APPENDIX 8-3

Karst Assessment Report

FEHILY TIMONEY

DESIGNING AND DELIVERING A SUSTAINABLE FUTURE

KILLOSHULAN WIND FARM

Karst Assessment Report

Prepared for:

MKO

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Karst Assessment Report

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Abstract: Fehily Timoney and Company were engaged by MKO (Client) to undertake an assessment outlining the potential for karst at Killoshulan Wind Farm, Co. Kilkenny. The assessment identifies and evaluates potential surface and subsurface karst features using desk-study information, site reconnaissance, intrusive ground investigation and geophysical survey data.

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1. INTRODUCTION

1.1 Fehily Timoney and Company

Fehily Timoney and Company (FT) is an Irish engineering, environmental science and planning consultancy with offices in Cork, Dublin and Carlow. The practice was established in 1990 and currently has c.110 members of staff, including engineers, scientists, planners and technical support staff. FT deliver projects in Ireland and internationally in our core competency areas of Waste Management, Environment and Energy, Civils Infrastructure, Planning and GIS and Data Management.

FT have been involved in over 100 wind farm developments in Ireland and the UK at various stages of development, including feasibility, planning, design, construction and operation. As part of this work, FT has undertaken numerous karst assessments and karst risk assessments for a range of infrastructure and renewable energy projects located within limestone and karst-prone geological environments across Ireland, supporting planning, design and construction-stage risk management.

1.2 Scope of Karst Assessment

This Karst Assessment has been undertaken to identify and evaluate the potential for karst features within the Proposed Wind Farm site and to assess any associated risks to the proposed infrastructure. The assessment integrates desk study findings, site reconnaissance, geophysical surveys and intrusive ground investigation data to identify potential surface and subsurface karst features, inform infrastructure design, and establish appropriate mitigation and construction protocols where required. A Karst Risk Assessment has been completed to evaluate the likelihood and potential significance of karst-related hazards at each infrastructure location and to define the mitigation measures and construction controls necessary to manage identified risks.

1.3 Project Description

FT was engaged in June 2026 by MKO Ltd. to undertake a karst assessment of the Proposed Project.

The Proposed Wind Farm site is located approx. 6.0km northeast of Urlingford, Co. Kilkenny.

The Proposed Wind Farm site comprises an area of approximately 5.5km^2. The surrounding landscape comprises low hills with land-use comprising forestry and agricultural land.

The Proposed Project will comprise 10 no. wind turbines and associated hardstanding areas, 1 no. borrow pit, 2 no. temporary construction compounds, an on-site substation, battery energy storage system (BESS), upgrade of existing roads, construction of new site access roads, underground electrical connection cabling, road widening and accommodation works along the turbine delivery route, 1 no. meteorological mast, biodiversity enhancement measures, site drainage and all associated works as described in Chapter 4 of the EIAR. This will include the clear felling of trees around a number of the turbines. Although Turbine T04 formed part of Turbine Layout Iteration 2 and is referenced herein, it has since been descoped following completion of this assessment.

1.4 Karst

Karst features can be formed from the dissolution of soluble carbonate rocks such as limestone. The process by which limestone is dissolved is known as karstification and in Ireland typically produces features such as sinkholes, caves, enclosed depressions and turloughs.

To aid in the identification of potential surface and sub-surface karst features across the Proposed Wind Farm site, an extensive series of ground investigation and field reconnaissance surveys were undertaken. These comprised the following activities:

- Fehily Timoney and Company (FT) undertook a desk study to identify mapped karst features on or adjacent to the Proposed Wind Farm site. This study also incorporated a review of available aerial photographs, orthorectified photographs and digital terrain models to identify surface anomalies that may be attributed to karst features (information sources are prescribed in Section 2).
- FT undertook site reconnaissance on 23rd July and 28th August 2026 to ground truth findings from the desk study and to inform the need for further investigation.
- Ground Investigations Ireland (GII) undertook intrusive ground investigation (boreholes) between 14 and 29th May 2026, and again between the 22nd and 29th July 2026 to characterise ground and groundwater conditions at turbine locations.
- Apex Geophysics undertook geophysical surveys (ERT profiles) between the 30th April and 24th July 2026.
- Additional intrusive investigations (open holed boreholes) were undertaken at T01 and T02 on 2nd October 2026 to investigate features recorded in the geophysical survey.

1.5 Statement of Authority

This Report was written by Ian Higgins (FT Technical Director, PGeo, MSc in Geotechnical Engineering). Ian is a Technical Director with Fehily Timoney and has over 25 years' experience in geotechnical engineering. This report was reviewed by Aaron Clarke (FT Principal Geologist, PGeo). Aaron is a Chartered Principal Engineering Geologist with Fehily Timoney's Infrastructure Team, providing specialist geotechnical and geological advice for multi-disciplinary projects across Ireland and the UK. He has over 20 years' experience working as a geologist; of which, 11 years' have been spent within ground engineering.

2. DESK STUDY

2.1 Information Sources

Prior to undertaking the site walkover, a desk study was undertaken in June 2026 by FT Technical Director Ian Higgins (BSc, MSc, EurGeol, PGeo). The purpose of the study was to determine the baseline conditions within the Proposed Wind Farm site to provide relevant background information. The desk study involved an examination of the following sources of information:

- An audit of geological sites in Kilkenny (Clarke et al., 2012)
- Geology of Tipperary (Archer et al. 1996)
- Aerial imagery (accessed September 2026)
- Current and historical (6 inch and 25 inch) Ordnance Survey maps (1829-1841, 1897-1913)
- Mapping data of the area produced by the Geological Survey Ireland (GSI) (accessed September 2026)
    - *Quaternary subsoil geology*
    - *100k bedrock geology*
    - *Karst features*
    - *Geological heritage features*
    - *Aggregate potential*
    - *Landslide susceptibility*
    - *Catchment & Management Units*
    - *Groundwater Bodies Status and Risk*
    - *Drinking Water Protection Areas*
    - *Groundwater Resources (Aquifers)*
    - *Groundwater Wells and Springs*
    - *Groundwater Vulnerability*
- Datasets from the EPA (accessed September 2026)
- Durrow Groundwater Body (GWB) Description
- Lisdowney Groundwater Body (GWB) Description
- GSI Groundwater Programme: Enclosed Depression

2.2 Geological Mapping

2.2.1 Quaternary Geology

The quaternary geology (Figure 1), within the Proposed Wind Farm site, is predominantly composed of till derived from Namurian Sandstones and Shales, Bedrock outcrop or subcrop and Karstified bedrock outcrop or subcrop.

The TEAGASC soils classification (Figure 2) classifies most of the Proposed Wind Farm site as consisting of Bedrock outcrop or subcrop, and Karstified bedrock outcrop or subcrop. Till derived from Namurian sandstones and shales is present in limited extents.

2.2.2 Bedrock Geology

The bedrock (Figure 3) at the Proposed Wind Farm site consists of three separate formations:

- Killeshin Siltstone Formation: Muddy siltstone and silty mudstone
- Clogrenan Formation: Cherty, muddy calcarenitic Limestone
- Ballyadams Formation: Crinoidal wackestone/packstone limestone. The upper beds of the Formation are noted to "have some thick irregular karstically-eroded surfaces, covered with soft weathered brown clayboards" (GSI, 1996).

The aggregate potential maps show where it might be possible to find suitable rocks for building purposes as per the GSI. The majority of the Proposed Wind Farm site is classified as having high crushed aggregate potential (Figure 4).

2.2.3 Structural Geology

Structural mapping indicates the presence of a single northeast-southwest trending regional fault passing through the Proposed Wind Farm site. Total vertical displacements along these faults are unknown. An unconformity (gap in the geological record) forms the boundary between the Killeshin Siltstone and the Clogrenan Formations.

There are no GSI regional cross-sections available for the Proposed Wind Farm site. The closest cross-section is the Moneygall-Owning section, located approximately 13km to the southwest.

