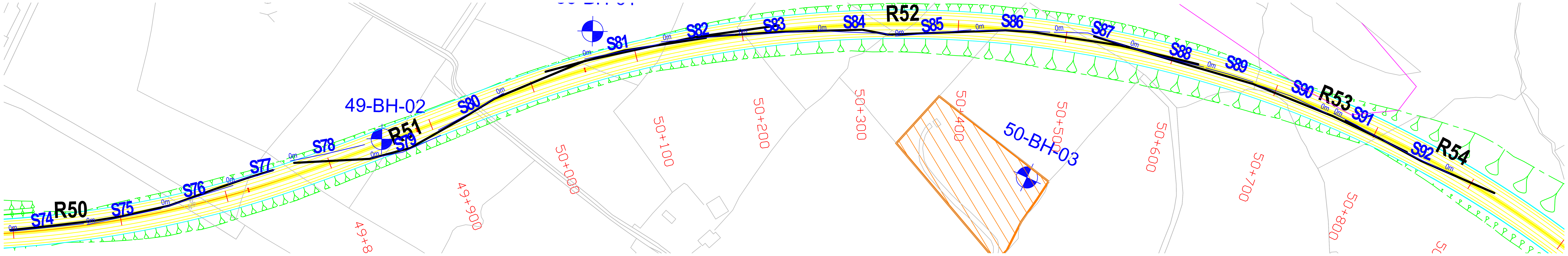
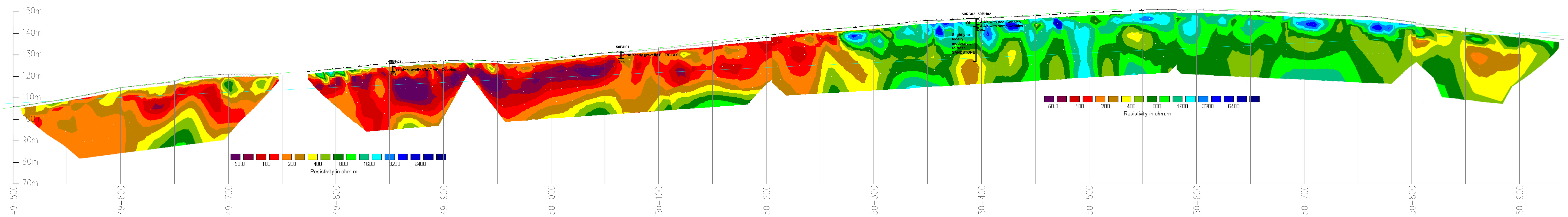


FIGURE 2: 2D Resistivity & Seismic Velocity Profiles
Scale 1:2000



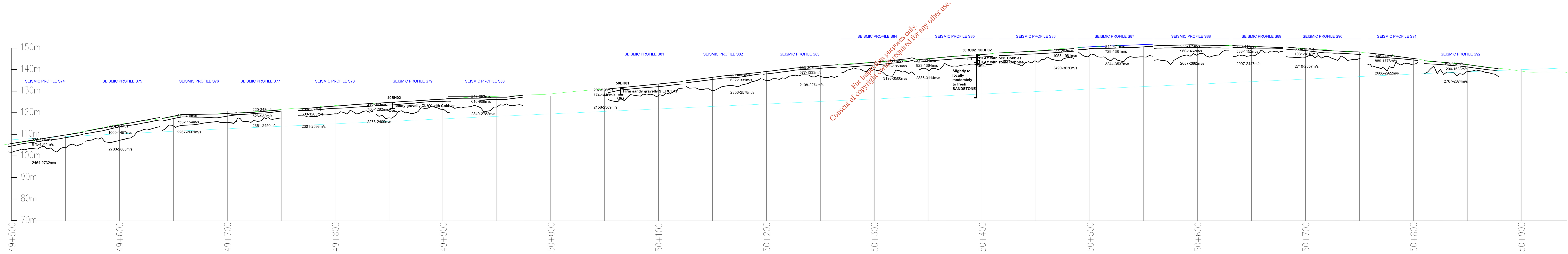
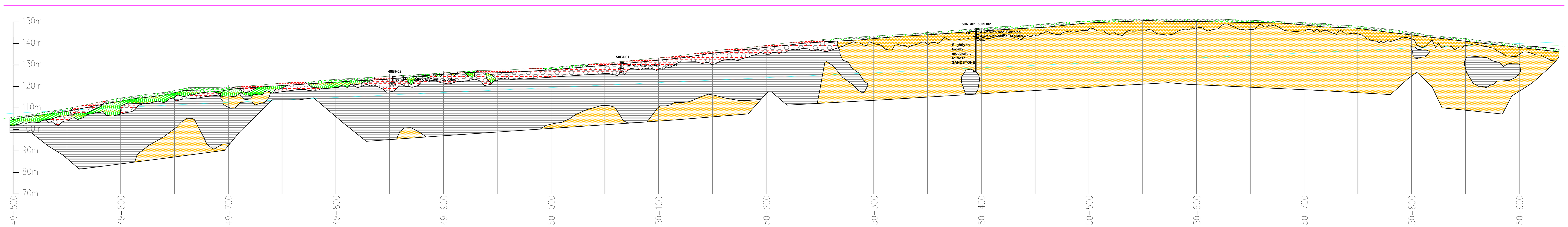
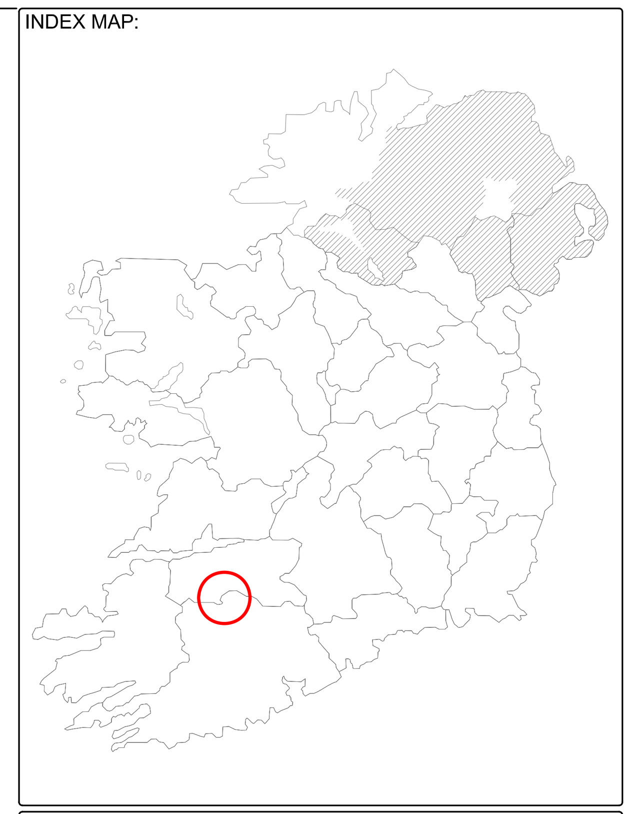


