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National Parks and Wildlife Service

ASSESSMENT OF MAIN CONTRIBUTING FACTORS LEADING TO THREE MAJOR PEATLAND FAILURES IN LEITRIM, KERRY AND DONEGAL

PROJECT SUMMARY REPORT

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PROJECT SUMMARY REPORT

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Abstract: Task 7 of the project involves the preparation of an overarching report detailing the findings of the literature review, methods, results discussion, conclusions, and recommendations of the study.

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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.100 members of staff, including engineers, scientists, planners and technical support staff. We 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 both Ireland and the UK at various stages of development i.e. preliminary feasibility, planning, design, construction and operational stage and have established themselves as one of the leading engineering consultancies in peat stability assessment, geohazard mapping in peat land areas, investigation of peat failures and site assessment of peat.

1.2 Project Description

The Services that form this project comprise carrying out a detailed scientific assessment, using available data and data provided, along with appropriate site visits, to determine the main contributing factors that led to a series of peatland landslides located in Counties Donegal, Leitrim and Kerry. The aim of the project was to characterise the environmental setting of the landslides, determine the main contributing factors to the failures and further determine any shared conditions that may identify susceptibility in 3 additional areas of interest to GSI and NPWS.

The results of this assessment will be used to assess the potential to update Geological Survey Ireland's National Landslide Susceptibility Map and to produce technical notes for documentation(s) related to peatland land use and peat stability in Ireland.

This Report covers the following: Submit a synthesis, or overarching, report, detailing the finding of the focused literature review, methods, results, discussion, conclusions, and recommendation of the study. All data and analyses produced as part of this study in addition to the technical notes produced as part of task 4, 5 and 6 should also be submitted.

A total of seven tasks were undertaken as part of the project:

- Task 1 - A comprehensive literature review focused on the contributory factors to peat failures and peat stability.
- Task 2 - Assess and analyse available data and data (provided by GSI/NPWS) within the relevant catchment areas to determine the main environmental factors (geological, geomorphological, ecohydrological, climatic) and, where potentially relevant, the anthropologic factors that contributed to the 3 major peatland failures recorded in Ireland in 2020.
- Task 3 - Identify sites or locations within the study area sites where key data is lacking and collect accordingly via focused field visits (in order to validate the analyses carried out under Task 2).
- Task 4 - Assess the potential to update the National Landslide Susceptibility Map and associated database using data collated and analysed in this project.

- Task 5 - Produce a short technical note to identify data gaps (with respect to peatland failures and peat stability) related to impact assessments and planning associated with infrastructural developments and other land uses/land use changes that have the potential to affect blanket bog and allied peatland habitats.
- Task 6 - Produce a technical advisory note that will be of assistance to planning authorities and government agencies for informing the assessments of potential impacts of proposed land use changes (e.g. infrastructural developments, peat extraction, forestry operations etc.) on key blanket bog features and properties including geology, geomorphology, stratigraphy, structure, ecology, ecohydrological functioning and directly or indirectly on peat stability.
- Task 7 - Submit a synthesis, or overarching, report, detailing the finding of the focused literature review, methods, results, discussion, conclusions and recommendations of the study (this report).

1.3 Project Reports

Reports issued as part of this Project are as follows:

- Task 1 - Literature review of Conditioning and Triggering Factors in Peat Failures
- Task 2 and 3 - Main factors considered to have contributed to three major peat failures in 2020
- Task 4 - Potential to update National Landslide Susceptibility map
- Task 5 - Data gaps relating to impact assessments and planning
- Task 6 - Impact assessment of land use change on blanket bog/peatland habitats
- Task 7 - Project Summary Report (this report)

2. Study Areas

A total of six study areas were examined as part of this project. These comprise three locations of recent peat failures (all occurring in 2020), and three locations of historical peat failures, as shown in Table 4.1 below. The three control sites were proposed in order to be used as comparison sites to determine if any locations contained similar conditions to those at the three 2020 failure sites.

Table 2-1: Project Study Areas

Active Sites	Control Sites
Shass Mountain, Co. Leitrim	Knocknageeha, Co Kerry
Meenbog, Co. Donegal	Cuilcagh/Anierin, Co Leitrim/Cavan
Mount Eagle, Co. Kerry	Geevagh, Co Leitrim/Sligo

2.1 Active Sites

A summary of the three study areas is provided below.

2.1.1 Meenbog, Co. Donegal

This landslide is classified as a **bogflow** and occurred within an area of open upland blanket bog and afforested blanket bog at Meenbog on 12 November 2020, during the construction of a wind turbine access road across blanket bog. The surrounding lands are heavily afforested in commercial conifer plantations located on peatlands.

The following outlines the planning history of the site at Meenbog:

- 2016: Case PA05.PA0040 Provision of up to 49 no. Wind Turbines, two permanent Meteorological Masts, two 110kv Electrical Substations and all associated works at Meenbog and other townlands, County Donegal. Permission Refused.
- 2018: Case PA05E.300460. Provision of 19 no. wind turbines, one permanent Meteorological Mast, one 110kv Electrical Substation and all associated works. Permission Granted. The planning conditions attached to this Permission included “The developer shall ensure that construction works associated with the upgrade of the existing access track adjacent to the Croaghonagh Bog Special Area of Conservation (site code: 000129) shall not encroach upon the Special Area of Conservation.”
- 2019: Case reference PM05E.303729. Proposed alteration to utilise a larger rotor diameter which remains within the consented design envelopes and parameters of the previously approved Meenbog Wind Farm (ABP-300460-17). Permission Granted.
- 2023 (October): Case reference LS05E.314062. Leave to Apply for Substitute Consent for alterations to the permitted Meenbog Wind Farm. Permission Granted.
- 2024 (January): Case reference SH05E.318669. Request for an Extension of Time for an Application for Substitute Consent for a windfarm. Permission Granted.

- 2024 (Lodged 2 April): Case reference SU05E.319466. Substitute Consent application for 25 no. deviations from the permitted Meenbog Windfarm development (granted under ABP PA05E.300460). Live case (no decision as of 29/10/2024).
- 2024 (10 April): High Court Judgement by Mr. Justice David Holland (Docket number 2023/96 MCA, Donegal County Council v Planree Ltd.) prohibiting any further development on the Meenbog Wind Farm site. Decision appealed by Planree Ltd (reviewed by the Court of Appeal in October 2024).

The failure scar morphology comprises 3 distinct parts, namely an upper scar and lower scar which provided the source area for the failed peat, and a run-out trail along which the failed peat was deposited. The scar morphology indicates that failure was most likely a flow slide.

The run-out distance of the failed material was estimated as 3.2km. The total volume of displaced peat based (as estimated in Dykes, 2022) on a mean peat depth of slightly less than 3m gives the failure a volume of 65,000m^3.

The bogflow entered and flowed in the Shruhangarve stream and then flowed into the Mourne Beg River. (The eastern part of the site drains to the Shruhangarve stream which flows for about 2.4km from the site in a northeasterly direction where it joins the Mourne Beg River).

2.1.2 Shass Mountain, Co. Leitrim

This landslide is also classified as a **bogflow** and occurred on the 28 June 2020 at Shass on the southwestern end of Boleybrack Mountain, 6km northeast of Drumkeeran, Co. Leitrim, approximately 1.2km to 1.4km upstream of the Dawn of Hope bridge. The slide initiated within an area of upland blanket bog on a south facing slope and extended retrogressively upslope into a densely afforested area of upland blanket bog.

The evacuated peat initially entered existing watercourses and deposited large volumes of peat for example (c. 25,000m^3 upstream of Dawn of Hope bridge and 15,000m^3 at Courcuill Upper). The peak flow height of the peat above Dawn of Hope bridge was up to 4.5 m. Based on a failure area of 10ha combining the upper and lower scars, the total estimated volume of failed peat is estimated as 260,000m^3.

The deposited peat thickness was up to 3 metres but deceasing downstream and at Courcuill Lower it was estimated as generally < 0.4m in thickness. Collectively the excavated peat covered an area of 45 ha (111 acres) and resulted in flooding of the flood plains in the townlands of Corcormick and Derrindangan and erosion of the watercourse down to Courcuill Upper (iCRAG, 2020).

The majority of the peat carried downstream of the Dawn of Hope bridge remains on these flood plains. The Diffagher River carried some peat sediment and other debris to Lough Allen, approximately 8.45km from the starting point, where it has been observed washed up on the shoreline, e.g. at Corry Strand (RPS, 2020).

The failure scar is defined in 2 parts, namely:

- Upper scar. This comprised the main source area of the failed material. The upper scar is 450m long and 200m to 250m wide. The head of the failure scar is within the forestry plantation, where 2 notable head features are readily apparent. The estimated total area of the upper scar is 8ha.
- Lower scar. The lower part of the failure scar followed an existing incised stream channel where there appeared to be scouring of material, and a net removal of material. Based on inspection this is assumed not to extend as far as the Dawn of Hope bridge. Below this scar there was a net accumulation of failed material. The lower scar along the incised channel was 700m long by about 20m wide. The estimated total area of the lower scar is 2ha.

The peat failure occurred on the south-western part of Boleybrack Mountain Special Area of Conservation (SAC) (Site Code: 002032). Boleybrack Mountain SAC comprises an extensive upland blanket bog and heath covered plateau situated to the north of Lough Allen in Co. Leitrim. The SAC is bounded on the north and south by commercial conifer forestry plantations, and on the west by the Scardan River. It is designated for protection of Annex I Habitats' Directive habitats: Natural dystrophic lakes and ponds [3160]; Northern Atlantic wet heaths with *Erica tetralix* [4010] European dry heaths [4030]; *Molinia* meadows on calcareous, peaty or clayey-silt-laden soils (*Molinion caeruleae*) [6410]; and Blanket bogs [7130/7130*] (* if active bog).

2.1.3 Mount Eagle, Co. Kerry

This peat failure is classified as a **peat slide and debris slide** and commenced within a densely afforested area of upland blanket bog on 15 November 2020 on Mount Eagle, County Kerry. The peat failure extended upslope into the adjacent blanket bog in the Mount Eagle Bog Natural Heritage Area (Site Code 002449) which is designated for the protection of blanket bog and associated habitats.

Details of the failure are also reported in the Irish Farmers Journal (2020).

The total length of the source area or upper failure scar is estimated to be 650m long by about 30 to 50m average width. (Dykes (2022) reports that the width increases from ~30 m at the head to ~60 m throughout the lower half).

The lower part of the failure scar within the forestry plantation is narrower, which suggests that this represents material running out from the scar and is likely not part of the failure scar. Based on the above the estimated plan area of the failure scar covers 2.6ha.

It is understood that peat debris from the failure entered a nearby tributary stream of the River Clydagh, which originates from this area. At least several hundred tonnes of solids are likely to have reached natural watercourses with much of this eventually polluting the River Clydagh.