Structural measurements of bedding taken from outcrop locations by the GSI, indicate bedding dips range from 5 to 16°. Dip directions are varied, but are generally towards the northeast or northwest.

2.2.4 Bedrock Aquifer

Groundwater mapping (Figure 5) indicates that the southern half of the Proposed Wind Farm site is underlain by a Regionally Important Aquifer – Karstified (diffuse). This is important in the context of the Proposed Wind Farm site as the bedrock aquifer indicates the potential for karst processes. In contrast, the northern half of the Proposed Wind Farm site is underlain by a Poor Aquifer - Bedrock which is Generally Unproductive except for Local Zones.

2.2.5 Groundwater Body (GWB) Report

The Groundwater Body (GWB) is the management unit under the Water Framework Directive (WFD), the GWB identified for the Proposed Wind Farm site was Lisdowney for the northern half of the Proposed Wind Farm site and Durrow for the southern half of the Proposed Wind Farm site. Durrow GWB is classed as a karstic system with transmissivity of between 5 and 3,000m^2/day. Groundwater flow is indicated to occur in a southeasterly direction.

2.2.6 Wells and Springs

There are 25 wells mapped within 1km of the Proposed Wind Farm site and these are summarised in Table 2-1. Eight of the wells are mapped within the Killeshin Formation, 1 in the Clogrenan Formation and 16 within the Ballyadams Formation. The nearest spring is recorded along the western boundary of the Proposed Wind Farm site. The distance (in the table) of the well from the Proposed Wind Farm site was taken as the shortest distance between the well and nearest Proposed Wind Farm site boundary. The southern portion of the Proposed Wind Farm site is within the Balief group water scheme preliminary source protection area zone of contribution.

Table 2-1: Summary of well locations

Location ID	Easting	Northing	Type	Total Depth (m bgl)	Current Use	Yield Class (yield m^3/day)	GSI Location Accuracy (m)	Approx. Distance to Nearest Infrastructure Element (m) Note 1
2315NWW010	235590	167680	Borehole	17.7	Unknown	Poor (21.8)	1000	500
2315NWW011	233840	164820	Dug well	4.3	Agricultural and domestic use	Poor (31.1)	1000	800
2315NWW023	232440	166400	Borehole	122.4	Agricultural and domestic use	Poor	50	900
2315NWW025	235740	168550	Borehole	26.5	Domestic use	Moderate	50	1000
2315NWW028	236240	167890	Borehole	20	Agricultural and domestic use	Poor (10.9)	50	1200
2315NWW029	236230	167890	Borehole	12	Agricultural and domestic use	Null	20	1200
2315NWW030	235620	165380	Borehole	156.0	Agricultural use	Failure	20	260
2315NWW063	236440	164000	Borehole	12.2	Unknown	Null	20	1000
2315NWW064	236080	163700	Borehole	3.1	Unknown	Null	50	1000
2315NWW065	236150	163840	Borehole	23.4	Unknown	Null	50	260
2315NWW089	232680	166670	Borehole	40	Agricultural and domestic use	Poor	20	800
2315NWW095	235510	168510	Borehole	13.7	Unknown	Null	20	1000
2315NWW100	235610	168530	Dug well	5.0	Agricultural and domestic use	Null	20	1000
2315NWW105	236710	167950	Borehole	14.0	Domestic use	Poor	20	1100
2315NWW106	236220	167750	Borehole	13.0	Agricultural and domestic use	Null	20	1100
2315NWW144	235140	164510	Dug well	6.1	Agricultural and domestic use	Null	20	700
2315NWW146	236150	164300	Dug well	-	Agricultural and domestic use	Null	20	650
2315NWW147	236710	164360	Dug well	6.2	Domestic use	Null	20	1000
2315NWW148	235960	163710	Dug well	-	Unknown		20	1000
2315NWW158	235200	166220	Borehole	54.9	-	Failure	20	510
2315NWW184	237000	166070	Borehole	35.1	-	Failure	500	1400
2315NWW186	234440	168330	Borehole	62.4	Domestic use	Moderate (43.6)	1000	1200
2315NWW191	233820	164780	Dug well	0.9	Domestic use	Poor (24.0)	1000	800
2315NWW195	232890	166760	Borehole	-	Agricultural and domestic use	Null	20	800
2315NWW203	236280	163580	Borehole	73.2	Domestic use	Poor (16.4)	20	1000

Note 1 – measured from the edge of the well boundary.

Table 2-2: Summary of spring locations

Location ID	Easting	Northing	Yield Class	Yield (m^3/day)	GSI Location Accuracy (m)	Distance to Nearest Infrastructure Element (m)
2315NWK003	633353	666881	-	-	20	200

Yield within the wells range from poor to moderate (10.9 to 43.6m^3 per day). These yields suggest that the underlying bedrock is locally productive.

2.2.7 Mapped Karst Features

Both the Ballyadams and Clogrenan Formations are considered to be susceptible to the formation of karst, as they are both considered to be 'clean' limestones with only limited deposits of mudstone or shale partings. The GSI Groundwater mapping (Figure 6) indicates a number of karst features across the Proposed Wind Farm site. In the northwest of the Proposed Wind Farm site, a series of springs are recorded which mark the boundary (an unconformity) between the limestone of the Clogrenan Formation and the Siltstone of the Killeshin Formation. In the southern half of the Proposed Wind Farm site a series of enclosed depressions and swallow holes are recorded. These are associated with a fault that runs through the Proposed Wind Farm site and also the interpreted boundary between the Ballyadams and Clogrenan Formations. Separately, a cave is noted close to the edge of the Proposed Wind Farm site (Poll Chnoc an Spa) within a database of Irish caves (Fogg, 1994), which is located close to the Proposed Wind Farm site boundary to the south of T05 (Proposed Wind Farm turbine layout).

Table 2-3 summarises these GSI mapped karst features:

Table 2-3: Summary of mapped karst features within the Proposed Wind Farm site Boundary.

Mapped Karst Feature	Easting	Northing	Underlying Bedrock Geology	Approx. Distance to Nearest Infrastructure Element (m)
Spring	633353.2	667231.2	Boundary between Killeshin and Clogrenan Formation	200
Spring	633353.2	667081.3	Boundary between Killeshin and Clogrenan Formation	200
Spring	633353.2	666881.3	Boundary between Killeshin and Clogrenan Formation	200
Spring	633323.2	666651.4	Boundary between Killeshin and Clogrenan Formation	200
Swallow Hole	633913.1	665871.5	Clogrenan Formation	290
Swallow Hole	634982.9	666351.4	Clogrenan Formation	400
Swallow Hole	634982.9	666311.4	Clogrenan Formation	400
Swallow Hole	635042.9	666291.4	Clogrenan Formation	400
Swallow Hole	634962.9	666371.4	Clogrenan Formation	400
Enclosed Depression	635292.3	665769.4	Ballyadams Formation	200

Mapped Karst Feature	Easting	Northing	Underlying Bedrock Geology	Approx. Distance to Nearest Infrastructure Element (m)
Enclosed Depression	635292.2	665697	Ballyadams Formation	230
Enclosed Depression	635298	665577.5	Ballyadams Formation	360
Enclosed Depression	633660.5	665877.5	Clogrenan Formation	330
Enclosed Depression	635194.9	666148.4	Ballyadams Formation	150
Enclosed Depression	635294.9	665649.9	Ballyadams Formation	250
Enclosed Depression	635100.4	665709.2	Ballyadams Formation	290
Enclosed Depression	634711.8	666092.7	Clogrenan Formation	70
Enclosed Depression	635434.4	665774.9	Ballyadams Formation	85
Enclosed Depression	635313.1	665509.9	Ballyadams Formation	330
Enclosed Depression	635911.6	664767.4	Ballyadams Formation	70
Karst outcrop	635027.5	665933.7	Ballyadams Formation	110
Karst outcrop	635049.1	665661.9	Ballyadams Formation	350
Enclosed Depression	635100.1	665630	Ballyadams Formation	350
Enclosed Depression	635406.5	665658.9	Clogrenan Formation	160
Enclosed Depression	635419.5	665628.2	Clogrenan Formation	160
Enclosed Depression	635374.6	666212.1	Ballyadams Formation	350
Enclosed Depression	634732.7	666114.9	Ballyadams Formation	70
Enclosed Depression	635063	665624.8	Ballyadams Formation	370
Enclosed Depression	634963.3	665670.9	Ballyadams Formation	360
Enclosed Depression	635115.1	665594.9	Ballyadams Formation	380
Enclosed Depression	634762.6	666155.3	Ballyadams Formation	70
Karst outcrop	634908	666253.8	Clogrenan Formation	60
Karst outcrop	634770.7	666120.7	Clogrenan Formation	100
Karst outcrop	634870.3	666201.7	Clogrenan Formation	<10
Karst outcrop	634711.5	666060.9	Clogrenan Formation	100
Enclosed Depression	635296.6	665675.6	Ballyadams Formation	240

Note 1 – these springs are not included in the GSI's Wells and Springs data set.

