ROAD DESIGN IN KARST LANDSCAPES: THE M17/M18

ARUP & BARRY TRANSPORTATION

BUILDERS SISK CONTRACTORS
Established 1859

Roadbridge

Lagan
CONSTRUCTION GROUP

Geological Survey
Suirbhéireacht Gheolaíochta
Ireland | Éireann

ENGINEERS IRELAND

Geotechnical Society

iah aih

INTRODUCTION

- Overview and Hydrogeology – Les Brown (ARUP)
- Geotechnical Design of Karst - Esther Madden (ARUP)
- Karst Features Encountered on Site -Deirdre O'Hara (Barry Transportation)

M17/M18 INTRODUCTION AND HYDROGEOLOGY

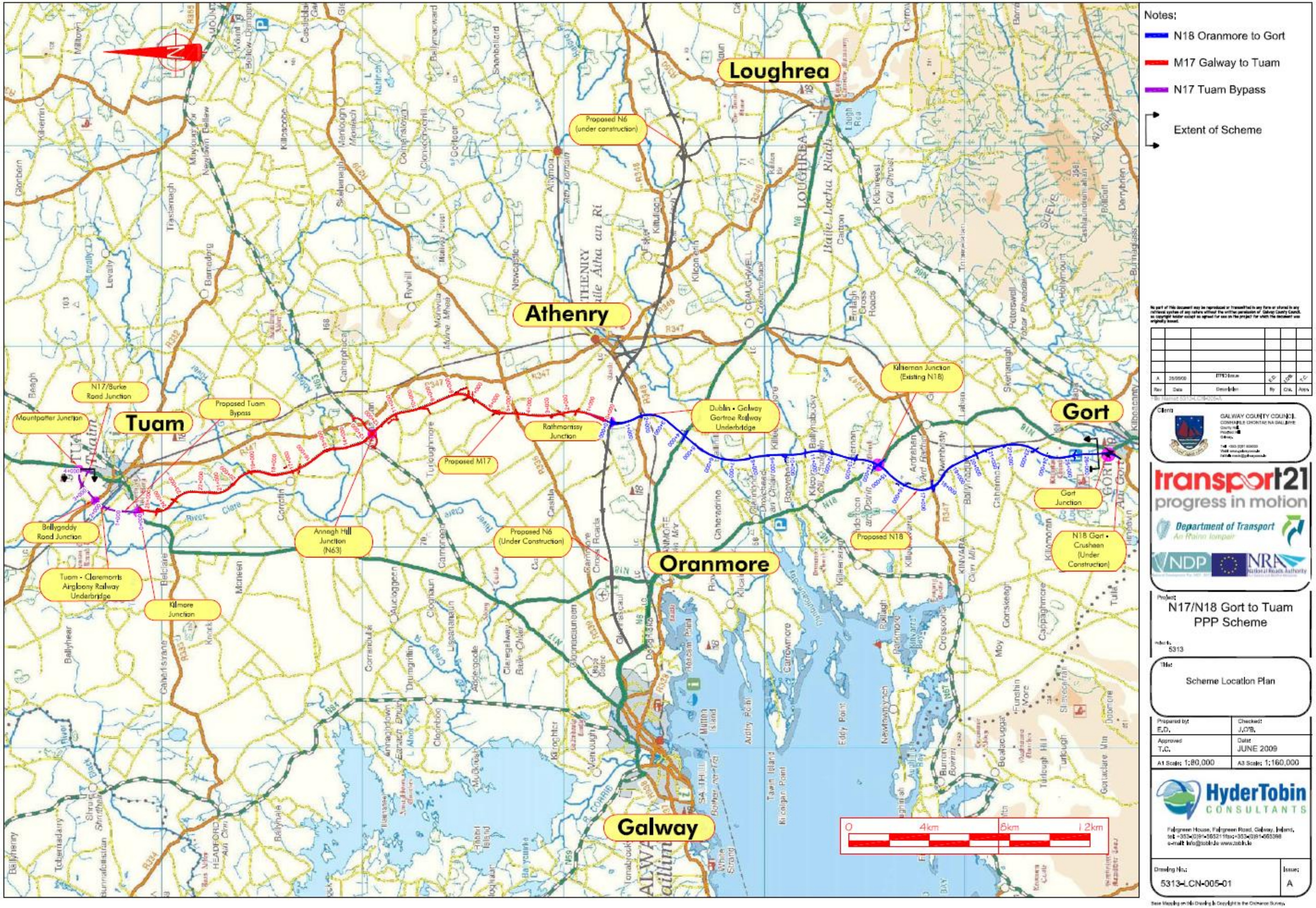
Les Brown BSc MSC PhD

ARUP BARRY TRANSPORTATION

TIMELINE

- 1999 – 2006: Route Selection and EIS
- 2005 – 2007: Planning approvals
- 2008 – 2014: Procurement
- 2015 – 2017: Construction
- Planned opening first quarter 2018
- Motorway opened September 27th, 2017

© Photo: Barrow Coakley Photography Tel: 087-2856527, 17th October 2017

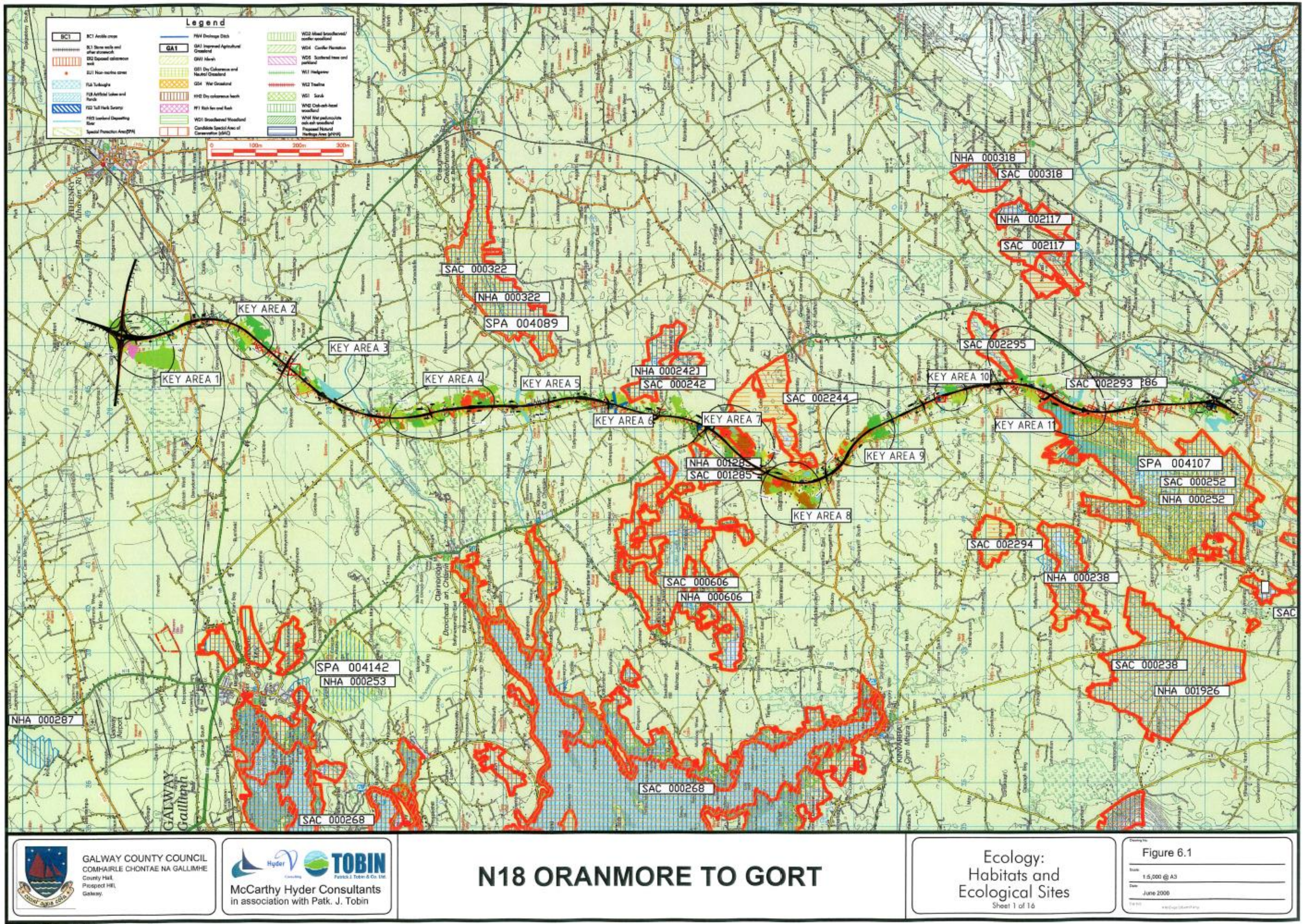


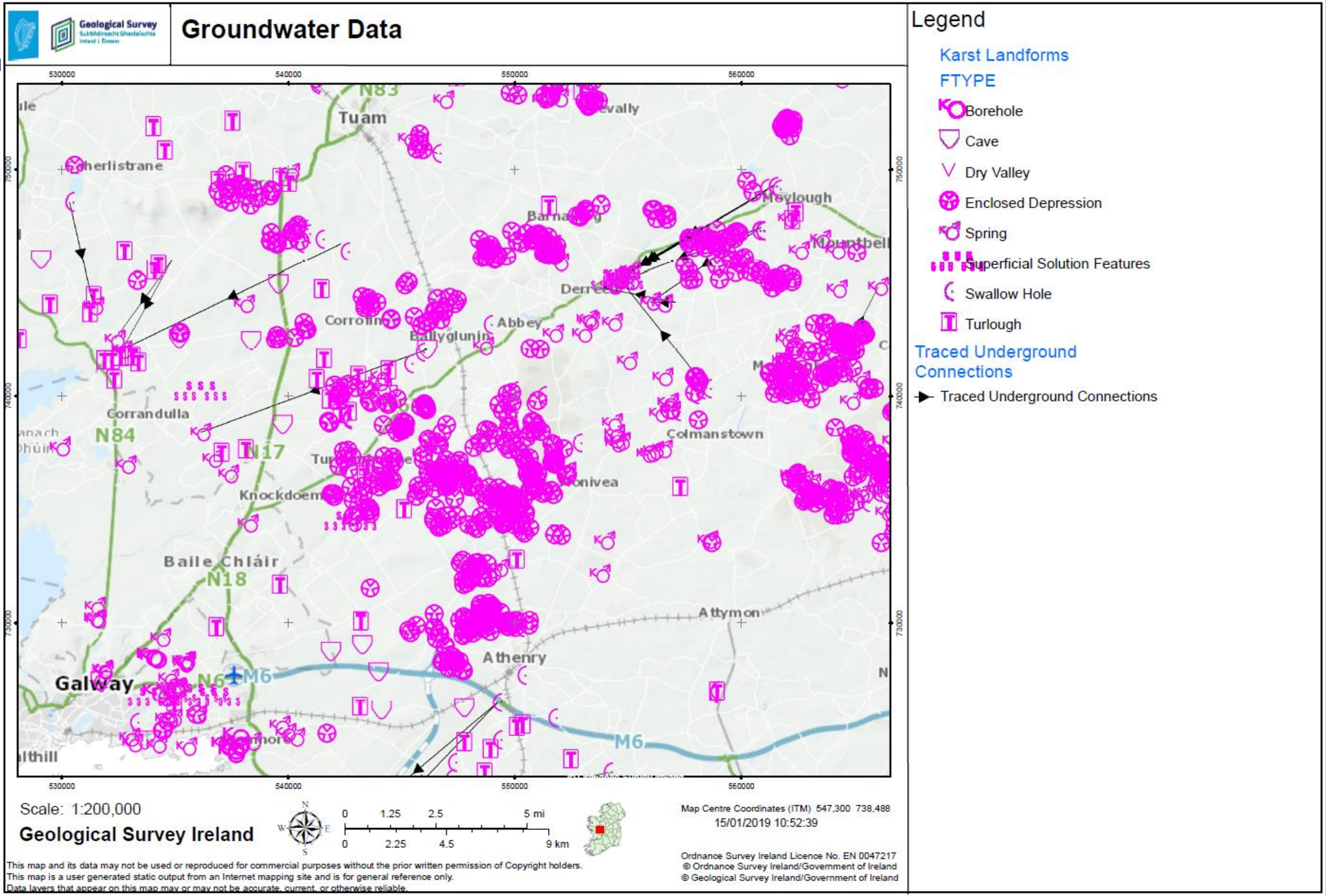
Notes:
N18 Oranmore to Gort
M17 Galway to Tuam
N17 Tuam Bypass
Extent of Scheme
Loughrea
Athenry
Tuam
Oranmore
Galway
Gort
Proposed N6 (under construction)
N17/Burke Road Junction
Mountpotter Junction
Proposed Tuam Bypass
Rathmorrissy Junction
Dublin - Galway Gortroe Railway Underbridge
Killeenan Junction (Existing N18)
Proposed M17
Bellygaddy Road Junction
Tuam - Claremorris Airglooney Railway Underbridge
Kilmore Junction
Annagh Hill Junction (N63)
Proposed N6 (Under Construction)
Proposed N18
Gort Junction
N18 Gort - Crusheen (Under Construction)
0
4km
8km
12km
GALWAY COUNTY COUNCIL
transport21
progress in motion
Department of Transport
NDP
NRA
National Roads Authority
Project:
N17/N18 Gort to Tuam
PPP Scheme
5313
Title:
Scheme Location Plan
Prepared by: E.D.
Checked: J.O'B.
Approved T.C.
Date: JUNE 2009
A1 Scale: 1:80,000
A3 Scale: 1:160,000
HyderTobin
CONSULTANTS
Drawing No.: 5313-LCN-005-01
Issue: A

KEY DESIGN AND CONSTRUCTION CHALLENGES

ARUP BARRY TRANSPORTATION

- Three contractors – two designers
- Regionally important karst aquifers
- Numerous groundwater dependant terrestrial ecosystems
- Seasonal groundwater flooding
- Areas of significant geotechnical karst risk


Legend
NHA 000318
SAC 000318
NHA 002117
SAC 002117
SAC 000322
NHA 000322
SPA 004089
KEY AREA 1
KEY AREA 2
KEY AREA 3
KEY AREA 4
KEY AREA 5
KEY AREA 6
KEY AREA 7
KEY AREA 8
KEY AREA 9
KEY AREA 10
KEY AREA 11
NHA 000242
SAC 000242
SAC 002244
SAC 002295
SAC 002293
NHA 001285
SAC 001285
SPA 004107
SAC 000252
NHA 000252
SAC 002294
NHA 000238
SAC 000606
NHA 000606
SAC 000238
NHA 001926
SPA 004142
NHA 000253
NHA 000287
SAC 000268
SAC 000268
GALWAY COUNTY COUNCIL
COMHAIRLE CHONTAE NA GAILLIMHE
County Hall,
Prospect Hill,
Galway.
TOBIN
McCarthy Hyder Consultants
in association with Patk. J. Tobin
N18 ORANMORE TO GORT
Ecology:
Habitats and
Ecological Sites
Sheet 1 of 16
Figure 6.1
1:5,000 @ A3
June 2000