FIGURE 3: Geological Interpretation
Scale 1:2000 (Hz), (Vertical x 2)

Kiltorcan Fotmation
Yellow & red Sandstone & green Mudstone (from GSI)



INDEX MAP:



LEGEND:
- R6 — 2D Resistivity Profile
- S9 — Seismic Profile
- Soft to firm sandy gravelly CLAY/SILT
- Firm to stiff sandy gravelly CLAY/SILT
- Loose to Medium Dense clayey SAND/GRAVEL
- Medium Dense to Dense clayey SAND/GRAVEL
- MUDSTONE
- Highly to Moderately Weathered SANDSTONE
- SANDSTONE
- Borehole Depth to Refusal

NOTES:

TITLE: GEOPHYSICAL SURVEY

PROJECT: M20 Cork to Limerick

CLIENT: WYG

DRAWING: Ch 49+500 to 50+900

DRAWING NUMBER: 10017_05

SCALE: Horz 1:2000 (Vert x 2)

DATE: January 2010

DRAWN: YOC | CHECKED:

REVISION:	DATE:	DRAWN:	CHECKED:
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Appendix 7

SOIL PERMEABILITY TEST
(Of clay layer under the landfill)

GLOVER SITE INVESTIGATIONS LIMITED

CORK COUNTY COUNCIL
ENVIRONMENT DEPARTMENT
INNISCARRA

Mr Kieran Coffey
Environmental Directorate
Cork County Council
Inniscarra
Co Cork

Our ref: 10-116/GG

2 June 2010

We enclose:

Cork Landfill
Permeability test

In confirmation of our earlier emails we enclose the result of the permeability testing of the specimen prepared by remoulding the provided samples, excluding the sample of loose waste TP1.

Testing was conducted in accordance with Clause 6 of *BS 1377-6:1990 Methods of test for soils for civil engineering purposes—Part 6: Consolidation and permeability tests in hydraulic cells and with pore pressure measurement.*

The remoulded test specimen was prepared by amalgamating the supplied samples using compaction in accordance with Clause 3.3 of *BS 1377-4: 1990 Methods of test for soils for civil engineering purposes—Part 4: Compaction-related tests*

We also enclose our Invoice No. 10-116 for the testing.

We trust this is satisfactory but please contact us if you have any queries.

Yours sincerely
GLOVER SITE INVESTIGATIONS LTD

Dr Gabriel Gallagher

8 Drumahiskey Road,
Balnamore,
Ballymoney,
Co. Antrim
BT53 7QL
T +44 (028) 2766 2083
F +44 (028) 2766 4875
e admin@glover-si.com
i www.glover-si.com

Date	6th May 2009	
Client	GSI	
Test	Constant Head Permeability	
Site	CC Landfill	
Sample Reference		S-2
Layer		NA
Depth m		N/A
Sampling Method		Proctor

Sample type	Clayey Silt
Sample Height mm	100
Sample Diameter mm	101.4
Sample Volume cm3	807
Initial Wet Mass g	1895
Final Wet Mass g	1900
Dry Mass g	1596
Bulk Density Mg/m3	2348
Dry Density Mg/m3	1977
Initial Water Content %	18.7
Final Water Content %	19.0

Index Properties

[redacted]

Saturation Stage

Initail B Value	<0.8
Back Pore Water Pressure During Saturation kPa	550
Cell Pressure kPa	530
Final B Value	0.95

Consolidation Stage

Cell pressure kPa	600
Back Pore Water Pressure kPa	550
Duration of Consolidation h	24

Permeability Stage

Temperature C^o	20
Cell Pressure kPa	600
Pore Water Pressure (Top) kPa	570
Pore Water Pressure (Bottom) kPa	550
Average Effective Stress kPa	40
Head Difference kPa	20
Head Loss kPa	1
Net Head difference m	1.94
Sample Height m	0.1
Hydraulic Gradient i	19.37
Flow Rate cm3/min	0.0055
Area of the Sample cm2	79.0
Permeability m/s	6.0E-10