In summary, a total 36 no. karst features are mapped by GSI within and immediately adjacent to the Proposed

Wind Farm site boundary. These include:

- 21 no. (60%) enclosed depressions (dolines),
- 5 no. (13%) swallow holes
- 6 no. (16%) karst outcrops; and
- 4 no. (11%) springs

2.3 Review of Aerial Photography

A review of the aerial photography for the Proposed Wind Farm site and wider area was undertaken to identify landforms that may represent potential surface karst features. In total, 36 no. individual landforms suspected of being attributed to karst processes were identified as part of this review. The distribution of their locations is presented in Figure 6. The majority of features identified as part of this review are included in GSI's karst mapping. Where possible, these locations were visited as part of the site reconnaissance (discussed in Section 3).

All of the landforms identified as part of this review were observed as having a broadly circular to oval shape. These sometimes form as clusters while other times forming in smaller numbers or as isolated occurrences. These broadly circular features display varying diameters, typically ranging from 10m across to 35m across. Their morphology suggests that these features are most likely enclosed depressions.

In general, these features appear to follow broadly linear trends, which are often parallel or perpendicular to the main fault line that passes through the Proposed Wind Farm site, which may represent smaller unmapped faults in the bedrock. The significance of these linear patterns indicates a correlation between the Proposed Wind Farm site's structural geology and the formation of karst features.

Potential karst features identified in the aerial photography were later assessed on site through reconnaissance surveys (discussed in Section 3).



Plate 2.1: Circular landforms (enclosed depressions) adjacent to turbine T03



Plate 2.2: Outcrop showing epikarst weathering 100m southeast of T04

3. SITE RECONNAISSANCE

A site reconnaissance survey was undertaken on 23rd July and 28th August 2026. The survey work was completed by FT Technical Director Ian Higgins (BSc, MSc, PGeo, EurGeol). The purpose of the survey was to:

- verify the presence of potential surface karst features identified as part of the aerial photography and previous ground investigations; and
- where possible, to identify additional karst features not visible on aerial photography

In total 19 no. out of the 36 no. features previously identified were visited. The remaining 17 no. locations were not visited as they are either outside of the Proposed Wind Farm site boundary or not close to proposed infrastructure but have been considered when assessing the potential karst risk at specific locations.

Of the locations visited:

- 12 no. were recorded as enclosed depressions
- 2 no. were recorded as sinkholes
- 1 no. was recorded as a spring and
- 4 no. were recorded as exposed bedrock displaying karst weathering.

Representative photos of these features are presented in Appendix C. Additional features, not included on the GSI mapping, were also noted, mainly to the south and east of T04 (Proposed Wind Farm turbine layout) where epikarst features were recorded on bedrock outcrops.

In general, the enclosed depressions were circular in shape, had a bowl like morphology, and were typically between 1 and 3m in depth. The sinkhole recorded to the northeast of T04 (Proposed Wind Farm turbine layout) is approximately 6m deep (although it likely extends deeper below ground level) and steep sided, with bedrock exposed in the side slopes at the bottom of the sinkhole. The feature identified as a ‘cave’ within the forestry south of T05 (Proposed Wind Farm turbine layout) appears to be a sinkhole, or is possibly partially infilled, as no obvious opening could be found. This feature was >10m deep and 30-40m in diameter.

Where the surface expressions of these features were considered to be inconclusive or where the feature may be a result of other processes (e.g. glacial landform or potentially man-made) they were recorded as “possible” karst features. It is noted that the recorded features within agricultural lands have been partially infilled by the landowner in the past, and as such it is unclear , with the exception of the feature northeast of T04 (Proposed Wind Farm turbine layout), if these features are active.

4. INTRUSIVE GROUND INVESTIGATION

Ground investigations at the Proposed Wind Farm site were undertaken in a phased manner, with each stage informing the scope of subsequent investigations.

An initial investigation comprising 13 no. trial pits was undertaken by GDG in November 2022. The findings of this work informed a more detailed intrusive investigation completed by Ground Investigations Ireland (GII) in May 2026, comprising 9 no. rotary cored boreholes. The Ground Investigation Factual Report is presented in Appendix D.

Following review of the initial borehole results, additional investigations were undertaken during July 2026, comprising 3 no. rotary cored boreholes and an Electrical Resistivity Tomography (ERT) geophysical survey to further assess subsurface conditions and potential karst development.

Based on the findings of the geophysical survey and subsequent recommendations by Apex, a further phase of targeted investigation was completed on 2 October 2026, comprising 5 no. open-holed boreholes at Turbines T01 and T02 to investigate potential karst features identified during the survey.

The purpose of the GI was to:

- determine ground and groundwater conditions at the turbine and substation locations; and
- to verify the presence of potential karst features identified through the desk study and the resulting geophysical survey.

Data derived from the geophysical survey was subsequently reprocessed using findings from the intrusive ground investigation.

In general, ground conditions encountered during the ground investigation correspond with published GSI mapping. A summary of the ground investigation findings are presented in the following sections. Where potential karst features are identified they are highlighted and discussed.

An interpretation of the combined desk study, site reconnaissance, geophysical survey and ground investigation findings is presented in Section 6.

4.1 Trial Pitting

Findings from the trial pitting are summarised in Table 4-1.

Table 4-1: Summary of ground and groundwater conditions within the trial pits

Hole ID	Topsoil		Coarse-Grained Till		Soft to Firm Fine-Grained Till		Groundwater Strike (mbgl)	Infrastructure Element Tested
	From (mbgl)	To (mbgl)	From (mbgl)	To (mbgl)	From (mbgl)	To (mbgl)		
TP-01	0.0	0.2	0.2	0.6 (Note 1)			-	T01
TP-02	0.0	0.3	0.3	0.5 (Note 1)			-	
TP-03	0.0	0.4			0.4	2.0 (Note 1)	2.0	T02
TP-04	0.0	0.1			0.1	0.8 (Note 1)	-	T03

Hole ID	Topsoil		Coarse-Grained Till		Soft to Firm Fine-Grained Till		Groundwater Strike (mbgl)	Infrastructure Element Tested
	From (mbgl)	To (mbgl)	From (mbgl)	To (mbgl)	From (mbgl)	To (mbgl)		
TP-05	0.0	0.1			0.1	2.2 (Note 1)	-	T04
TP-06	0.0	0.1			0.1	1.0 (Note 1)	2.7	T05
TP-07	0.0	0.1	0.1	0.6	0.6	0.7 (Note 1)	-	
TP-07a	0.0	0.5			0.5	2.3 (Note 1)	-	
TP-08	0.0	0.6			0.6	2.5 (Note2)	-	
TP-11	0.0	0.3	0.45	0.7 (Note 1)	0.3	0.45	-	
TP-12	0.0	0.2	0.2	0.75 (Note 1)			-	
TP-13	0.0	0.3			0.3	2.2 (Note 1)	1.5	
TP-16	0.0	0.3			0.3	2.8 (Note 1)	2.6	

Note 1 – Bedrock encountered at base of trial pit.
Note 2 – Pockets of black organic material recorded 1.7-2.5m bgl.