The 2020 landslide occurred adjacent to a previous landslide in the forestry plantation and in a similar topographic scenario (prior to March 2018). The head of the 2020 failure however extended into the open blanket bog upslope of the forestry plantation. Given the shape of the peat failure scar, the likely mode of failure was a progressive bog slide which downslope degraded into a debris slide before being channelised as a flow, which in many cases results in a long run-out. The run-out distance was estimated as 2.5km.

2.2 Control Sites

In addition to the three failures sites, three control sites were provided by GSI for review as part of these works. These were at Knocknageeha, Co. Kerry, Cuilcagh/Anierin and Geevagh, both Co. Sligo/Leitrim. Each of these three sites has recorded historical peat failures of various types.

These sites were reviewed to determine if any locations contained similar conditions to those at the three failure sites (see section 2.4 of the report for task 2 and 3 of this project). The review of these areas was undertaken remotely, with no site visits or analysis of rainfall data. Limited reviews of other of publicly available datasets from the GSI, NPWS and EPA were carried out.

The three control areas did not record many locations that were considered to match the conditions at the three failure sites. However, the historical failures were believed to be triggered by rainfall; associated with a range of conditioning factors at the three sites, including deep peat, open excavations (Knocknageeha), and steep slopes (Cuilcagh, Geevagh).

3. Peat Failure Classification

3.1 Types of Peat Failures

There are numerous general classifications available for landslides, but most are based on morphological factors and provide very little discrimination with respect to the various types of peat failures. There are only a few formal classification of peat failures which use essentially morphological factors; however, these do provide a starting point for peat failure classification based on contributory factors, see table below. These are taken from Dykes & Warburton (2007).

The failure types are also shown schematically in Figure 3.1. It should however be noted that not all failures would necessarily fall within one of the peat failure types listed below, and some may be a hybrid type that exhibits characteristics of a number of different types of peat failures, especially in relation to the formation of bog slides, bog flows and peat flows.

Table 3-1: Example of peat failure classification

Type	Description
Bog bursts	Flow failure of raised bogs
Bog flow	Flow failure of blanket bogs
Bog slides	Shear failure and sliding of blanket bogs on a shearing surface
Peat slides	Shear failure at peat–mineral interface in blanket bogs
Peaty-debris slides	Shear failure within mineral substrate beneath blanket bogs
Peat flows	Natural failures of other types of peat deposits including flow failure caused by head-loading

The classification of peat failures into categories such as those given in Table 3-1 allows assessment of the following through reference to historical peat slides of similar type:

- Improved prediction of most likely failure locations
- Likely volume of failures
- Likely run-out distance of failures
- Potential environmental impacts of failures

For example, the main triggering factor for numerous peat failures is considered to be intense rainfall (Boylan et al, 2008). In many cases, these failures occur in shallow peat on steeper slopes with relatively high shear strength and the volume and run-out distance tends to be limited; examples of these are failures that occurred at Pollatomish (in 2003), and failures on the Inishowen Peninsula (in 2017), in contrast to larger-scale peat failures that have occurred in deeper peat on shallower slopes, for example at Derrybrien (in 2003) and at Meenbog (in 2020).

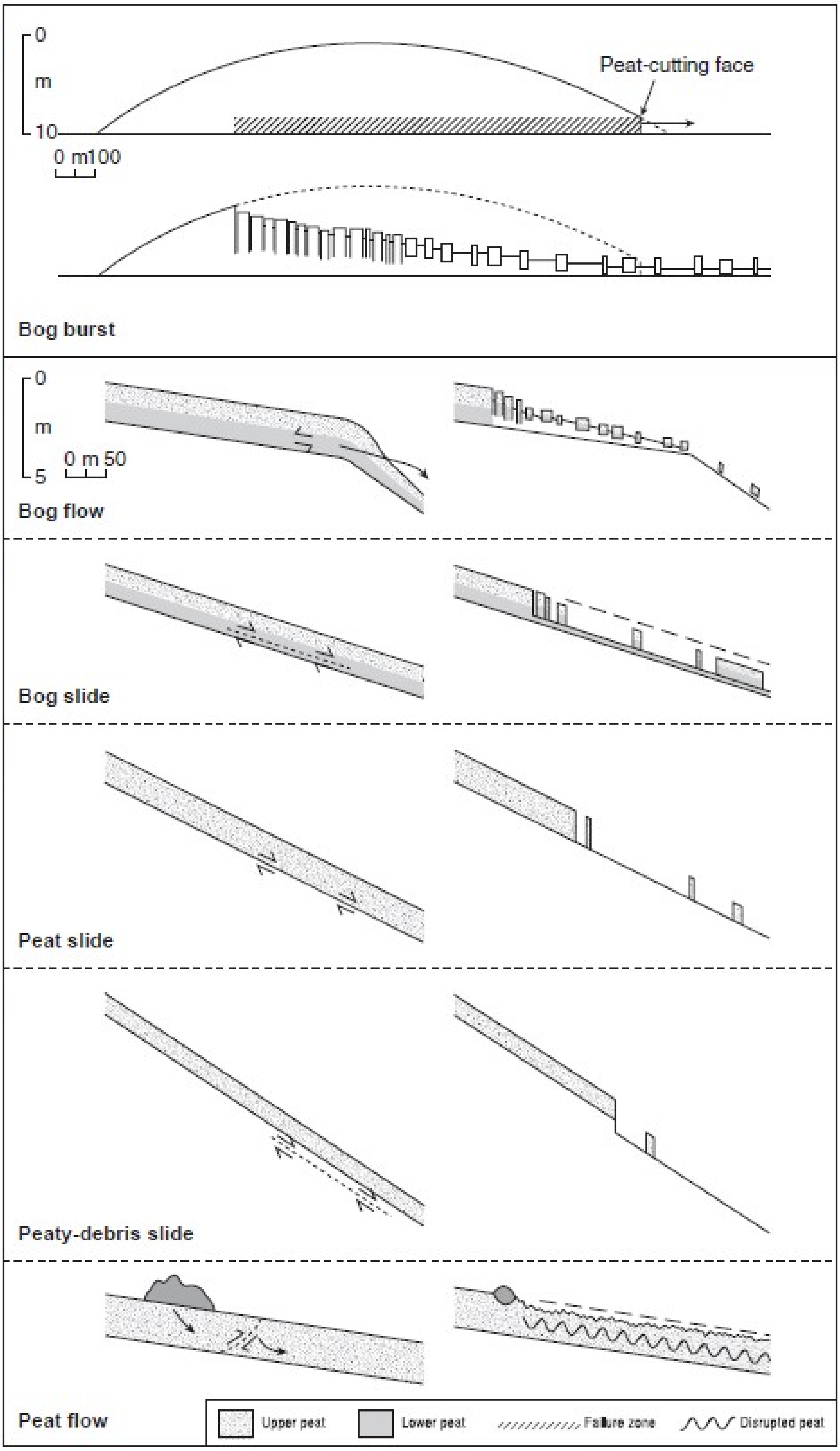


Figure 3.1: Peat Failure Types (Dykes and Warburton, 2007)

4. Literature Review (Task 1)

Task 1 of the Project was to conduct a comprehensive literature review focused on the contributory factors to peat failures and peat stability. The review also incorporates aspects of land use and the examination of potential conditioning factors for the main land uses (including afforestation (drainage patterns/growth stage of plantation etc.), peat-cutting factors/drainage and cutting methods e.g. 'sausage -machine' cutting etc., land use change and the physical and geotechnical characteristics of peat failures in Ireland and internationally (the latter where environmental conditions are comparable to those in Ireland).

4.1 Introduction

FT undertook a review of available literature on peat slides, focussing on Irish examples but also including failures from locations such as England, Scotland and Canada. A comprehensive list of the papers and references reviewed is provided in the report for Task 1 of this project . The papers reviewed cover peat failures between 1896 and 2020, with over 50 no. individual failures identified, typically located on blanket bog. The majority of papers reviewed are dated from before 2014, and only a limited number appear to have been published on this subject between 2014 and 2023 (<10 papers). The failures range in size from small (<1,000m^3) to extremely large (around 5M m^3). This, however, only represents a small proportion of all of the failures recorded by GSI in the national landslide database, which currently lists in excess of 2,500 landslides. Within GSI's database around 50-55% of the recorded failures are related to peat even though peatlands only cover c.20% of Ireland.

4.2 Findings of Literature Review

An overview of the different types of peat failure based on Dykes and Warburton (2007a) has been provided in Section 3.1. Peat failures are divided into six different types of failures, namely: bog burst, bog flow, bog slide, peat slide, peaty-debris slides and peat flows.

Conditioning factors are characteristics of the peat or the landscape that may predispose an area to being susceptible to a peat failure.

Triggering factors are specific events or occurrences that can be directly linked to the onset of a peat failure.

A summary of the main conditioning and triggering factors identified in the literature review is provided below. Factors such as the physical characteristics of peat (such as strength), subsoil conditions, land use, hydrological conditions and geomorphology have all been identified as conditioning factors to peat failures. Trigger factors for failures included direct human impact and rainfall. It should be noted that based on the publications reviewed, no individual factor by itself is reported to trigger a peat failure. It should be noted that based on the publications reviewed, it is rare that one individual factor alone is reported to initiate a peat failure. This suggests that it requires a combination of two or more factors at the same location to initiate a peat failure, irrespective of the type of failure.

Table 4-1: Examples of potential conditioning and trigger factors for peat failures

Conditioning (C) or Triggering (T) factor	Description
Peat condition (C)	Type, depth, strength, structure, decomposition, water content. The properties of a bog peat soil are intimately bound up with the characteristics of the bog habitat that form it. Engineering properties of peat can be affected by historical and current land use.
Hydrology/Hydrogeology (C)	Stream density, drainage lines and flushes, quaking peat, bog pools. These are natural features in peatlands. Peat pipes (subsurface flows) may also occur and can be natural or may form by human impact. Seepage from the base of peat at exposures can also occur and mostly result from human activity in creation of peat exposures but can also occasionally be from animal activity. Bog hydrology can be altered by many land uses and activities.
Ecology/Vegetation (C)	Vegetation roots and partially decomposed plant matter in bogs form a top layer or mesh of fibrous matter (acrotelm) above more humified or decomposed weaker peat (catotelm). Vegetation can be modified or completely altered by reclamation/ forestry/ drainage/ grazing stock management/ peat extraction etc. which can in turn alter the above properties of the peat soils including strength and stability.
Subsoil (C)	Type, strength, structure, permeability
Bedrock (C)	Rock type, strength, structure, weathering, permeability
Land Use – Plantation Forestry (C)	The presence of forestry is in most instances associated with the presence of drains /or furrow and linear spoil mounds within the plantations. These alter the natural hydrology of the peatland and change peat properties and the cohesive integrity of peatlands through desiccation; shrinkage; cracking; pipe formation and other effects
Land Use – Infrastructure (C/T)	The construction of infrastructure (public and forestry roads, windfarms, etc.) can lead to both loading (filling) and unloading (excavation) of peat which can cause immediate failure. The infrastructure itself can also lead to long-term changes in peatland hydrology and vegetation including alterations in surface flow pattern and internal drainage patterns leaving peatlands more vulnerable to failures.
Land Use – Fires (C)	Fires have multiple effects including hydrological changes from removal of vegetation cover, reducing and increase in surface run-off through reduction of the amount of water taken up by plants, leading to saturation alternating with desiccation of the peat surface which can cause erosion, shrinkage, cracking etc. This can allow water ingress to lower peat layers or sub-peat substrate.
Land Use – Drainage (C)	The presence of drains results in hydrological, vegetation and acrotelm changes including lowering of the water level in a peatland and, importantly, alteration of surface flow patterns that in intact bog maintain diffuse bog surface flows. When drains are blocked (or too shallow) they trap water in the peat, saturating the peat, potentially reducing the shear strength, and increasing the risk of failure. However, blocking of drains can also be beneficial to improve ecosystem functioning and the resilience of the peat and the blanket bog ecosystem to weather extremes.
Land Use - Peat Cutting/Extraction (C)	Peat cutting can lead to the creation of unstable peat banks or the impounding of water within peat cuttings. Removing vegetation can leave open areas where water can collect, saturating the peat. Mechanical cutting of peat alters vegetation, acrotelm, hydrology, weakens the peat structure, and provides a preferential path for water ingress, which can lead to failure. The orientation of mechanical cuts can alter the impact, with cuts across a slope trapping water but cuts down a slope draining

