Technical Appendix 9.3.2: Geotechnical Assessment: Mine Risk Assessment;

Mining Risk Assessment

Unshinagh Wind Farm

22 September 2021

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Renewable Energy Systems Limited

Document history

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1. Introduction

1.1. Development Planning Process

This Mining Risk Assessment has been undertaken as part of a wider desk study and peat stability assessment for the proposed Unshinagh Wind Farm development. Natural Power Consultants (Natural Power) was commissioned by Renewable Energy Systems Limited (RES) to undertake this mining risk assessment for the proposed Unshinagh Wind Farm.

The assessment is informed by a desk study (Doc no. 1246507) using information obtained from published sources and through data received from GSNI (Geological Survey of Northern Ireland).

The risks associated with the wind farm layout are assessed within this report alongside the overview of potential risk mitigation strategies.

1.2. Development Proposals

Unshinagh Wind Farm will comprise of fourteen wind turbine generators and associated ancillary / access infrastructure. Each wind turbine will require a foundation system and adjoining crane hardstand to facilitate construction and future maintenance. The turbines will be served by an access track network, meteorological mast and substation building. Electrical cabling will connect each turbine element with cabling following the access track network. There will be a temporary construction compound established for the duration of the construction phase. This will house temporary offices, stores and welfare facilities for the civil works contractor.

The proposed access for the site is to be a new track off Slanes Road. Track spurs to the infrastructure locations will be constructed to provide site access to each turbine location. Open grassland used for livestock grazing surround the track on either side.

1.3. Existing Reports

The following reports pertain to the development and should be read in conjunction with this detailed mining risk assessment. Table 1.1 provides a summary of key references:

Table 1.1: Existing Reports

Document	Reference	Issue Date
Unshinagh Desk Study and Phase 1 Peat Survey	1246507	April 2021
Unshinagh Phase 2 Peat Slide Risk Assessment	1262630.	September 2021

Source: Natural Power

1.4. Location

The Ushinagh Wind Farm is located in Northern Ireland. The proposed development area occupies a 5.5km^2 area situated 3.5km south west of Carnlough, County Antrim. Figure 1.1 gives the regional location of the site and Figure 1.2 shows the local site layout.

Table 1.2 presents the proposed turbine locations for the development.

Access to the site is from various 4x4 farm access tracks, off from the Slane Road, that runs along the south of the site boundary.

Source: Natural Power, Bing Images

Figure 1.1: Regional Site Location

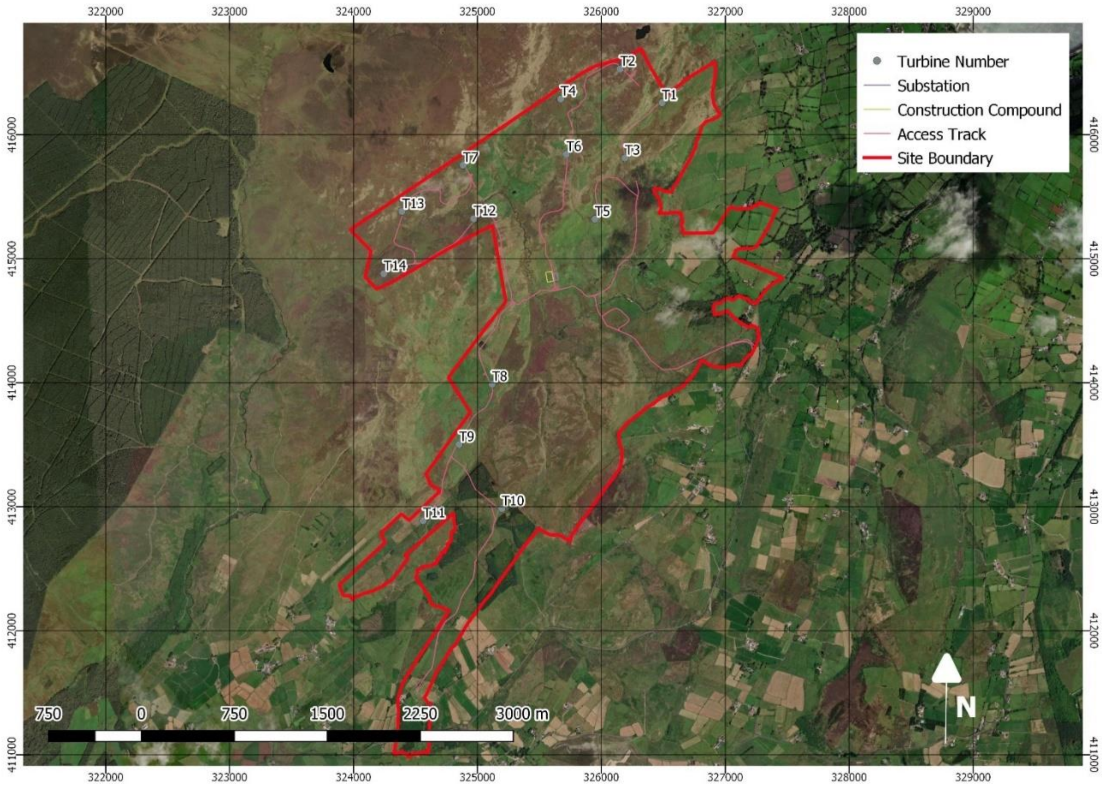

Figure 1.2: Unshinagh Wind Farm site layout

Table 1.2: Indicative Turbine Coordinates (ING)

Turbine ID	Easting	Northing
T1	326489	416258
T2	326152	416531
T3	326190	415813
T4	325672	416289
T5	325948	415319
T6	325717	415843
T7	324884	415754
T8	325118	413988
T9	324852	413503
T10	325196	412984
T11	324561	412887
T12	324969	415323
T13	324391	415381
T14	324244	414880

Source: NPC, Co-ordinates provided by RES.

1.5. Site Description

A detailed description of the site is provided within the Natural Power Desk Study (April 2021) should be read alongside this report. The site is predominantly open hillside of moorland and grass fields that are used for grazing, it is topographically undulating but the site area is located on the south-eastern facing slopes of Binnagee hill.

Typical ground conditions for the upper and lower extents for the site are shown in Figure 1.3 and Figure 1.4.

Source: Natural Power Phase 2 Study (September 2021)

Figure 1.3: Looking North from the approximate location of T3 towards the summit of 'Binnagee'.

Source: Natural Power Phase 2 Study (September 2021)

Figure 1.4: Looking southwest from the approximate location of T10.

1.6. Surrounding Area

There are two dwellings within the site boundary and one unnamed farm building. These are shown in Table 1.3 with proximity to the nearest wind farm infrastructure. Out-with the development boundary the main infrastructures have been identified in Table 1.4, there are numerous individual farm buildings and houses situated along Slanes Road and Ballymena Road that have not been individually described. No existing structure has been found to be at risk from the development.