Key findings from the trial pitting are presented below:

- No evidence of karst features (such as voiding or piping within the superficial deposits) were recorded within the trial pits.
- The most dominant strata type recorded was fine-grained (cohesive) till, which was encountered in 10 no. trial pits.
- Coarse-grained till was encountered in 5 no. trial pits.
- Possible bedrock was recorded at the base of all of the trial pits at depths ranging from 0.5 to 2.8m bgl.
- Groundwater strikes (typically described as seepages) were recorded in 4 no. trial pits at depths ranging from 1.5 to 2.7m bgl. These seepages are likely the result of a perched water table.

4.2 Rotary Boreholes

Findings from the rotary boreholes are summarised in Table 4-2.

Table 4-2: Summary of ground conditions within the rotary boreholes

Hole ID	Medium dense to dense Coarse-Grained Till		Firm to very stiff Fine-Grained Till		Bedrock		Possible karst feature recorded (Y/N)	Element Tested
	From (mbgl)	To (mbgl)	From (mbgl)	To (mbgl)	From (mbgl)	To (mbgl)		
BH-01	0.0	1.1			1.1	22.0	N	T01
BH-02	1.7	4.0	0.0	1.7	4.0	15.0	N	T02
BH-03			0.00	0.8	4.8	15.0	N	T03
BH-04			0.00	3.1	3.1 24.1	9.9 (Note 1) 30.5	Y	50m northwest of original location of T04

Hole ID	Medium dense to dense Coarse-Grained Till		Firm to very stiff Fine-Grained Till		Bedrock		Possible karst feature recorded (Y/N)	Element Tested
	From (mbgl)	To (mbgl)	From (mbgl)	To (mbgl)	From (mbgl)	To (mbgl)		
BH-04A			0.00	1.55	1.55	30.0(Note 2)	N	T04 (original)
BH-ALT-T4			0.00	0.6	0.6	30.0 (Note 3)	N	T04 (revised location)
BH-T4-NW			0.00	1.45	1.45 15.8 21.5	7.0(Note 4) 21.5 28.0	Y	15m northwest of original location of T04
BH-05	0.00	2.0			2.0	10.0	N	T04*
BH-05B			0.00	2.5	2.5	15.0	N	T04*
BH-ALT-T5			0.00	2.25	2.25	30.0	N	T04*
BH-06			0.00	11.5	11.5	15.0	N	T09*
BH-07					0.00	7.0	N	Borrow Pit
BH-08					0.00	5.00	N	-

Note 1 – Clay infill from 9.9m to 24.1m bgl in BH04.
Note 2 – BH04A dissolution on core surface 7.1-7.4m bgl
Note 3 –. BH-ALT-T4 occasional dissolution on fracture faces 0.6-5.5m bgl
Note 4 – Clay infill from 7.0 to 15.8 and 20.1 to 21.5m bgl in BH-T4-NW
**Renumbered following removal of original turbine T04.*

Key findings from the rotary boreholes are presented below:

- The most dominant soil type recorded was fine-grained (cohesive) till, which was encountered in 6 no. boreholes.
- Bedrock (BH01 to BH-T04-NW) is typically described as medium strong to very strong, thin to medium bedded, dark grey, fine grained fossiliferous argillaceous limestone and massive grey limestone with styolites and calcite veins. Fresh to slightly weathered to occasionally moderately weathered. This stratum is dominated by two main joint sets which run sub-horizontally and sub-vertically through the core. These descriptions broadly correspond to the mapped geology and suggest that the limestone encountered within the boreholes belongs to the Clogrenan Formation and the Ballyadams Formation.
- Also recorded (BH-05 to BH-08) is a very weak to weak dark grey thinly bedded fine grained Mudstone with rare pyrite lenses. Partially to distinctly weathered to residual in places.
- Bedrock in borehole BH-04 was logged as having no argillaceous material and as having 'strong effervescence' (reaction to dilute HCL) and is therefore likely has a high $CaCO_3$ content, making it more susceptible to karstification.
- Evidence of significant karst features was recorded within the following boreholes:
    - **BH-04** – the borehole recorded a Clay layer between 9.9 and 24.1m bgl, below the bedrock at 3.1m bgl. It should be noted that borehole BH-4 was not drilled at the turbine location, but some 50m northwest of T04.
    - **BH-T4-NW** – the borehole recorded a Clay layer from 7.0 to 15.8, and from 20.1 to 21.5m bgl, below the bedrock at 1.45m bgl. It should be noted that borehole **BH-4-NW**

was drilled close to the Turbine Iteration No. 2 location for T04 to investigate an area of low resistivity highlighted in the geophysical survey.
    - Loss of water was recorded by the driller in **BH01** between ground level and 6.0m bgl
    - Additional open holed boreholes at T01 (1 no.) and T02 (3 no.) recorded evidence of karst infill (clay) at varying depths.

- Groundwater monitoring wells were installed in 3 no. boreholes. Groundwater readings indicate a groundwater level of between 13.5 and 22.65m bgl in the bedrock.

5. GEOPHYSICAL INVESTIGATION

A geophysical survey was undertaken by Apex Geophysics Ltd as part of the overall GI works to identify and delineate potential sub-surface karst features at all turbine locations that were being considered for the Proposed Wind Farm site. The geophysical survey report forms part of the factual report by GII included in Appendix D. The investigation was undertaken in two phases between the 30th of April and 24th July 2026 and comprised the following survey methods:

- 26 no. Electrical Resistivity Tomography (ERT) profiles (two orthogonal ERT profiles at each of the 11 no. original turbine locations under consideration, plus two profiles close to the Turbine Iteration No. 2 T04 and T05 locations)
- 64 no. Seismic Refraction profiles (two sets of orthogonal runs comprising two or three profiles at each of the 11 no. turbine locations as part of Layout Iteration 2, plus additional sets close to Turbines T04 and T05 (Turbine Iteration No. 2 layout).
- Microgravity survey at the revised location for T04, comprising a grid of 160 points.

The objectives of the survey was to:

- assess the depth to bedrock
- identify the type of bedrock
- identify any potential karst features faults/fissure zones within the bedrock and Quaternary deposits.

Data derived from the geophysical survey was subsequently reprocessed using findings from the intrusive ground investigation.

5.1 Findings

Of the 11 no. turbine locations that were surveyed, anomalies within the limestone bedrock were recorded at 3 no. turbine locations (T01, T02 and T04 (Turbine Iteration No. 2 location)). These anomalies are described in the geophysical survey report as possible highly weathered/fissured/karstified Limestone.

It is important to note the since this survey, the following changes have been made to the turbine locations where potential anomalies were identified:

- T04 (Turbine Layout Iteration 2) – initially relocated approximately 55m southeast of its initial proposed location. Additional ERT, Seismic lines and a microgravity survey were undertaken at a revised turbine location. BH04NW drilled at the area of low resistivity shown in Figure 4-1 below recorded a clay-filled cavity between 7.0 and 15.8m bgl. This led to the turbine being removed from the final layout (refer to Chapter 3, Section 3.2.5.2 of the EIAR).

The anomalies identified at T01 (R5/R6), T02 (R11/R12) and T04 (R3/R4) (removed post-date of geophysics and descoped) present as zones of karstified bedrock through interpreted limestone bedrock.

It is not known from the survey results whether these anomalies represent a circular or linear feature in plan. An example of one of these features, taken from the geophysical survey report (Appendix D) is presented in Figure 5-1.

Results of this survey are further discussed in *Section 3* of the geophysical survey report and illustrated within *Appendix D: Drawings* of the same report (presented in Appendix D).