Measured Permeability k m/s

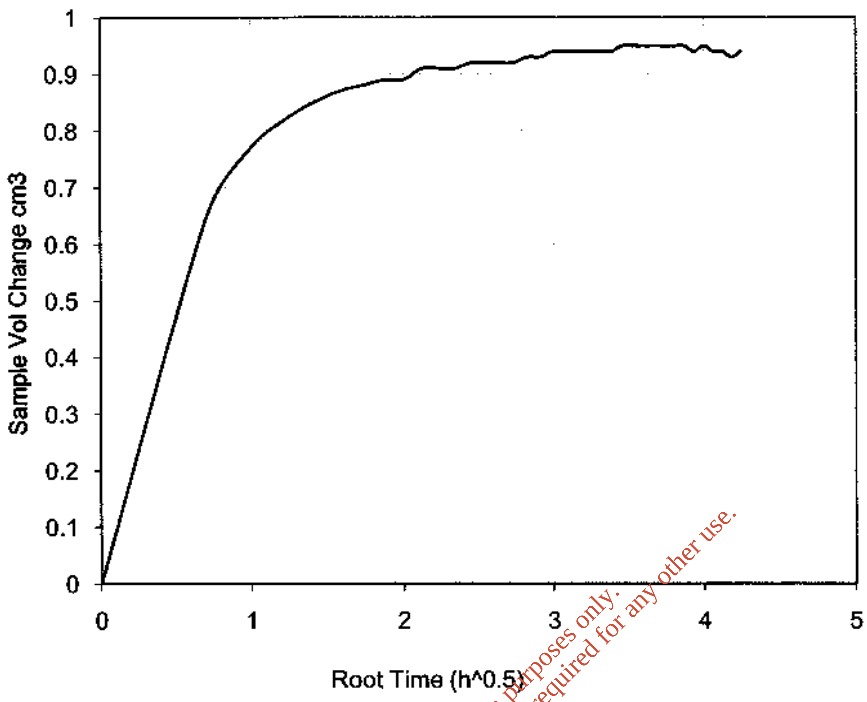
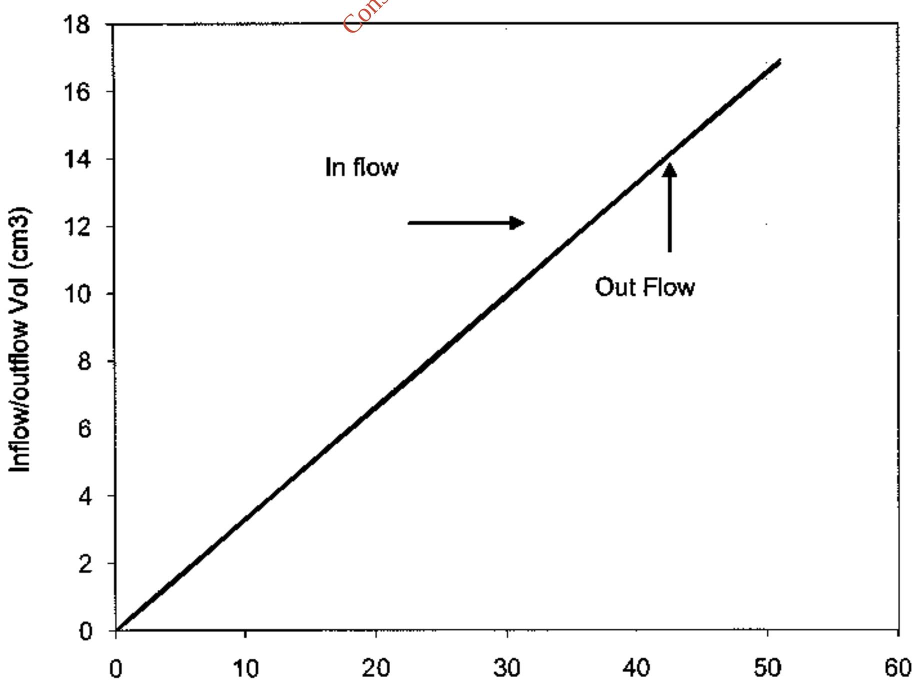


Figure 1 Volume Change Vs Root Time (Consolidation Stage)



Appendix 8

1st DRAFT MITCHELSTOWN GROUNDWATER BODY DESCRIPTION

Mitchelstown GWB: Summary of Initial Characterisation.

Hydrometric Area Local Authority	Associated surface water features	Associated terrestrial ecosystem(s)	Area (km^2)
18 Cork & Limerick Co. Cos	**Rivers:** Clydagh, Blackwater, Araglin, Awbeg, Funshion, Farahy, Douglas, Bregoge, Gradoge, Ogeen, Sheep, Behanagh, Castlepook, Attychrane, Geeragh. **Lakes:**Loughananna.	(000012) Ballinvoneer Pond; (000092) Kilcolman Bog; (001049) Eagle Lough; (000899) Ballindangan Marsh; (000074) Awbeg Valley (below Doneraile); (000075) Awbeg Valley (above Doneraile); (000085) Glanworth Ponds; (001029) Araglin Valley; (002036) Ballyhoura Mountains; (001829) Ballinaltig Beg Pond; (001561) Awbeg Valley Castletownroche; (000073) Blackwater River Callows; Blackwater Valley.	549

Topography	This GWB occupies a large low-lying area in North Cork that includes elongate east west trending valleys extending from Buttevant to Mitchelstown in the north, and Mallow to Fermoy in the south, and an intervening area. The body is generally flat to gently undulating (20-190 m OD). The highest ground occurs around the margins of the body.	
Geology and Aquifers	**Aquifer categories**	**Rkd**: Regionally important karstified aquifer dominated by diffuse flow (73%) **Ll:** Locally important aquifer, moderately productive only in local zones (24%) **Pl:** Poor aquifer, generally unproductive except for local zones (3%) These areas may need to have classification changed *Lm: Locally important aquifer which is generally moderately productive (0.3%)* ***Rf:** Regionally important fissured aquifer (0.2%)*
	Main aquifer lithologies	Dinantian Pure Unbedded Limestones (58%), Dinantian Pure Bedded Limestones (15%), Dinantian Lower Impure Limestones (12%), Dinantian Upper Impure Limestones (12%), Dinantian (early) Sandstones, Shales and Limestones (2%). *There area also some tiny areas of Namurian Shales (0.3%)Devonian Old Red Sandstones (0.3%) and Basalts & other Volcanic rocks (0.3%).*
	Key structures	During the Variscan Orogeny rocks in the South Munster region were compressed from the south into a series of folds on east west axes. Subsequent erosion generally stripped the more soluble Carboniferous Limestones from the fold crests or ridges (anticlines) exposing the harder, more resistant sandstones underneath. The Carboniferous Limestones were preserved in the fold troughs (synclines) which today line elongate east-west trending valleys separated by the intervening sandstone ridges. The youngest rocks are at the centre of the syncline. Extensive fracturing and faulting accompanied the folding of the rocks which has significantly enhanced the permeability of the limestones in this region. This body covers an area that includes the Mitchelstown Syncline, the Buttevant Syncline and the Churchtown Anticline and the western end of the Fermoy-Lismore Syncline. Figure 1 shows a cross section through the Mitchelstown Syncline in the east of the body. These major synclines are large upward facing open structures. Second and third order folds are developed on the flanks of the major folds. The synclines are cut by a series of shear faults trending approximately north-south and a series of thrust faults with a general east-west trend. The occurrence of thrust faults and transverse faults may have an influence on groundwater flow. The transverse faults divide the area into compartments and can act as preferential flow zones. Some thrust faults may act as barriers causing springs to rise near the thrust fault plane. Thrust faults within formations may act as a focus for karstification because the limestone has been weakened (Ree & Rot, 1981). Frequent jointing is also recorded in the pure limestones in this region. From geological observations it is known that the direction of the joints is broadly north-south and east-west. From cave plans for Castlepook cave, east of Buttevant, it can be seen that karstification is best developed along north south joints (Ree & Rot, 1981). A similar influence of north south jointing on karstification is seen in the pure limestones of the Cloyne and Midleton GWBs in east Cork.