Table 1.3: Structures and Residences within the Development Area

Existing Structures	Easting	Northing	Nearest Infrastructure	Distance to Nearest Infrastructure (metres)
Unnamed Farm Structure	327178	414807	T5	700m
Farm House and Buildings	326952	415095	T5	1,000m
Residential House	326236	414659	T5	1,350m

Source: Google Earth, QGIS

Table 1.4: Structures and Residences External to the Development

Existing Structures	Easting	Northing	Nearest Infrastructure	Distance to Nearest Infrastructure (metres)
Slane Road	325641	412251	T10	850m
Farms to the West	323823	412057	T11	1,100m
Carnlough	328541	417028	T1	2,100m

Source: Google Earth, QGIS

2. Geological Setting

British Geological Survey (BGS) mapping information and datasets have been reviewed in conjunction with relevant GSNI digital datasets including mine entry registers, mine abandonment plan catalogue and developmental risk areas.

2.1. Superficial deposits

Peat: BGS information indicates the presence of peat only in discrete areas of the proposed development. Peat surveys undertaken by Natural Power Consultants in April and September 2021 confirm the majority of the site to have no peat accumulations. An interpolated peat depth map of all 1,195 soil probes collected during the peat survey is shown below. The deepest recorded areas of peat are in excess of 5.0m, these are in localised pockets and avoided by any proposed windfarm infrastructure.

Source: Natural Power

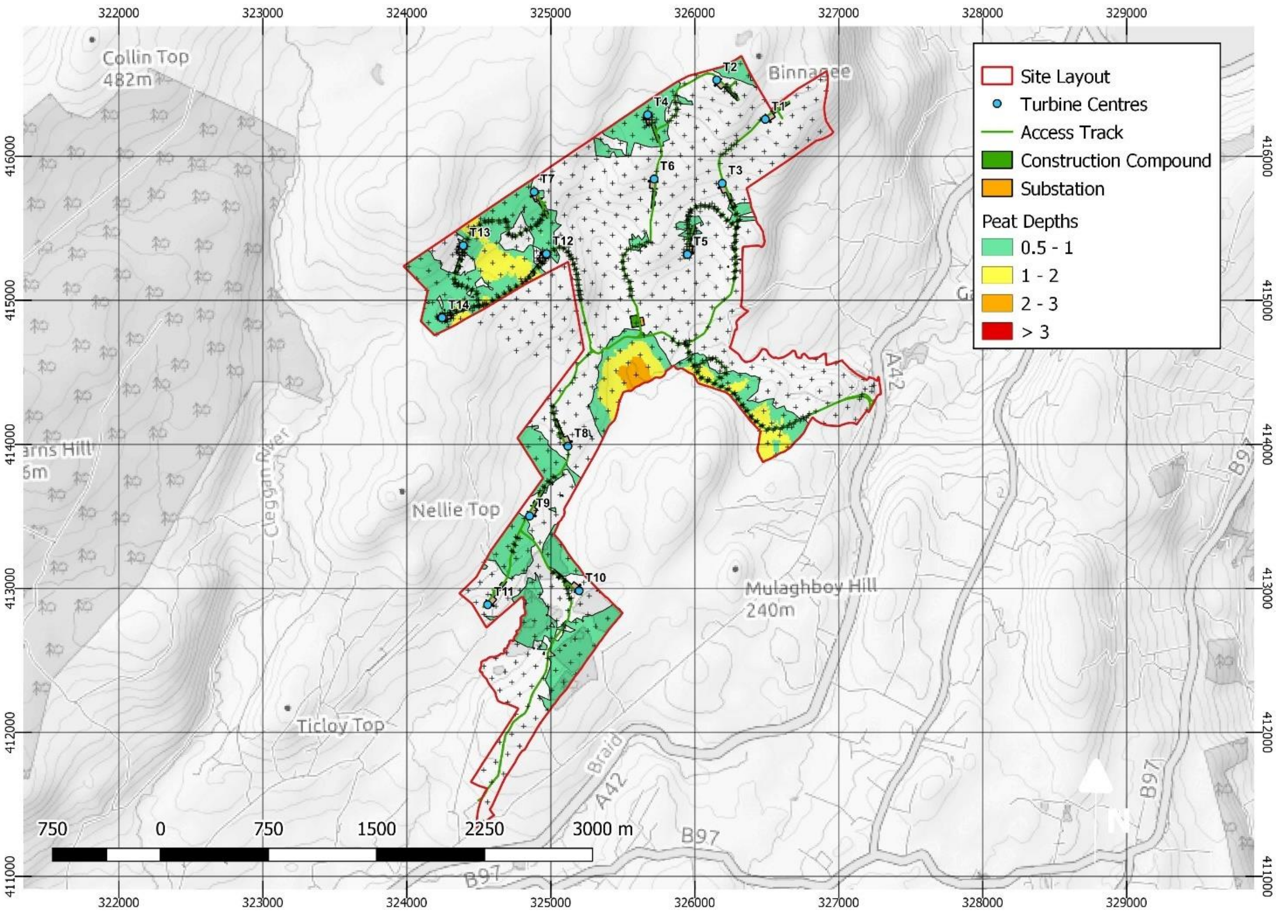

Figure 2.1: Peat Depth Map

Glacial deposits: Described as 'Till – Diamicton' deposited within the last 2 million years. Made up of material ranging from clay to large boulders, this material is generally poorly sorted and undifferentiated.

The BGS online engineering viewer description is summarised as follows: Firm to hard gravelly sandy CLAY with many cobbles and boulders. Often fissured, with occasional interbeds of sand and gravel. Generally low permeability. Foundations are generally good, but there is potential for differential settlement. Excavation is easy, with material staying stable if dry. May be suitable for general cohesive fill depending on grading, plasticity and water content. During the site investigation it is important to determine the deposit thickness and lithological variation. Presence of laminated silts and clay, as well as any water bearing strata.

Source: British Geological Survey © NERC 2021, Google Earth Professional background imagery.