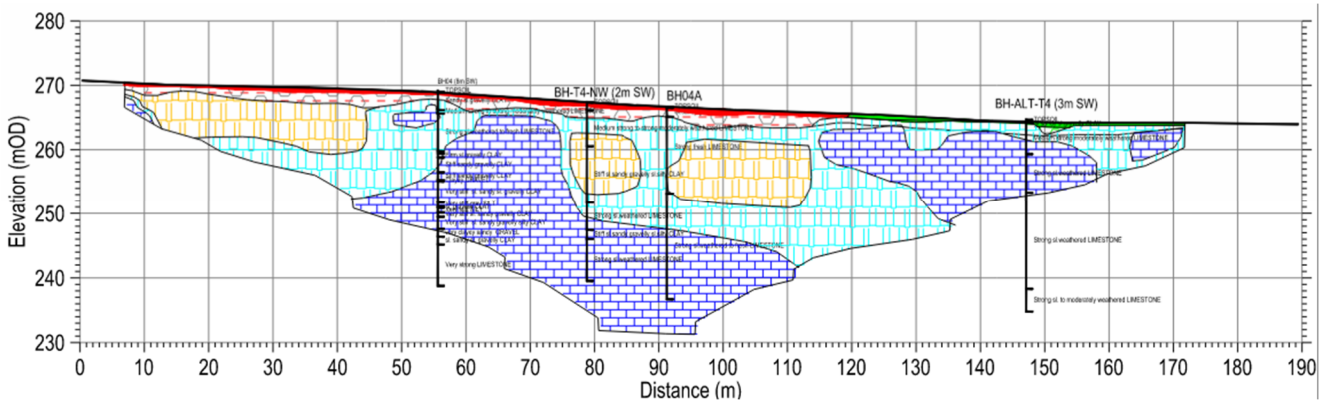


Plate 5.1: ERT Profile R4 showing interpreted potential karst features at the Turbine Layout Iteration No. 2 T04 location (yellow hatched areas in centre of image)

Findings from the geophysical investigation are summarised in Table 5-1

Table 5-1: Summary of Survey Findings

Turbine ID (Turbine Layout Iteration 2)	Investigation Method	Ground Interpretation
T01	ERT, Seismic	Loose to medium dense overburden underlain by moderately to slightly weathered/fractured/karstified limestone and possible dolomite/mudstone and slightly weathered/fractured to fresh limestone at the turbine centre, with a zone of weathered bedrock with clay infill to the north and east of the turbine centre.
T02	ERT, Seismic	Sandy gravelly clay with some clayey silty sand/gravel over bedrock. Moderately to slightly weathered/fractured/karstified limestone at the turbine centre with high resistivity (>1,000 Ohm-m) slightly weathered to fresh limestone approximately 15m south of the base. Zone of weathered bedrock with clay infill 15m from the turbine base indicated on ERT profiles.
T03	ERT, Seismic	Sandy gravelly clay, clayey silty sand/gravel and minor sand/gravel over shallow bedrock. Moderately to slightly weathered/fractured limestone underlain by slightly weathered to fresh limestone.
T04	ERT, Seismic	Sandy gravelly clay and clayey silty sand/gravel over shallow bedrock. Moderately - slightly weathered/fractured/karstified limestone. Within the bedrock zones of low resistivity are recorded, indicating the presence of potential karstified bedrock.
T04 (Alt)	ERT, Seismic, Microgravity	Loose to medium dense clayey silty sand/gravel over shallow bedrock. Within the bedrock zones of low resistivity are recorded, indicating the presence of potential karstified bedrock.
T05/Alt T05	ERT, Seismic	Clayey silty sand/gravel with some sandy gravelly clay southeast and northeast of the turbine centre over bedrock (mudstone). Depth to bedrock between 2.0 and 10.5m bgl.
T06	ERT, Seismic	Sandy gravelly clay with small 'pockets' of silt/clay and an area of clayey silty sand/gravel, approximately 30m NE of the base, over bedrock (mudstone). Depth to bedrock between 4.0 and 9.5m bgl.

Turbine ID (Turbine Layout Iteration 2)	Investigation Method	Ground Interpretation
T07	ERT, Seismic	Sandy gravelly clay (up to 4.5m in thickness) with some minor 'pockets' of silt/clay over bedrock (mudstone).
T08	ERT, Seismic	Sand/gravel and clayey silty sand/gravel (up to 4m in thickness) over shallow bedrock (mudstone).
T09	ERT, Seismic	Sandy gravelly clay (up to 5m in thickness) over bedrock (mudstone).
T10	ERT, Seismic	Sandy gravelly clay (up to 9m in thickness) over bedrock (mudstone).
T11	ERT, Seismic	Sandy gravelly clay with some silt/clay at depth (>6m bgl). No bedrock indicated within 10m of existing ground level.

6. INTERPRETATION OF FINDINGS

Findings from the intrusive ground investigation indicate the underling bedrock of the Clogrenan and Ballyadams Formations are susceptible to localised karstification. No karst features or voids were identified within the recovered rock core samples of the Killeshin Formation, which is a mudstone and siltstone and as such is not considered to be susceptible to karst formation. A conceptual site model (CSM) is provided in *Chapter 9: Hydrology & Hydrogeology* of the EIAR.

The findings from the walkover surveys indicate the presence of surface karst features. These typically present as clusters of oval or circular shallow bowl-shaped depressions (thought to be dolines), which broadly follow linear trends. These linear patterns occur both parallel and perpendicular to mapped faults and bedrock boundaries, suggesting they are a surface expression of the Proposed Wind Farm site's structural geology. The morphology of these features and the geological environment in which they occur suggest they are dolines, and their formation is likely been influenced by the presence of a fault and an unconformity within the Proposed Wind Farm site. As such there is considered to be a lower risk of karst features outside of these linear features, based on the desk study, field observations and GI results.

The following description of dolines is taken from the GSI Groundwater Programme [Ref 8]:

> *"Collapse dolines usually occur very suddenly where the bedrock or subsoil material collapse into and underlying void. Cover collapse dolines, sometimes known as dropout dolines are very common in Ireland. They occur in karst areas covered by unconsolidated material, such as glacial till. They form by the sudden downward movement of the overburden and usually form in areas where the overburden is somewhat cohesive. They occur in a process called 'piping', where a soil or subsoil arch, which has formed due to removal of material at the bottom of a layer of overburden, suddenly gives way (White, 1988). Although there must be a highly efficient pathway established for sediment transportation in order for the soil arch to form and grow, a large bedrock hollow is not necessary for their development. Cover collapse dolines are characterised by vertical or steep-sided collapses, with a very sharp break in slope and often have stepped sides, where soil is exposed. Over time, however, their slopes may degrade and infilling sediment may build up giving these dolines the morphology of solution dolines."*

The formation of a cover collapse doline is described below and presented in Plate 6-1:

A. Solutional openings in the bedrock wash material downward,

B. A small arch forms in the subsoil where the material is being washed away from

C. The void grows in size as more material is being down washed until it reaches a critical point and starts to rupture

D. The arch suddenly collapses as it can no longer support its own weight,

E. Overtime the vertical sides will degrade and the hole will become less deep.

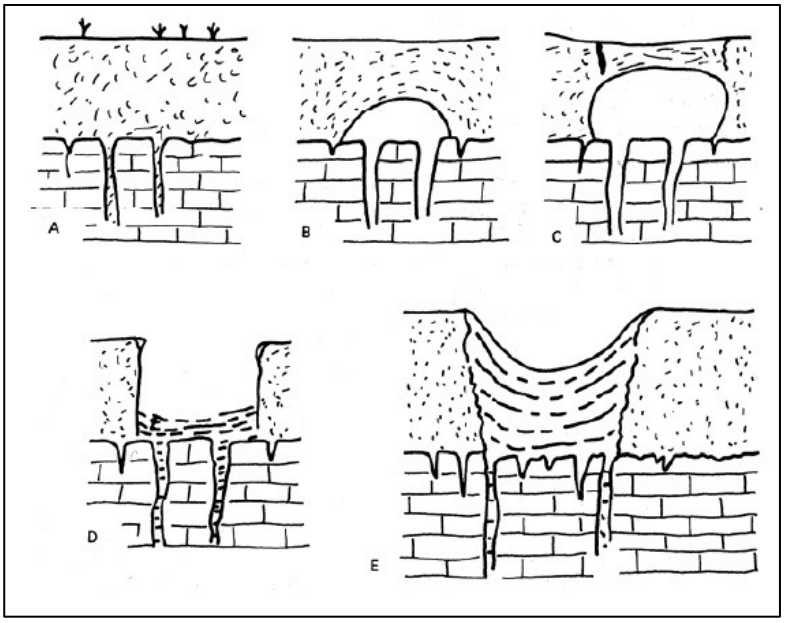


Plate 6-1: Formation of a cover collapse doline (GSI Groundwater Programme)

From data and site observations attained as part of this assessment, it is believed that cover collapse dolines are the main geological process producing surface karst features across the Proposed Wind Farm site.