	Key properties	The pure unbedded limestones of the South Munster region are highly productive. Faults and joints were enlarged by karstification as groundwater moved through the limestones. There are numerous surface karst features in these limestones (e.g. caves, enclosed depressions, swallow holes) Transmissivity in the pure unbedded limestones can range from a few m^2/d to a few thousand m^2/d. A pumping test at a public supply borehole at Kildorrery gave a specific capacity of 860 m^3/d/m and estimated transmissivity of 1700-2000 m^2/d. This borehole is believed to tap a fault zone. Other boreholes near the Kildorrery supply borehole had estimated transmissivities of 1-10 m^2/d, much lower than for the pumping well. One borehole drilled to over 90 m met no water. It would appear that these boreholes never intersected the major fault zone, or any smaller fault zone. (Kelly 2000). Pumping test data from a public supply borehole at Olivers Cross indicate a transmissivity of 280 m^2/d (using the observation well data). The porosity is 0.025, and permeability is estimated at about 10 m/d. Flow velocity was calculated to be about 4 m/d. Test pumping at Downing Bridge public supply borehole and at Teagasc's Moorepark research farm suggests transmissivities ranging 15-3400 m^2/d, and permeabilities ranging 10-200 m/d. (Motherway, 1999). The porosity is considered to be about 0.025. Groundwater velocity at Downing Bridge was estimated to be about 30 m/d in the vicinity of the borehole. In general, velocities range 4-2500 m/d within the Waulsortian Limestone. In 1979 a tracing test was carried out by the G.S.I. at a sinkhole/swallow hole in Aghern, Fermoy. A spring 1.1 km to the southeast of the swallow hole showed a positive trace within 11 hours, indicating a velocity of about 100 m/hr. (Kelly & Motherway, 2000) The pure bedded limestones which include the Liscarroll and Caherduggan Limestone Formations are also highly productive but show less evidence of karstification. In the impure limestones, transmissivities are lower; they will generally be in the range 5-20 m^2/d but may be higher where karstification has occurred. Groundwater gradients will also be steeper than in the pure limestones. The Copstone Limestone Formation occurs between the pure limestones of the GWB and is much less permeable as it contains chert and shale bands. The Ballysteen & Ballymartin Limestones occur at the margins of the GWB and dip beneath the pure limestones (Figure 1). Storativity is low in all aquifers, but may be enhanced by overlying sand and gravel deposits where they are in continuity with the underlying limestone and provide them with additional storage.
	Thickness	The Dinantian Pure Unbedded Limestones (Waulsortian Limestone) are estimated as being about 750 m thick in the Fermoy Syncline and somewhat less in the Mitchelstown Syncline (Sleeman & McConnell, 1995). Most groundwater flow may occur in an epikarstic layer a couple of metres thick and in a zone of interconnected solutionally-enlarged fissures and conduits that extends approximately 30 m below this. However deeper flows can occur. In the Impure Limestones that occur at the margins of this GWB, most groundwater flow occurs in an upper weathered layer of a few metres and a zone of interconnected fissures often not extending more than 15 m from the top of the rock, although occasional deep inflows associated with major faults can be encountered. Impure limestones are also much less susceptible to karstification.
Overlying Strata	**Lithologies**	This GWB is primarily covered by glacial till. Till derived from Namurian Shales and Sandstones dominates in the west and southwest of the body, while till derived from Devonian Sandstones occurs in the east and north, and a smaller area of limestone-derived till occurs in the southwest. No Groundwater Protection Scheme has yet been prepared for North Cork and subsoil permeability has not been mapped in detail. Frequent areas of rock outcrop and shallow rock occur within the body. Alluvium also occurs, in particular in the extreme northwest and southeast of the GWB and along the major river channels. Some sand and gravel deposits are mapped in the northeast of the body. *Subsoil Types identified in Mitchelstown GWB by Teagasc Parent Material Mapping (Draft): Alluvium (A); Limestone sands and gravels (Carboniferous) (GLs); Lake sediments undifferentiated (L); Made Ground (Made); Rock outcrop and rock close to surface (Rck); Raised Peat (RsPt); Till –Devonian Sandstone Till (TDSs); Limestone Till (TLs); Namurian Sandstone and Shale Till (TNSSs).*
	Thickness	There are many areas throughout this GWB with subsoils of <3m where rock outcrop is common. Currently available depth to bedrock data from borehole logs within this GWB ranges 1-20 m. Most subsoil depths are <10 m although isolated points of deep subsoil do occur. The underlying pure unbedded limestone in this GWB is highly karstified and likely to have a very irregular bedrock surface. Subsoil depths in these areas can therefore be highly variable within short distances.
	% area aquifer near surface	
	Vulnerability	A Groundwater Protection Scheme for North Cork has not yet been prepared and no Groundwater Vulnerability map is available. It is likely that frequent areas of Extreme Vulnerability occur within this GWB close to rock outcrop, shallow rock and karst features such as swallow holes, collapse features and sinking streams. Areas of High to Low Vulnerability cannot be delineated at this time.