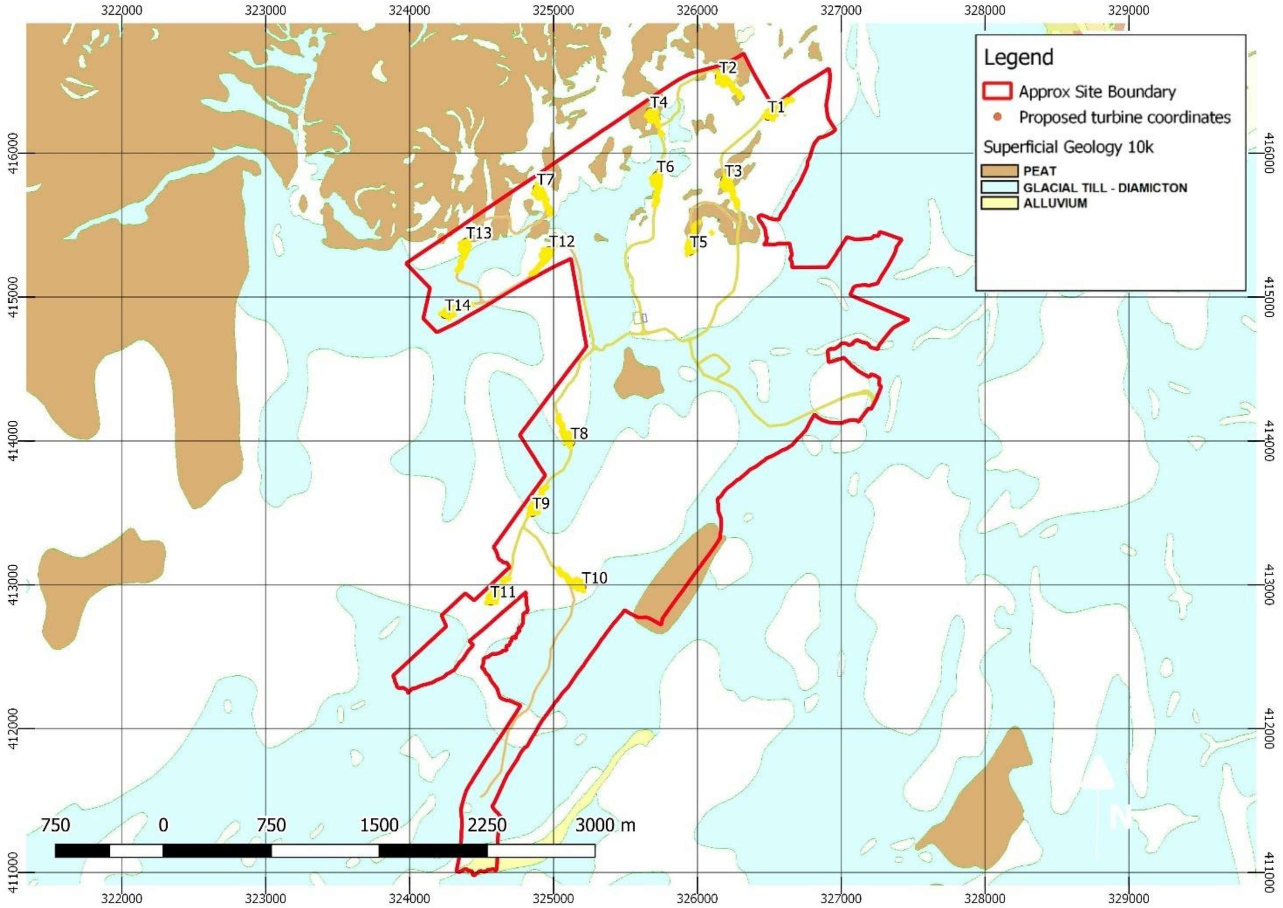

Figure 2.2: Superficial Deposits on Site

2.2. Solid Geology

The Lower Basalt is present beneath the majority of the site, with an inferred fault separating it from the Upper Basalt in the north-eastern side of the site. This was confirmed during the site survey, basaltic lava flows were identified at all outcrops exposed on site.

During the site survey x5 outcrops were noted to have exposed lava flows and palaeosols. Figure 2.2 shows a photo of one exposure, approximately 500m southeast of turbine T5. A 3m thick basaltic lava flow is shown to the left of the outcrop. This is overlying a red lens-like palaeosol on the right of the exposure. Examples of these are present throughout the site, and likely extend below the surface.

The basalt is very strong, and generally massive with frequent fractures. The palaeosol material is highly weathered, weak to medium strong, highly fractured. The extent of these likely permeates throughout all the upper and lower basalts. Outcrop locations are presented on Map A3 : Solid Geology.

The Basalt layers are underlain by the Ulster White Limestone. Due to the unknown thicknesses of basalt it is important to highlight, as this can be a particularly problematic strata. Hazards include, weak layers, voids, as well as variable water content.

Source: Natural Power Phase 1 Survey (March 2021)

Figure 2.2: Lava flow covering underlying paleosol

Table 2.1 summarises the BGS engineering description for the listed bedrock geological units present on site.

Table 2.1: British Geological Survey Regional Engineering Geology.

Unit	Description	Foundations
Basalt	Very strong jointed fine grained basaltic rock. May be locally altered to very weak clay. Low permeability with flow through discontinuities. May include other fine grained mafic rocks and interbedded tuffs	Foundations are very good in fresh or slightly weathered rock, but highly weathered rock and presence of palaeosols may need to be accounted for. Highly weathered material may be excavatable, but fresher material may require blasting. Suitable for granular fill. It should be noted that some basalts may exfoliate to a slight extent after long periods of weathering.
Chalk	Weak to strong porous fine-grained CHALK and CHALKY LIMESTONE. Flint nodules and beds are frequent, and thin clay/mudstone beds. Lots of discontinuities present throughout. Weathers to calcareous silt. Dissolution hollows and pipes present under thin superficial cover. Very high to medium permeability	Potentially good foundation conditions, but largely dependent on nature and thickness of weathered zone. Possible presence of dissolution cavities. Soakaways near karstic structures are not advisable. Generally, requires ripping and blasting, weathered material can be excavated with hard digging. Clay infills may give rise to stability problems. May be suitable for selected granular fill but can degrade quickly by weathering if used in association with wet cohesive soil.

Source: Natural power

The BGS online viewer indicates the site is underlain by the Upper and Lower Basalt Formation. Figure 2.3 below shows the GSNI Solid Geology layer.