Geological Survey
Suirbhéireacht Gheolaíochta
Ireland | Éireann
Groundwater Data
Legend
Karst Landforms
FTYPE
Borehole
Cave
Dry Valley
Enclosed Depression
Spring
Superficial Solution Features
Swallow Hole
Turlough
Traced Underground Connections
Traced Underground Connections
530000
540000
550000
560000
750000
740000
730000
Tuam
N83
Corrandulla
N84
N17
Knockdoe
Baile Chláir
N18
Galway
N6
M6
Athenry
Attymon
Colmanstown
Abbey
Ballyglunin
Moylough
Scale: 1:200,000
Geological Survey Ireland
0
1.25
2.5
5 mi
0
2.25
4.5
9 km
Map Centre Coordinates (ITM) 547,300 738,488
15/01/2019 10:52:39
Ordnance Survey Ireland Licence No. EN 0047217
© Ordnance Survey Ireland/Government of Ireland
© Geological Survey Ireland/Government of Ireland
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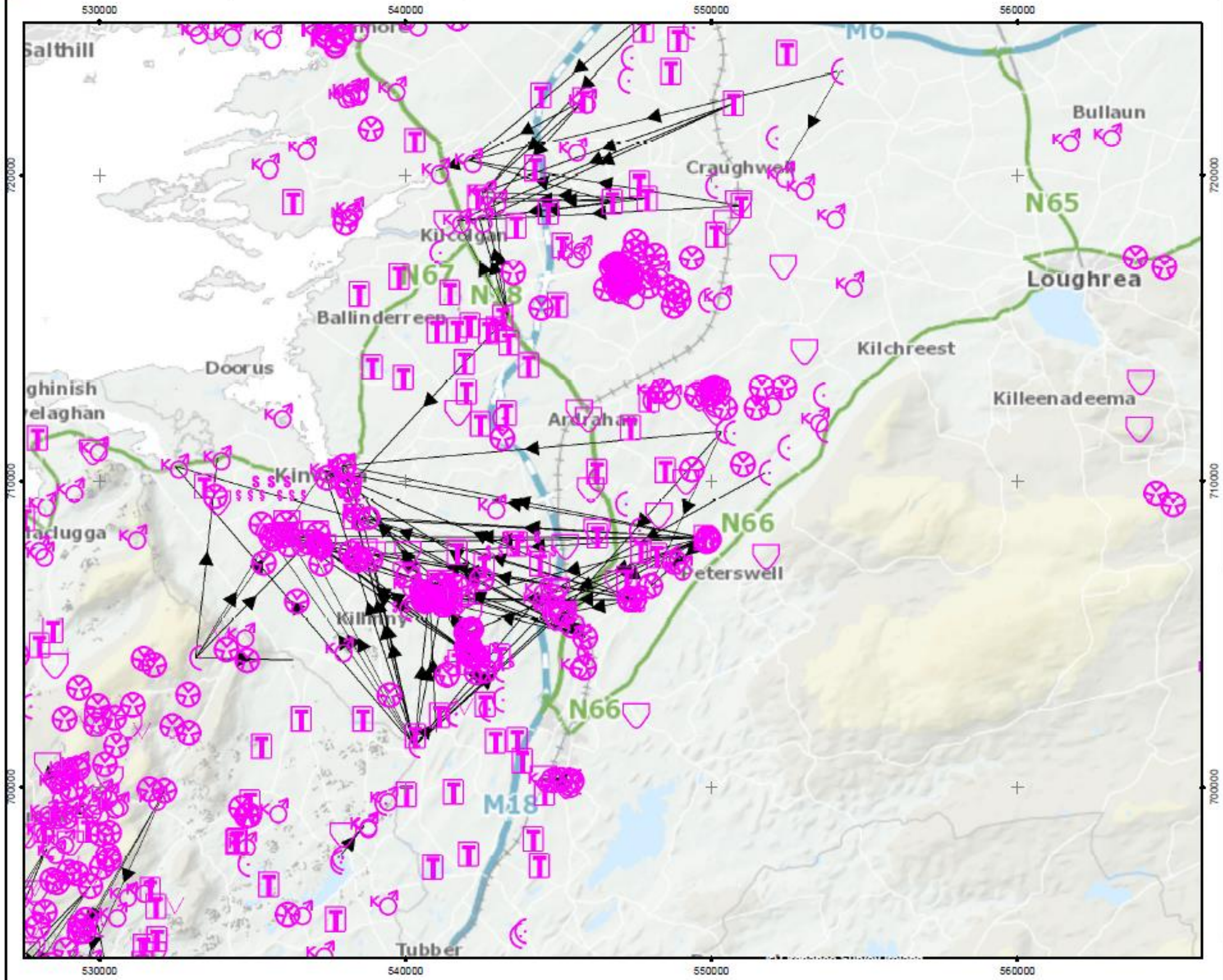
Groundwater Data



Scale: 1:200,000

Geological Survey Ireland

0 1.25 2.5 5 mi

0 2.25 4.5 9 km

Map Centre Coordinates (ITM) 546,771 709,701
15/01/2019 10:54:59

Legend

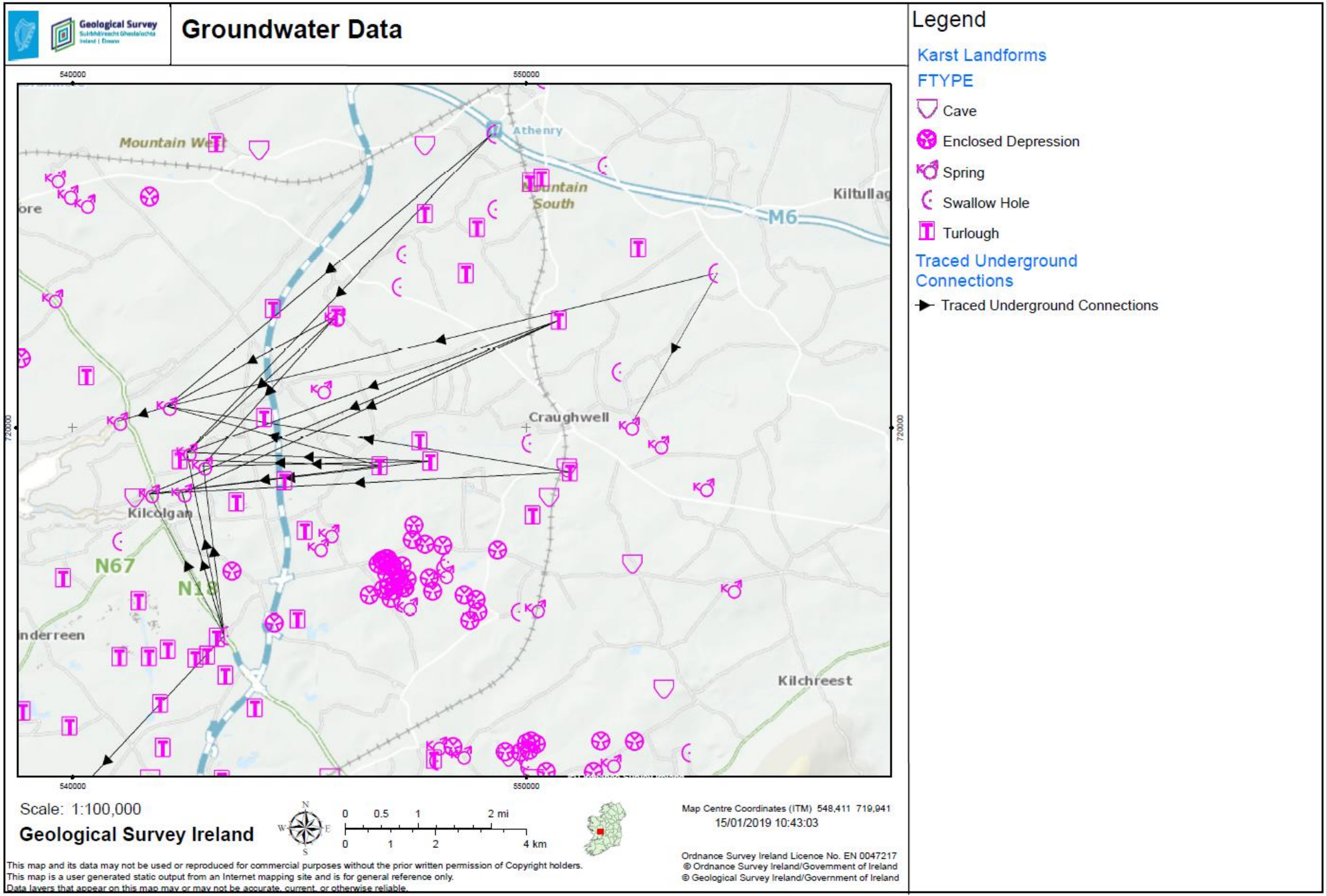
Karst Landforms

FTYPE

- Borehole
- Cave
- Dry Valley
- Enclosed Depression
- Spring
- Superficial Solution Features
- Swallow Hole
- Turlough

Traced Underground Connections

- Traced Underground Connections



Geological Survey
Groundwater Data
Legend
Karst Landforms
FTYPE
Cave
Enclosed Depression
Spring
Swallow Hole
Turlough
Traced Underground Connections
Traced Underground Connections
540000
550000
720000
Mountain West
Athenry
Mountain South
Kiltullag
M6
Craughwell
Kilcolgan
N67
N18
inderreen
Kilchreest
Scale: 1:100,000
Geological Survey Ireland
0 0.5 1 2 mi
0 1 2 4 km
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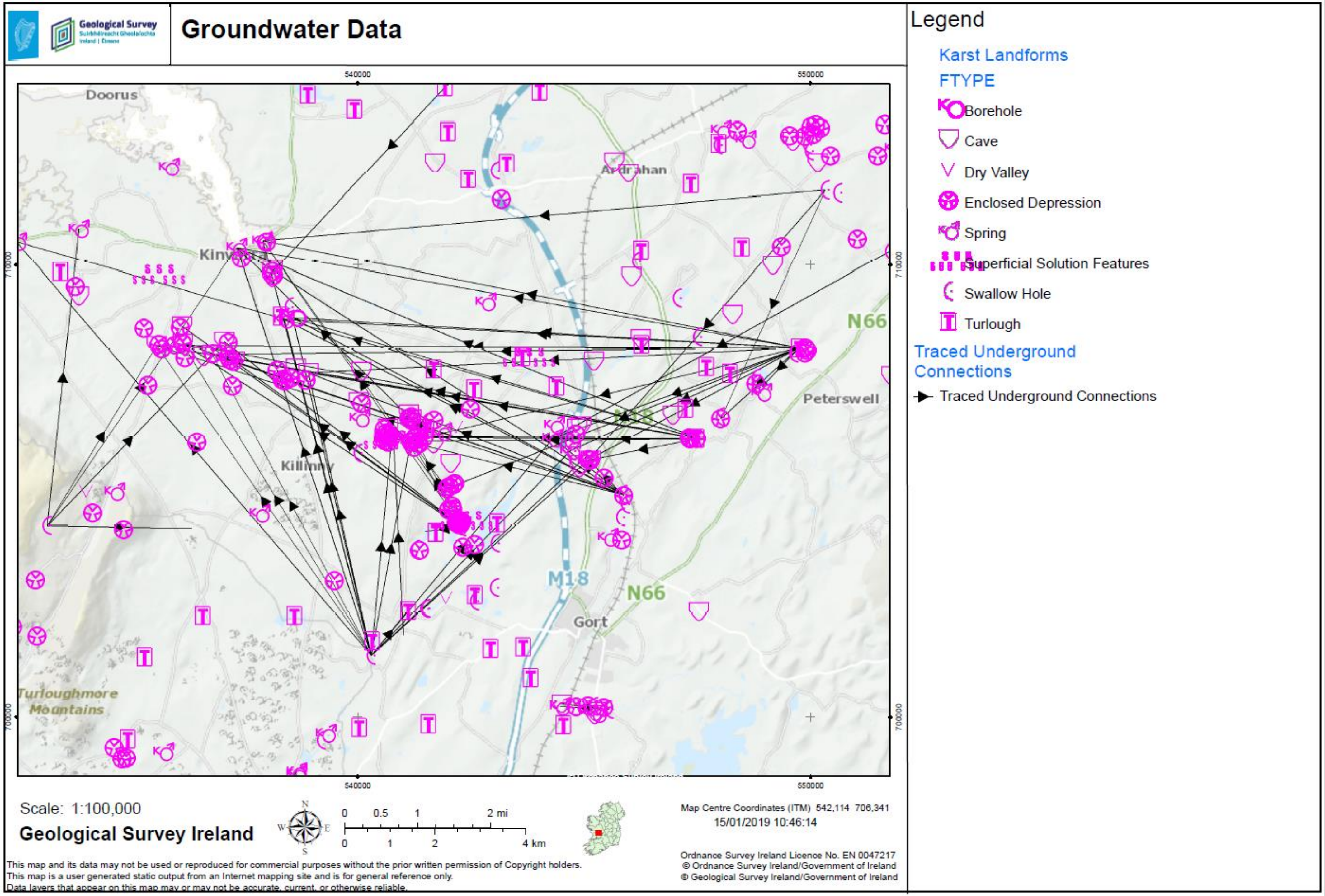
Geological Survey
Groundwater Data
Legend
Karst Landforms
FTYPE
Borehole
Cave
Dry Valley
Enclosed Depression
Spring
Superficial Solution Features
Swallow Hole
Turlough
Traced Underground Connections
Traced Underground Connections
Doorus
Kinvara
Ardrahan
Killinny
Peterswell
Gort
Turloughmore Mountains
N66
M18
540000
550000
710000
700000
Scale: 1:100,000
Geological Survey Ireland
0 0.5 1 2 mi
0 1 2 4 km
Map Centre Coordinates (ITM) 542,114 706,341
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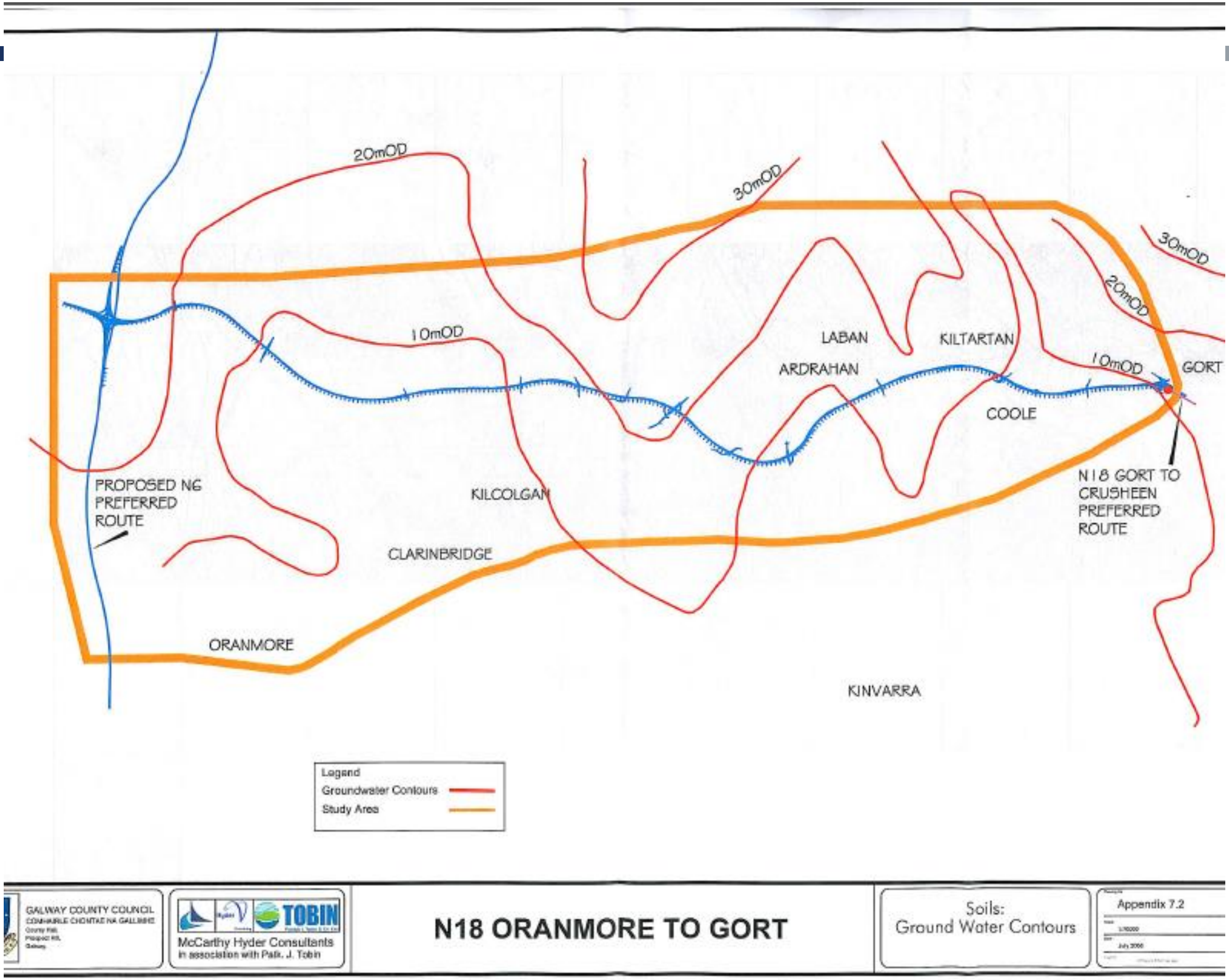
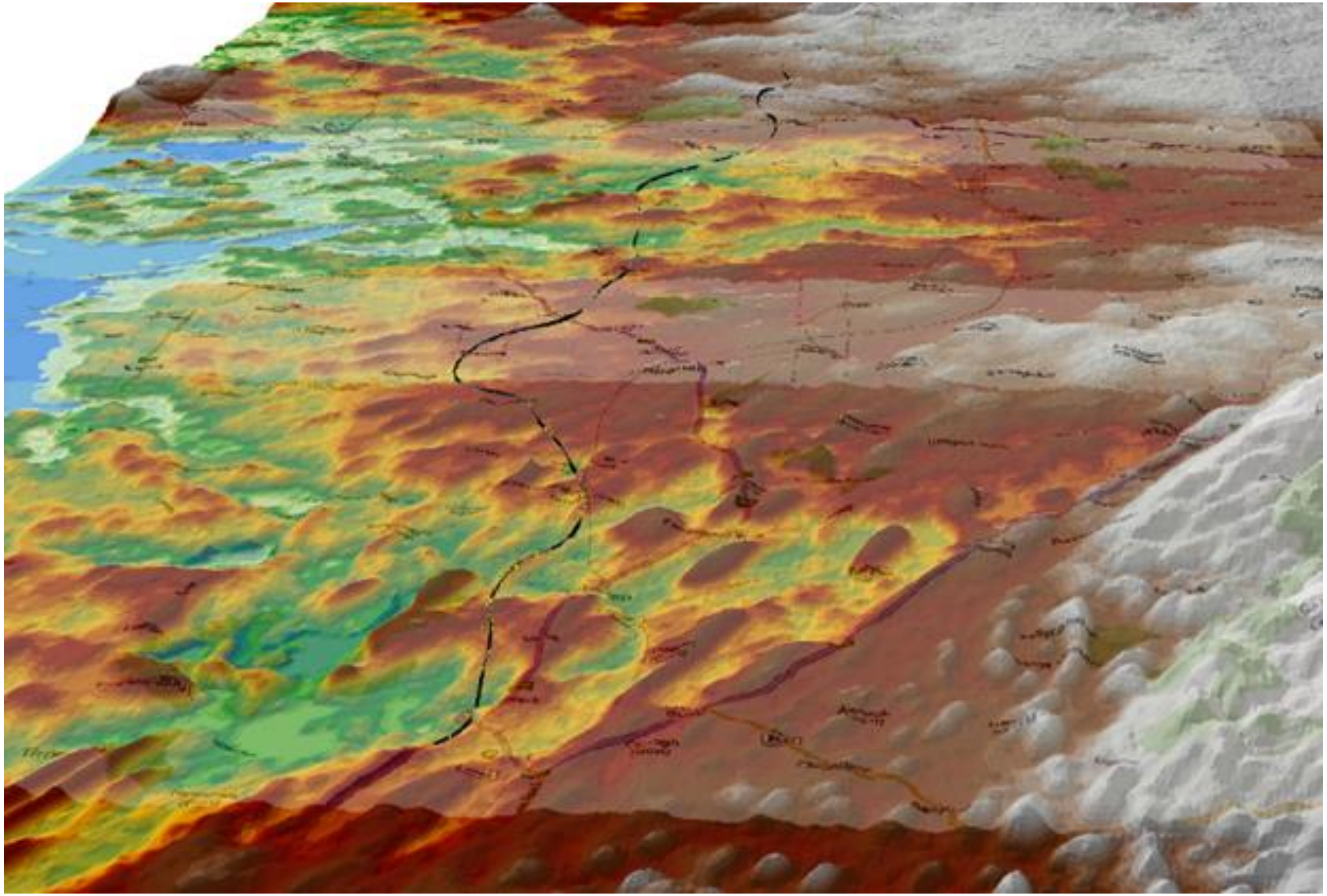
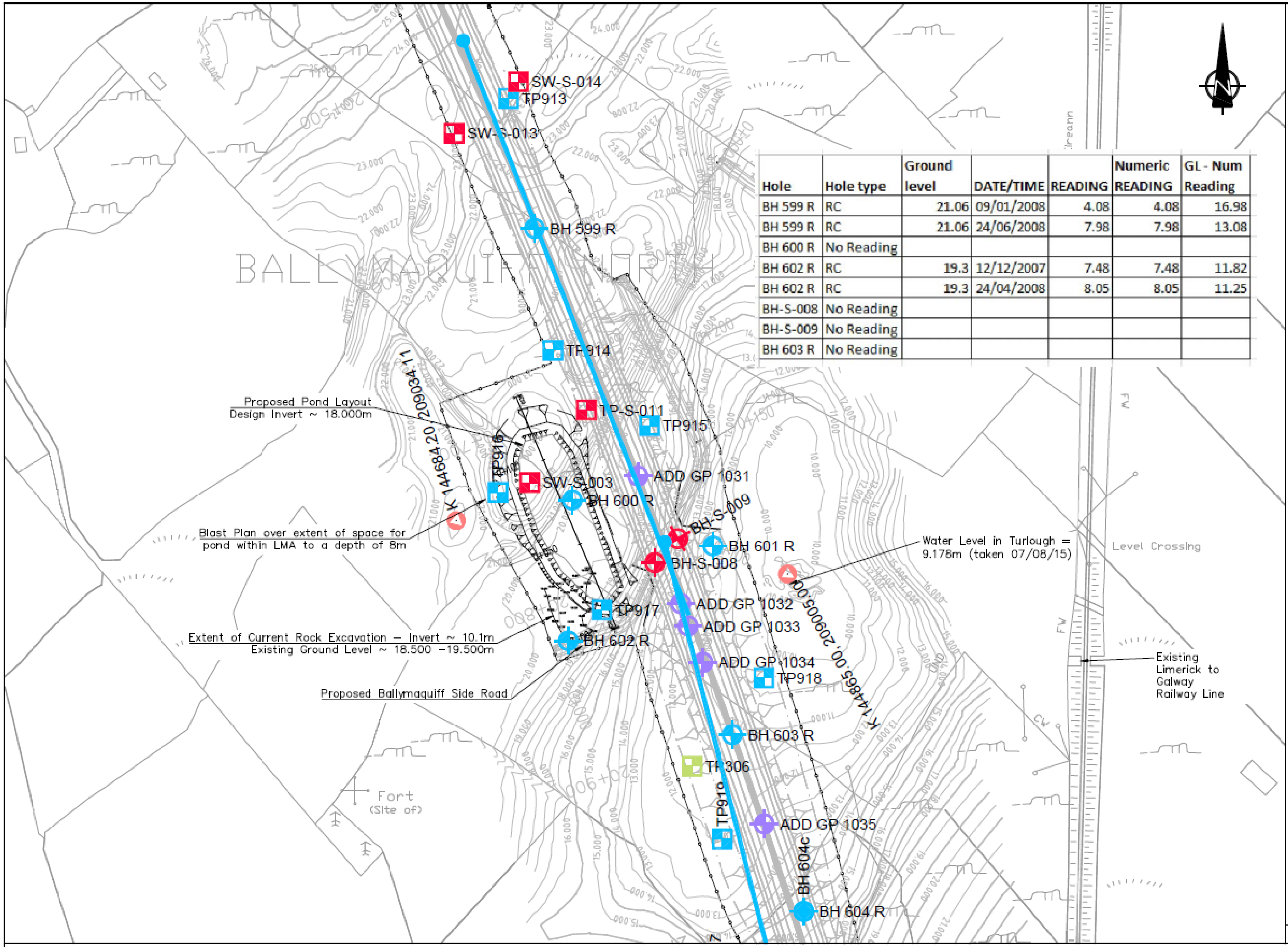