Recharge	**Main recharge mechanisms**	The Devonian ORS ridges to the north, east and south of this GWB (Ballyhoura, Knockmealdown & Glenville GWBs), as well as areas underlain by Namurian rocks to the west (Rathmore & Rathanacally GWBs) provide abundant runoff which supplies recharge to the limestone aquifer in the valleys. The low permeability rocks around the margins of the body however (Lower Limestone Shales, Ballymartin and Ballysteen Limestones) generally prevent throughflow from the underlying productive Kiltorcan-type sandstones which occur at the edges of the Ballyhoura and Knockmealdown uplands in the north and east, acting as a confining layer. In the GWB itself both point and diffuse recharge will occur. Swallow holes and collapse features provide the means for point recharge to the karstified aquifer. Diffuse recharge will occur over the entire GWB via rainfall percolating through the subsoil. The lack of surface drainage in several parts of this GWB indicates that potential recharge readily percolates into the groundwater system. In this highly productive aquifer there are some low-lying areas with a high water table, where a proportion of the effective rainfall is rejected due to lack of storage space in the aquifer.
	Est. recharge rates	
Discharge	**Large springs and high yielding wells (m^3/d)**	*Note: The following data need to be checked and updated by RBD Project Consultants.* Data from GSI Well Database: Patrician Academy Mallow (2180 m^3/d); Mart Well, Mallow; Assolas, Kanturk (545 m^3/d); Mitchelstown (654 m^3/d); Ballyenahan North (916 m^3/d); Spaglan, Mallow (475 m^3/d) Public Supplies for which Source Protection Reports have been prepared by GSI: Castletownroche – Redstone Spring (8861m^3/d) & Ballinvoher Spring (5888 m^3/d); Kilworth – Downing Bridge Bore (1500 m^3/d); Glanworth - Ballykenly Spring (4000 m^3/d); Kildorrory – Glenavuddig Bridge Bore (720 m^3/d maximum pump capacity); Olivers Cross, Parkadallane, Bore (1282 m^3/d). Additional data from EPA Groundwater Sources List: Donneraile, Shanballymore (Spring - CON034) (3200 m^3/d); Ballyclough Co-Op, Buttevant (Bore – CON 094) (545 m^3/d); Ballyclough Co-Op, Doneraile (Bore – CON 095) (545 m^3/d); Mitchelstown Co-Op, Clonmel Rd (Bores – CON109) (7273 m^3/d) Downing Bridge (CON158) (2500 m^3/d) *Note: Charleville RWS (CON026) draws water from the confined portion of the Ballyhoura Kiltorcan GWB).*
	Main discharge mechanisms	Groundwater discharges to large springs within the GWB and to the rivers and streams crossing the GWB. Some spring lines occur where bedding planes intersect the sides of valleys (eg Redstone and Ballinvoher Springs of Castletownroche WS). Others may be fault controlled.
	Hydrochemical Signature	The groundwater in this body is dominated by calcium and bicarbonate ions. Hardness can range from moderately hard to very hard (200 mg/l to >400 mg/l (as $CaCO_3$). Spring waters tend to be softer as throughput is quicker and there is less time for the dissolution of minerals into the groundwater. Groundwater alkalinity is high, up to 400 mg/l (as $CaCO_3$). These hydrochemical signatures are characteristic of clean limestone. Like hardness and alkalinity, electrical conductivities can vary greatly. Typical limestone water conductivities (EC) are of the order of 500-700 µS/cm Lower values suggest that the residence times of some of the sources are very short. Due to the high level of interaction between groundwater and surface water in karstic aquifers, microbial pollution can travel very quickly from the surface into the groundwater system. The normal filtering and protective action of the subsoil is often bypassed in karstic aquifers due to the number of swallow holes, dolines and large areas of shallow rock. The hydrochemical signature of groundwater from public supply wells in the Mitchelstown GWB is demonstrated in an expanded Durov plot in Figure 3 below.

Groundwater Flow Paths	The rocks of this GWB are devoid of intergranular permeability. Groundwater flow occurs in the many faults and joints, in the pure limestones these openings have been enlarged by karstification. Because of the high frequency of fissures in this region, overall groundwater flow is thought to be of a diffuse nature, although solutionally enlarged conduits and cave systems do occur. Groundwater flow in the pure limestones occurs in an upper shallow highly karstified weathered zone in which groundwater moves quickly in rapid response to recharge. Below this is a deeper zone where there are two components to groundwater flow. Groundwater flows through interconnected, solutionally enlarged conduits and cave systems that are controlled by structural deformation. In addition there is a more dispersed slow groundwater flow component in smaller fractures and joints outside the larger conduits. Groundwater level data range from 1-21 m below ground level. Typical annual fluctuation of the water table ranges up to 6 or 7 m. Hydrographs for a number of wells within this GWB are shown in Figure 3 below. Groundwater in this GWB is generally unconfined. The highly permeable aquifer supports a regional scale flow system. At a local scale groundwater flow direction may not follow local topography due to flow in karstified conduit systems. Groundwater flow paths can be up to several kilometres long, but may be significantly shorter in areas where the water table is very close to the surface. Regional groundwater flow will be away from the surrounding uplands towards the main rivers draining the valleys. The impure limestones that outcrop around the margins of the body and underlie the pure limestones are much less productive, although zones of enhanced permeability may occur in the vicinity of fault zones and areas of intensive fracturing. Limited karstification can also occur. These impure limestones act as a confining layer overlying the productive Kiltorcan-type Sandstones which surround the uplands to the north and east. Groundwater levels are generally shallow in the impure limestones (<10 m below ground surface), and commonly less than 3 mbgl. Local groundwater flows are determined by the local topography.
Groundwater & Surface water interactions	The karstic system allows rapid interchanges of water between surface and underground. Swallowholes and caves receive surface water, and groundwater is discharged to surface as springs or as baseflow to rivers crossing the groundwater body. There are numerous NHAs within this GWB with varying degrees of dependence on groundwater. Kilcoleman Bog/Marsh (000092) is fed by calcareous groundwater (NHA Site Synopsis). Ree & van Rot (1981) discuss the influence of the groundwater system on Kilcoleman Marsh. Eagle Lake (1049) displays many of the characteristics of a turlough, and is believed to be the only turlough-type lake in Cork (NHA Site Synopsis).