Source: British Geological Survey ©NERC 2021

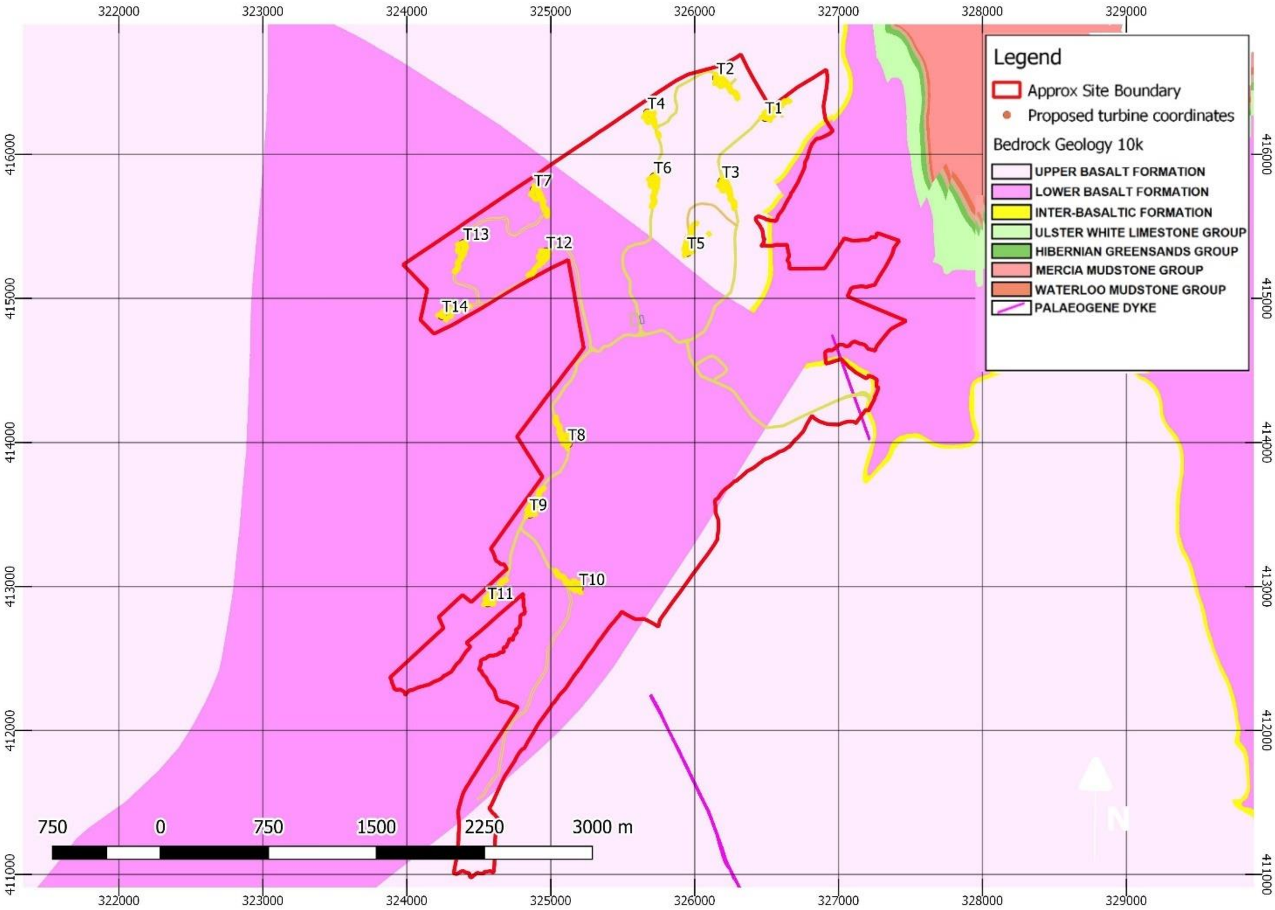

Figure 2.3: Bedrock Geology on Site.

2.3. Made Ground

There is no recorded made ground on the GSNI Geoindex within the site boundaries, however during the peat survey it was noted; made ground and presence of non-natural material such as bricks at discrete areas of the site. It is most likely that this ground is due to the construction of access tracks for the agricultural use of the site. Presence of made ground should be further investigated during a geotechnical / geo-environmental site investigation.

2.4. Historical Borehole Records

Following review of geological mapping; the GSNI Geo-Index was searched for all relevant exploratory borehole records within or surrounding the Development. There are no existing borehole records within the development, area or within 1km of the site boundary.

2.5. Landslides

The GSNI Geoindex shows no records of historic landslides both within and surrounding the site boundary. In addition to this no landslides were recorded on the geomorphological map or noted during the site walkover.

3. Development History

A detailed examination of the historical development at the site has been carried out as part of the desk study assessment (Report no.146507). It is noted that none of the mine entries identified by the GSNI are shown on the historical mapping.

As part of this mining risk assessment the development history of the site in relation to mining is summarised in Table 3.1 below.

Table 3.1: Development History

Map Name	Map Date	Description
OSNI Historical Edition 2	1846 - 1862	No mining features shown on the mapping, although three building in the location of the present day Culinane Farm.
OSNI Historical Edition 3	1900 -1907	Increased number of buildings around the Cullinane Farm. Two 'Old Level (Ironstone)' features mapped to the west of Cullinane.
OSNI Historical Editon 5	1919 - 1963	No significant change.

Source: The National Library of Scotland

3.1. GSNI Records

The Geological Society of Northern Ireland were able to provide the following:

Past Mining Activity

- The development is in the likely zone of influence from the Cullinane Mine an extensive producer of Bauxite.
- The Cullinane Mine is indicated to have been last worked in 1893.
- A plan of the Cullinane Mine Workings (MP31).
- The location and possible past usage of multiple mine entries inside or close-by to the site boundaries described as adits and workings. Records may be incomplete and consequently there may exist in the local area mine entries of which The GSNI has no knowledge.

3.2. Mine Abandonment Plans

A comprehensive review of the GSNI mine abandonment plans has been undertaken as part of this detailed risk assessment. The location and approximate extent of abandoned workings have been determined with respect to the Development.

One abandonment plan for the Cullinane Mine was found to be within site boundaries. Figure 3.1 and table 3.2 below show this underground working recorded on the abandonment plan. Indicating that the south east corner of the site is predicted to be undermined at deeper levels. None of the turbines or infrastructure is located in an area that has been previously under mined. The worked depths of the Cullinane Mine are unknown with no record of depth on the mine plan.

Source: GSNI, Google Earth Professional

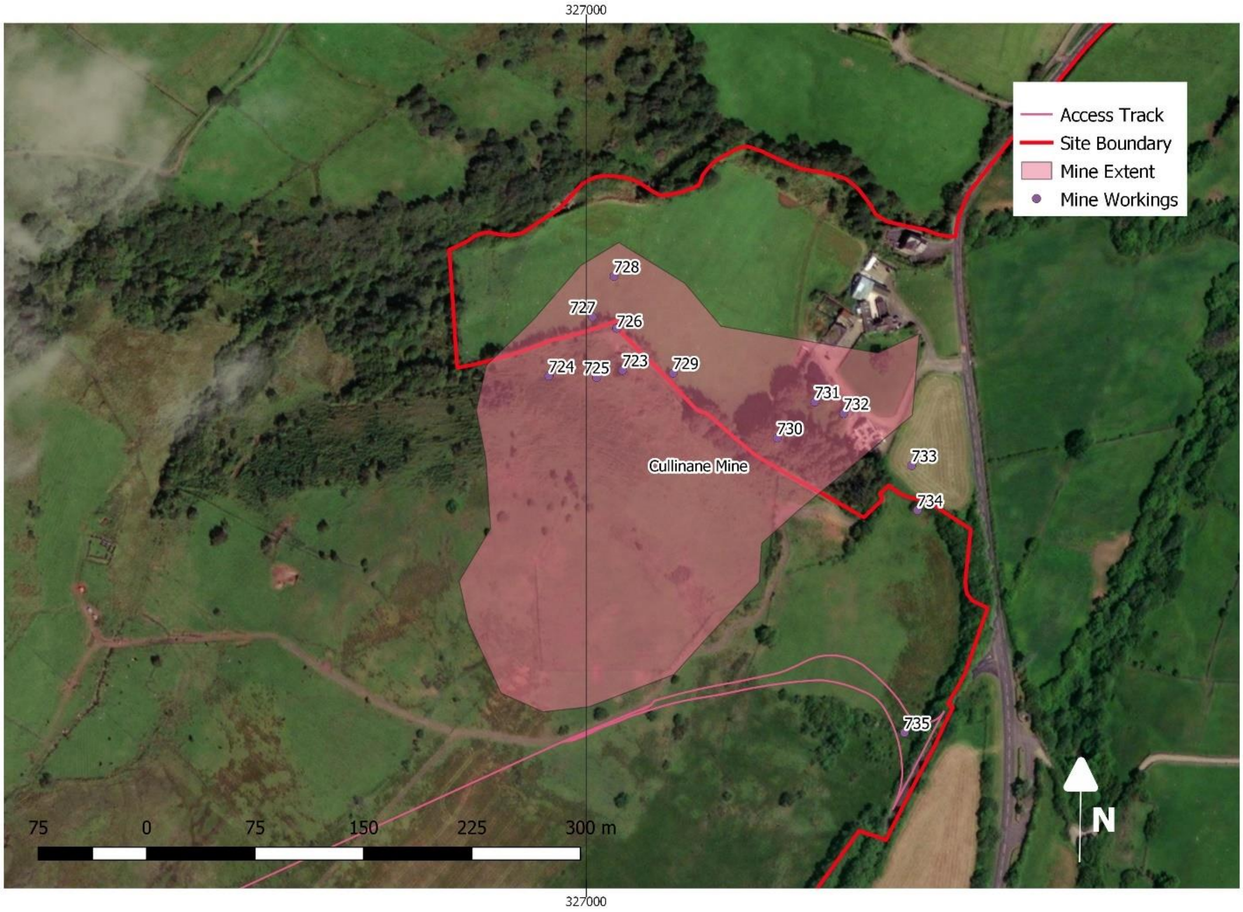

Figure 3.1: Abandoned Underground Mining Areas

Table 3.2: Abaondoned Mines on Site and the Structures they may affect

Description and Date	Areas Affected	Commodity	Approximate Depth of Workings (mbgl)
Ref: M3/481, Cullinane Mine	Access Track	Bauxite	Unknown