7. KARST RISK ASSESSMENT AND SITE PROTOCOL

7.1 Karst Risk Assessment

The karst risk has been based on assessment of the following geological and evidence-based risks:

- Underlying rock type.
- Thickness of overburden cover / depth to bedrock (the greater the overburden thickness the less chance for surface water to infiltrate through to the rock to cause solution weathering).
- Proposed depth of excavations (removal of cover over potential karst features)
- Overburden cover type; the nature of the material overlying the limestone bedrock can affect the type and severity of collapse. In granular materials, sinkholes develop slowly causing shallow depressions rather than sudden collapse. In more cohesive materials, failure can be catastrophic and sudden (drop out) and as such a higher risk score is often appropriate.
- Proximity to known karst features e.g. swallow hole, pond or concentration of features, or areas where streams were noted on historic maps which may have disappeared underground e.g. dry stream beds.
- Logged feature in rotary core boreholes e.g. cavity, low/no TCR (Total Core Recovery), brecciated / broken zone of rock etc.
- Anomalies noted in the Geophysical Survey (sharp changes in resistivity may indicate voids or in filled cavities).
- Buried topsoil/organic matter at depth in cable percussive boreholes or trial pits (indicative of disturbed ground, infilled hollows or cavities).

The risk ratings adopted are as follows:

Table 7-1 Risk Assessment Ratings

Risk Category	Description
Negligible	No karst risk (bedrock is not limestone)
Low	Little to no karst risk, very unlikely that any karst features are present. Mitigation measures are unlikely to be required
Medium	Some karst development is possible which may lead to unstable ground or cavities. Following inspection of formation levels, design mitigation measures may be required.
High	Karst development is likely and active unstable ground and cavities already exist or may exist. Detailed assessment of the data, additional ground investigation and geophysical surveying is required, and mitigation or avoidance is likely to be required.

In treating karst features, the guiding principle is to avoid adversely affecting the existing hydrogeological regime. Where specific features are encountered, and depending on the circumstances, possible solutions may include bridging across the void at shallow depth or plugging the conduit at greater depth and backfilling over the plug, though care should be taken not to affect groundwater quality or change groundwater flows by completely blocking existing conduits. The assessment summarised below applies both to the turbine locations and the sections of access roads between the relevant turbines.

Table 7-2: Summary of Karst Assessment

Turbine ID (Final Proposed Turbine Layout)	Risk Rating	Summary
T01	High	Weathered bedrock and clay infill indicated from geophysical survey and boreholes, indicating the presence of a subsurface karst feature to the north of the turbine location, with a feature also present at a depth of 10m below the proposed base of excavation for the turbine. Presence of intact bedrock directly below proposed turbine excavation will provide sufficient engineering support for the construction of the turbine.
T02	High	Weathered bedrock and clay infill indicated from geophysical survey and boreholes, indicating the presence of a subsurface karst feature to the north and northeast of the turbine base. Turbine founded on gravel above weathered bedrock.
T03	Medium	No evidence of karst on geophysical survey or from boreholes but is in an area of recorded karst features. Turbine founded on weathered/intact Limestone bedrock.
T04*	Low	Limestone present at depth (20m bgl) below mudstone, but no significant risk associated with this given the thickness of mudstone present below the turbine base excavation (c. 16m).
T05*	Negligible	Mudstone present, non-carbonate rock, negligible risk.
T06*	Negligible	Mudstone present, non-carbonate rock, negligible risk.
T07*	Negligible	Mudstone present, non-carbonate rock, negligible risk.
T08*	Negligible	Mudstone present, non-carbonate rock, negligible risk.
T09*	Negligible	Mudstone present, non-carbonate rock, negligible risk.
T10*	Negligible	Mudstone present, non-carbonate rock, negligible risk.

*Turbines renumbered following the removal of the original T04

7.2 Karst Protocol

The karst risk or potential for karst features along the access road alignments and at turbine locations has been characterised in the Karst Risk Assessment. The designer will further review the risk of features affecting works and outline any change to risk and locations during construction. A standard set of solutions is available in the SED drawings for typical features and dimensions encountered.

A Karst protocol, provided in Appendix E, has been developed to translate the karst risk to the construction stage.

In all cases the formation level is to be checked by the Project Geotechnical Engineer for any local soft / weak or loose areas. The RE is to be notified if any soft / weak or loose areas are identified.

Due to potential karst risks around T01 and T02 and extending along the access road towards T04, the following investigations shall be carried out:

- Formations for embankments or cuttings to be proof rolled and observed for signs of weakness; and
- Formations for structure (turbine) foundations to be proof rolled as above. The excavation shall be

extended to rock head (where feasible) in areas where the karst risk is high or where evidence of karst features is encountered during overburden excavation.

Karst features identified within the works areas will be investigated as shown in the flowchart in Appendix E. The results will be documented for each feature. Where karstic features are encountered, they will be investigated by excavating a trial pit. Following the findings of this trial excavation the RE will consider if further additional ground investigation is required. The Project Geotechnical Engineer will direct the Contractor on which Standard Earthwork Detail (SED) to employ. Where the feature is more extensive than shown on the SEDs the designer will design the remediation measures. The design will be certified by an independent Cat III checker before implementation. Each karstic feature and the remediation measures will be documented and include in the Safety File for the operational phase of the project.

Features identified will be investigated by probing or further proof rolling as appropriate to be agreed between the RE and the Contractor. The R Project Geotechnical Engineer may require additional ground investigation, including geophysical surveys, rotary boreholes, or other intrusive techniques, as agreed on site. Such investigations form a routine component of the detailed design process for infrastructure developments in areas of potential karstification and may be undertaken to verify ground conditions, refine foundation designs, and confirm the suitability of proposed infrastructure locations, irrespective of the preliminary karst risk classification.

Where karst features are identified the details as shown on the SEDs (as illustrated on drawings P26-112-FT-XX-XX-SD-GE-0001 to 0004 – Appendix B) will be used as instructed by the RE. Where a significant karst feature is suspected below a turbine foundation, a structural solution, such as a raft footing spanning over the feature, or a piled foundation, will be considered.

8. SUMMARY, CONCLUSIONS & RECOMMENDATIONS

8.1 Summary

The southern portion of the Proposed Wind Farm site is entirely underlain by Carboniferous Limestone of the Clogrenan and Ballyadams Formations. Several potential surface karst features were identified throughout the Proposed Wind Farm site as part of a desktop study. A site reconnaissance was undertaken to ground truth these features. The site reconnaissance also identified potential surface karst features not recorded as part of the desktop study.

To aid in the karst assessment, a combined non-intrusive (ERT, Seismic and Microgravity survey) and intrusive (boreholes and trial pits) ground investigation was carried out. Findings from the geophysical investigation identified a number of interpreted sub-surface anomalies within the underlying limestone bedrock.