20mOD
30mOD
30mOD
20mOD
10mOD
10mOD
LABAN
KILTARTAN
GORT
ARDRAHAN
COOLE
N18 GORT TO CRUSHEEN PREFERRED ROUTE
PROPOSED N6 PREFERRED ROUTE
KILCOLGAN
CLARINBRIDGE
ORANMORE
KINVARRA
Legend
Groundwater Contours
Study Area
GALWAY COUNTY COUNCIL
TOBIN
McCarthy Hyder Consultants
in association with Patk. J. Tobin
N18 ORANMORE TO GORT
Soils:
Ground Water Contours
Appendix 7.2





Hole	Hole type	Ground level	DATE/TIME	READING	Numeric READING	GL - Num Reading
BH 599 R	RC	21.06	09/01/2008	4.08	4.08	16.98
BH 599 R	RC	21.06	24/06/2008	7.98	7.98	13.08
BH 600 R	No Reading					
BH 602 R	RC	19.3	12/12/2007	7.48	7.48	11.82
BH 602 R	RC	19.3	24/04/2008	8.05	8.05	11.25
BH-S-008	No Reading					
BH-S-009	No Reading					
BH 603 R	No Reading					

FOR INFORMATION

Notes:

1. This Drawing is only to be used for the Design Element identified in the title box. All other information shown on the drawing is to be considered indicative only.

Project: N17 / N18 Gort to Tuam PPP Scheme

Title: Ballymaquiff Hydrogeological Assessment
Extent of Over Excavation
Plan

Drawn: EOD | Original scale: 1:1000 @ A1 | Drawing No. N18-0500-00SKE-014 | Revision: DR-A
Checked: EOD | Date: August 2015
Approved: EOD

DR-A | EOD | 24/08/15 | Issued For Information

TYPES OF KARST FEATURES

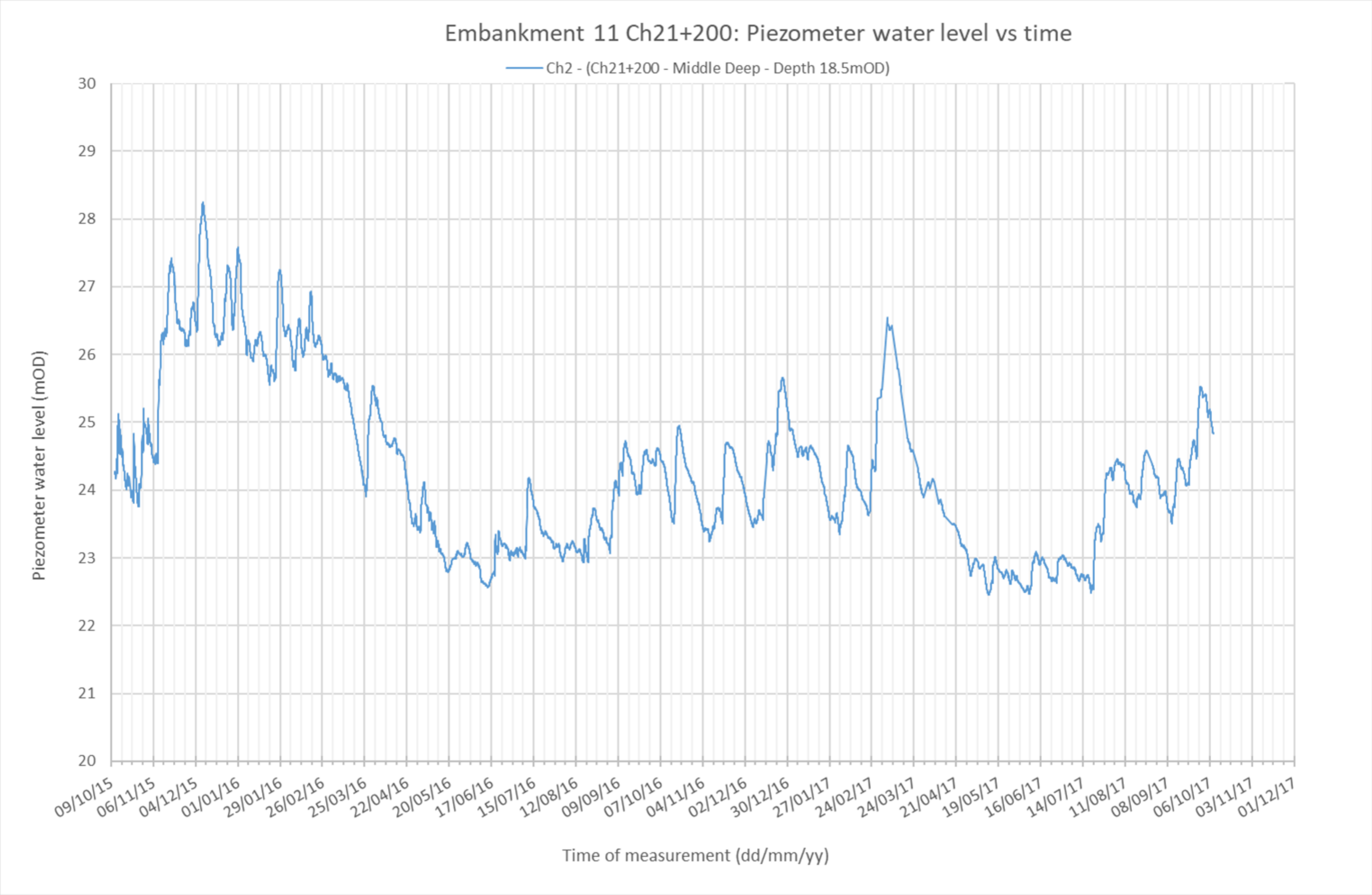
ARUP
BARRY TRANSPORTATION


VOLVO
JCB

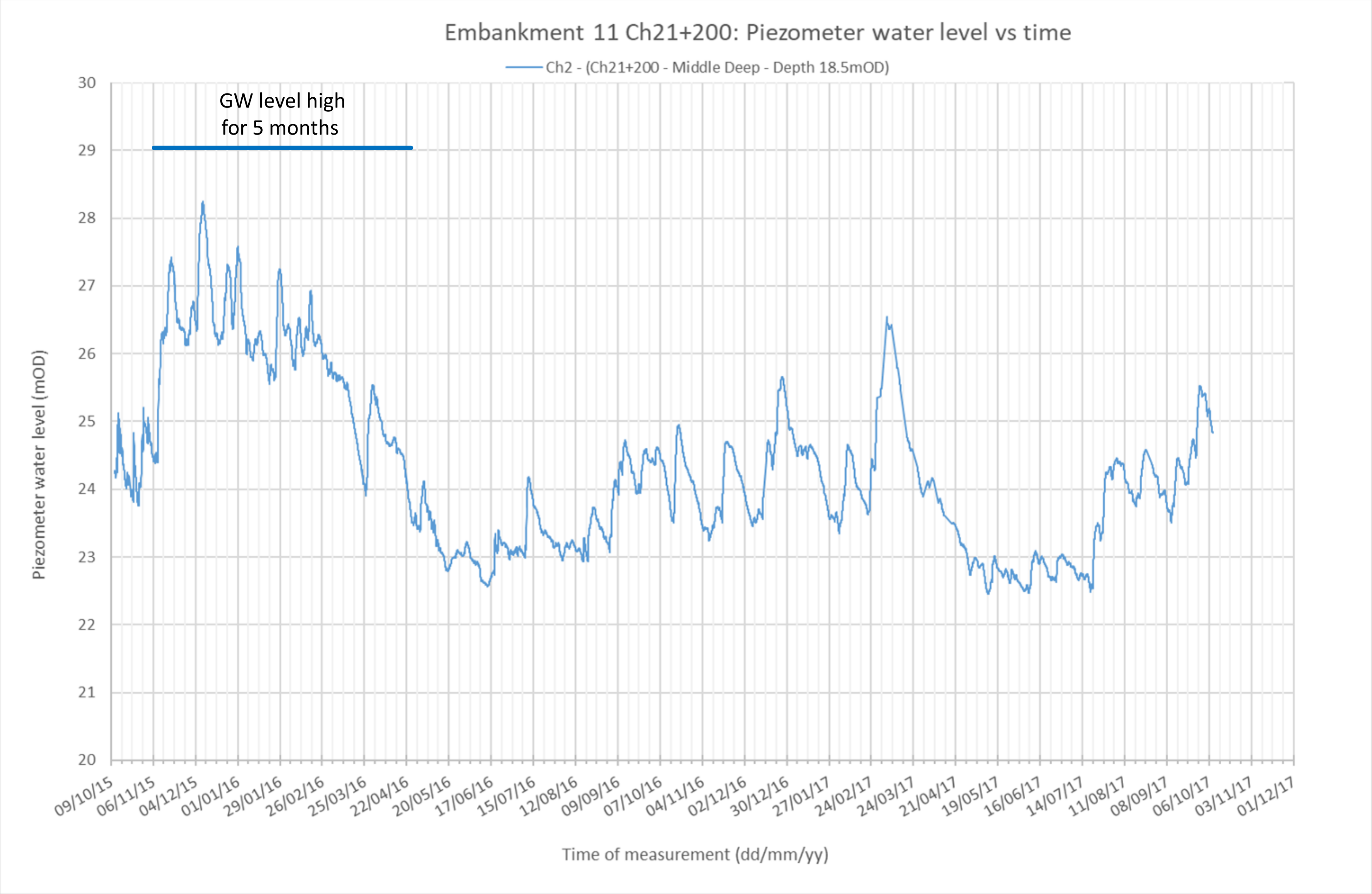
FLOODING NOVEMBER 2015

ROAD DRAINAGE - FLOODING

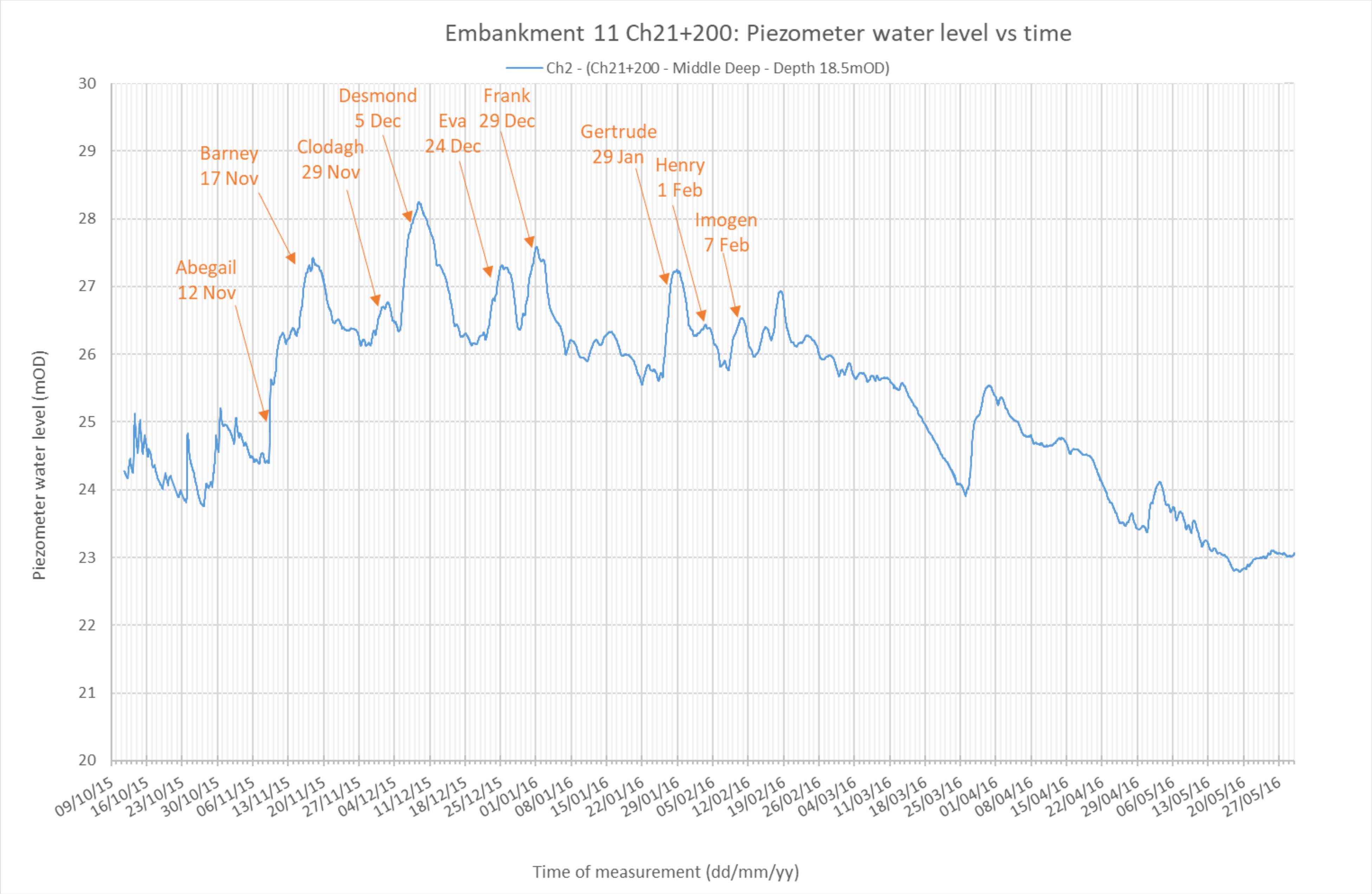
- Winter 2015/2106
- Known Flood Levels (2008/09) were not exceeded
- A number of new areas were assessed
- Designs adjusted as required
- Stress Tests carried out on drainage designs for multiple storm events and combinations