Source: GSNI, Natural Power

The mine abandonment plan for the Cullinane Mine is considered to be of moderate reliability due to the detail of the plan. However, the precise location cannot be confirmed due to the age and precision of survey in the late 19th Century.

3.3. History of Surface Extraction

The GSNI Geoindex indicates that the development is not within the boundary of an opencast site from which minerals have been removed using opencast methods in the past. At present, there is evidence of minor quarried faces across the site that are shown on the geomorphological map of the site.

4. Mining Hazards

As identified by the information provided by the GSNI there is the potential for underground workings within the vicinity of the development. The likely methods of mining and mineral extraction can be associated with specific hazards. This discussion is informed by author experience and recent publications including the Abandoned mine workings manual CIRIA C758D, (2019). Figure 4.1 below shows data from the GSNI, indicating areas the areas of highest risk for the development.

Source: Natural Power, GSNI, Google Sattelite

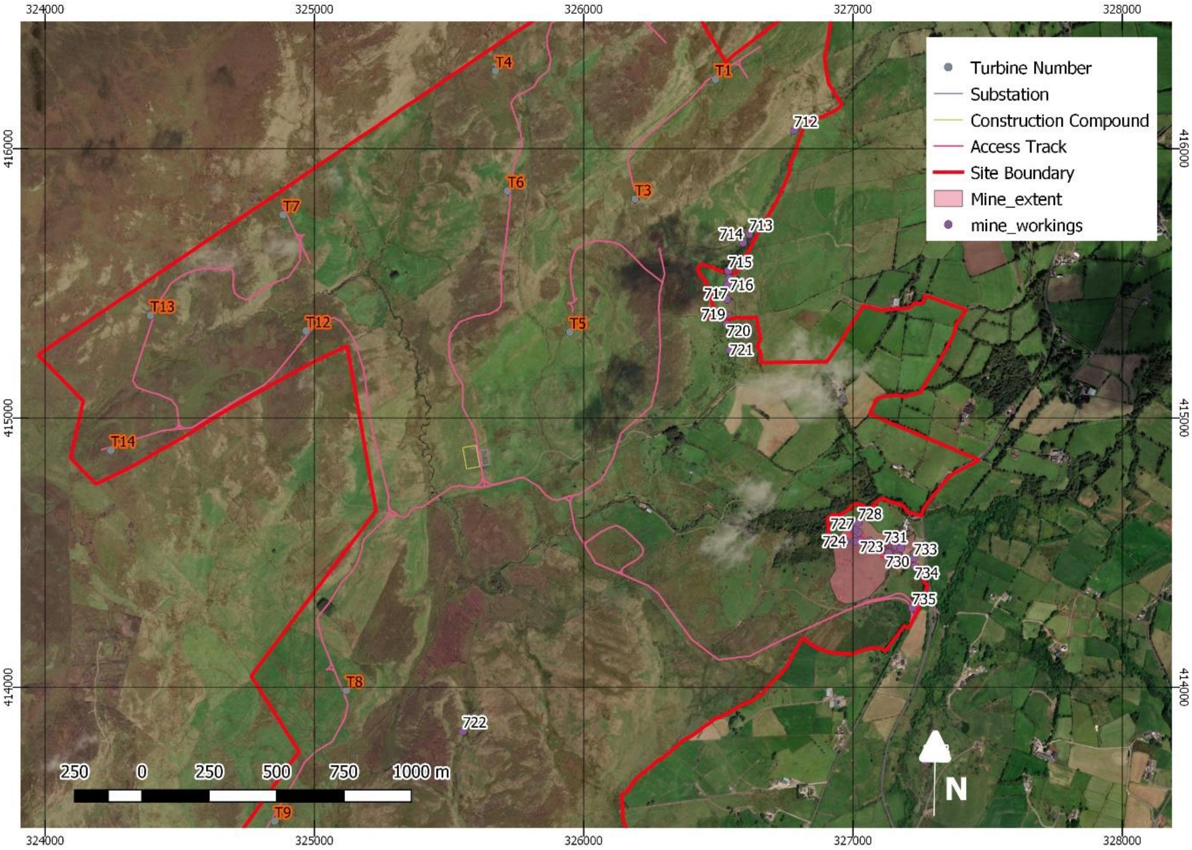

Figure 4.1: Mining Hazards in relation to the windfarm.

4.1. Mine Entries

Accompanying the Cullinane Mine the GSNI has identified a series of mine entries (two workings and twenty-three adits) that are inside or within 100m of the site boundary. The use of these entries is mostly unspecified but likely to have been used for the following:

- Testing holes;
- Pumping and removal of groundwater;
- Ventilation.

There are 13No. mine entries located over or very close by to the supposed extents of the Cullinane Mine, these are entry numbers 723 – 735. The GSNI states these were abandoned in 1893. Figure 4.2 below shoes a photo looking across the areas of field where there adits are identified. There was no evidence of any adits. or past mining history, identified during the Natural Power walkover. However, there is the possibility these may be buried or concealed by later land improvement / agricultural practices.

Source: Natural Power Phase II Survey (September 2021)

Figure 4.2: Photo view South-east close to Adit no.734.

Mine entry no.722 is described as the Aughareamlagh Working, no further information is provided on this area. The locations provided by the GSNI locates this working to be approximately 450m south-east of T8. An extensive walkover of the site area identified no direct evidence of historic mine workings here, Figure 4.3 is a photo taken looking approximately south over the proposed area of these mine workings.

Source: Natural Power Phase II Survey (September 2021)

Figure 4.3: Photo taken looking south over the area of the historic 'Aughareamlagh' Working.

The remaining mine entries (no's. 712 – 721) are located along the north-eastern fringe of the site approximately half way up a topographic ridge line of pronounced steeper terrain. This ridge runs in an approximately north-south direction and is vegetated with long grass, ferns, gorse and small trees. A detailed walkover of this area of the site did not identify any surface evidence of historic mining activity. There was one outcrop of the possibly targeted bauxite however this did not appear to have been worked and was exposed by the stream, see Figure 4.4.

Source: Natural Power Phase Two Survey (September 2021)

Figure 4.4: Exposure of Paleosol likely to have been the targeted mining layer located close to mine entry 716.