Conditioning (C) or Triggering (T) factor	Description
	water from a peat body.
Land Use - Peat Loading/Construction on Peatlands (T)	Stockpiling of peat or other materials on a peat bog following excavation/extraction causing bearing capacity failure within the peat (peat flow), such as at Derrybrien (2003).
Land Use - Agriculture	Drainage/reclamation/high stock density/grazing management/trampling etc. alter bog vegetation, peat, and bog hydrology with multiple consequences such as denudation/desiccation/decomposition/ shrinkage/cracking/erosion.
Topography/Geomorphology (C)	Concave/Convex breaks in slope. Peat failures may occur on both shallow and steep slopes.
Dry Weather (C)	Excessive drying of upper layer of peat leading to cracking of peat can provide a preferential pathway for water ingress when rain falls, which can lead to peat failure through saturation of the lower peat weaker layers.
Substrate conditions at base of peat (C)	Presence of an impermeable layer or soft clay at the base of the peat can provide a slip surface for the peat (a peat slide rather than shear failure of the peat).
Peat Pipes/Soil Pipes (C)	The presence of peat pipes, while allowing drainage of the peat, can cause erosion at the base of the peat and following rainfall events result in the buildup of a water pressure head.
Rainfall (T)	Sudden intense rainfall leading to excess porewater pressures in peat, leading to failure. It can also cause erosion/scouring of shallow peat on steep slopes. Increased frequency of extreme rainfall events is linked to human induced climate change which may impact peat stability.
Anthropogenic Climate Change (C)	Apparent increase in annual rainfall over the past 50 years, characterised by more frequent intense rainfall events, especially in summer. Higher average temperature in summer may lead to more drying of upper peat layers during summer, increasing near surface cracking and providing additional pathways for water to flow into the base of the peat. It can also change species composition allowing heath species to invade which can further alter natural ecosystem structure and functioning. No detailed research appears to be available on the impact of climate change on peat stability.

From a geotechnical perspective, the most important factors in peat stability, as reported in the literature reviewed for this study, are considered to be the peat depth, peat strength, peat permeability, break in slope and the morphology of the base of the peat (Boylan et al 2008, Dykes and Jennings 2011, Dykes and Warburton, 2007b).

With regard to hydrology and hydrogeology, the drainage of peat, both natural and man-made, is considered to be a highly important factor in the stability of a peat deposit. Peatland vegetation, peat soil, and peatland hydrology are inextricably interlinked and modification of one affects the other two in a complex feedback loop. Natural peatland vegetation creates the peat and is also an important factor in regulating the hydrological regime of the peatland.

The presence of structures such as peat pipes located at the base of a peat deposit has been linked to several peat failures. Peat pipes can allow water to access the deeper weaker catotelm peat layers or the peat /sub-peat interface which can instigate failure. These peat pipes can form either naturally or as a result of artificial drainage.

The most common reported trigger factor within the reviewed peat failures was rainfall. This rainfall can either be an intense, short term rainfall event or a prolonged period of higher-than-average rainfall. However, such rainfall appears to require a range of conditioning factors, several specifically linked to peatland ecohydrology and ecosystem functioning, to trigger a failure.

A summary of the conditioning and triggering factors associated with the different types of failures reviewed is also provided (Table 4-2). A combination of such conditioning and triggering factors is required for a peat failure to occur even though rainfall is the one triggering factor that is reported for each failure type however this is chiefly because there are readily accessible rainfall data (though not often at site level).

Table 4-2: Conditioning and Triggering Factors from Literature

Failure Type	Conditioning and Triggering Factors
Bog bursts/flows	Rainfall, peat strength, land use, human impact: removal of peat banks (lateral support), convex brake in slope (Bog flows)
Bog slides	Rainfall, peat strength, land use, presence of highly humified peat, break in slope, human impact: machine cutting of peat, peat loading
Peat slides	Rainfall, break in slope, land use, human impact: change in drainage pattern, peat loading
Peaty-debris slides	Rainfall, steep slopes, impermeable layer below peat
Peat flows	Rainfall, human impact: peat loading

5. Review of Available Data (Task 2)

The aim of Task 2 was to assess and analyse available data (and data provided by GSI/NPWS) within the relevant catchment areas to determine the main environmental factors (geological, geomorphological, ecohydrological, climatic) and, where potentially relevant, the anthropologic factors that contributed to the 3 major peatland failures recorded in Ireland in 2020.

5.1 Introduction

A number of publicly available datasets from the GSI, NPWS and EPA were reviewed to gather background data on the three sites prior to undertaking site visits to the three failure sites. Additional information, such as LiDAR data for Meenbog; high quality aerial imagery for Shass Mountain; Conservation Ranger report and images for the Mount Eagle peat failure was provided by GSI and/or NPWS.

5.2 Meenbog

5.2.1 Soils and Geology

The majority of the study area around the Meenbog failure is recorded as blanket peat. The peat cover ranges in thickness from 0m to 5.8m and is underlain by various strata on the site such as glacial till (in thin layers), weathered rock and bedrock. The bedrock underlying the site comprises Precambrian quartzites, gneisses and schists with granites and intrusive rocks. GSI's mapping indicates that the bedrock dips (at 40 to 50 degrees) to the NE. A fault, the Laghy Fault, which is 40km long and trends NW-SW, is indicated to the southeast of the failure area. Multiple rock outcrops are indicated on the bedrock 100k map and outcropping rock was observed by GSI during a site visit. The rockhead dipped NE.

5.2.2 Topography

The general topography across the Meenbog study area is undulating, described as mountain to hill/mountain ridge on GSI's Physiographic Units Map. This indicates relatively varied topography, often with relatively steep slopes, as found in locations across the Meenbog study area.

The LiDAR data available for this site allows for refined slope analysis to be carried out. The approximate failure point for the Meenbog failure occurred close to a convex break in slope between an almost flat area to the west/southwest and a shallow (2-4 degree) slope to the east. This change in slope is considered to be a conditioning factor in the failure, even though the slopes would be considered to be shallow in general terms.

5.2.3 Landslide Susceptibility

The landslide susceptibility of the study area around Meenbog ranges from low to high based on GSI's susceptibility mapping. The failure site is classified as having low susceptibility to failure, with a rise to moderately low susceptibility to the east of the failure on the shallow slope towards the Shruangarve stream. This is to be expected given the relatively shallow slopes present in the area around the peat failure, as slope angle is one of the factors used in GSI's landslide susceptibility methodology. GSI's landslide mapping was designed for landslides in general, not specifically peat failures, and as such is does not specifically consider the possibility of specific peat failure mechanisms or the possibility of peat failures on relatively shallow slopes.

5.2.4 Geomorphology

The Meenbog peat failure remains on the outskirts of any major geomorphological features with a Moraine Ridge being the nearest recorded feature to the failure, however as this feature is present at a lower level within the Barnesmore Gap, it does not appear to have influenced the location of the peat failure.

The southern part of the site is dominated by a ridge line that extends northeast from Carrickaduff Hill. The top of the ridge line varies in elevation from 180 to 310mOD. The northern part of the site is within the Bunadaowen River valley, which runs parallel to the ridge line.

The top of the Carrickaduff Hill ridge line comprises in many places a broad level surface. Eastwards the ridge line declines in elevation and a number of broad level benches are present, again with notable depths of peat. Slope gradients along the ridge line are typically from 1 to about 10 degrees, with locally up to about 20 degrees.

Adjacent to the high point (at 313mOD) of the ridge line there is an elongated small water body, Carrickaduff Lough. The lough is located within a short steep-sided narrow valley aligned along the axis of the ridge line. This valley feature is possibly controlled by the structural geology control or is a relict glaciation feature.

The northern side of the ridge line comprises a relatively uniform slope which is drained by a number of tributary streams that flow into the Bunadaowen River. The southern side of the ridge line comprises a more varied slope profile with locally steeper sections as a result of rock near-surface. A limited number of streams are located on the southern slope and drain into the Glendergan River.

The peat cover on the ridge line comprises an almost continuous cover of blanket peat. Multiple rock outcrops are indicated on GSI's bedrock mapping. The peat cover shows little signs of erosion, though it has been heavily dissected by drainage excavated prior to the planting of the trees and by forestry access roads.

5.2.5 Hydrology

Regional and Local Hydrology
The Meenbog site is situated within the Bunadaowen, Mourne Beg River and the Glendergan River catchments. Both catchments are within the larger Mourne River catchment, which itself is part of the larger Foyle catchment. Most of the site drains directly into the Bunadaowen River which flows in a northeasterly direction through the northern part of the site. The failure occurred close to the edge of the catchment of the Shruanagarve River, which flows to the northeast to the Mourne Beg River.

The Bunadaowen River joins the Mourne Beg River about 0.3km to the north of the site. Within the Bunadaowen River catchment the area is also drained by several tributary streams which flow in a general northerly direction towards the Bunadaowen River. Based on the EIAR for Meenbog Wind Farm (2017), the streams are typically deeply incised, narrow eroding streams with a width of 0.5m to 1m.

The eastern part of the site drains to the Shruhangarve stream which flows for about 2.4km from the site in a northeasterly direction where it joins the Mourne Beg River. The 12 November peat failure entered and flowed in the Shruhangarve stream and then flowed into the Mourne Beg River.

Forestry Drainage

Within the site there are numerous man-made drains, mostly installed prior to the planting of the forestry but drains are also present within the open area of blanket bog upslope of the failure location. Based on the EIAR (2017), the forestry plantations at the site are generally drained by a network of mound drains which typically run perpendicular to the topographic contours of the site and feed into collector drains, which discharge to interceptor drains down-gradient of the plantations. The forestry drainage pattern is influenced by the local topography, ground conditions, layout of the forestry plantations and existing access roads, as would be typical of upland forestry plantation on peatlands in Ireland.