Embankment 11 Ch21+200: Piezometer water level vs time
Ch2 - (Ch21+200 - Middle Deep - Depth 18.5mOD)
Piezometer water level (mOD)
30
29
28
27
26
25
24
23
22
21
20
09/10/15
06/11/15
04/12/15
01/01/16
29/01/16
26/02/16
25/03/16
22/04/16
20/05/16
17/06/16
15/07/16
12/08/16
09/09/16
07/10/16
04/11/16
02/12/16
30/12/16
27/01/17
24/02/17
24/03/17
21/04/17
19/05/17
16/06/17
14/07/17
11/08/17
08/09/17
06/10/17
03/11/17
01/12/17
Time of measurement (dd/mm/yy)



Embankment 11 Ch21+200: Piezometer water level vs time
Ch2 - (Ch21+200 - Middle Deep - Depth 18.5mOD)
GW level high
for 5 months
Piezometer water level (mOD)
30
29
28
27
26
25
24
23
22
21
20
09/10/15
06/11/15
04/12/15
01/01/16
29/01/16
26/02/16
25/03/16
22/04/16
20/05/16
17/06/16
15/07/16
12/08/16
09/09/16
07/10/16
04/11/16
02/12/16
30/12/16
27/01/17
24/02/17
24/03/17
21/04/17
19/05/17
16/06/17
14/07/17
11/08/17
08/09/17
06/10/17
03/11/17
01/12/17
Time of measurement (dd/mm/yy)


Embankment 11 Ch21+200: Piezometer water level vs time
Ch2 - (Ch21+200 - Middle Deep - Depth 18.5mOD)
Piezometer water level (mOD)
Time of measurement (dd/mm/yy)
30
29
28
27
26
25
24
23
22
21
20
09/10/15
16/10/15
23/10/15
30/10/15
06/11/15
13/11/15
20/11/15
27/11/15
04/12/15
11/12/15
18/12/15
25/12/15
01/01/16
08/01/16
15/01/16
22/01/16
29/01/16
05/02/16
12/02/16
19/02/16
26/02/16
04/03/16
11/03/16
18/03/16
25/03/16
01/04/16
08/04/16
15/04/16
22/04/16
29/04/16
06/05/16
13/05/16
20/05/16
27/05/16
Abegail 12 Nov
Barney 17 Nov
Clodagh 29 Nov
Desmond 5 Dec
Eva 24 Dec
Frank 29 Dec
Gertrude 29 Jan
Henry 1 Feb
Imogen 7 Feb

MITIGATION AGAINST FLOODING

- Road Design Levels
- Drainage Blanket
- Flood Relief Culverts

ROAD DRAINAGE – SPECIAL REQUIREMENTS

- Sealed Drainage - All of the M18 road drainage to be sealed
- Northern section mainly attenuation pond to surface water – southern section mainly infiltration basins to groundwater
- Regionally Sensitive Aquifer – Hydrogeological Assessments
- Seasonal flooding (reference level 2008-2009 peak +1m)

ROAD DRAINAGE - ATTENUATION

Constructed Wetland and Soakaway

- Infiltration System
- Excavation in Rock
- Proximity to SAC and Local Group Water Scheme
- Area of Seasonal Flooding