Results from the combined desktop study, site reconnaissance and ground investigations suggest that karst risk within the Proposed Wind Farm site is confined to the limestone of the Ballyadams and Clogrenan Formations, located below T01 to T03. While T04 (Proposed Wind Farm Turbine layout) is mapped by the GSI as being within the Ballyadams Formation, drilling results indicate the presence of the Killeshin Formation (siltstone and mudstone) close to the surface, with limestone, likely to be part of the Ballyadams Formation, present at a depth of 20m bgl.

8.2 Conclusions

Surface karst features (predominantly dolines) are present in certain areas of the Proposed Wind Farm site within the Clogrenan and the Ballyadams Formations. These features are believed to form along a fault line that create zones of weakened and fractured rock beneath the overlying Quaternary deposits (predominantly Glacial Till), as well as along an unconformity between the Clogrenan Formation and the Killeshin Formation. The result is a broadly circular bowl-shaped depressions of varying widths and depths.

As the majority of these features have been intentionally backfilled by the landowner over the years, it is not clear if the formation of new features is actively occurring across the Proposed Wind Farm site, however it is considered unlikely based on the findings of the site reconnaissance and the ground investigation works.

No karst features were observed within the underlying siltstone of the Killeshin Formation present through the centre and north of the Proposed Wind Farm site. No evidence of significant karst features such as caves were noted within the Proposed Wind Farm site as part of this assessment.

8.3 Recommendations

As karst features are present within the southern portion of the Proposed Wind Farm site, covering the Proposed Wind Farm site entrance road and T01 to T03, the design of the wind farm infrastructure in this area should account for this geology. The remainder of the Proposed Wind Farm site is not considered to be susceptible to the formation of karst features. Any surface depressions or suspected doline features within the footprint of the turbine bases, hardstands, construction compounds or access roads should be removed by excavation of the existing soils and replacement with engineered fill and geogrid reinforcement. See drawing P26-112-XX-XX-SED-GE-0003 for a sample arrangement for the fill and geogrid over a suspected or identified karst feature, which would apply to roads and hardstands. For turbine bases, a structural solution (such as piling) would likely be required. The construction of the wind farm main infrastructural elements should be overseen by a geotechnical engineer with experience in identifying surface karst features.

9. REFERENCES

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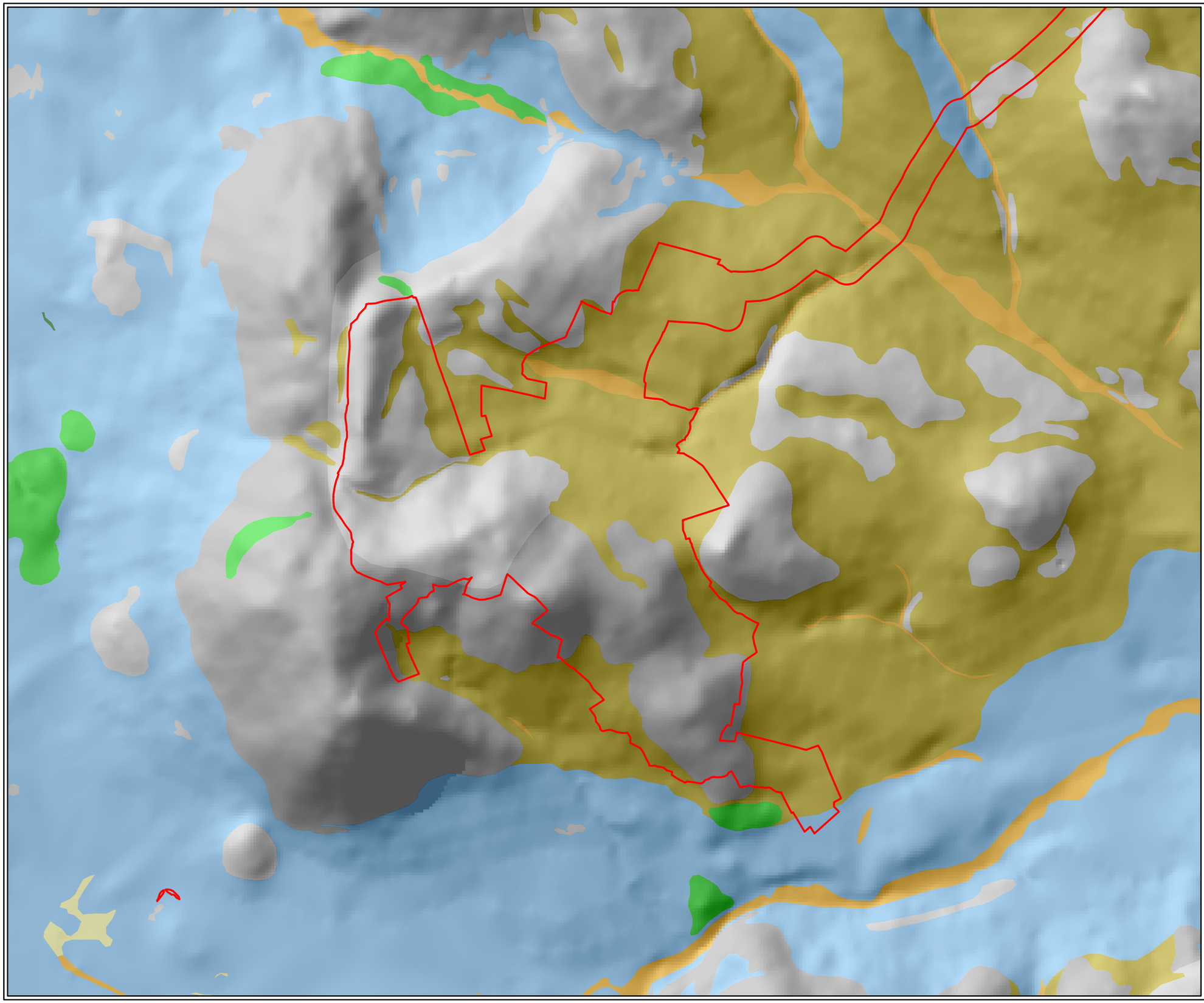
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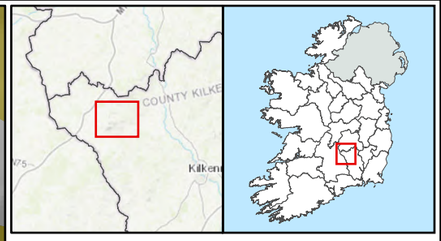
APPENDIX A

Figures

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Legend

- Site Boundary
- A, Alluvium
- BasEsk, Eskers comprised of gravels of basic reaction
- GLs, Gravels derived from Limestones
- KaRck, Kartsified bedrock outcrop or subcrop
- L, Lacustrine sediments
- Rck, Bedrock outcrop or subcrop
- TLs, Till derived from limestones
- TNSSs, Till derived from Namurian sandstones and shales