The mound drains and ploughed rill drains are generally spaced about 15 to 20m and 2m respectively. Interceptor drains are generally located both up-gradient (cut-off drains) and down-gradient of forestry plantations. Interceptor drains are also located up-gradient of forestry access roads.

The catchment area upslope (south) of the failure is divided, with the western side draining to an interceptor or collector drain on the western edge of the open peatland, and from there draining to the Bunadaowen River and the eastern side draining to a collector drain that runs south-north, following the edge of the felled forestry, at a break in slope. This drains outfalls to the east towards the Shruhangarve stream at several locations, the most prominent of which is at a topographical low point some 80m to the south of the failure.

Firebreaks have also been excavated on this site and generally run in a North-South direction. It is not known how the material excavated from the fire breaks was reused on the site.

5.2.6 Hydrogeology

The Precambrian quartzites, gneisses and schists, which are mapped and underlie the Meenbog site are classified by GSI as a Poor Aquifer, comprising bedrock which is generally unproductive except for local zones (Pl) and has groundwater flows of less than $10m^2/d$.

The Precambrian rocks generally have an absence of inter-granular permeability, and most groundwater flow is expected to be in the uppermost part of the aquifer comprising a broken and weathered zone typically less than 3m thick, a zone of interconnected fissuring 10m thick, and a zone of isolated poorly connected fissuring typically less than 150m (GSI, 2004).

Overburden (glacial till) is only present in pockets across the site, is limited in thickness and is laterally disconnected. The potential for groundwater flow at the base of peat is considered to be limited.

The vulnerability rating of the aquifer in the area around the peat failure ranges between “Moderate to High” and this reflects the varying depth of local subsoils and peat. In areas where subsoil is shallow or absent and where bedrock is outcropping, such as to the south of the failure location, an Extreme (E) or Extreme (X) Rock at or near Surface vulnerability rating is given. Extreme (X) indicates bedrock at or within 1m of the surface. Extreme (E) indicates bedrock at or within 1m to 3m of the surface.

Due to the low permeability nature of the Precambrian bedrock aquifer underlying the site, groundwater flowpaths are likely to be short (30 – 300m), with groundwater discharging to nearby streams and small springs. This means there is a low potential for groundwater dispersion and movement within the aquifer. There is a lack of mapped springs and flush areas at the site, and this suggests that groundwater has a limited local influence at this site. Bedrock aquifer properties can be considered a conditioning factor since the relative impermeability of the underlying rock will not facilitate drainage of surface water and, is instead more likely to cause flow at the base of the peat where it lies directly on bedrock.

5.2.7 Ecology

Orthophotography indicates that the Meenbog failure site is located within an area of upland peatland habitat (blanket bog and heath) surrounded by conifer plantations on blanket peat. The flat topography of the area in which the failure occurred represents conditions that favoured deeper peat formation and blanket bog.

Rows of drains running north-south through the open bog to the south of the failure are visible in orthophotography. These drains are absent from the areas to the west, east and south-east of the failure, and in pre-failure orthophotography they are also absent from the area of the failure.

Meenbog wind farm EIAR (EIAR – 2017.11.22 – F) identified the peatlands in the area of the failure as Upland blanket bog/Wet heath Mosaic (PB2/HH3) and the EIAR habitat map identifies the entire area as this mosaic. More nuanced detail is provided in the habitat description, which notes that blanket bog is present in flatter areas (i.e. at the failure site), while wet heath is present on steeper ground. The failure site is identified as Upland blanket bog in a photograph, with Wet heath noted as covering the higher elevation in the background. (Blanket bog (7130/7130*) and Wet Heaths (4010) are Habitats Directive Annex I habitats). Active Blanket bog is Code 7130* and is a priority habitat. It is defined as having a significant area of vegetation that is normally peat-forming. Most of the blanket bog at this site would conform to Active Blanket bog habitat (7130*).

The presence of White-beaked sedge (*Rhynchospora alba*) was noted in this mosaic. This species occurs in very wet conditions and is typically indicative of either the Annex 1 habitat 'Depressions on peat substrates of the *Rhynchosporion* [7150]', or the sub-community *Rhynchospora alba* quaking bogs within the Annex 1 habitat 'Transition mires and quaking bogs [7140]', the latter of which would be associated with deep peat with a very high water content.

No commentary on the wetness or physical state of the blanket bog in this area was included in the EIAR habitat description, other than noting blanket bog occurred in flatter areas while wet heath was present on steeper slopes. The photograph of the failure area included in the EIAR shows a densely vegetated surface, similar in character to the vegetation surrounding the failure which persists at present.

The site is not overlapped by any protected areas; however, the peat failure drains to the Mourne Beg River within the Finn River SAC (002301) via the Sruhanagarve River which receives drainage flows from the site approx. 500m from the failure inception point. The SAC is approx. 2.4km downstream of the point the peat failure entered the Sruhanagarve.

5.2.8 Rainfall

A number of weather stations are in the vicinity of the site, and these have been used to examine recorded rainfall data as they are considered to be good proxies for rainfall pattern and magnitude at the site. The nearest weather station to the site is the Met Éireann Lough Mourne Automatic Climate Station (ASC) some 5.3km to the north of the failure site. The rainfall data from the Met Éireann Weather Station at Finner, near Bundoran some 34km to the southwest of the failure site has also been used.

The results of the rainfall analysis are given below.

(1) The rainfall data from the Lough Mourne ASC shows that the wettest period in 2020 was in February and March 2020. The highest daily rainfall was recorded on 21st February 2020 (68mm). On 11 November 2020 the day preceding the peat failure the daily rainfall amount was 28mm. On the day of the failure the daily rainfall amount was only 6mm.

(2) In 2020 from the Lough Mourne ASC, the daily rainfall amount was 30mm or greater on the 10 days preceding the failure on 12 November 2020. In the month preceding the failure, there were four days where the rainfall exceeded 25mm, however there is no evidence that peat failures occurred on the site immediately after this rainfall.
(3) Using the data from Finner Weather Station, for all antecedent rainfall duration periods the rainfall amounts preceding the peat failure on 12 November 2020 were exceeded a number of times during 2020, and also a notable number of times since 2011. This indicates that (antecedent) longer duration period rainfall events were not a significant contributory factor to the peat failure.
(4) The nearby Barnesmore station also recorded a similar rainfall event on 28 June 2020 to that which occurred at Shass Mountain without any evidence of peat failure on the site.
(5) What is particularly notable with respect to rainfall duration periods is the sustained dry spell in April and May 2020, which exceeds all previous dry spells recorded since 2011 at Finner.
(6) The significant and sustained dry spell in April and May 2020 nationally was one of the driest recorded for this period. All rainfall totals across the country were below their Long-Term Average (LTA) for the period with the driest on record for Dublin and Meath. At Finner, rainfall was 58% of the average expected amount (Met Éireann 2020).
(7) The Finner records show the lowest recorded 7 and 14-day cumulative rainfall amounts occurred in April 2020.
(8) A review of the Finner records for the preceding 10 years shows annual rainfall ranging from 1067 (2013) to 1691mm (2015), with 1492mm recorded in 2020.

5.2.9 Land Use/Site History

Historical aerial photography was examined for the site covering the years 1995 to 2020. Based on this examination and on published information, there were no apparent peat failures on the site prior to construction of the Meenbog wind farm. The closest failure recorded is some 3.5km to the west of the site (Barnesmore) and occurred in 1963. This failure is noted to have occurred at a break in slope, adjacent to an area where sand and gravel had been removed and drainage trenches had been ploughed nearby to drain the peat for cutting.

The area to the south and west of the 2020 failure is notable because it has never been planted with forestry. This would typically represent an area where poor tree growth was expected and hence poor returns, or because of a particularly wet area of deep peat which was difficult to drain, or where it would have been considered dangerous for an excavator to traverse the bog.

The presence of relict peat failures or clustering of relict failures would indicate that site conditions existed that pre-dispose a site to failure. The site has been extensively planted with conifers for a number of years and with felling having been carried out at various locations with no signs of peat failure. However, there are a number of significant differences between wind farm construction operations and forestry operations therefore direct parallels cannot be made between the potential effects on peat stability of these different operations.

There is no indication, from the examination of orthophotography (from 1995 to 2020), that any recent peat failure had occurred at any locations in the immediate vicinity of the Meenbog site.

At the time of the failure an wind farm access road was under construction at the location of the failure. The road was being constructed using a ‘floating’ technique, which uses either one or multiple layers of geogrid reinforcement within a layer of crushed rock to create an access road without excavating any peat. In the case of Meenbog, brash (in the form of tree trunks and offcuts) was being placed along the line of the access road to act as an additional layer below the road to spread the loading from the road over a larger area. This type of construction is often used in the construction of roads within forestry when crossing peatland/blanket bog areas.

5.3 Shass Mountain

5.3.1 Soils and Geology

The majority of the study area around the Shass failure is recorded as blanket peat, with areas of till derived from Namurian sandstone and shales present at lower elevations across the study area. Outcropping or subcropping rock is indicated in the stream bed upstream of the Dawn of Hope bridge and also to the southeast of the failure location.

The bedrock underlying the study area comprises Namurian sandstone and shales: the Dergvone and Gowlaum Shale Formations and the Briscloonagh Sandstone Formation (GSI, 2022). Two faults are noted close to the peat failure, one trending northeast-southwest and the other northwest-southeast. The northeast-southwest trending fault approximately coincides with a break in slope to the southeast of the failure area and lies ~450m SE of the failure The bedding in these bedrock formations is recorded as being almost horizontal (<10 degrees dipping east).

Investigations undertaken as part of a study by Holohan et al (2021), indicate the presence of a layer of soft clay below the peat at locations adjacent to the failure scar. This layer was at least 0.5m in thickness. Peat thickness ranges from 1.7m to 5.5m at the failure site thus all indicative of blanket bog.

5.3.2 Topography

The general area around the failure site comprises a relatively constant slope falling to the south at an angle of around 4 to 8 degrees. The ground to the east and south of the failure falls to the south/southeast at an angle of 3 to 4 degrees for around 250m, where a convex break in slope is noted. This break in slope is linked to a number of historical peat failures, but not to the 2020 failure. The slope to the north of the failure is around 4 degrees and there is a slight increase in slope angle (convex break in slope) close to the assumed failure point (to around 6 degrees), which appears to form the headwaters of a stream.

The slight convex break in slope upslope of the 2020 failure would not be considered to be a significant contributing factor to the failure.

5.3.3 Landslide Susceptibility

The landslide susceptibility of the study area around Shass ranges from low to high based on GSI's mapping. The failure site is classified as having low to moderately low susceptibility to failure, which is to be expected given the relatively shallow slope angles, as slope angle was one of the main factors used in the landslide susceptibility methodology. GSI's landslide mapping was designed for landslides in general, not specifically peat failures, and as such is does not specifically consider the possibility of specific peat failure mechanisms or the possibility of peat failures on relatively shallow slopes.