Conceptual model	• This GWB occupies a large low-lying area in North Cork that includes the elongate east west trending valleys (limestone synclines) extending from Buttevant to Mitchelstown in the north, and Mallow to Fermoy in the south, and the low-lying area underlain by limestone that connects them. The body is generally flat to gently undulating (20-190 m OD). • The GWB is bounded by the contact with the underlying Kiltorcan-type Sandstones to the east (Ballyhoura Kiltorcan and Cappoquin Kiltorcan GWBs), the contact with the Dinantian (early) Sandstones, Shales and Limestones (Glenville GWB) to the south and the contact with the overlying Namurian rocks to the west (Rathmore GWB) and the contact with impure limestones to the northeast (Newtown Ballyhay GWB). The Southwestern RBD boundary forms part of the GWB boundary in the east and north west. • The GWB is composed mainly of diffusely karstified, highly permeable pure limestones with a narrow underlying layer of less permeable impure limestone around the margins of the body. To the north and east of the body are narrow productive Kiltorcan-type sandstones which are partially confined by the impure limestones at the north and eastern margin of this GWB. To the north east and south are ridges of low permeability sandstones. Low permeability Namurian rocks overly the limestones to the west. • The regional structural deformation that created the characteristic South Munster sandstone ridge (anticline)-limestone valley (syncline) topography was accompanied by intense fracturing and high frequency jointing (N-S jointing dominates) within the limestone synclines. Subsequent karstification of these openings has significantly enhanced the permeability of the pure limestones. Karst features such as cave systems, sinking streams, springs, swallow holes and other collapse features are common in this GWB. • Groundwater flows through the many faults and joints formed by deformation that were subsequently enlarged by karstification. Most groundwater flow occurs in an upper shallow highly karstified weathered zone of a few metres thick in which groundwater moves quickly in rapid response to recharge. Below this is a deeper zone where there are two components to groundwater flow. Groundwater flows through interconnected, solutionally enlarged conduits and cave systems that are controlled by structural deformation (influence of N-S jointing). In addition there is a more dispersed slow groundwater flow component in smaller fractures and joints outside the larger conduits. Generally this connected fractured zone extends to about 30 mbgl in pure limestones, although deeper flows do occur. • Groundwater in this body is unconfined. Groundwater gradients are very flat in the permeable limestones (0.001-0.002). The highly permeable aquifer can support regional scale flow systems. Groundwater flow paths can be up to several kilometres long, but may be significantly shorter in areas where the water table is very close to the surface. Overall groundwater flow is away from the surrounding uplands to the main rivers draining the valleys. • Recharge to this GWB is both point and diffuse. The uplands surrounding this GWB provide runoff which supplies recharge to the limestone aquifer in the valley. Swallow holes, collapse features and sinking streams provide the means for point recharge to the karstified aquifer. Diffuse recharge will occur over the entire GWB via rainfall percolating through the subsoil. The lack of surface drainage in much of this GWB indicates that potential recharge readily percolates into the groundwater system. • There are likely to be many areas of Extreme Vulnerability within this GWB near of rock outcrop and shallow rock and in the vicinity of karst features such as swallow holes and enclosed depressions. In a highly karstified aquifer such as this GWB the underlying limestone will have a very irregular surface. Subsoil depths in this GWB can therefore be highly variable within short distances. • There is a high degree of interaction between surface water and groundwater in this GWB. Swallow holes and caves receive surface water, and groundwater is discharged to surface as springs or as baseflow to rivers crossing the groundwater body.
Attachments	
Instrumentation	**Stream gauges:** 18003*, 18004*, 18005*, 18006*, 18007, 18008*, 18013, 18022, 18023, 18024, 18027*, 18030, 18032, 18035, 18036*, 18055, 18057, 18058, 18102. * Specific Dry Water Flow Data available. **EPA Water Level Monitoring boreholes:** (CON055) Bowens Court; (CON144) Ballyclough Co-op (Buttevant); (CON148) Box Cross East – 138; (CON149) Box Cross Middle – 139; (CON150) Box Cross West – 140; (CON151) Cahermee Cross; (CON155) Summer Park. (Note (CON026) Charleville RWS draws water from the confined portion of the Ballyhoura Kiltorcan GWB). **EPA Representative Monitoring points:** (CON034) Doneraile /Shanballymore WS; (LIM007) Ballyagran-Castletown. (Note (CON026) Charleville RWS draws water from the confined portion of the Ballyhoura Kiltorcan GWB).

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Disclaimer	Note that all calculation and interpretations presented in this report represent estimations based on the information sources described above and established hydrogeological formulae

Figure 1: Schematic Cross Section through the Mitchelstown Syncline

(From Geology of East Cork – Waterford Sheet 22. 1:100,000 Bedrock Map Series, Geological Survey of Ireland.)

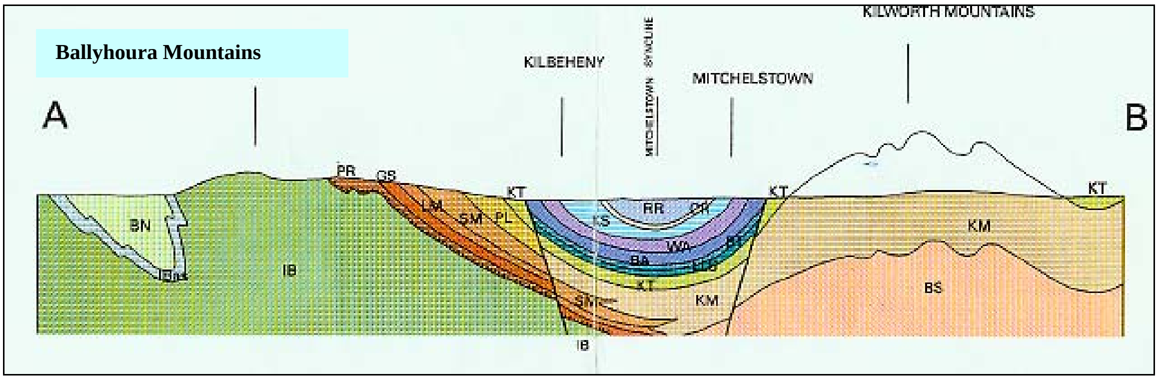


Figure 2: Hydrochemical signature

(EPA Representative Monitoring)