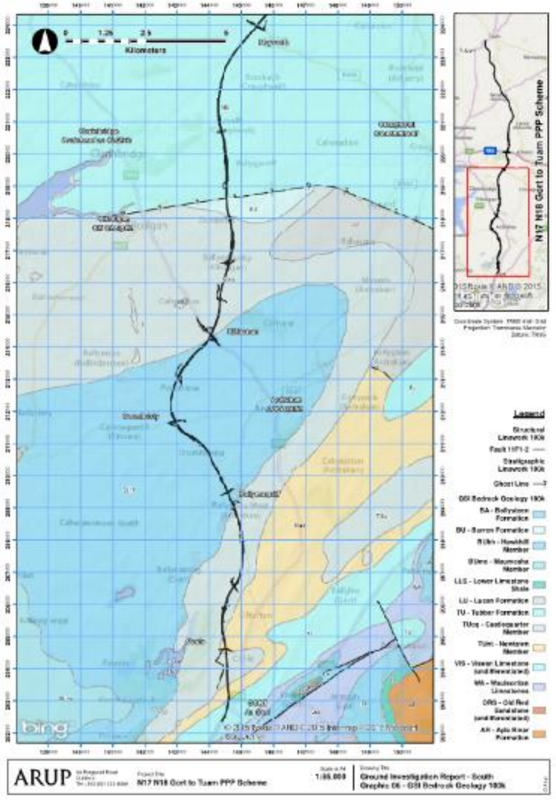
GEOTECHNICAL DESIGN FOR SOUTHERN SECTION

ARUP BARRY TRANSPORTATION

Esther Madden

BSc MSC MIEEI CENG

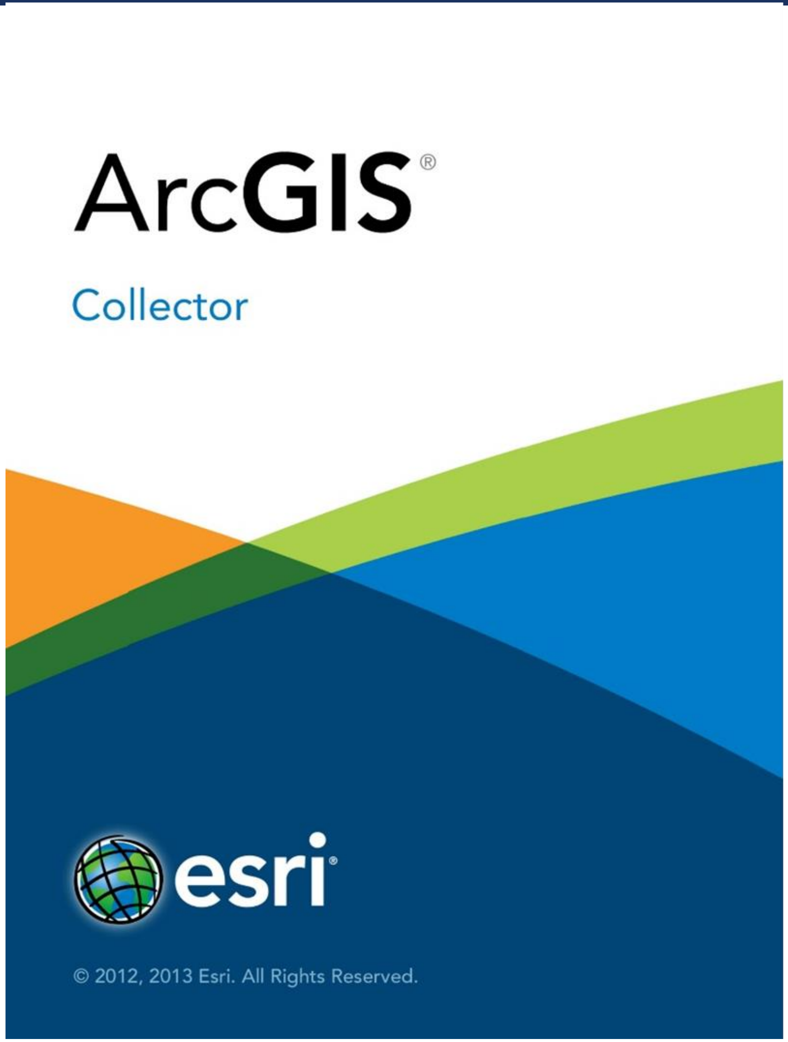
DESK STUDY



GSI Geology map and karst landforms via ArcGIS

SITE WALKOVER

ARUP BARRY TRANSPORTATION



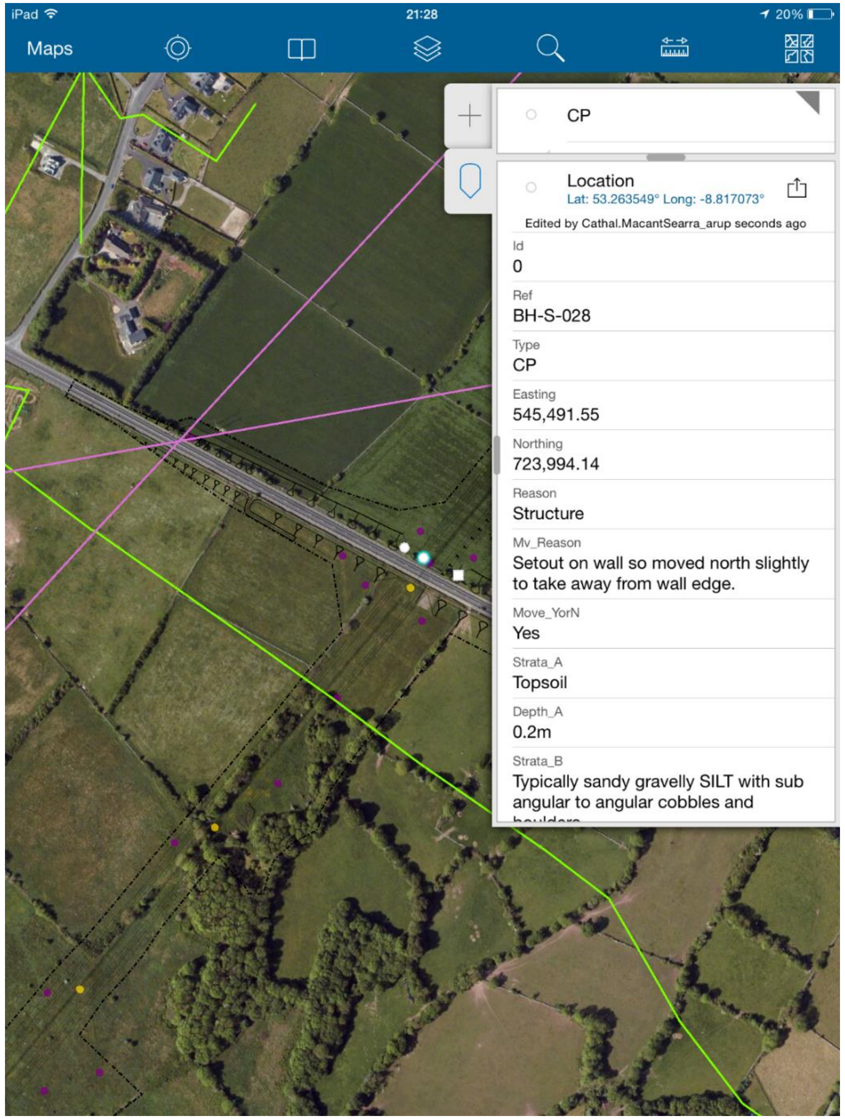
Tablet Application

M17N18

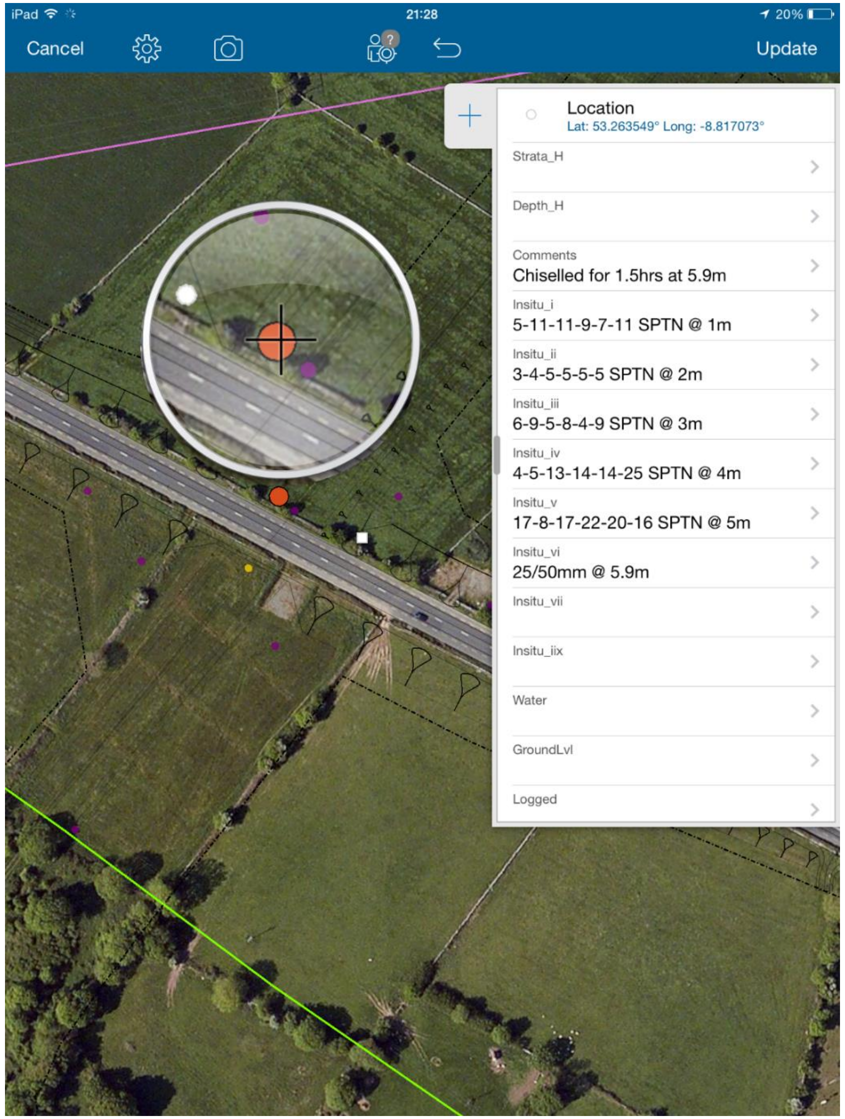
Supplementary Ground

Investigation

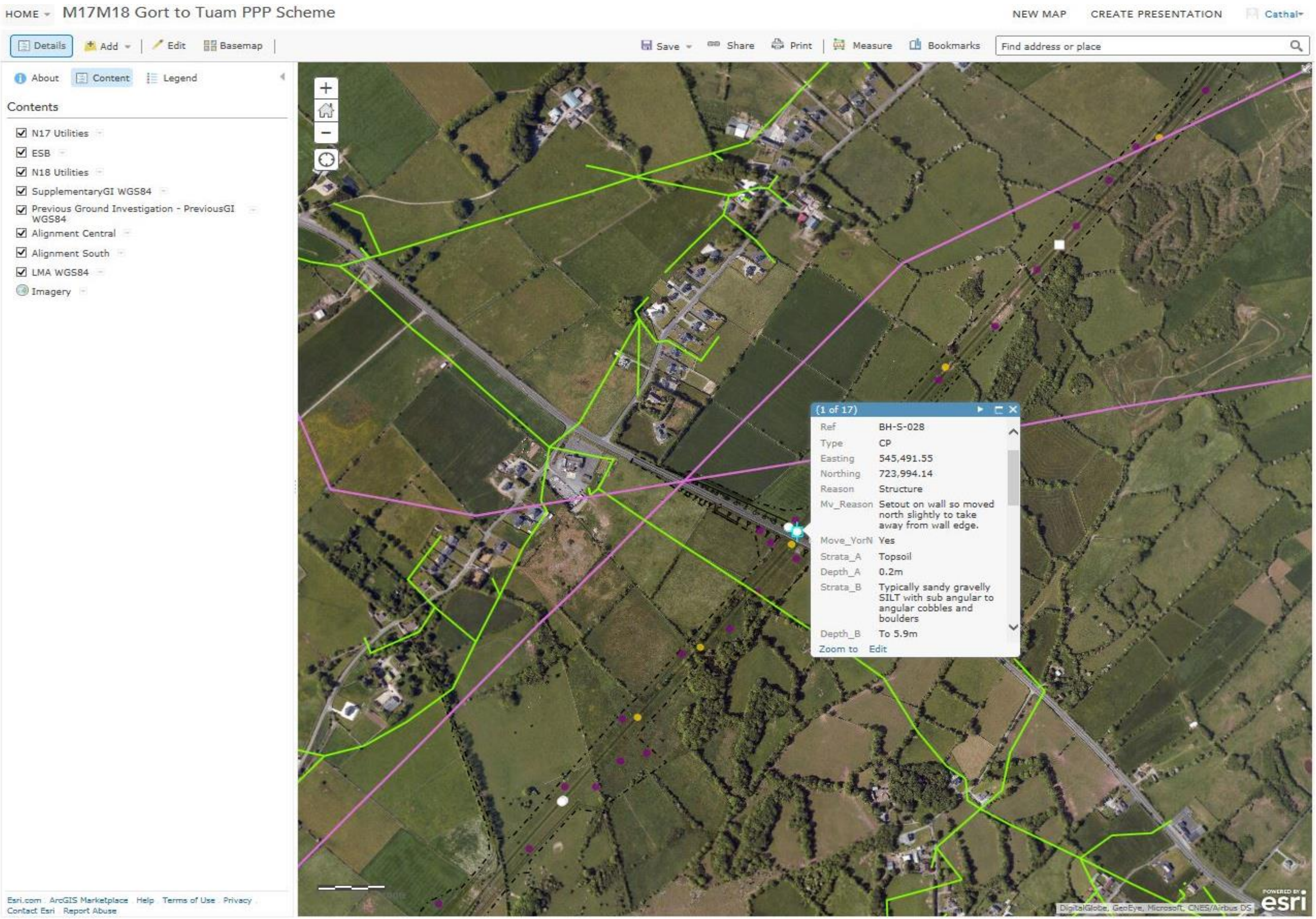
Monitoring



- Access relevant datasets in the field



- Capture geo-referenced information including photos



All recorded information available on ArcGIS Online







CONCLUSION

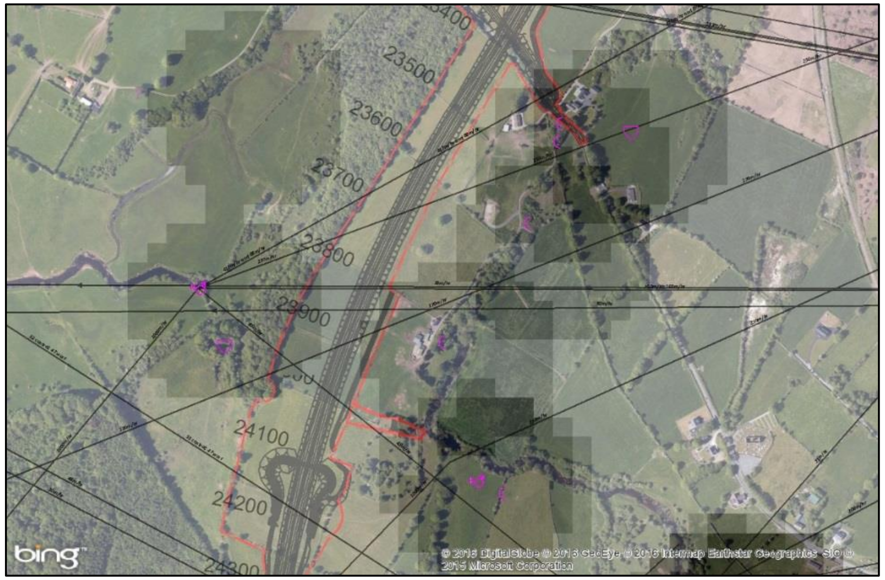
These applications can effectively feed into generating and managing a digital model throughout the life cycle (BIM)

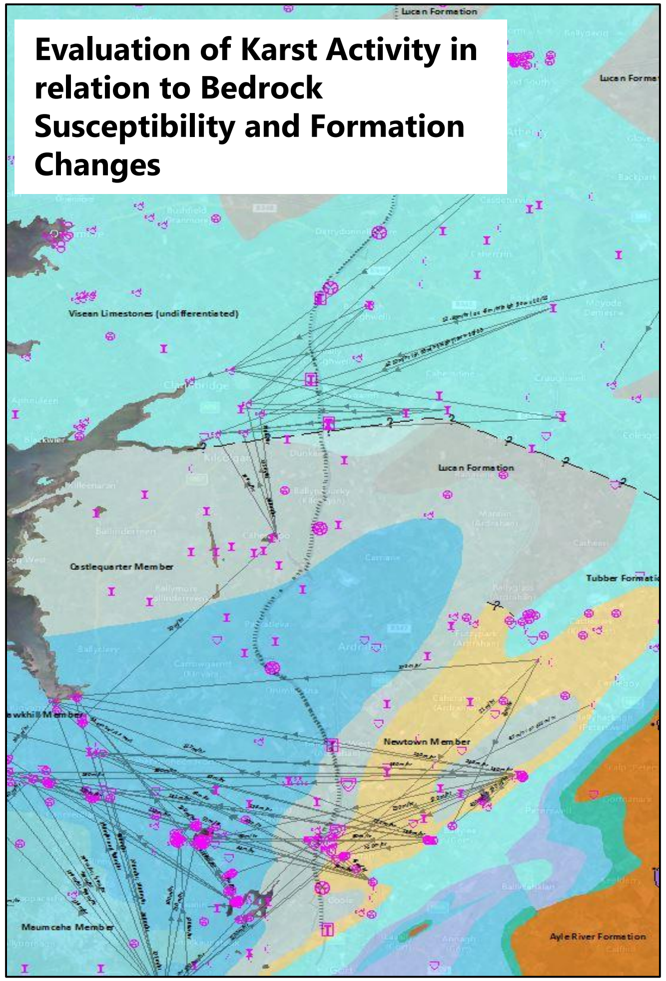
Applications:

- Ground Investigations
- Karst Mapping
- Resident Engineers for geotechnical works

KARST RISK ASSESSMENT

ARUP BARRY TRANSPORTATION

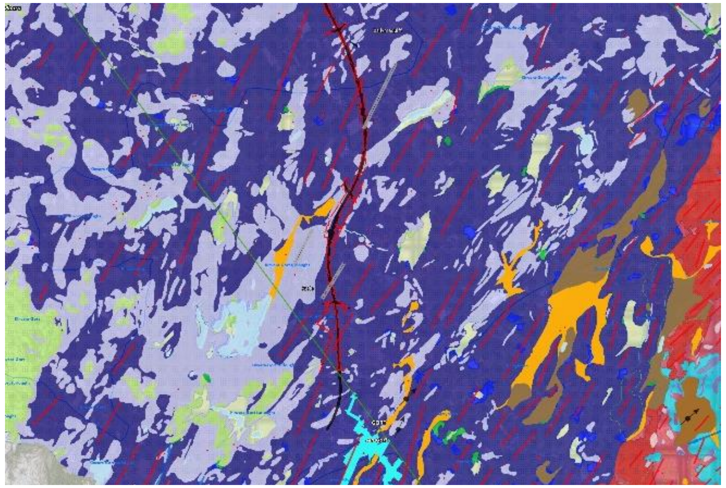




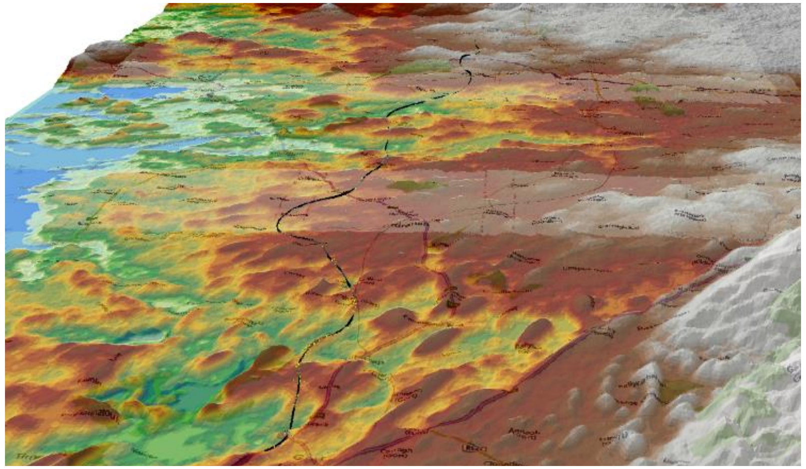
Evaluation of Karst Activity in relation to Bedrock Susceptibility and Formation Changes

Detailed Assessment of Areas of High Karst Activity

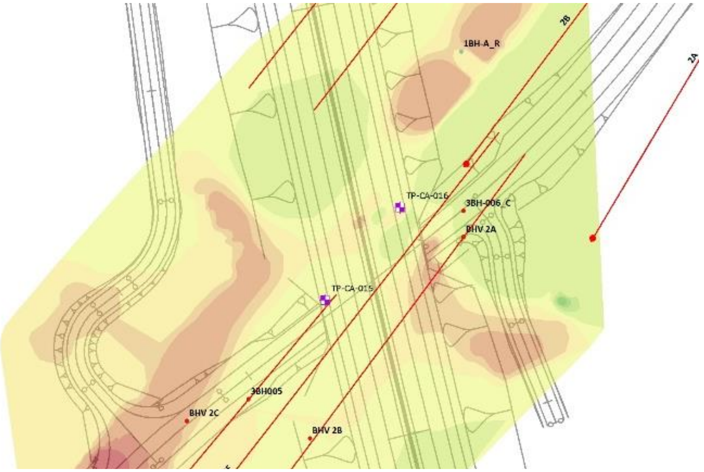
Alignment data, field / site walkover information, services and utilities



Regional Geological, Hydrogeological, and Environment available from relevant bodies



3D information including topographical contouring, alignment, geological surfaces



Ground investigation data, geophysical results (ground conductivity, microgravity)

Risk Assessment

Length (m)	% of al	Risk
9+530	43	High
11+510		Medium
1+160		Low

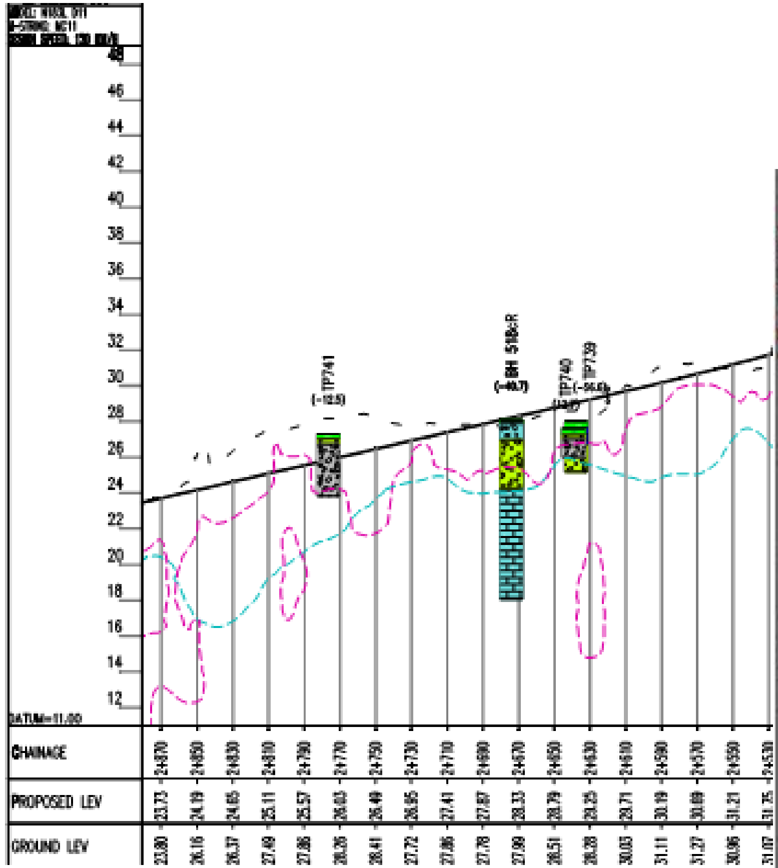
Application of blanket geotextile across 95% of alignment and piling of high percentage of structures!!

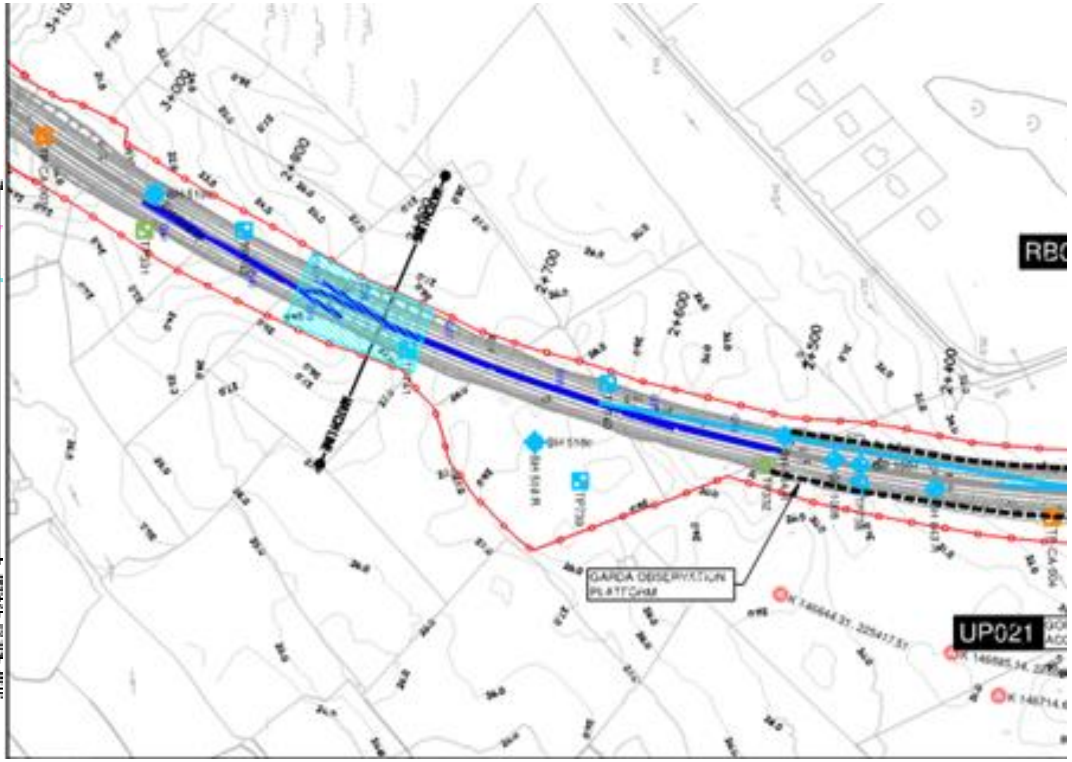
22+300

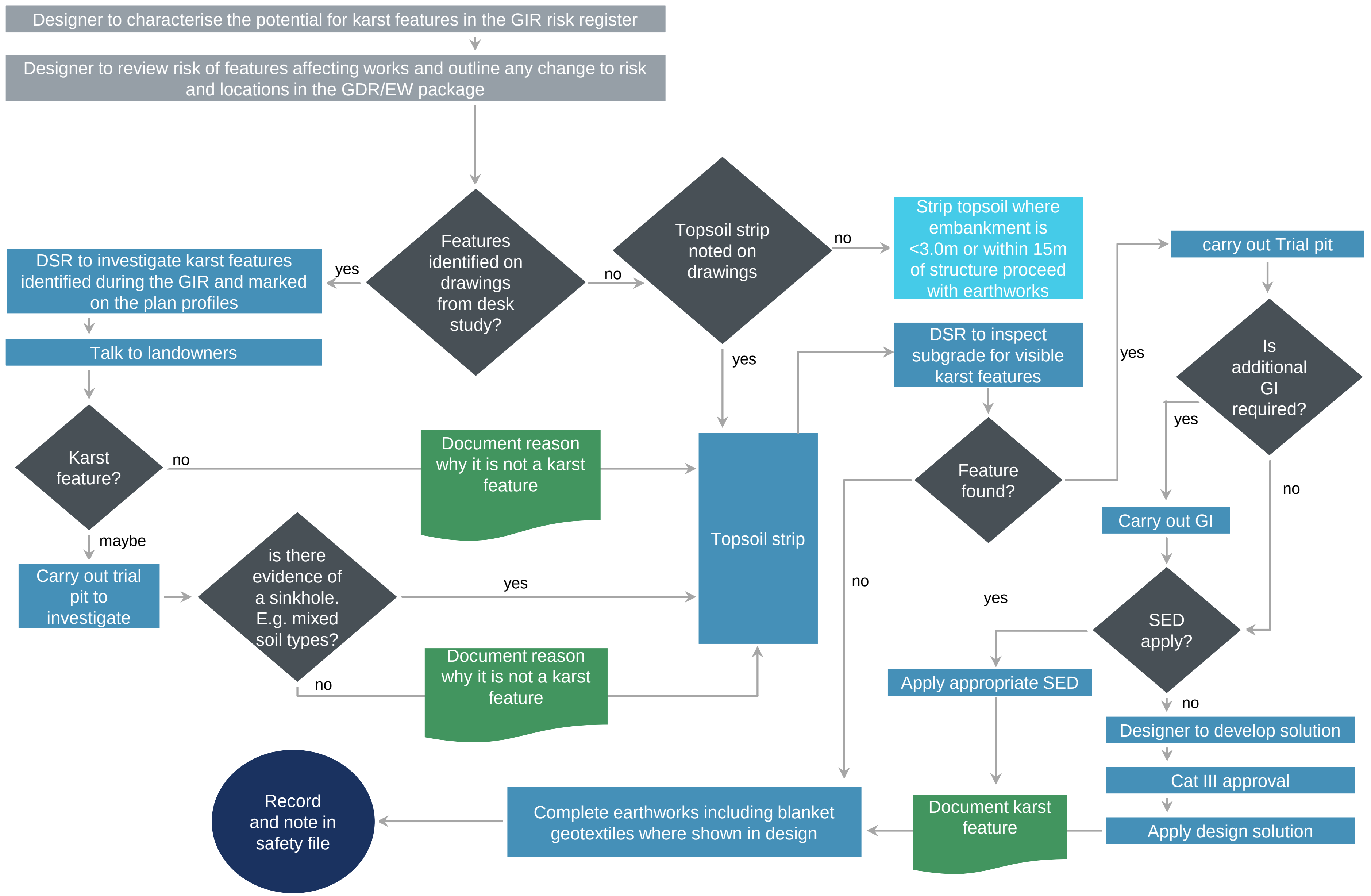
Length (m)	% of Alignment	
9+530	43%	High Risk
11+610	52%	Medium Risk
1+160	5%	Low Risk