A number of localised historical failures (three no.) are associated with valley heads some 600m to the southeast of the 2020 failure. The historical failures correspond to a convex break in slope to the south/southeast of the 2020 failure, however these are not related to the more recent failure.

5.3.4 Geomorphology

The quaternary geomorphology of the study area around Shass Mountain is composed of deglacial landforms and ribbed moraines.

The overall topography is that of a mountain streamlined plateau. The maximum elevation within the study area is 340mOD, with the ground falling along a relatively uniform slope to a level of 280mOD at the failure site. The sides of the plateau in the study area are drained by a series of streams that eventually flow into Lough Allen.

The peat cover on the plateau around the failure comprises an almost continuous cover of blanket peat. The blanket peat cover shows little signs of erosion, but significant areas upslope of the open blanket bog where the peat failure commenced are densely afforested and thus heavily dissected by forestry drainage and occasional access roads. A convex break in slope is present some 250m to the south and southeast of the 2020 failure.

5.3.5 Hydrology

Regional and Local Hydrology

Regionally the Shass Mountain site is located within the Owengar catchment and is immediately adjacent to the Shannon (Upper) catchment. The lands affected by the Shass Mountain peat failure drain to the southwest to an unnamed tributary of the Diffagher River. The Diffagher River and tributaries drain the lands between Lough Allen and Behaval Lough, with headwaters reaching up into Boleybrack Mountains to the northeast and Corrie Mountain to the west. The Diffagher also forms an outflow from Belhavel Lough.

Drainage patterns within this catchment are believed to converge towards a point that coincides with the toe of the surface of rupture.

Forestry Drainage

Within the site there are numerous man-made drains, mostly installed to drain the blanket bog for establishment of the forestry plantations. The forestry drainage pattern is influenced by the local topography, ground conditions, layout of the forestry plantations and existing access roads, as would be typical of any upland peatland forestry site in Ireland. The forestry plantations are generally drained by a network of mound (rill) drains which typically run perpendicular to the topographic contours of the site and feed into collector drains, which discharge to interceptor drains down-gradient of the plantations. The rill drains are generally spaced about 15m to 20m apart. Interceptor drains are generally located up-gradient (cut-off drains) and down-gradient of forestry plantations. Interceptor drains are also located up-gradient of existing forestry access roads.

The interceptor drain along the southern boundary of the forestry should have been directing water towards the west, which would connect into the stream which drains to the south. It appears, however, that this drain has historically allowed some water to discharge onto the open peatland, as can be seen in the flushes visible in the colour aerial photograph. However, it can be seen from the pre-forestry aerial imagery that some of these flushes are natural features, but some may have been augmented by the volumes of forestry drainage run-off which is diverted onto this slope.
Modelling of the drainage pattern (Holohan et al, 2021) has shown that the slide source area occupies much of a small catchment on the western side of this upland area at Shass. Drainage within the catchment converges towards a point that coincides with the toe of the slide source area.

5.3.6 Hydrogeology

The Namurian sandstones and shales, which are mapped to underlie the Shass Mountain site are classified by GSI as a Poor Aquifer, comprising bedrock which is generally unproductive (PU). and typically exhibits groundwater flows of less than 10m^2/d.

The Namurian rocks generally have an absence of inter-granular permeability, and most groundwater flow is expected to be in the uppermost part of the aquifer comprising a narrow broken and weathered zone, a zone of interconnected fissuring 10m thick (GSI, 2003).

The vulnerability rating of the aquifer in the area around the peat failures ranges between "Moderate to High" and this reflects the varying depth of local subsoils and peat. In areas where subsoil is shallow or absent and where bedrock is outcropping, such as to the southeast and southwest of the failure location, an Extreme (E) or Extreme (X) Rock at or near Surface vulnerability rating is given. Extreme (X) indicates bedrock at or within 1m of the surface. Extreme (E) indicates bedrock at or within 1 to 3m of the surface.

Due to the low permeability nature of the Namurian bedrock aquifer underlying the site, groundwater flowpaths are likely to be short (30 – 300m), with recharge emerging close by at seeps and surface streams.

The soft clay mapped below the peat, where present, is likely to impede recharge to bedrock, or conversely block or divert bedrock spring emergence to downslope areas where the clays are thinner or absent.

There are an apparent abundance of mapped flushes and headwater springs in the upland area around this failure site, and this suggests that groundwater has a potential local influence on the eco-hydrology of the bog.

5.3.7 Ecology

Boleybrack Mountain Special Area of Conservation (SAC) (Site Code: 002032) comprises an extensive upland plateau situated to the north of Lough Allen in Co. Leitrim. The SAC is bounded on the north and south by forestry plantations, and on the west by the Scardan River. The peat failure started in the south-west of section of the SAC.

Orthophotography indicates the site of the peat failure is in an area of upland peatland (blanket bog and/or heath) bordered by conifer plantations to the west and north. The relatively flat topography of the site favours deep blanket bog formation.

The areas to the south and east are predominantly open. Flushes can be inferred from variations in vegetation colour and patterns visible in orthophotography. The flushes become visible channels further downslope, as flows of surface water coalesce to carve small valleys in the hillside. The flush patterns visible in 1995 aerial imagery (pre-afforestation) sweep south and west in the north-western corner and centre of the site, southwards in the south-central portion, and south-east in the eastern part. While some alteration of flush patterns is evident due to the east-west forestry collector drain and peat spoil bank in the north of the site (focusing of flows through narrower points and diversion of water to the western end of the drain), the same general pre-afforestation flush patterns existed before the peat failure however their ecology and hydrology would be altered by the additional water volumes diverted though them by the forestry drainage.

Pre-failure orthophotography from 2013 indicates flushes fed from the conifer plantation upslope were focused through points along the plantation/bog interface. These points are considered to align with breaks in the peat spoil bank which allowed water from upslope to continue flowing towards the bog. All the surface flushes draining south/west ran towards the failure inception. One narrow flush running directly south towards the failure inception which was visible in earlier imagery is no longer visible in post-failure imagery (this flow is now likely to travel east along the forestry drain before entering the eroded area).

Prior to the failure, the south/west-aligned flush patterns converged on the valley head running towards the un-named tributary of the Tullilntowell stream. The surface drainage patterns described above align with the inferred drainage patterns identified by iCRAG in the RPS Factual Report (2020) where they were noted to converge on the failure inception location.

A high abundance of *Sphagnum* moss in forestry drains upslope of the bog was noted during an NPWS site visit (Fernandez and Douglas, 2022), indicating substantial and regular flows of surface water downhill through the conifer plantation occur. It is considered that prior to the afforestation, based on surface flush patterns visible in 1995 orthophotography there would have been a more diffuse pattern of flow on the general bog surface and more directional flows within these flushes whereas the current dense of pattern forestry drains running parallel with the direction of slope would have considerably increased the volumes water within the drains and diverted it either through cracks and fissure that are likely to be have formed beneath the afforested bog as it is of > 20 years planted) and/or out onto the blanket bog and flushes above the peat failure initiation site. Low cover of *Sphagnum* in the north-western corner of the area upslope of the failure site was noted during the NPWS site visit which may mean that surface flows may have been diverted into such cracks and fissure beneath the plantation or that such flows were intercepted by the interceptor drain upslope of this location.

A fence line separating the eastern part of the site from the west can be seen in pre-failure orthophotography (parts of the fence were carried away with the peat failure but other sections remain). The area inside the fence (to the south-east) is visibly darker where heather is more dominant. Green patches indicating the presence of grass are visible on both side of the fence line in orthophotography but are more extensive on the western side/outside of the fenced area. This contrast suggests more intensive grazing has occurred outside (west of) the fence. The presence of trees (invading conifers) inside the fence also indicates lower grazing pressure in the enclosed area, as noted in the NPWS site visit report.

5.3.8 Rainfall

A number of weather stations are located in the vicinity of the site, and these have been used to examine recorded rainfall data. The nearest weather station to the site is the Met Éireann Manorhamilton (Amorset) weather station some 12km to the north of the failure site, at an elevation of 77mOD.

The results of the rainfall analysis are presented below.

(1) The rainfall data from the Manorhamilton weather station shows that the wettest period in 2020 was in February and March 2020. The highest daily rainfall in this period was recorded on 8th February 2020 (56mm). In the week prior to the peat failure on 28 June 2020 there were three days where rainfall exceeded 20mm. On the day of the failure the daily rainfall amount was 60.6mm, with 38mm recorded on the preceding day, and on another two days in the preceding week the rainfall exceeded 20mm.
(2) A similar amount of rainfall (56mm) was recorded on 8th February, however there is no indication that this event led to any peat failures in the area.
(3) Rainfall data from Dromohair shows 48mm of rain on the day of the failure, with a total of 80mm of rain recorded in the week prior to the failure.
(4) What is particularly notable with respect to rainfall duration periods is the sustained dry spell in April and May and early June 2020.

(5) The significant and sustained dry spell in April and May 2020 nationally was one of the driest recorded for this period. All rainfall totals across the country were below their Long-Term Average (LTA) for the period with the driest on record for Dublin and Meath (Met Éireann 2020).
(6) The significant and sustained dry spell would have likely caused drying of the peat surface which may have led to cracking of the near surface peat particularly along forestry furrows and drainage lines within the forestry.
(7) A comparison with the preceding 10 years of rainfall data indicates that 2020 (1815mm) recorded the highest rainfall within that decade (range 1428-1815mm), despite the dry spell in April and May. Only one other day (14 November 2015, 61.1mm) recorded in excess of 60mm of rainfall over the decade.

5.3.9 Land Use/Site History

Historical aerial photography was examined for the site covering the years 1995 to 2020.

Prior to the 2020 failure there were several small peat failures close to the failure site. These failures are clustered to the southeast of the 2020 failure and are located at a convex break in slope which appears to coincide with a mapped fault in the bedrock but may also be due to the outcropping pattern in the area. Little is known of these failures, but from aerial photography two of the failures are located in what appear to be stream channels or headwaters.

5.4 Mount Eagle

5.4.1 Soils and Geology

The majority of the study area around the Mount Eagle failure site is recorded as blanket peat, with areas of Till derived from Namurian sandstone and shales present at lower elevations across the study area. Occasional areas of bedrock outcrop/subcrop areas also recorded across the study area.

The bedrock underlying the study area comprises sandstone, siltstone and shales from the Cloone Flagstone Formation, the Glenoween Shale Formation and the Feale Sandstone Formation. Multidirectional regional dips are noted. An NNW-SSE trending fault is indicated 500m west-northwest of the failure location and is three kilometres long.

5.4.2 Topography

The Mount Eagle peat failure site is located at an elevation approximately 430mOD. The area around the failure site comprises a relatively constant slope falling to the north at an angle of around 5 degrees.

There are no obvious concave or convex breaks in slope that are often associated with the locations of peat failures, however there is a slight convex break in the slope to the north of the 2020 failure with the slope angle increasing from 4 to 6 degrees to around 6 to 8 degrees.