Adits are mine entries which enter the ore bearing strata in a sub-horizontal orientation from the ground surface. Adits are generally sited where outcrops are at the surface with the adit forming the 'mouth' of the mine. The underground working would progress sub-horizontally along the ore seam and get progressively deeper. Adits are often obscured at the surface and may have been backfilled or sealed on abandonment.

The type of backfill of a mine entry will determine its short and long-term stability. Makeshift plugs may have been formed haphazardly at intermediate depths with backfill resting on top of these improvised plugs of often wood, timber or abandoned machinery.

Assuming that the stated abandonment year of 1893 applies to all of these adits, it is possible that minor backfilled adits would no longer be visible at the surface.

There are no known mine shafts, workings or adits identified or predicted at any turbine locations.

Figure 4.5 below shows mine entries in the development. Table 4.1 contains data on mine shafts and adits found inside or within 100m of the site boundaries.

Source: Natural Power, GSNI

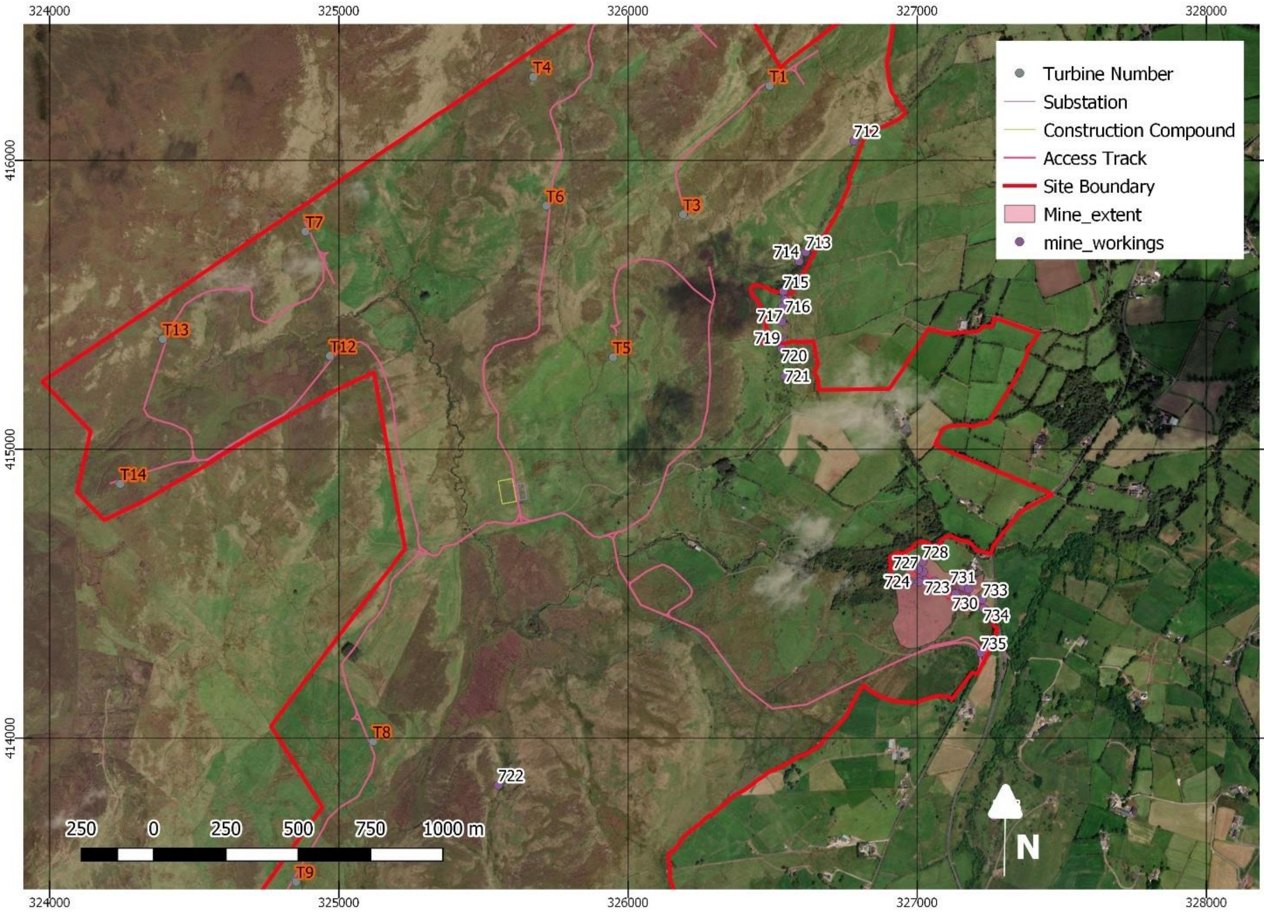

Figure 4.5: Location of mine workings on the site overview.

Table 4.1: Mine Entries In or Within 100m of Site Boundaries

Mine Entry Reference	Name	Type	Easting	Northing
712	UNSHINAGH MOUNTAIN ADIT	Adit	326781	416068
713	UNSHINAGH MOUNTAIN ADIT G	Adit	326614	415683
714	UNSHINAGH 'A' TRIAL ADIT?	Adit	326591	415651
715	UNSHINAGH MOUNTAIN ADIT F	Adit	326537	415546
716	POSSIBLE WORKING-UNSHINAGH NORTH	Working	326542	415518
717	UNSHINAGH NORTH ADIT E	Adit	326534	415494
718	UNSHINAGH 'B' ADIT	Adit	326531	415441
719	UNSHINAGH NORTH ADIT C	Adit	326525	415385
720	UNSHINAGH SOUTH ADIT B	Adit	326531	415348
721	UNSHINAGH 'C' ADIT	Adit	326542	415253
722	AUGHAREAMLAGH WORKING	Working	325551	413837
723	CULLINANE 'A' ADIT	Adit	327025	414546
724	CULLINANE ADIT	Adit	326974	414542
725	CULLINANE ADIT	Adit	327007	414541
726	CULLINANE OUTLET ADIT	Adit	327021	414575
727	CULLINANE WATER LEVEL-OUTLET ADIT	Adit	327004	414583

Mine Entry Reference	Name	Type	Easting	Northing
728	CULLINANE WATER LEVEL ADIT	Adit	327019	414611
729	CULLINANE OUTLET ADIT	Adit	327060	414544
730	CULLINANE 'B' ADIT	Adit	327132	414499
731	POSSIBLE ADIT CULLINANE	Adit	327158	414524
732	CULLINANE ADIT	Adit	327178	414516
733	CULLINANE 'C' TRIAL ADIT?	Adit	327225	414480
734	CULLINANE TRIAL LEVEL	Adit	327229	414449
735	CULLINANE TRIAL LEVEL	Adit	327220	414295

Source: GSNI Records

4.2. Mineral Extraction

Room and Pillar extraction in coal or ironstone seams proceeds through partial extraction, this technique was utilised for most mine workings before 1940. Between 10% and 40% of the ore is left in-situ to form pillars that support the roof of the mine. The geometry of this natural support is often random but may become more systematic and geometrical. Where seams have been over-worked there may be a long-term subsidence threat.