EARTHWORKS DRAWINGS

ARUP BARRY TRANSPORTATION

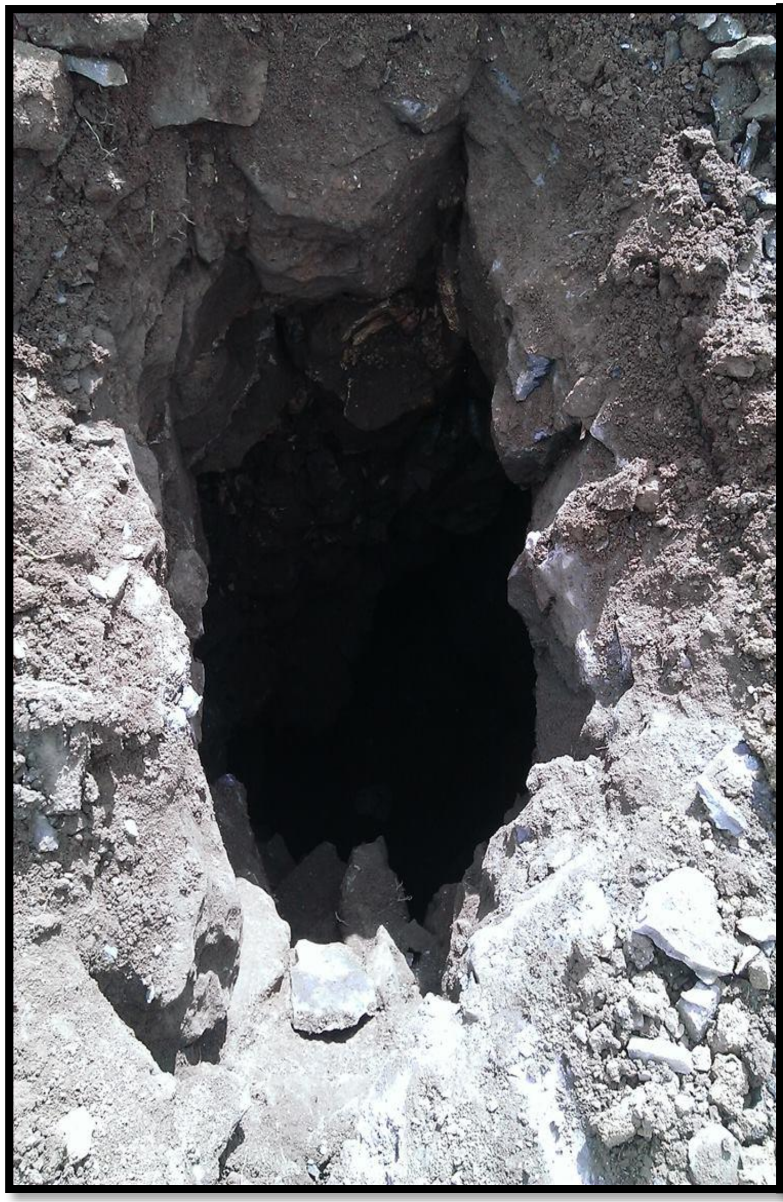




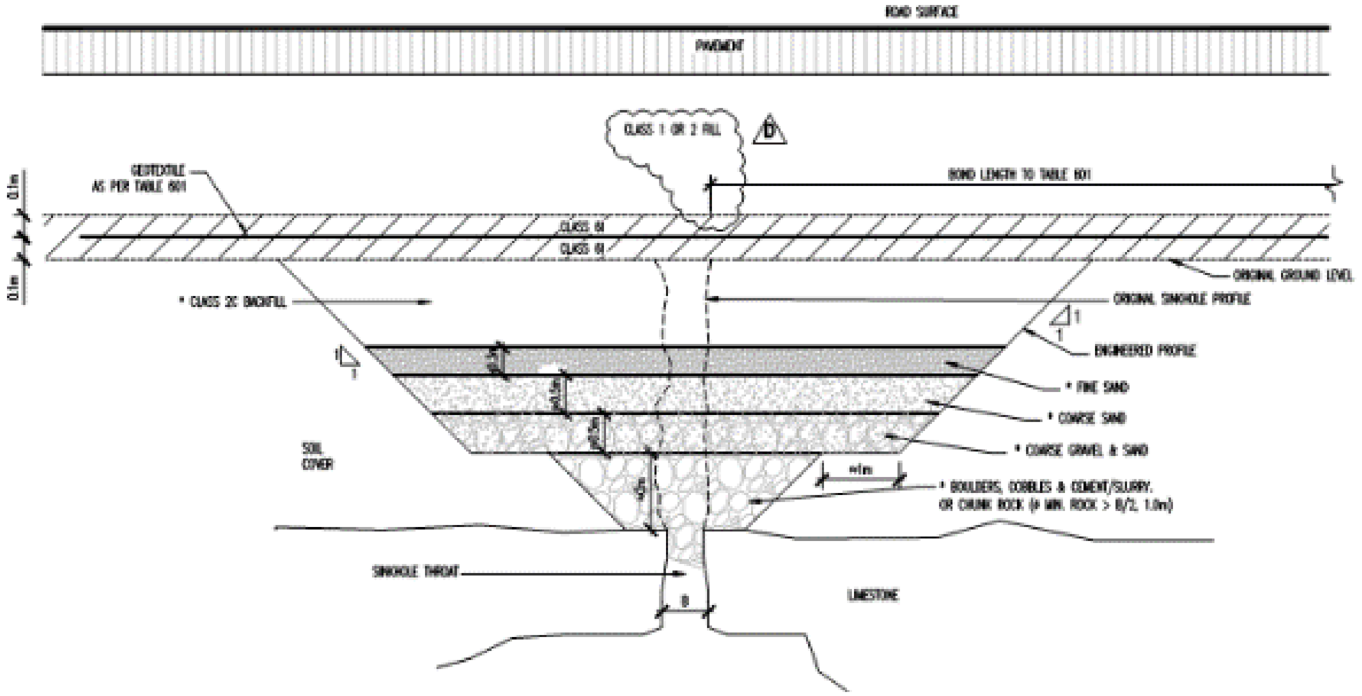


Designer to characterise the potential for karst features in the GIR risk register
Designer to review risk of features affecting works and outline any change to risk and locations in the GDR/EW package
Features identified on drawings from desk study?
yes
DSR to investigate karst features identified during the GIR and marked on the plan profiles
Talk to landowners
Karst feature?
no
Document reason why it is not a karst feature
maybe
Carry out trial pit to investigate
is there evidence of a sinkhole. E.g. mixed soil types?
yes
no
Document reason why it is not a karst feature
no
Topsoil strip noted on drawings
no
Strip topsoil where embankment is <3.0m or within 15m of structure proceed with earthworks
yes
Topsoil strip
DSR to inspect subgrade for visible karst features
Feature found?
yes
carry out Trial pit
Is additional GI required?
yes
Carry out GI
no
SED apply?
yes
Apply appropriate SED
no
Designer to develop solution
Cat III approval
Apply design solution
no
Document karst feature
Complete earthworks including blanket geotextiles where shown in design
Record and note in safety file


CH 4+500 NBL
Ch 4+600 NBL
4+400 to 4+680 Batter NBL
FILL @ Existing R446 East
Sub Grade check R446 West
FORMATION @ 4+600 to 4+700



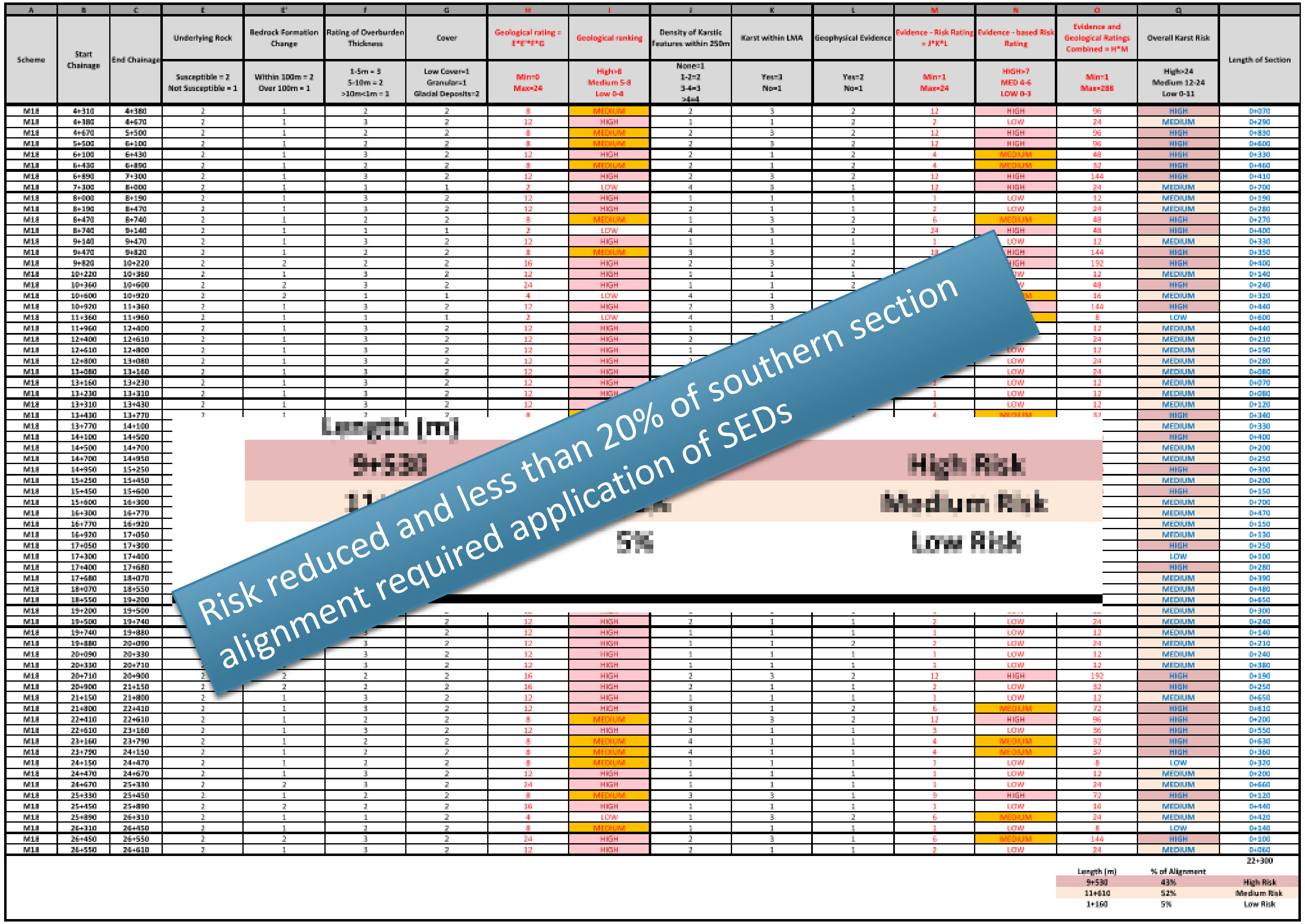

TYPICAL SOLUTION



BENEFITS OF KARST PROTOCOL

- Use Karst protocol to reduce need for blanket geotextile and piles
- Standard set of solutions available for typical features and dimensions encountered
- Excavation to inspect rock head is more accurate than geophysics if depth to excavation is practical

Benefit of karst protocol



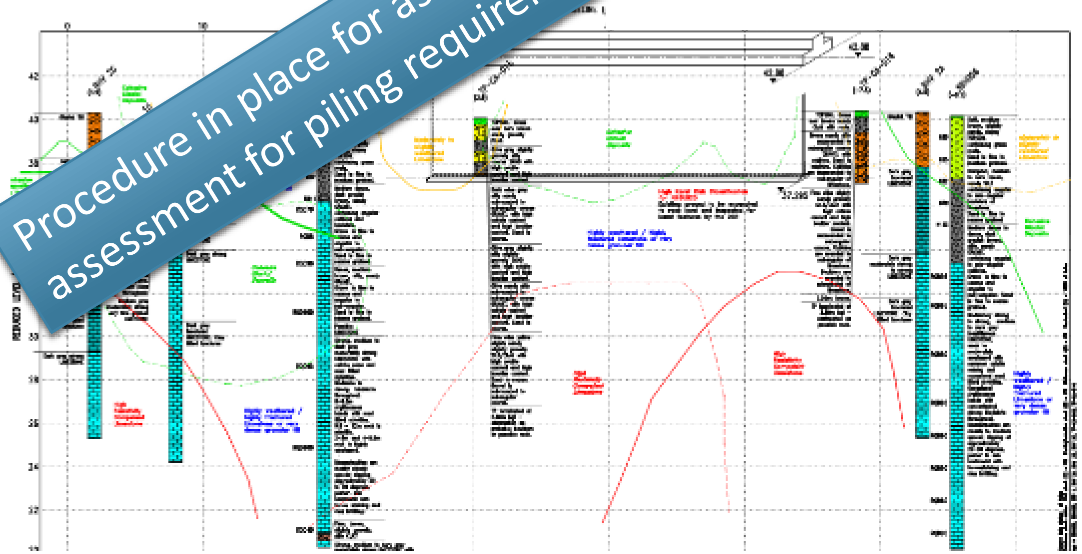
Benefit of karst protocol

A detailed review of the geophysical survey information, exploratory data and site walkover / surface inspections was undertaken at the footprint of N18U023. After a thorough examination of the information available, the location of the structure has been classified as a 'high' karst risk. The factors pertaining to this classification are as follows:

- Samples of weathered rock uncovered during the 2014 investigation were examined and found to consist of soft weathered fossiliferous Limestone, with evidence of water permeation and movement. Samples of such rock were found in clusters above sandy Clay at TP-CA-016, indicating the infilling of cavities in the karstified rock.
- Anomalies recorded in the electrical resistivity profiles directly at the struc[...] footprint indicate the likelihood of infilled cavities. Although the grou[...] conductivity results do not correlate which such anomalies, the int[...] notes indicate that the anomalies were not highlighted possibl[...] depth or conductive nature of the features.
- Numerous zones of highly weathered/fractures rock, zones of low recovery and evidence of infilled cavities/voids were logged in both the open hole (BHV 2A, 2B, 2C) and core holes (3BH005 and 3BH006) at the structure location. Log descriptio[...]dicate generally closely spaced discontinuities with common evid[...]er permeation due to calcite veining and mud filled stylolite[...]
- Numero[...]rying in diameter, where noted in the sur[...]re footprint. A significant number of the [...]he fields to the north of the structure.

[...]gh karst risk of the structure location, the existing ground [...] rock level, which will subsequently be inspected by the DSR [...]s. The strata beneath the bridge foundations shall be inspected by [...]r potential karst features following stripping of topsoil. The DSR [...] also conduct a thorough examination of the surrounding area for any [...]tential karst features.