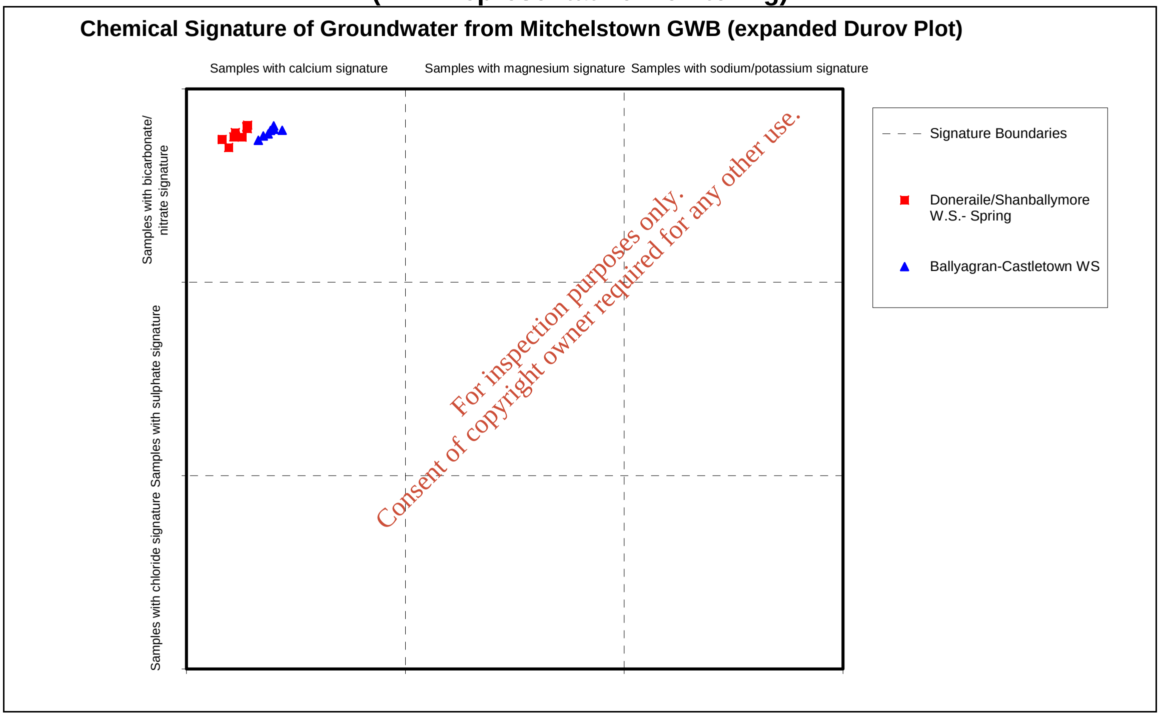
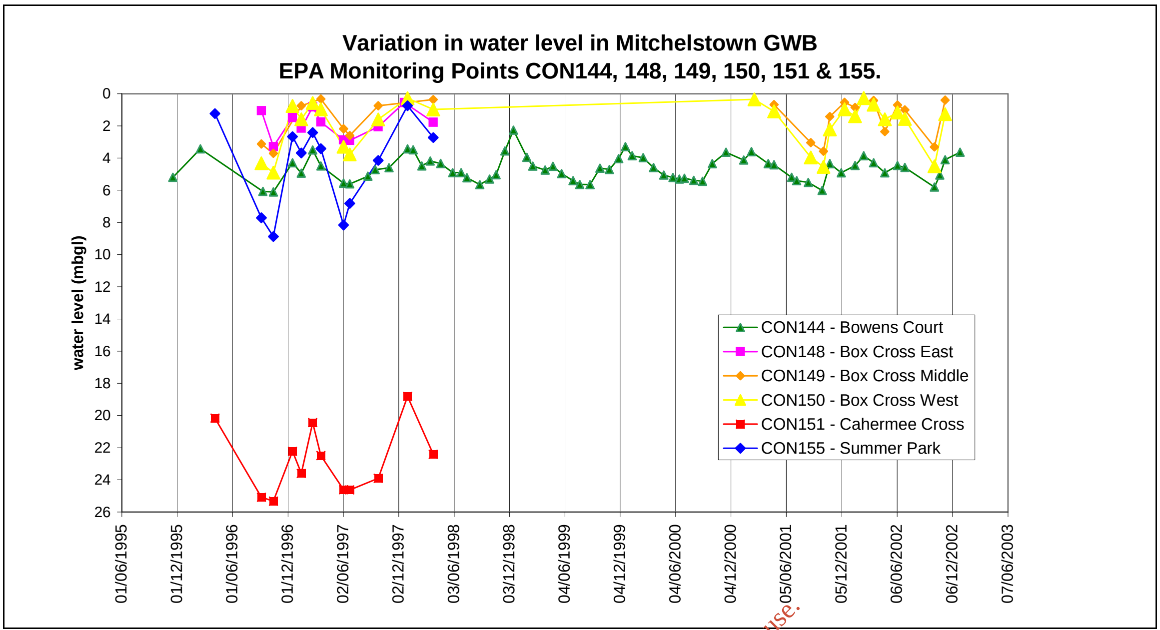
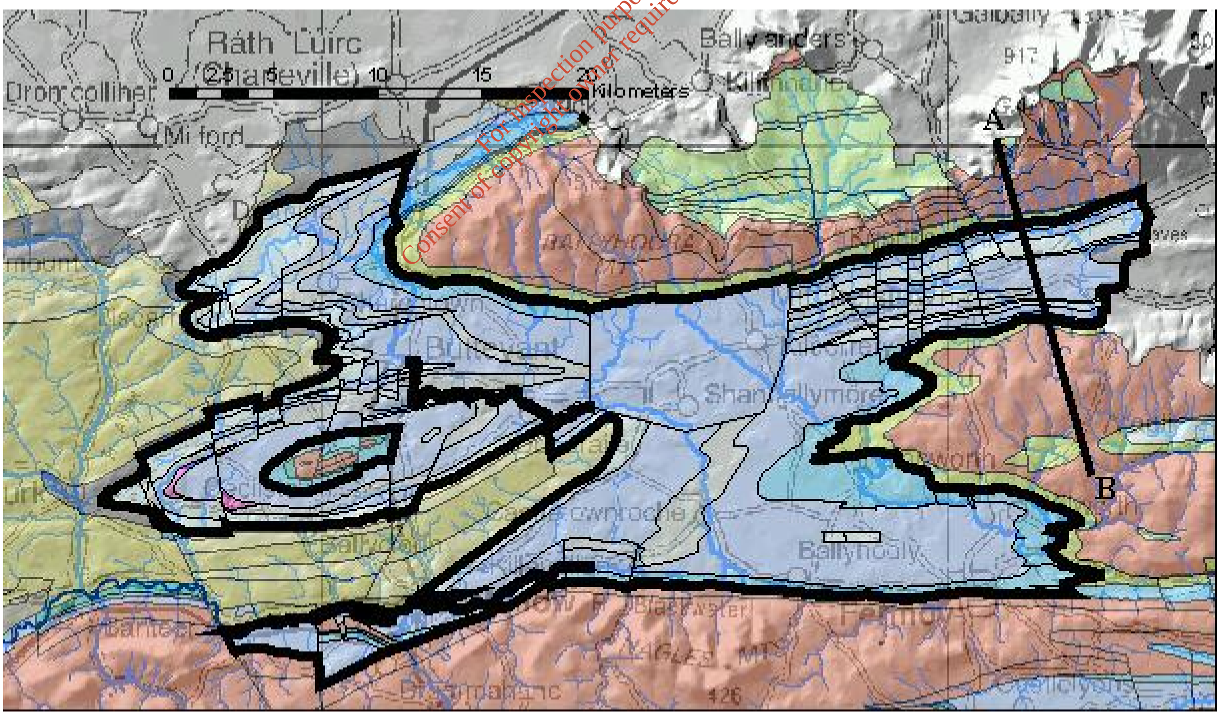


Figure 3: Groundwater hydrographs
(EPA Hydrographs)



Mitchelstown GWB (For Reference)