5.4.3 Landslide Susceptibility

The landslide susceptibility of the study area around Mount Eagle ranges from low to high based on GSI's mapping. The failure site is classified as having low to moderately low susceptibility to failure. GSI's landslide mapping was designed for landslides in general, not specifically peat failures, and as such is does not specifically consider the possibility of specific peat failure mechanisms or the possibility of peat failures on relatively shallow slopes.

There are no historic failures noted in GSI's national landslide database, however aerial photography shows a failure immediately adjacent to the 2020 failure, on the west side of the 2020 failure. An exact date for this failure is not known, however it appears to have occurred between 2013 and 2018. This peat failure post-dated the planting of the forest.

5.4.4 Geomorphology

Mount Eagle encompasses sub-glacial lineation with streamlined bedrock. The overall topography is that of a mountain streamlined plateau. The maximum elevation within the study area is 450mOD, with the ground falling along a relatively uniform slope to a level of 430mOD at the failure site. This slope continues to the north and is drained by a series of streams that feed into the Glenagharan stream.

There was a previous failure located adjacent to the 2020 failure site. This failure appears to have occurred between 2013 and 2018. This earlier failure has altered the geomorphology of the area very close to the 2020 failure site, forming a shallow depression in the slope.

5.4.5 Hydrology

Regional and Local Hydrology
Regionally the Mount Eagle site is located within the Feale subcatchment. The lands affected by the Mount Eagle 2020 peat failure drain to the north into the Clydagh River.

Forestry Drainage
Within the forestry plantation at the 2020 failure site there are man-made drains, installed prior to planting to drain the peat. The forestry plantations are generally drained by a network of mound (rill) drains which typically run perpendicular to the topographic contours of the site and feed into collector drains, which discharge to interceptor drains down-gradient of the plantations.

An excavated firebreak (approximately 5m in width) is visible on the upslope side of the forestry in the orthophotography. This firebreak would act as a cut-off drain upslope of the forestry, likely connecting to the north-south trending drains within the forestry. It appears that this material was deposited on the peat up slope of the firebreak.

The rill drains appear to be spaced about 15m to 20m apart. Interceptor drains are generally located up-gradient (cut-off drains) and down-gradient of forestry plantations. Interceptor drains are also located up-gradient of existing forestry access roads.

5.4.6 Hydrogeology

The Namurian sandstones, mudstones and shales, which are mapped as underlying the Mount Eagle site are classified by GSI as a Locally Important Aquifer, comprising bedrock which is moderately productive in local zones (LI) and typically exhibits groundwater flows of less than $10m^2/d$.

The Namurian rocks generally have an absence of inter-granular permeability, and most groundwater flow is expected to be in the uppermost part (upper 15m) of the aquifer comprising a narrow broken and weathered zone, and a connected fractured zone below this (GSI, 2003). Where faulting is present this may result in a zone of higher permeability bedrock, increasing groundwater flow.

The vulnerability rating of the aquifer in the area around the peat failures ranges between "Moderate to High" and this reflects the varying depth of local subsoils and peat. In areas where subsoil is shallow or absent and where bedrock is outcropping, such as to the northeast and south of the failure location, an Extreme (E) or Extreme (X) Rock at or near Surface vulnerability rating is given. Extreme (X) indicates bedrock at or within 1m of the surface. Extreme (E) indicates bedrock at or within 1 to 3m of the surface.

Due to the low permeability nature of the bedrock aquifer underlying the site, groundwater flow paths are likely to be short (30 – 300m), with groundwater discharging to streams and small springs.

There are some mapped flushes and headwater springs in the upland area close to the failure site, but not associated with the failure location, and this suggests that groundwater has a potential local influence on the ecohydrology of the bog.

5.4.7 Ecology

The Mount Eagle peat failure of 2020 occurred near the upper region of the River Shannon catchment that flows down to the Lower River Shannon SAC. The Lower River Shannon SAC encompasses counties Clare, Cork, Kerry, Limerick, and Tipperary. This SAC supports several EU Habitats Directive listed habitats and species which includes sandbanks, reefs, alluvial forest, otters, river vegetation.

The 2020 peat failure occurred within Stack's to Mullaghareirk Mountains, West Limerick Hills and Mount Eagle SPA (004161), which is designated for Hen Harrier (*Circus cyaneus*) [A082]. The open bog south of the conifer plantation is within Mt. Eagle Bogs NHA (002449) which is designated for protection of peatlands [4]. The head of the 2020 failure extends into the NHA for approximately 25m.

Orthophotography from 1995 indicates the machine excavated firebreak in the open blanket bog along the northern margin of the conifer plantation was established at the same time as the area was planted. Subsequent orthophotography indicates the firebreak began to revegetate but was cleared again around 2013. Post-failure orthophotography from 2023 shows the firebreak revegetating again, but that revegetation is less prevalent around the head of the 2020 failure and south/east of the earlier (pre-2018) failure. Drains running north-south and east-west through open bog approx. 130m south-west of the failures are visible in orthophotography. The north-south aligned drain does not connect with the excavated firebreak – it ends roughly halfway between the ridge to the south and the firebreak.

High level habitat mapping obtained by request from NPWS prepared after the 2020 failure indicates the blanket bog south of the failure is unmodified. This is correct insofar as this area of bog was not directly targeted or drained, however the firebreak and drainage associated with the conifer plantation to the north of this open blanket bog is likely to have contributed to drying out of the bog.

Well-defined surface flush patterns in vegetation are not visible in the area of open bog upslope/south of the failures in the orthophotography. Flush patterns running south and south-west are visible further upslope near the summit of Mt. Eagle, perpendicular with mapped contours. The surface flush paths indicated by vegetation patterns near the summit can be assumed to continue along their same alignments towards the conifer plantation based on contour mapping. It is considered likely that surface flush patterns further downslope are obscured by dense *Molinia* tussocks.

5.4.8 Rainfall

A number of weather stations are in the vicinity of the site, and these have been used to examine recorded rainfall data. The nearest weather station to the site is the Met Éireann Castleisland (Coom) weather station some 3km to the north of the failure site, at an elevation of 157mOD. Data from Castleisland (Kilmurry) and Knocknagoshel was also reviewed.

The results of the rainfall analysis are given below.

(1) What is particularly notable with respect to rainfall duration periods is the sustained dry spell in April and May 2020.
(2) The significant and sustained dry spell in April and May 2020 nationally was one of the driest recorded for this period. All rainfall totals across the country were below their Long-Term Average (LTA) for the period with the driest on record for Dublin and Meath (Met Éireann 2020).
(3) The significant and sustained dry spell would have likely caused drying of the peat surface which may have led to cracking of the near surface zone of the peat, or made existing cracking worse, particularly along forestry furrows and drainage lines.
(4) The July and August monthly totals for Knocknagoshel, Coom and Kilmurry are all significantly higher than the nearest available Long-Term Average (LTA) at Valentia.
(5) Rainfall events in excess of 20mm were recorded during August (5 no.), September (1 no.) and October 2020 (4 no.).
(6) In the three weeks preceding the 2020 failure there were six days where rainfall in excess of 20mm was recorded at Knocknagoshal, and four days at Castleisland (Coom).
(7) A comparison with the preceding 10 years of rainfall data indicates that 2020 (1769mm) recorded the highest rainfall within that decade (range 1133-1769mm, average 1468mm), despite the dry spell in April and May. Only one day (11 September 2015, 66mm) recorded in excess of 60mm of rainfall over the decade.
(8) While there isn't a single rainfall event to act as a trigger at this location, it is likely that the frequent rainfall events of the preceding weeks triggered the failure.

5.4.9 Land Use/Site History

Historical aerial photography was examined for the site covering the years 1995 to 2020.

Prior to the 2020 failure there is evidence of a peat failure immediately adjacent to the 2020 failure. An exact date for this failure is not known, however it appears to have occurred between 2013 and 2018.
This peat failure post-dated the planting of the forest. The remainder of the area shows no signs of peat instability and appears to have been heavily forested for a considerable time.

6. Findings of Site Visits (Task 3)

The aim of Task 3 was to identify sites or locations within the study area sites where key data is lacking and collect accordingly via focused field visits (in order to validate the analyses carried out under Task 2). Produce a short report on the validation of analyses carried out under Task 2 and identify additional data sources and collect/calculate the cost accordingly.

6.1 Introduction

A series of site visits were undertaken to each of the three 2020 failure sites to examine the geotechnical, hydrological, hydrogeological and ecological conditions at each site. Site visits were undertaken by experienced practitioners in their respective disciplines.

6.2 Meenbog

6.2.1 Geotechnical

Peat depth data recorded during previous visits and site walkovers by Fehily Timoney was used to provide an indication of the peat depth around the area of the failure. Shear strength data from these visits was also reviewed. This indicated that the peat in the flat area around the edge of the failure had a shear strength of typically <10kPa (very soft, weak peat) and occasionally as low as 3kPa, with peat depths ranging from 1.7m to 4.5m. Peat depths on the shallow slope adjacent to the failure (east of failure) were generally shallower, ranging from 0.7m to 2.2m. The depth ranges indicate blanket peat. Peat strengths were recorded using a hand-held shear vane and ranged from 2-3kPa in the area of open blanket bog adjacent to the head of the failure, and up to 15-20kPa on the blanket bog slope to the east of the failure. The peat strengths recorded in the area of open blanket bog would be considered very low and are likely at the lower limit of what can be practically measured with the hand vane. The shear vane results show no appreciable strength gain with depth, which would be typical of a saturated peat mass that has remained essentially water-logged over time.

Slope angles recorded on site ranged from 1 to 6 degrees, with the area of the south and west of the failure point almost flat, and the areas to the east of the failure point with a slope angle of 4 to 6 degrees. Shallow bedrock was noted to the north of the failure in drains alongside a forestry track and also NE of the failure initiation point.

The failure scar morphology comprises 3 distinct parts, namely an upper scar and lower scar which provided the source area for the failed peat, and a run-out trail along which the failed peat was essentially deposited. The scar morphology indicates that failure was most likely a bog flow slide. Bog flow-slides are commonly recognised due to the scar forming a "bottleneck" morphology as material locally and retrogressively fails by localised sliding from the side and the upslope margins of the initial localised failure at the downslope margin (mouth) of the scar. Failed material subsequently flows out of the mouth of the scar.

The 3 distinct parts of the peat failure are described below:

(1) Upper scar. This comprised the primary source area of the failed material. The upper scar was about 260m long by up to about 120m wide. The head of the failure scar was within open peat land. The

southern part of the scar was also within open peat land. The northern part of the scar was within forestry plantation. The estimated total area of the upper scar is about 2.4ha.

(2) Lower scar. This comprised a secondary source area of the failed material. The lower scar is rectilinear and essentially follows the slope gradient. The lower scar was about 260m long by about 43m wide. The head of the lower scar is taken at the downslope mouth of the upper scar and essentially coincides with the upslope boundary of a recently felled forestry plantation. The lateral perimeter of the scar essentially follows the existing forestry furrows. The estimated total area of the lower scar is about 1.18ha.