Procedure in place for assessing structures and assessment for piling requirement

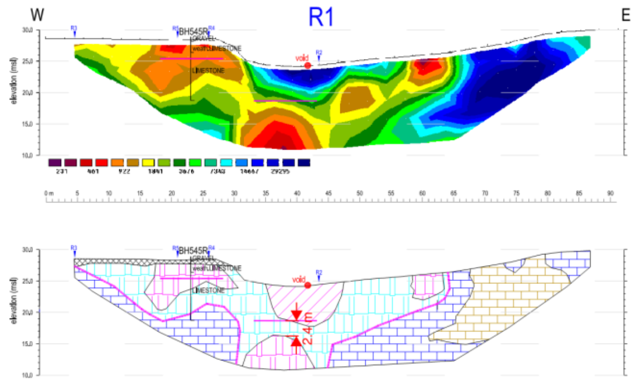


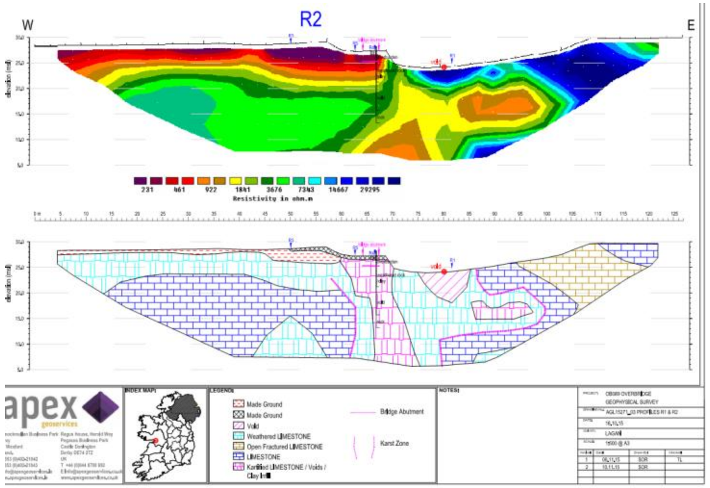
OB89 – karst uncovered

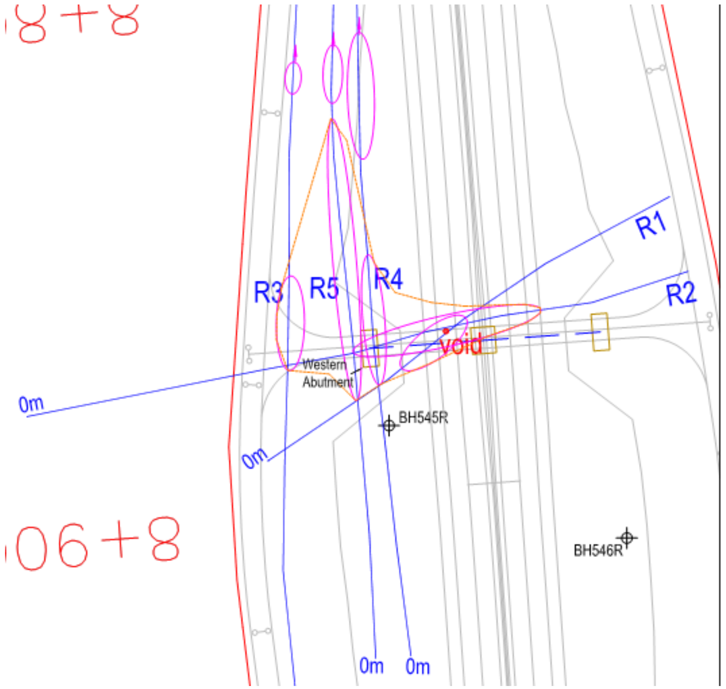
ARUP BARRY TRANSPORTATION

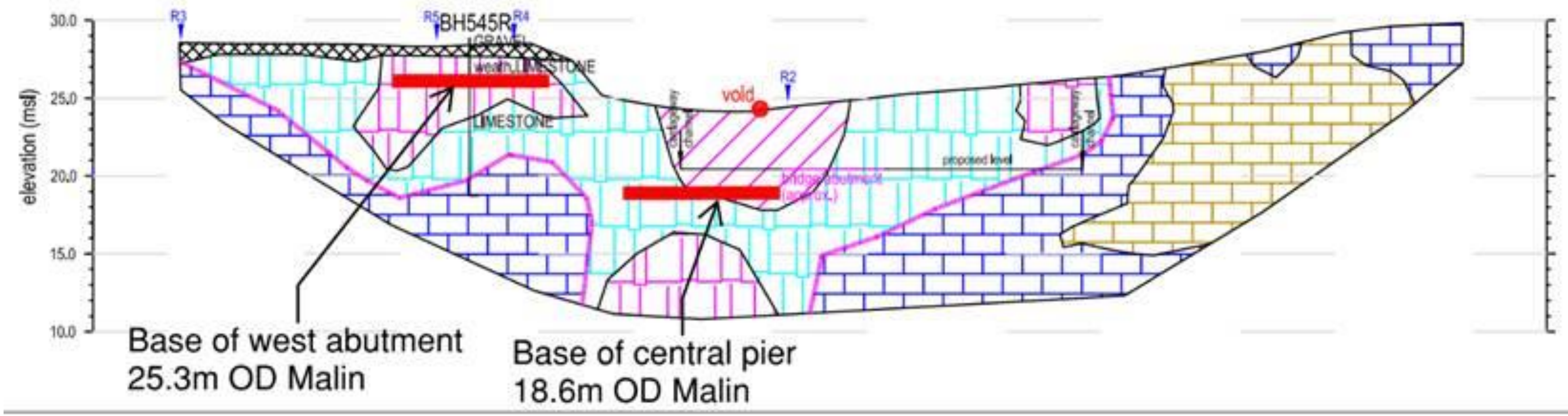


KARST SHOWN IN GEOPHYSICS AT WEST AND CENTRAL PIER DURING CONSTRUCTION








30.0
25.0
20.0
15.0
10.0
elevation (msl)
R3
R5
BH545R
R4
GRAVEL
weath. LIMESTONE
LIMESTONE
void
R2
proposed level
bridge abutment (approx.)
Base of west abutment
25.3m OD Malin
Base of central pier
18.6m OD Malin

Option 1 – Leave OB89 in place and remediate karst

- Central pier

Phase 1 rotary percussive and geophysics 3 to 4m above formation COMPLETE

Phase 2 Ground investigation – geophysics at actual formation and rotary percussive probes on grid to estimate extent of feature

Phase 3 Create safe working platform and carry out shell and auger boreholes to determine soil parameters and rotary coring 3m into rock for rock parameters

Clear out feature and determine extent

Backfill feature beneath pavement to SED

Scenario A

If void beneath structure foundation is small, backfill with inverted filter and design slab to span feature

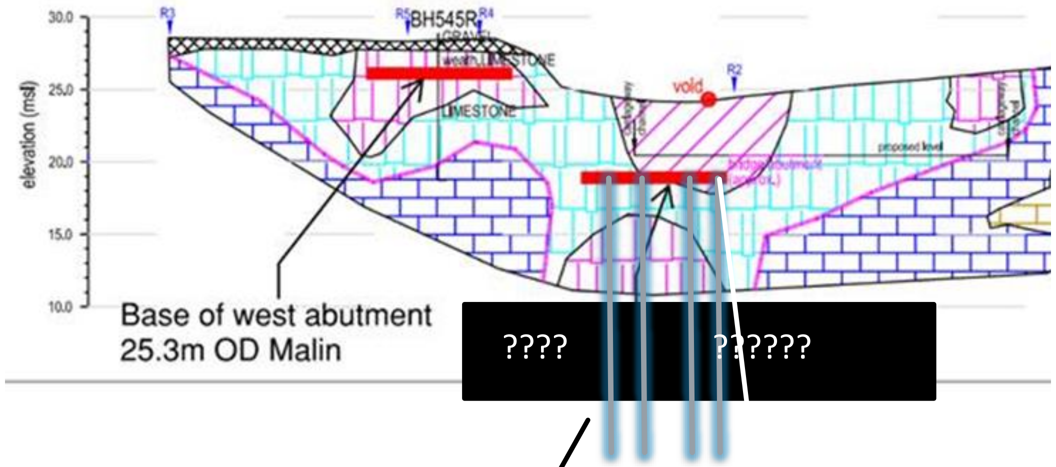
Scenario B

If feature is large and in filled with overburden and rock is at depth, design skin friction piles

Scenario C

If feature is large and rock is present, design rock socketed piles

SCENARIOS B AND C – LARGE OPEN OR IN FILLED FEATURE



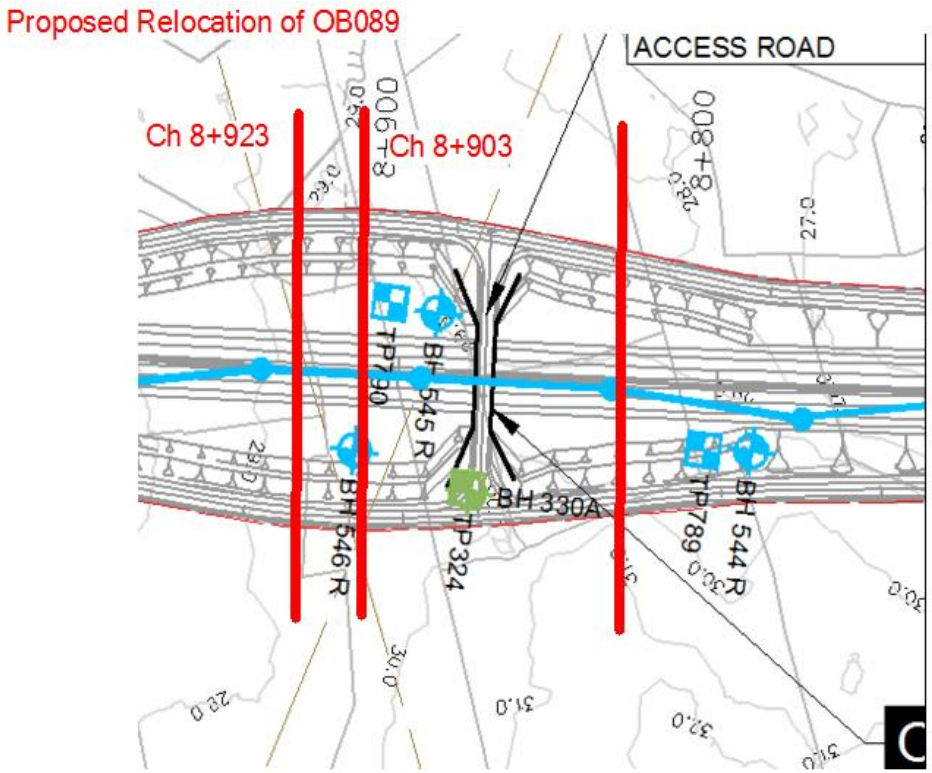
Either piles bearing in soil and on rock or 3m into rock – dependent on depth of competent rock from boreholes

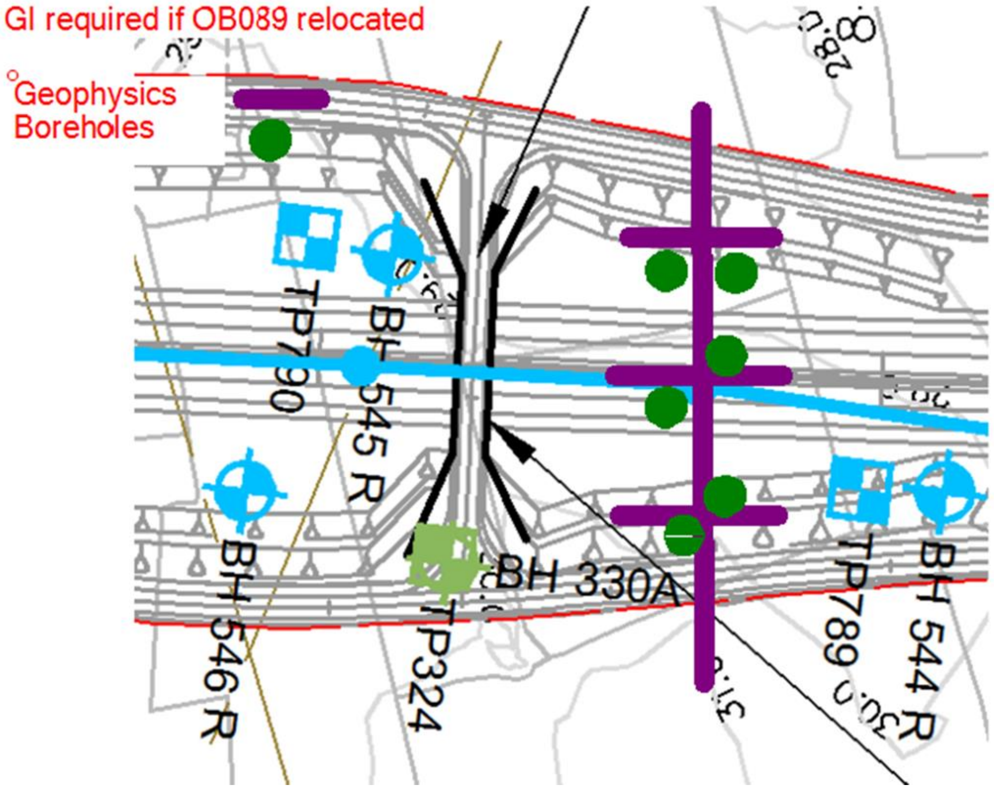
Type, depth, permanent casing and number TBC post design