List of Rock units in Mitchelstown GWB

Rock unit name and code	**Description**	**Rock unit group**	**Aquifer Classification**
Giants Grave Formation (GG)	Dark-grey siltstone & mudstone	Namurian Shales	Pl
Dinantian Limestones (undifferentiated) (DIN)	Undifferentiated Limestone	Dinantian Pure Unbedded	Rk^d
Liscarroll Limestone Formation (LL)	Grey, cherty bioclastic limestone	Dinantian Pure Bedded Limestones	Rk^d
Caherduggan Limestone Formation (CD)	Crinoidal limestone & some modular chert	Dinantian Pure Bedded Limestones	Rk^d
Hazelwood Limestone Formation (HZ)	Pale-grey massive mud-grade limestone	Dinantian Pure Unbedded Limestones	Rk^d
Copstown Limestone Formation (CT)	Dark-grey well-bedded muddy limestone	Dinantian Upper Impure Limestone	Ll
OMahonys Rock Formation (OM)	Wavy-bedded algal laminite limestone	Dinantian Pure Bedded Limestones	Rk^d
Rathronan Formation (RR)	Pale-grey massive mud-grade limestone	Dinantian Pure Unbedded Limestones	Rk^d
Croane Formation (CR)	Dark shaly cherty fine-grained limestone	Dinantian Upper Impure Limestones	Ll
Kilsheelan Formation (KS)	Limestone, occasionally cherty	Dinantian Pure Bedded Limestones	Rk^d
Johnstown Red Marble (JM)	Red, pink & cream limestone	Dinantian Pure Bedded Limestones	Rf
Waulsortian Limestones (WA)	Massive unbedded fine-grained limestone	Dinantian Pure Unbedded Limestones	Rk^d
Ballysteen Formation (BA)	Fossiliferous dark-grey muddy limestone	Dinantian Lower Impure Limestones	Ll
Ballymartin Formation (BT)	Limestone & dark grey calcareous shale	Dinantian Lower Impure Limestones	Ll
Lower Limestone Shale (LLS)	Sandstone, mudstone & thin limestone	Dinantian (early) Sandstones, Shales and Limestones	Pl
Ringmoylan Formation (RM)	Calcareous shale & crinoidal limestone	Dinantian (early) Sandstones, Shales and Limestones	Pl
Gyleen Formation (GY)	Sandstone with mudstone & siltstone	Devonian Old Red Sandstones	Ll
Subulter Volcanic Formation (SV)	Pyroclastic flow & fall deposits	Basalts & other Volcanic rocks	Ll

Appendix 9

RE-RUN OF SPR LINKAGES

Risk Screening/ Prioritisation

Table 1a LEACHATE: SOURC/HAZARD SCORING MATRIX			
WASTE TYPE	Waste FOOTPRINT (ha)		
	≤ 1ha	> 1 ≤ 5 ha	> 5ha
C&D	0.5	1	1.5
Municipal	5	7	10
Industrial	5	7	10
Pre 1977 sites	1	2	3

1a =	**5**

Table 1b LANDFILL GAS: SOURC/HAZARD SCORING MATRIX			
WASTE TYPE	Waste FOOTPRINT (ha)		
	≤ 1ha	> 1 ≤ 5 ha	> 5ha
C&D	0.5	0.75	1
Municipal	5	7	10
Industrial	3	5	7
Pre 1977 sites	0.5	0.75	1

1b =	**5**

Table 2a : LEACHATE MIGRATION: PATHWAYS	
GROUNDWATER VULNERABILITY (Vertical Pathway)	**Points**
Extreme Vulnerability	3
High Vulnerability	2
Moderate Vulnerability	1
Low Vulnerability	0.5
High - Low Vulnerability (use where vulnerability not on GIS)	2

2a =	**2**

Table 2b : LEACHATE MIGRATION: PATHWAYS	
GROUNDWATER FLOW REGIME (Horizontal Pathway)	**Points**
Karstified Groundwater Bodies (Rk)	5
Productive Fissured Bedrock Groundwater Bodies (Rf & Lm)	3
Gravel Groundwater Bodies (Rg and Lg)	2
Poorly Productive Bedrock Groundwater Bodies (Ll, Pl, Pu)	1

2b =	**5**

Risk Screening/ Prioritisation

Table 2c : LEACHATE MIGRATION: PATHWAYS	
SURFACE WATER DRAINAGE (Surface water pathway)	**Points**
Is there a direct connection between drainage ditches associated with the waste body and adjacent surface water body? Yes	2
If no direct connection	0

2c =	**0**

Table 2d : LANDFILL GAS: PATHWAY	
LANDFILL GAS LATERAL MIGRATION POTENTIAL	**Points**
Sand and Gravel, Made ground, urban, karst	3
Bedrock	2
All other Tills (including limestone, sandstone etc - moderate permabi	1.5
All Namurian or Irish Sea Tills (low permability)	1
Clay, Alluvium, Peat	1

2d =	**2**

Table 2e : LANDFILL GAS: PATHWAY (assuming receptor located above source)	
LANDFILL GAS LATERAL MIGRATION POTENTIAL	**Points**
Sand and Gravel, Made ground, urban, karst	5
Bedrock	3
All other Tills (including limestone, standstone etc - moderate permab	2
All Namurian or Irish Sea Tills (low permability)	1
Clay, Alluvium, Peat	1

2e =	**3**

Table 3a : LEACHAGE MIGRATION: *RECEPTORS*	
HUMAN PRESENCE (presence of a house indicaates potential private wells)	**Points**
On or within 50m of the waste body	3
Greater than 50m but less than 250m	2
Greater than 250m but less than 1km from waste body	1
Greater than 1km of the waste body	0

3a =	**2**

Risk Screening/ Prioritisation

Table 3b : LEACHAGE MIGRATION: RECEPTORS PROTECTED AREAS (SWDTE or GWDTE)	**Points**
Within 50m of waste body	3
Greater than 50m but less than 250m of the waste body	2
Greater than 250m but less than 1km from waste body	1
Greater than 1km of the waste body	0
Undesignated sites within 50m of waste body	1
Undesignated sites greater than 50m but less than 250m	0.5
Undesignated sites greater than 250m of the waste body	0

3b =	**1**

Table 3c : LEACHAGE MIGRATION: *RECEPTORS*	
AQUIFER CATEGORY (resource potential)	**Points**
Regionally Important Aquifers (Rk, Rf, Rg)	5
Locally Important Aquifers (Ll, Lm, Lg)	3
Poor Aquifers (Pl, Pu)	1

3c =	**5**

Table 3d : LEACHAGE MIGRATION: *RECEPTORS*	
PUBLIC WATER SUPPLIES (Other than private wells)	**Points**
Within 100m of site boundary	**7**
Greater than 100m but less than 300m or with in Inner SPA for GW supplies	5
Greater than 300m but less than 1km or within Outer SPA (SO) for GW supplies	3
Greater than 1km (karst aquifer)	3
Greater than 1km (no karst aquifer)	0

3d =	**3**

Table 3e : LEACHAGE MIGRATION: *RECEPTORS*	
SURFACE WATER BODIES	**Points**
Within 50m of site boundary	3
Greater than 50m but less than 250m	2
Greater than 250m but less than 1km	1
Greater than 1km	0

3e =	**1**