The target of the Culinane Mine is thought to be a 15cm – 60cm thick bed that was mined for Bauxite. The mine was considered an extensive producer of Bauxite prior to 1886. Due to the active time period of this mine, it is likely the mine was progressed using room and pillar workings.

Mine pillars may fail when they are too small to support the overburden and subsequently become overloaded by surface construction activities or are affected by erosion by fluctuating groundwater flow. Pillars may puncture into underlying soft deposits (‘seat earth’ / ‘fireclay’) and create an issue of long-term subsidence. The collapse of such features may be delayed and unpredictable. Primarily the thickness of dependable rock mass occurring below engineering rockhead is a critical factor in assessing propensity collapse to affect structures on the surface.

The adits to the north east of the site were for the extraction of iron ore. It is thought the targeted bed was approximately 35cm thick and the adits were driven into the escarpment possibly up to horizontal depths of 680m. It is unknown what, if any, support was used for progressing these adits.

Figure 4.6 below provides a diagram of the situation leading to surface collapse involving room and pillar workings.

Source: CIRIA C758D

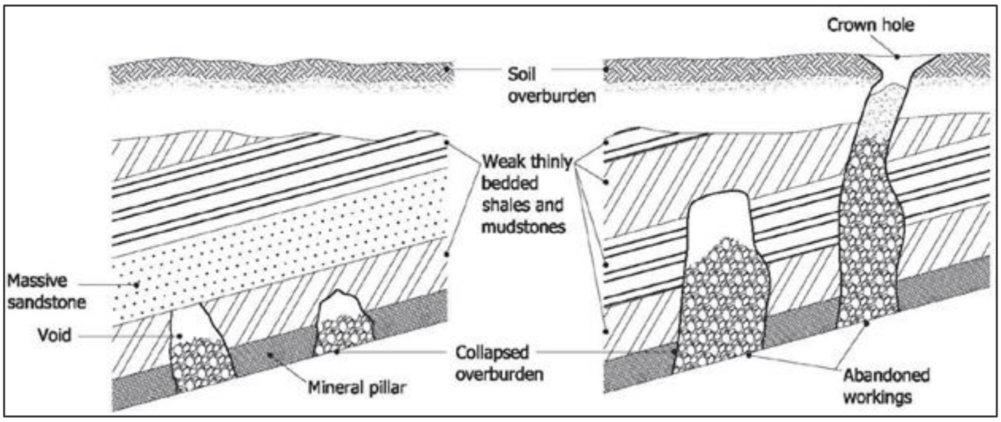

Figure 4.6: Mode of Failure for Room & Pillar workings.

Where deep superficial soil cover is present above bedrock level, the capability of the soil top bulk in a collapse and subsidence scenario should be considered. The latest CIRIA guidance indicates that with thick superficial deposits (>10m) of over consolidated soils can contribute to stability where there may otherwise be marginally insufficient rock mass cover. As an approximation a competent glacial soil may provide a contribution to the rock cover equivalent to half its thickness.

Considering the safe depth of rock mass and soil cover above a working should take into consideration a number of factors. These include:

- Overlying rock mass / strata quality and orientation of fractures/discontinuities;
- Groundwater regime;
- Ore extraction ratio;
- Multiple seam extraction and interaction of working;
- Level of intrusive site investigation information;
- Structural sensitivity and tolerable ground movements;
- Residual voidage (has significant collapse already taken place?)
- Foundation design (will foundations, span, bypass or cantilever over the potential zone of subsidence?)

4.3. Fault Reactivation

There are no direct fault linkages with the expected underground workings and the turbine infrastructure. It is not considered that the presence of any faults results in an increased risk factor.

4.4. Mine Gas

Abandoned mine workings are at risk of containing varying concentrations of hazardous gas. The composition of these gases is driven by the geology, extent and type workings. Mine atmospheres are frequently toxic, asphyxiant, flammable, carcinogenic or any combination of these. Given the complex network of workings connecting shafts and adits set within permeable strata, it is possible pathways exist for mine gas to escape and create a hazard.

Due to the distance of the underground workings to the turbine locations the risk of mine gas is considered to be low for the site however ground gas monitoring is recommended during future ground investigation.

5. Risk Assessment

Table 5.1 below addresses each main infrastructure element within the development and reviews the associated hazards and likelihood of collapse or subsidence. This is accompanied with a preliminary mitigation strategy to be taken forward as part of the detailed investigations, civil infrastructure, and foundation geotechnical design.

The initial risk is stated based on the review of qualitative factors detailed by this study.

5.1. Risk Scoring

Each turbine location and the access track infrastructure has been allocated a risk rating, resultant from a number of different factors (Proximity to underground mining features and geological setting). Table 5.1 indicates the qualitative risk assignments.

The following qualitative risk scoring system has been applied to the development and draws upon the consideration of mining risk factors and geotechnical complexity.

Proceed with Appropriate Control Measures				Further Investigation & Additional Control Measures			Stop, Re-design, investigate and control		
1	2	3	4	5	6	7	8	9	10

Table 5.1: Mining Risk Assessment – Wind Farm Infrastructure

Infrastructure Location	Risk	Comments
T1	Very Low (2)	The series of adits identified by the GSNI are located 350m south east of this position. It's considered very unlikely that these adits extend significantly towards the turbine position.
T2	Negligible (1)	No adits or working identified within 500m of the turbine location.
T3	Very Low (2)	450m south east are adits 173 to 175. No evidence of these adits was found during the site walkover however the extents and use of these adits is unknown.
T4	Negligible (1)	No adits or working identified within 500m of the turbine location.
T5	Very Low (2)	T5 is characterised with similar conditions to T3 and T1. Similarly, it has a number of mine adits 500m to the east. There is no surface evidence of these structures however in the absence of any mine or decommissioning plans the presence of unmapped features cannot be discounted .
T6	Negligible (1)	No adits or working identified within 500m of the turbine location.
T7	Negligible (1)	No adits or working identified within 500m of the turbine location.
T8	Very Low (2)	450m south east of the turbine location is the supposed location of the historic Aughareamlagh Working. There was no evidence of this historic working on the site walkover, however the possibility of workings should be considered during construction.

Infrastructure Location	Risk	Comments
T9	**Negligible (1)**	No adits or working identified within 500m of the turbine location.
T10	**Negligible (1)**	No adits or working identified within 500m of the turbine location.
T11	**Negligible (1)**	No adits or working identified within 500m of the turbine location.
T12	**Negligible (1)**	No adits or working identified within 500m of the turbine location.
T13	**Negligible (1)**	No adits or working identified within 500m of the turbine location.
T14	**Negligible (1)**	No adits or working identified within 500m of the turbine location.
Access Tracks	**Low (4)**	The main south eastern access track passes with 20m of the expected underground extents of the Cullinane Mine.

Source: Natural Power.

6. Conclusion

The proposed Unshinagh Wind Farm will require site investigation at each turbine location. These activities are generally conducted during the post consent and pre-construction phase of works. The turbine locations are not considered to be at risk of undergrounding mining beneath the turbine or crane hardstanding base.

The numerous mine entry locations on the site have been subject to a site walkover (September 2021) but no surface evidence of the historic mining activities was noted on the site.