Base of central pier at 18.6 m OD malin

OPTION 2 MOVE BRIDGE

ARUP BARRY TRANSPORTATION

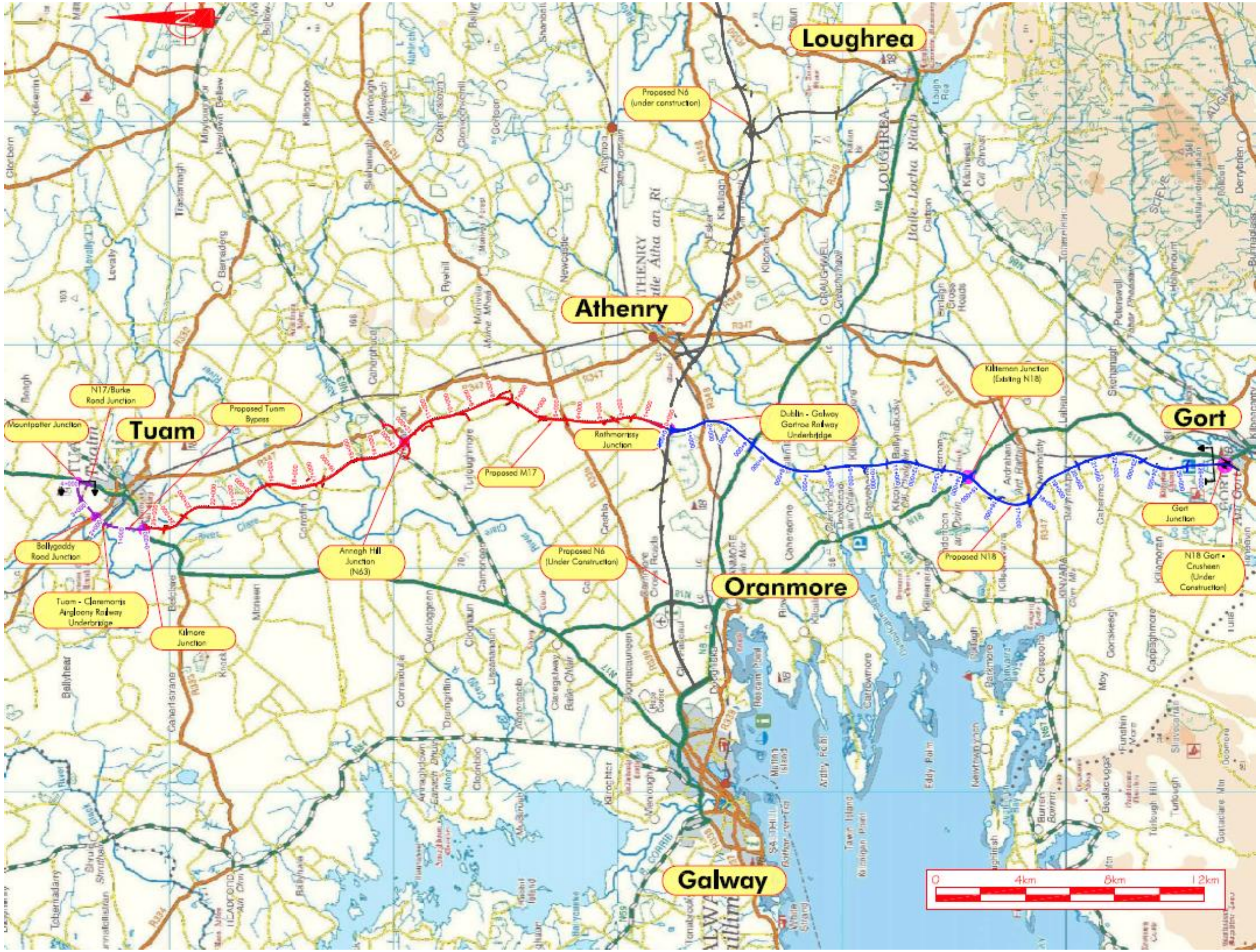




Reinstatement of karst feature at original location

M17/M18 KARST FEATURES ENCOUNTERED ON SITE

Deirdre O'Hara BSc MSc HDipPM CEng MIEI PGeo



M17/M18 PROJECT MAP

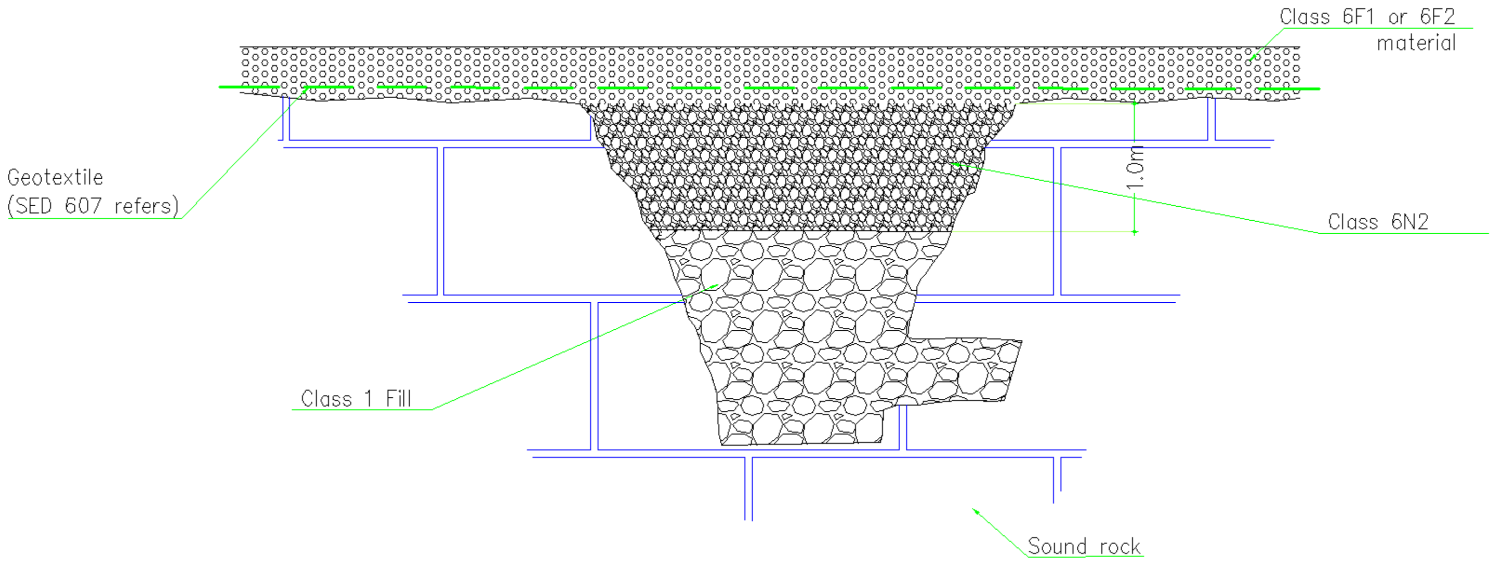
M17/M18 KARST FEATURES ENCOUNTERED ON SITE

- Drop outs in rock
- River Nanny
- Ballinphuil Bridge
- Ballygaddy Bridge

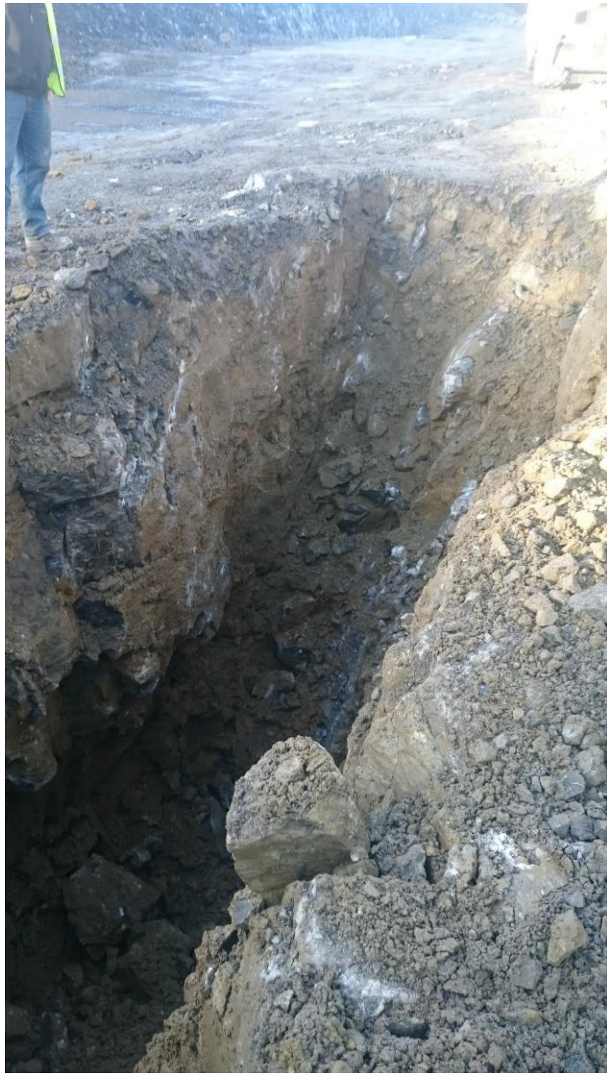
DROP OUTS IN ROCK

DROP OUTS IN ROCK

- Northern Section encountered a large number of drop outs at rock surface
- Followed the Karst features protocol
- Rock head was closely examined following excavation
- Proof Rolled
- Following of conduit karst features at rock surface
- SED 602-amended



ARUP
BARRY
TRANSPORTATION



PROOF ROLL ON ROCK

- Damage to roller
- Solved by placing a layer of rock dust from quarry
- ***Advantages***
  - Free
  - Will not block voids if present
  - Will prevent damage to roller

DROP OUTS IN ROCK

RIVER NANNY-GEOTECHNICAL RISK ITEMS

ARUP BARRY TRANSPORTATION

- Soft Ground
- Sheet Piles
- Pile Driving
- Karst


CRANE HIRE LTD

RIVER NANNY-PILE 16

During construction of Pile 16, the last pile on the eastern side of the south abutment was driven to a level of 8.74mOD. All other piles were driven to levels ranging from 20-21mOD.

A rotary cored borehole directly east of Pile 16 encountered rock at 20.67mOD. It is likely that Pile 16 has been driven into an infilled karst feature.

The pile driving records below the expected rock head level, indicate a driving resistance of approximately 130kN/m along the pile, which provided adequate support to the pile shaft.

The presence of an infilled karst feature was mitigated against by drilling adjacent to the last pile and proving rock, in accordance with the Karst Protocol that was developed as art of the design.

This indicated that the feature was narrow and confined, the pile driving records proved the infill material was of a sufficient strength to provide a safe bearing capacity and there was also redundancy in the adjacent pile.

BALLINPHUIL OVERBRIDGE

BALLINPHUIL OVERBRIDGE EAST ABUTMENT

- 2 additional RC
- 0.55m void
- Cover of 4.55m
- Waltham and Lu (2007)
- Safe Void Cover ratio t/w=0.5
- Rock Mass Rating
- Karst Features Protocol followed at surface

CENTRAL PIER

- Formation level at 4m below rock head level
- 2 additional RC Boreholes
- A number of small voids and clay infilled features
- Waltham and Lu?
- 13 additional percussive boreholes

BALLINPHUIL OVERBRIDGE CENTRAL PIER

- Percussive drilling produced venting in other holes
- Measured grouting of 15 holes
- Voids encountered at varying levels
- Grouting stopped
- Decision to excavate to 3m through rock to investigate what was happening

BALLINPHUIL OVERBRIGE CENTRAL PIER

- 8m to solid rock-proven by the percussive drill holes
- Sides rock
- 8m wide
- 12m long
- 8 No. conduit karst features converging into a central clay filled void

BALLINPHUIL OVERBRIDGE

- Beams were already in production
- SLS 5mm
- Linking the conduit karst features using a 0.5m wide no fines concrete surround to allow for continuation of groundwater flow.

CENTRAL PIER FINAL DESIGN SOLUTION

BALLINPHUIL WEST ABUTMENT

NO KARST FEATURE AT THE STRUCTURE

INVESTIGATED THE SIDE SLOPE


KOMATSU
PC
490
LC

BALLYGADDY OVERBRIDGE

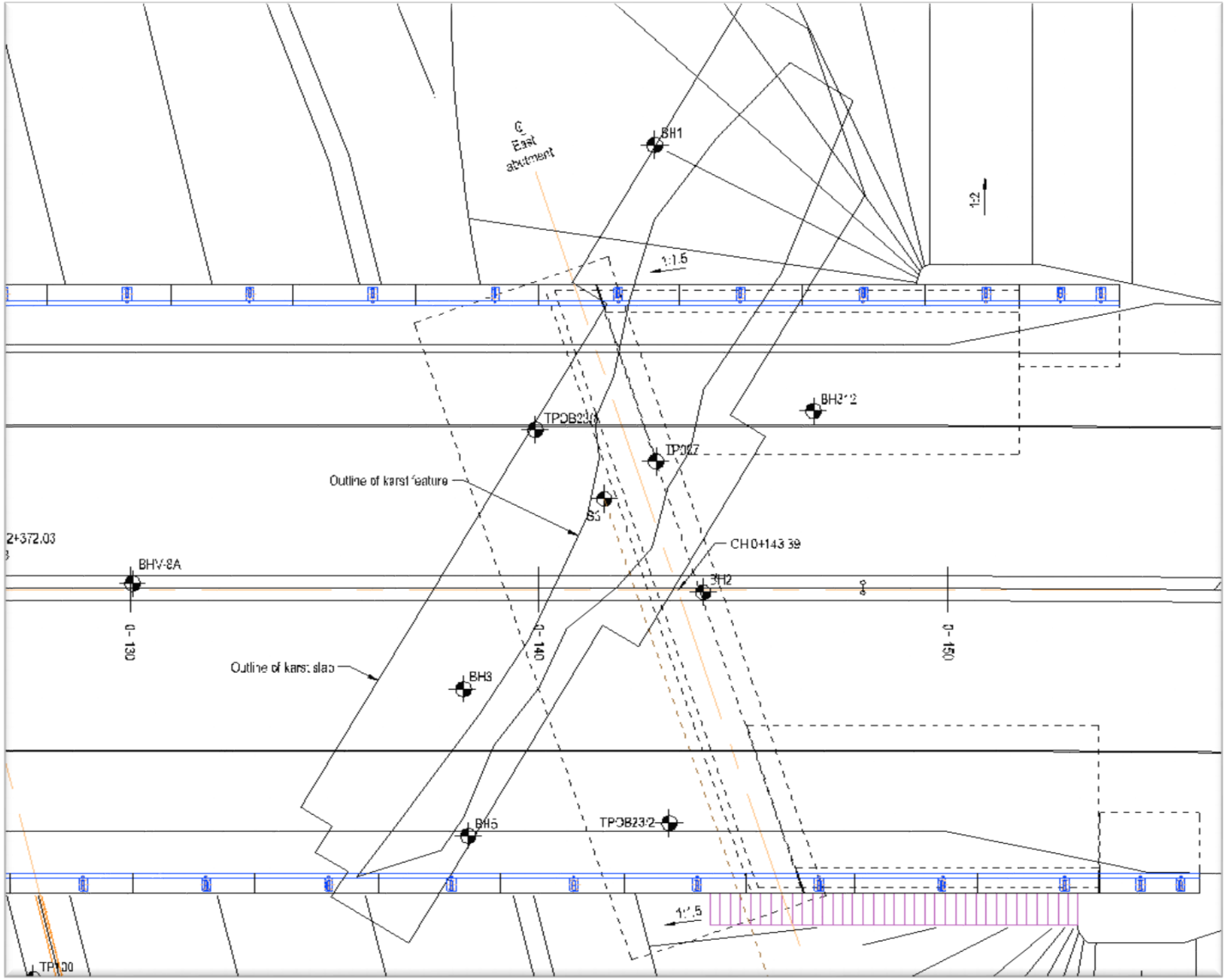
M17 BALLYGADDY OVERBRIDGE

- Large Linear Karst Feature
- Saturated sand filled void
- 3.5m width
- Minimum 20m in length
- 11-13m to solid rock

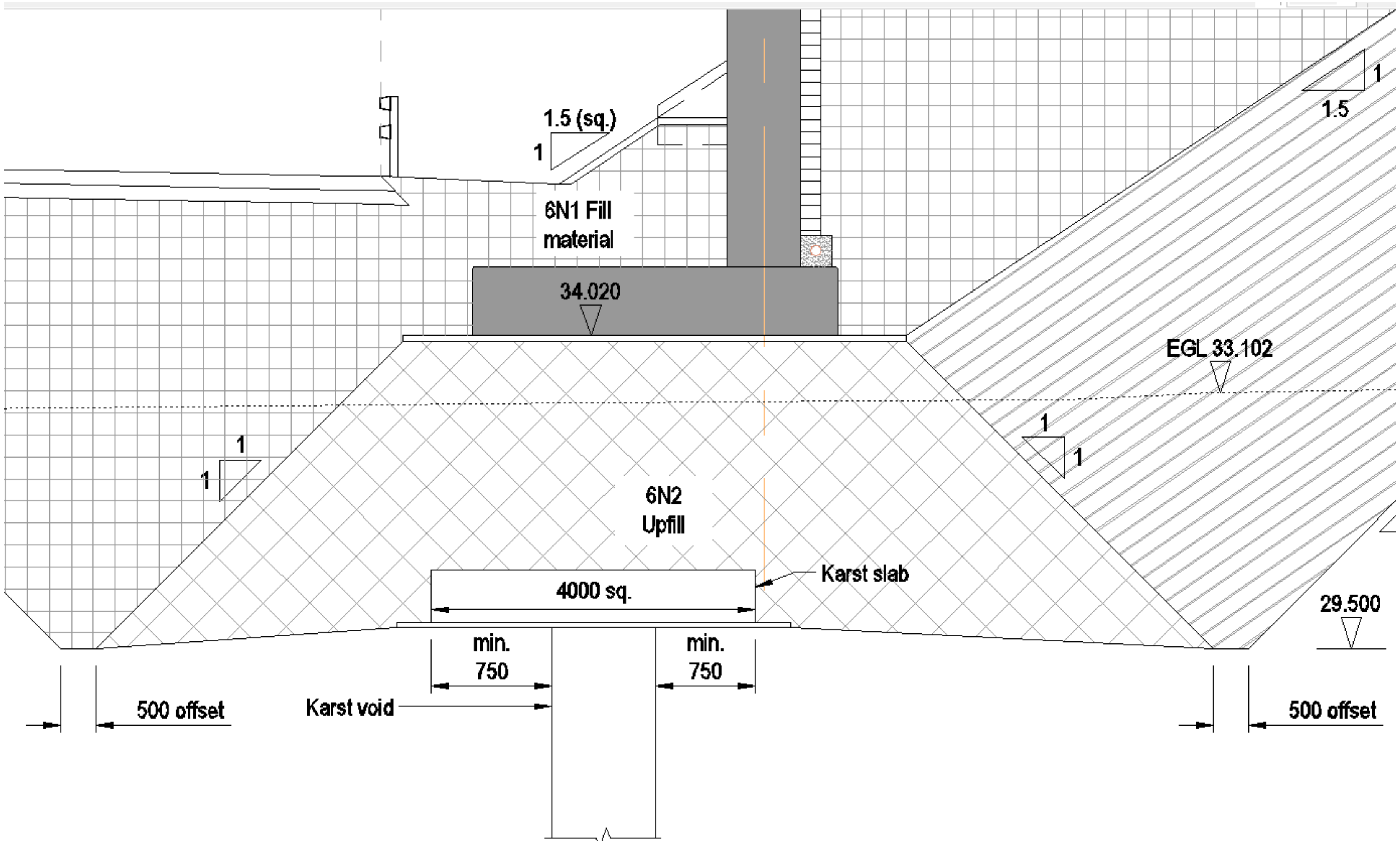
OPTIONS CONSIDERED

BALLYGADDY BRIDGE DESIGN SOLUTION

- 2 D resistivity survey (5 No. Lines)
- Ground Penetrating Radar (GPR)
- 5 No. Rotary cored holes
- Bridge over the karst feature



East abutment
BH1
1:2
1:1.5
BH3'2
TPOB23/1
TP027
Outline of karst feature
S5
2+372.03
CH 0+143.39
BHV-8A
BH2
0 - 130
0 - 140
0 - 150
Outline of karst slab
BH3
BH5
TPOB23/2
1:1.5
TP100



1.5 (sq.)
1
1
1.5
6N1 Fill material
34.020
EGL 33.102
1
1
1
1
6N2 Upfill
Karst slab
4000 sq.
29.500
min. 750
min. 750
500 offset
Karst void
500 offset

BALLYGADDY BRIDGE DESIGN SOLUTION

- Karst slab 850mm thick
- 4m wide reinforced concrete karst slab to span the void, minimum 750mm wide bearing onto rock on both sides
- Due to the shape of the void, the karst slab had to be staggered across the foundation area

Thank you:

Barry Transportation-Liam Prendiville (Director), Eamon Daly PM

Arup- Mike Evans (Director) Emer O'Dea PM, Martin Allen PM

Roadbridge-John Duggan, Paraic McCarthy, Steve Salvin

Sisk-Pat Lucey, Noel Curtis

Lagan- John Philbin

3rd Party Checkers; Conor O'Donnell (AGL), Paul Quigley (GDG), Ciaran Reilly (Formerly GDG, now Ciaran Reilly & Associates), Ian Higgins (Agec), Aine Walsh (Agec)

DSR Joe Reilly & all DSR site staff, Aidan Stewart (Photography)

Geological Survey Ireland, Irish Association of Hydrogeologists & the Geotechnical Society of Ireland

QUESTIONS?

ARUP BARRY TRANSPORTATION