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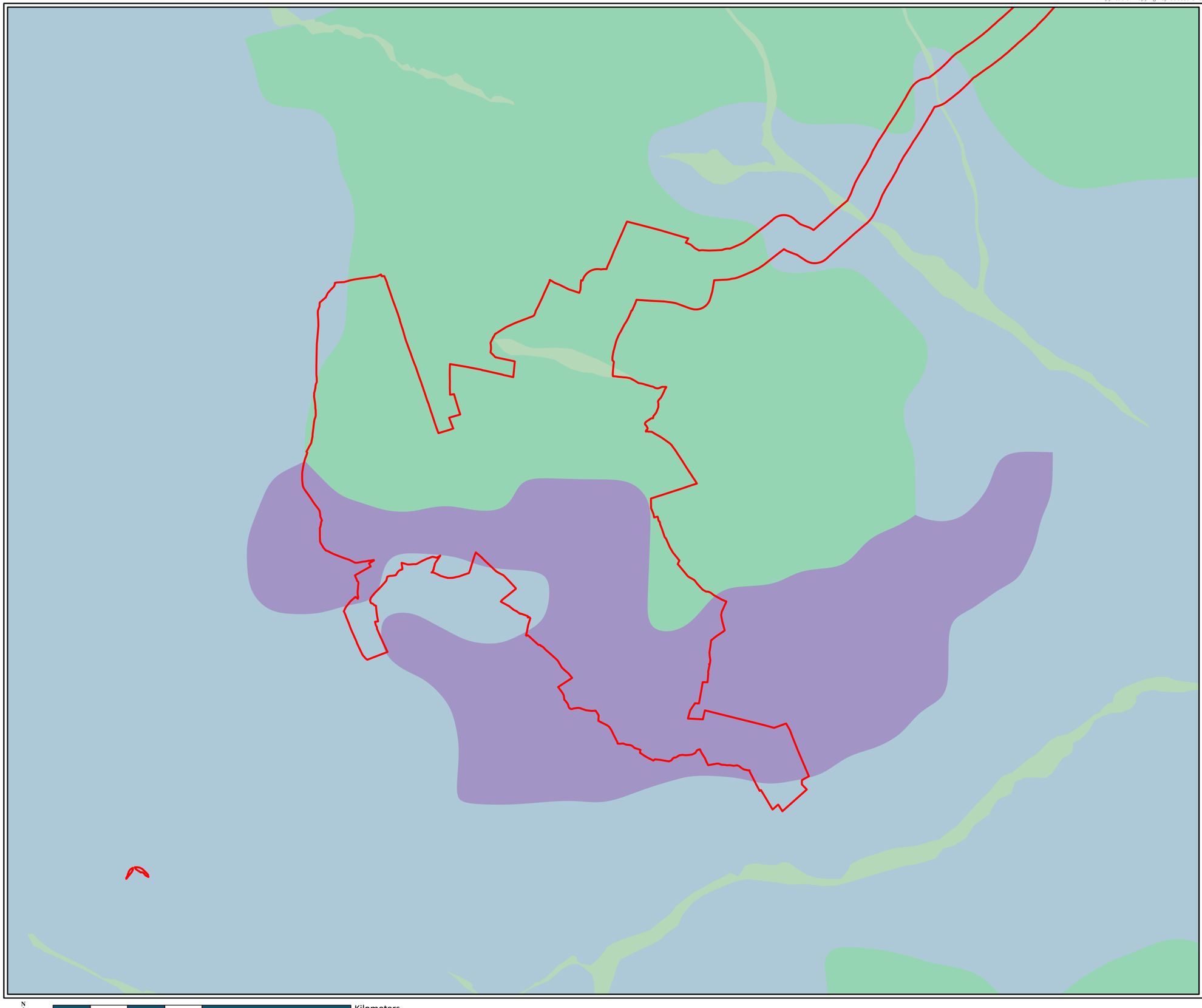
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Legend

- Site Boundary
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- Fine loamy drift with silIceous stones
- Fine loamy drift with siliceous stones
- River alluvium

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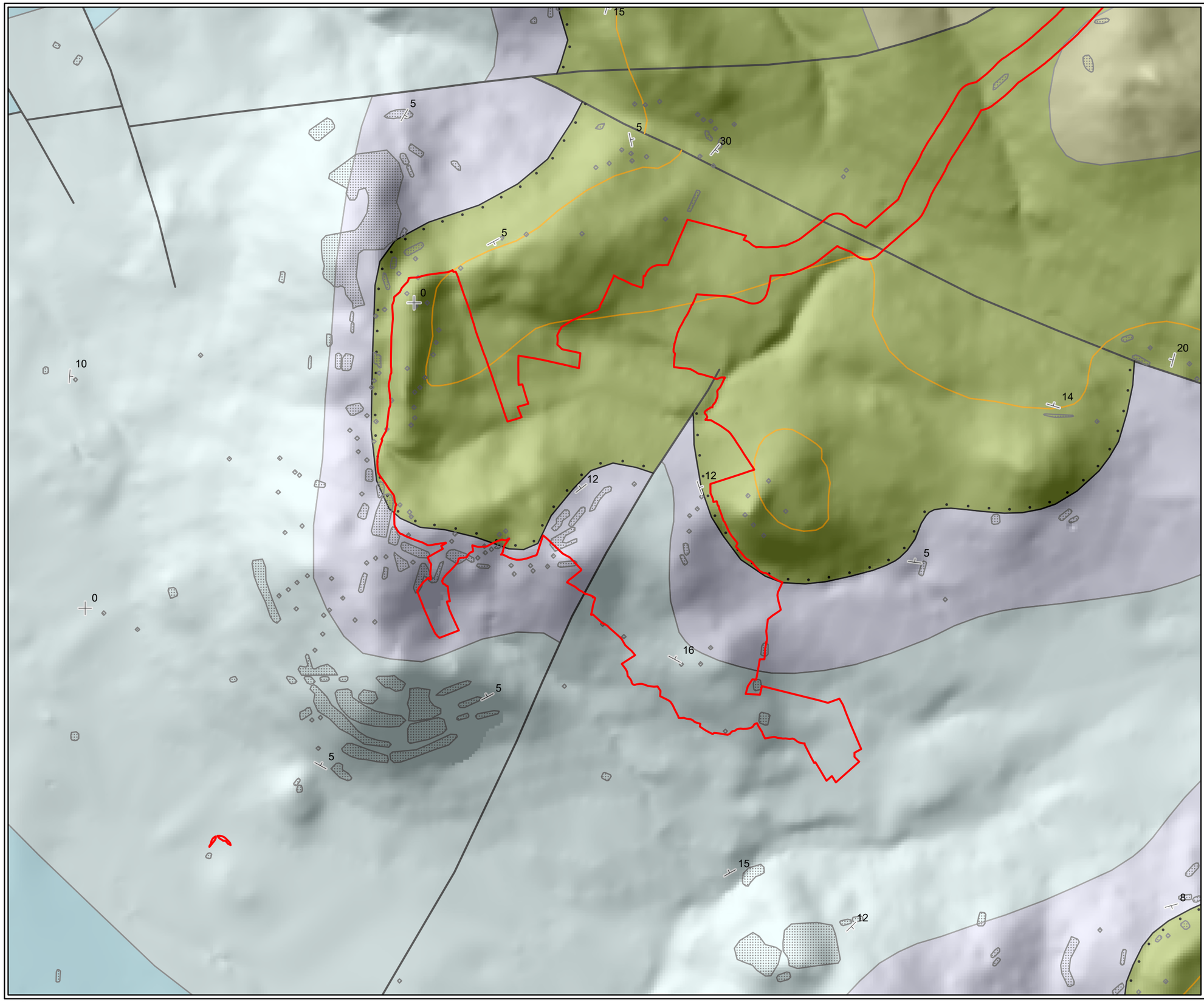
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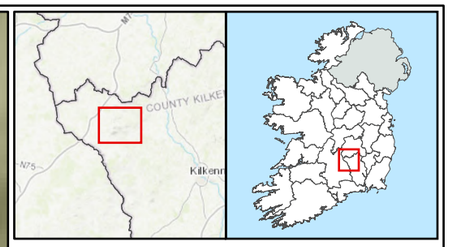
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Legend

- Site Boundary
- Ballyadams Formation
- Clogrenan Formation
- Durrow Formation
- Bregaun Flagstone Formation
- Killeshin Siltstone Formation
- Bedrock Outcrops
- Horizontal Bedding
- Strike and dip of bedding, way up unknown
- Fault
- Thin stratigraphical unit, diagrammatic
- Unconformity, dots on younger side

N W E S

0 0.5 1 2 Kilometers

TITLE: Bedrock Geology			
PROJECT: Killoshulan Wind Farm			
FIGURE NO:	3		
CLIENT:	MKO		
SCALE:	1:26,214	**REVISION:**	0
DATE:	07/10/2026	**PAGE SIZE:**	A3

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