The proposed southern access track passes within 20m to the possible underground extents of the Cullinane Mine and the presence of possible underground workings here of an unknown depth should be considered during the investigation, design and construction process.

Following this risk assessment it is concluded that a site investigation should proceed, and the mining risk assessment report may require further update alongside targeted mitigation following the conclusion of intrusive investigations.

7. Recommendations

Subject to planning approval Natural Power recommends that a geotechnical and geo-environmental ground investigation is undertaken in accordance with BS EN 1997: 2:2007 and should comprise the following elements:

- Ground investigation should be designed for Geotechnical Category 3 Structures with sufficient data gathered concerning the ground and groundwater conditions at and around the proposed wind turbine locations. The final depth of investigation should be determined by the encountered ground conditions however for shallow foundations it is recommended that the investigation depth is greater than 2 times the anticipated foundation width below formation level.
- The depth of superficial overburden deposits should be determined at all proposed temporary and permanent construction locations. A sampling regime should be adopted whereby soil, rock and groundwater samples are obtained according to the geological conditions, hydro-geological conditions and the likely imposed construction loads.
- Non-intrusive geophysical investigation of targeted areas across the access track in closes proximity to the area of working should be considered. Electrical resistivity profiling, ground probing radar (GPR), electromagnetic and gravity imaging are potential methods of identifying shafts and sub-surface voids prior to undertaking intrusive investigations. Geophysical investigation may be a cost effective non-intrusive technique of further refining the ground investigation scope and risks during the pre-construction planning phase of development.
- Trial excavations should be undertaken at each wind turbine location and along key sections of proposed infrastructure. Shallow superficial deposits should be logged in detail with representative samples obtained and scheduled for geotechnical laboratory testing. Where appropriate; in situ strength testing should be undertaken and details of any groundwater recorded. Where areas of artificial ground are identified these should be delineated and sampled against relevant geochemical suites. Where solid geology is encountered a rock mass assessment should be undertaken with details of compressive strength and discontinuity spacing recorded.
- The rock mass should be characterised to sufficient depths beneath the proposed wind turbine foundations and key infrastructure sites. Site investigation for construction purposes should allow for rotary core drilling and recovery of high-quality core samples necessary for establishing a geological ground model and shall be used to assess the likely design requirements of foundation structures.
- Detailed logging of all exploratory holes should be undertaken in accordance with BS EN 14688 / 14689 to define the rock mass characteristics and identify any salient shallow mining features.
- The drilling/investigation methodology should be agreed with The GSNI prior to being undertaken and should account for the hazardous ground gas, mine water discharge and poor rock mass ground conditions. A detailed assessment of any impact upon mine water drainage should be undertaken prior to drilling with suitable contingencies plans in place.
- The prior written permission of the GSNI will be required to investigate and/or treat any mine workings or mine entries.

7.1. Controlling the Risk

Following completion of a detailed geotechnical ground investigation there will be a requirement to consider the requirement for ground improvement and stabilisation options if so required. This should be undertaken as part of a detailed review of the design requirements for foundations and access infrastructure at the development.

The following hierarchical discussion of the best practice methods for construction over shallow abandoned mine workings details the primary approaches. These methods should be considered as part of the wider concept of the wind farm layout design and the use of available micro-siting options for the wind farm infrastructure.

Raft Foundations

Construction of low-rise and relatively lightly loaded structures on rafts or reinforced strip footings may be a suitable solution over shallow mine workings at a marginal depth. Any subsidence would generally be accommodated across the large area of the raft foundation and therefore would only be suitable for non-sensitive structures. This may not be applicable to wind turbine foundations but may be a viable option for control building foundations and other similar lighter loaded structures.

Excavation and Backfilling

This approach is only viable at depths typically of less than ~7m. This is due to the large volume and complex earthworks required for deeper excavation and backfill operations. Generally, where voids and backfilled / collapse zones are encountered at shallow depths, these would be identified and delineated as part of the ground investigation. During site preparatory works, these areas would be excavated and backfilled with engineering grade material where appropriate. This approach effectively removes the risk from collapse of shallow and near surface mining features.

Where shallow or near surface workings are encountered the most economical approach to ground stabilisation would be excavation and backfilling. Should such features be proven to extend to deeper levels beyond 10m below ground, and of an interconnecting nature, excavation and back filing may not be a viable option.

Piled Foundations

A deeper foundation design may be adopted where encountered shallow mine workings are between approximately 5 and 30m below ground level. Piled foundations would transfer design loads imposed by the wind turbine generator to deeper stratigraphic levels and below the influence of shallow mine workings. Consideration should be made for the prevailing ground conditions, where deeper boring through sandstone may become un-economic. The rock mass characteristics determined during a ground investigation may also rule out a piled option as issues such as steeply dipping strata liable to sliding failure can be problematic for piled foundations. Critical to such foundation designs would be the effect of groundwater on both the stability of the foundation and on the surrounding ground. Where pathways are created during installation of deeper foundations, there may be an increased risk of destabilisation of the ground due to an increased influx of groundwater. Further management of hazardous ground gas would also be required for piled structures. The final design of the wind turbine foundations should be considered by suitably qualified designers after a comprehensive ground investigation has been completed.

Grouting

Where a predictable distribution of shallow abandoned mine workings has been identified during a ground investigation the option of drill and grouting methods to stabilise sub-surface voids and collapse zones may be a consideration. A typical approach would be the following sequence:

- 100mm drill holes are advanced to the level of workings within the influence of the proposed turbine foundations. The drill holes would be arranged on a grid of between 3 – 6m across the area of the foundation.
- The area of grouting would generally extend beyond the footprint of a shallow gravity foundation to encompass the zone of influence from loading.

- Perimeter grouting is initially undertaken, whereby a seal surrounds the mined area beneath the foundation. Perimeter grout is stiffened by adding coarse gravel. The perimeter grouting operation produces cones around drill holes bored on a 1.5m centre which then coalesces to create a wall within the mine. The volume inside the grout perimeter is then injected with lower strength foamed concrete or lean rock paste to prevent the roof collapse between sound pillars of rock within the shallow workings.

Load tests should be undertaken following curing of the grouted mine workings as parts of a system of quality control and the effectiveness of the ground stabilisation tested in relation to the proposed design loads.

Mine Entry Treatment

The primary control measure should be avoidance where it is possible to micro-site the track alignment to maintain safe proximity from recorded mine entries. 20m is the guidance figure provided.

Where possible the use of geosynthetic reinforcement and low bearing pressure ‘floating’ access infrastructure to avoid stressing the mine shaft area may be considered.

Where adjustment in the access track alignment cannot be achieved or floating type access cannot be designed at these locations, any incidental mine entry locations will require excavation, inspection, backfill and capping in accordance with CIRIA C758. The following safety provisions shall be in place:

- Dimensioning and establishment of operational exclusion zone and working area;
- Site specific induction for all relevant operatives;
- Designed platform roadway for plant access;
- Personnel in operations area to wear inertia safety harnesses attached to suitable anchorages.
- Emergency rescue planning in place and practiced.

The primary method of treatment shall be remote drill and grout with reinforced concrete cap installed.

8. References

Online References:

http://mapapps2.bgs.ac.uk/geoindex/home.html

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