(3) Run-out trail. The run-trail follows the Shruhangarve stream for about 2.44km where it passes the Shruhangarve bridge and then extends a further 0.74km to the Mourne Beg River. The total distance along the Shruhangarve stream is about 3.18km.

6.2.2 Hydrological/Hydrogeological

A site visit was undertaken to identify both the natural and artificial drainage present around the area of the 2020 peat failure.

The upper failure scar extends into an area of flat, open blanket bog. A review of aerial photography combined with ground truthing from on-site inspection indicates some existing drains within the open blanket bog and these generally drained to perimeter interceptor drains relating to the surrounding forestry. The area of the failure scar appears to have been previously undrained, suggesting that the blanket bog may have been too soft and wet to support forestry machinery.

The area surrounding the upper failure scar comprises standing forestry on blanket bog to the north and west, felled forestry on blanket bog to the east and northeast, and open blanket bog and higher ground to the south, which is a mixture of open ground and forestry.

The site visit has identified three zones of drainage (Figure 6.1) at the site that have direct relevance to the peat failure event:

- **Zone A:** Relatively intact open blanket bog characterised by diffuse overland flow across flat vegetated ground towards the north-eastern corner of the open blanket bog area. Not all the open blanket bog drained to this outfall, as some areas drain east and west.
- **Zone B:** Forestry drainage from the north, with linear flow along the bounding interceptor drain, directing flow to the east towards the likely inception point of the failure.
- **Zone C:** Runoff from the blanket bog forestry and the open blanket bog drained to the east down a steeper slope in the forestry drainage associated with the felled area, which had rill drains and collection drains. The head of this transition zone appears to be a critical area for the peat failure. Downstream of this area, the forestry drainage flows into the Shruhangarve stream.

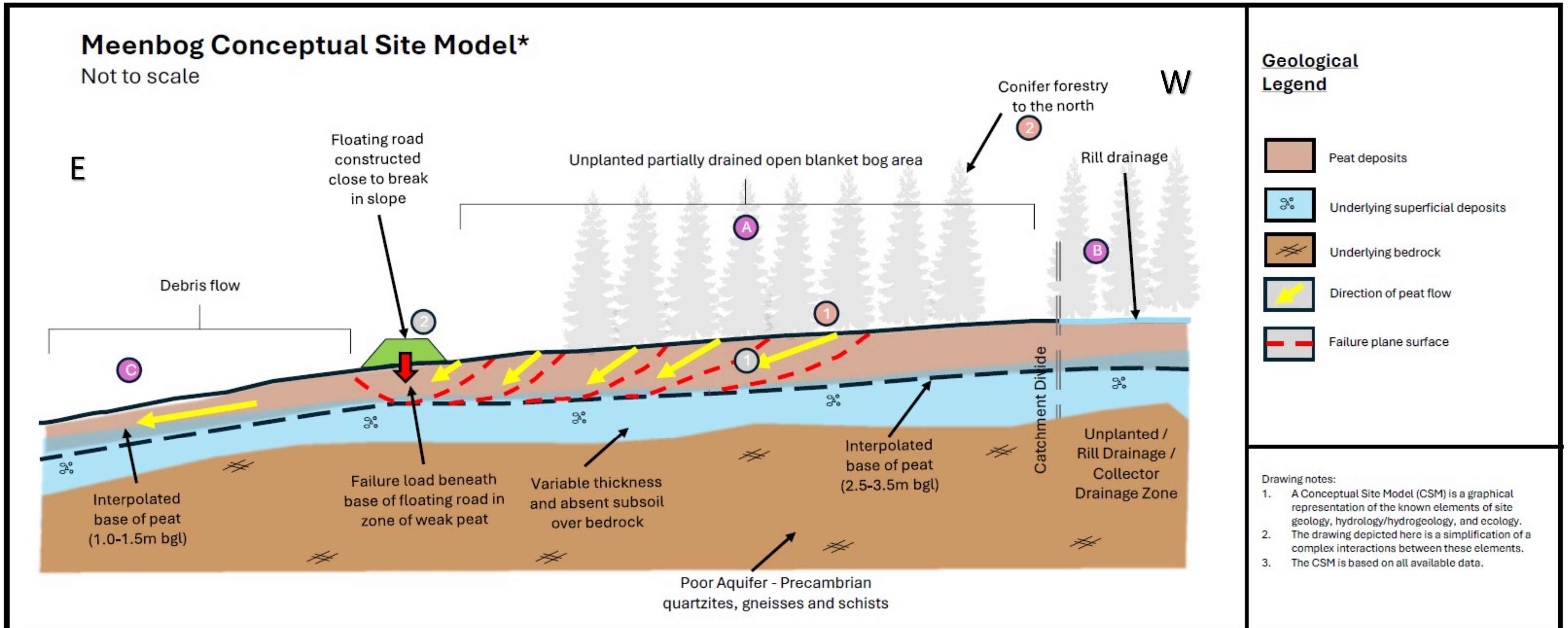
6.2.3 Ecological

Ecological surveys were completed on 17th and 18th August 2022. The survey sought to characterise the habitats to Fossit classes (Fossitt, 2000) and vegetation characteristics of the area around the peat failure, and to check for any features, plant species or assemblages which could potentially indicate conditions conducive to the peat failure.

Vegetation was recorded using 2 x 2m squares (Relevé). All species within each Relevé were identified and a percentage cover value for each species was assigned. Relevés were targeted to capture the transition from forestry to open bog, and to compare areas with and without drains. A total of 13 plots were surveyed.

Full botanical survey results are included in Appendix C of the report for Task 2 and 3 of this project, which provides species lists and percentage cover for each survey location.

Two habitat types are present in the immediate area: upland blanket bog (Fossitt class PB2) surrounding the failure and conifer plantation (Fossitt class WD4) to the west and north surrounding the open bog. The forestry was planted on blanket bog. Transitional vegetation characterised by higher grass cover and lower heather cover forms an ecotone between the areas of open upland blanket bog and conifer plantation. The upland blanket bog habitat was surveyed in detail.



CSM Geological/Geotechnical Notes:

*This cross-section is a simplification of a very complex geological/geotechnical area.

1. Area of deep (up to 4.5m), low strength (<5kPa) peat on upslope side of floating road.
2. Construction of floating road, adding an external load in area of break in slope from upslope flat area to a 2-4° slope downslope.

CSM Hydrological/Hydrogeological Notes:

*This cross-section is a simplification of a complex hydrological/hydrogeological area.

A. **Zone A:** Relatively intact, partially drained, open blanket bog characterised by diffuse overland flow across relatively flat vegetated ground towards the north-eastern corner. Not all the open blanket bog drained to this outfall, as some areas drain east and west.

B. **Zone B:** Forestry drainage from the north, with linear flow along the bounding interceptor drain, directing flow to the east towards the likely inception point of the failure.

C. **Zone C:** Runoff from the blanket bog forestry and the open blanket bog drained to the east down a steeper slope in the forestry drainage associated with the felled area, which had rill drains and collection drains. The head of this transition zone appears to be a critical area for the peat failure. Downstream of this area, the forestry drainage flows into the Shruhangarve Stream.

CSM Ecological Notes

*This is a simplification of the ecology at the Meenbog failure site.

1. Upland Blanket Bog (Fossitt Habitat Type PB2) within unplanted area, the dominant habitat in the area.
2. Conifer plantation (Fossitt Habitat Type WD4) to the west and north surrounding the open bog. The forestry was planted on blanket bog.

Figure 6.1: Meenbog Conceptual Site Model

6.3 Shass Mountain

6.3.1 Geotechnical

The failure occurred within a southerly facing slope covered in open blanket peat with a forestry plantation at the head of the failure.

The failure scar is defined in 2 parts, namely:

- Upper scar. This comprised the main source area of the failed material. The upper scar was about 450m long by about 200m wide. The head of the failure scar was within the forestry plantation, where 2 notable head features are readily apparent. The estimated total area of the upper scar is about 8ha.

- Lower scar. The lower part of the failure scar followed an existing incised stream channel where there appeared to be scouring of material, and a net removal of material. Based on inspection this is assumed not to extend as far as the Dawn of Hope bridge. Below this scar there was a net accumulation of failed material (run-out trail). The lower scar along the incised channel was about 700m long by about 20m wide. The estimated total area of the lower scar is about 2ha.

The total area of the upper and lower scars is about 9ha. A report into the failure (RPS, 2020) records the total affected area above the Dawn of Hope bridge as 11.9ha.

Peat depth data recorded during a site walkover was used to provide an indication of the peat depth around the area of the failure. Shear strength data from these visits was also reviewed. This indicated that the peat in the area around the edge of the failure had a shear strength of typically 6-30kPa, with peat depths ranging from 1.7m to 5.0m. Peat strengths were recorded using a hand-held shear vane. Slope angles recorded on site ranged from 2 to 6 degrees.

Based on the above, the estimated failure volume is about 250,000m^3, of which a notable proportion has remained within the upper scar. The RPS report has estimated that approximately 160,000m^3 of material was deposited in the townlands of Corcormick, Corcuhill Lower and Derindangan.

Given the shape of the upper scar, the likely mode of failure was a flow slide followed by lateral and downslope movement of intact peat rafts (acrotelm) into the upper scar. Downslope the failed peat debris degraded and became channelised as a flow within the incised stream before eventually becoming fully suspended within the water in the stream. In this manner, peat debris can be carried many kilometres downstream becoming more diluted all the while.

6.3.2 Hydrological/Hydrogeological

A site visit was undertaken to identify both the natural and artificial drainage present around the area of the Shass 2020 peat failure.

The tract of planted forestry upslope of the failure is large in spatial area (109,110m^2). The forestry drainage comprises north-south aligned rill drainage at approx. 5m centres that transfers runoff downslope to an east-west heavily overgrown narrow (0.2-0.3m wide) interceptor drain. Prior to the failure the interceptor drain over-spilled to the downstream open blanket bog through gaps in a vegetated soil berm that occurs to the south of the forestry and the interceptor drain. There was a post and wire fence to the south of the spoil berm prior to the failure, but some of this fence has been pulled downhill with the failure.

During the field visit void space or cracking was identified at the base of the interceptor drain, and also along the alignment of rill drains within the forestry where the two lobes of the peat failure extend up into the forestry block.

The shape of the failure scar, specifically the two separate failure arms extending towards the forestry, indicate that a topographic drainage channel along the mineral substrate surface may have been present in these locations. The large rainwater inputs from the forestry drains can be expected to have exerted very high and possibly artesian water pressures around this channel (as observed elsewhere: Dykes and Warburton 2008), promoting the very localised flow and its own lateral retrogressive margins.

The site visit has identified three zones of drainage (Figure 6.2) at the site that have direct relevance to the peat failure event:

- **Zone A:** Forestry drainage via linear rill drains to an interceptor drain from the forestry block north of the failure. Water from the interceptor drain overspilled at discreet outfall locations onto the open bogland to the south.
- **Zone B:** This is the transition zone between Zones A and C. Flow from Zone A was transferred as overland flow and collected into an emerging stream head to the southwest. There was flushed vegetation evident in this area prior to the failure. This area has been significantly modified by the failure.
- **Zone C:** Runoff from Zone B collected into the unnamed tributary of the Diffagher River that flows to the southwest of the failure, and this stream carries water downstream to Lough Allen. Runoff emerging from the failure scar still flows into the stream.

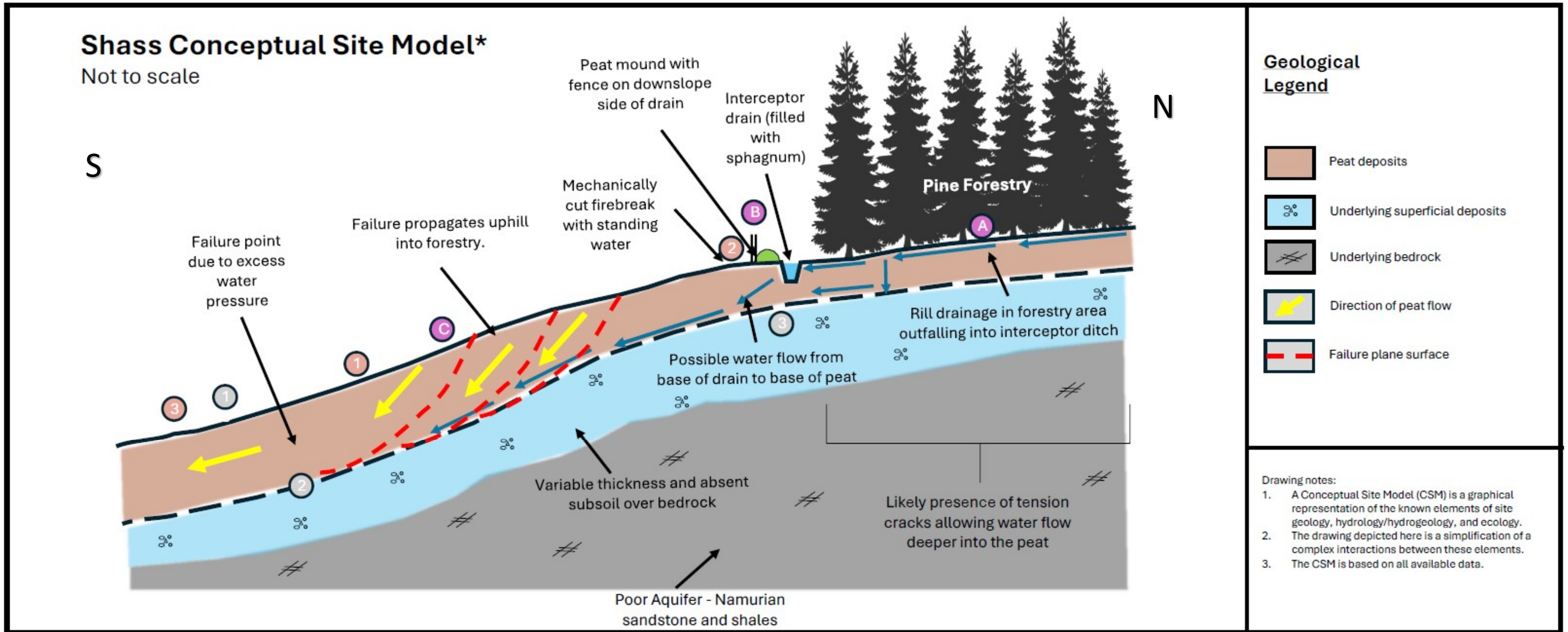
6.3.3 Ecological

Surveys of the Shass failure site were completed on 16th and 17th August 2022. The survey sought to characterise the habitats and vegetation characteristics of the area around the peat failure, and to check for any features, plant species or assemblages which could potentially indicate conditions conducive to the peat failure.

Vegetation was recorded using 2 x 2m squares (Relevé). All species within each Relevé were identified and a percentage cover value for each species was assigned. Relevés were targeted to capture the transition from forestry to open bog (including the mechanical firebreak), and on flushes and a historical failure south-east of the landslide. Two survey plots (S24 and S25) were also positioned to sample inside and outside the fence to the south of the failure. A total of 25 plots were surveyed.

Full botanical survey results are included in Appendix C of the report for Task 2 and 3 of this project, which provides species lists and percentage cover for each survey location.

Four main habitat types (Fossitt, 2000 classification used) are present in the area: upland blanket bog (PB2) surrounding the peat failure; conifer plantation (WD4) on blanket bog to the west and north of the open bog; poor fen and flush (PF2) in the western and eastern parts of the habitat survey study area, and wet heath (HH3) occurring on the firebreak peat spoil bank and within the historical failure at the south-eastern corner of the habitat survey study area. The upland blanket bog, flush and wet heath habitats were surveyed in detail.



CSM Geological/Geotechnical Notes:

*This cross-section is a simplification of a very complex geological/geotechnical area.

1. Area of low strength deep peat (up to 4.5m) present downslope of forestry within headwaters of stream
2. Presence of soft clay layer at base of peat may have provided a sliding surface, especially when combined with likely water flow along base of peat.
3. Likely presence of cracks at base of forestry furrows and interceptor drain allowing water to flow into base of peat.

CSM Hydrological/Hydrogeological Notes:

*This cross-section is a simplification of a complex hydrological/hydrogeological area.

(A) **Zone A:** Forestry drainage via linear rill drains to an interceptor drain from the forestry block north of the failure. Water from the interceptor drain overspilled at discreet outfall locations onto the open bogland to the south.

(B) **Zone B:** This is the transition zone between Zones A and C. Flow from Zone A was transferred as overland flow, and collected into an emerging stream head to the southwest. There was flushed vegetation evident in this area prior to the failure. This area has been significantly modified by the failure.

(C) **Zone C:** Runoff from Zone B collected into the unnamed tributary of the Diffagher River that flows to the southwest of the failure, and this stream carries water downstream to Lough Allen. Runoff emerging from the failure scar still flows into the stream. Possible groundwater influence in this area pre-failure.

CSM Ecological Notes

*This is a simplification of the ecology at the Meenbog failure site.

1. Upland Blanket Bog (PB2) is the dominant habitat in the area, covering the open hillside and occurring as remnant strips running through the surrounding conifer plantations. This habitat type encompasses both intact blanket bogs, and also an excavated firebreak running around the plantation margins which has been recolonised by vegetation
2. Vegetation communities close to the firebreak are indicative of wetter conditions along the firebreak and drying out of the adjacent intact blanket bog.
3. Three flushed area were noted around the site of the failure. The flushes were both rush and grass/sphagnum dominated

Figure 6.2: Shass Conceptual Site Model

6.4 Mount Eagle

6.4.1 Geotechnical

The failure occurred within a north facing slope covered in blanket peat located within a forestry plantation. It is assumed that the failure occurred on 15 November 2020, which is three days after the Meenbog peat failure.

The failure scar is estimated to be about 650m long by about 30 to 50m average width. The lower part of the failure scar within the tree plantation is narrower, which suggests that this represents material running out from the scar and is likely not part of the failure scar. This lower part of the scar, which is about 200m long by 20m wide, has not been included as part of the failure scar. Based on the above the estimated plan area of the failure scar covers about 2.6ha. Assuming the average failed peat depth is 2m, then failure volume is 52,000m^3, of which a notable proportion typically would remain within the area of the failure scar.

The recent peat failure in November 2020 occurred at a similar location to the earlier failure (pre 2018). The head of the recent failure extends into the open peatland beyond the forestry plantation. Given the shape of the recent peat failure scar, the likely mode of failure was a progressive peat slide which downslope degraded into a debris slide before being channelised as a flow, which in many cases results in a long run-out. It is understood that peat debris from the failure entered a nearby tributary stream of the River Clydagh, which originates from this area.

Hand-held shear vane strength testing was carried out at selected locations around the head of the failure within the forestry and in the open peat land during the site visit. The hand vane results indicated undrained shear strengths in the range 12 to 44kPa, with an average value of about 22kPa. The peat depth was on average about 2.5m. In general, the recorded undrained shear strength of the peat was not significantly low at the test locations. Unfortunately, the peat strength in the central part of the failure is not known.

6.4.2 Hydrological/Hydrogeological

A site visit was undertaken to identify both the natural and artificial drainage present around the area of the 2020 peat failure.

There is an east-west aligned ridge running to the south of the failure scar. The peak of the ridge is approximately 280m south of the top of the failure scar. The natural drainage from the northern flank of this ridge consists of diffuse overland sheet flow, which typically drains to either natural watercourses with narrow incised channels, or the runoff is intercepted by the firebreak present along the southern side of the forestry plantation.

The tract of planted commercial forestry downslope of the failure site is large in spatial area with internal interceptor drains operating typically along firebreaks, running east-west, and ultimately draining to the north. There is a rill drainage network within the forestry, and these generally run east-west, which is parallel to the ground slope. Rill drains are typically spaced 10-15m apart and are approx. 0.2-0.3m deep. A number of the interceptor drains along the edge of the firebreak were observed to be deep (approx. 1.5m) and incised.

During the site walkover, some cracking and void space was noted in the peat within the interceptor drain that runs east-west in the first firebreak in the forestry on the eastern side of the head of the 2020 peat failure. The interceptor drain appears to have opened (widened), slightly closer to the failure site, but movement was noted at least 50-80m from the failure site. This opening could have occurred as a result of the failure event, but it may also indicate a pre-existing weakness in the peat along that interceptor drain, either in the form of a break and weakness in the acrotelm or by causing desiccation and cracking in the catotelm peat along that alignment. This firebreak and the area around it also appears to either have not been planted, or there may have been stunted forestry growth locally (evident from historic aerial photographs), which also could suggest some pre-existing wetness or hydrological anomaly.

The site visit has identified three zones of drainage at the site (Figure 6.3) that have direct relevance to the peat failure event:

- **Zone A:** Relatively intact blanket bog characterised by diffuse overland sheet flow as the primary flow regime.
- **Zone B:** This is the transition zone between Zones A and C. Flow from Zone A is intercepted by the firebreak, and transfers runoff to the forestry drainage system (Zone C) via overspill outfalls to interceptor drains. The flow along the firebreak is linear and causes peat erosion depending on its velocity, and some local ponding of water occurs along the firebreak. This zone is the critical zone for the peat failure.
- **Zone C:** Drainage in this zone is via forestry rill drains and interceptor drains. The flow paths are modified, are linear, and flow is likely to be rapid. Rill drainage is parallel to slope and interceptor drains or perpendicular to slope. The interceptor drains, within the forestry, transfer runoff downslope to the natural incised watercourse channels described above.

6.4.3 Ecological

The ecological survey sought to characterise the habitats and vegetation characteristics of the area around the landslide, and to check for any features, plant species or assemblages which could potentially indicate conditions conducive to the landslide.

The survey targeted the blanket bog uphill of the failure and the conifer plantation/blanket bog ecotone including the mechanical firebreak between the conifer plantation and blanket bog. Target notes were recorded at each location. All species visible at the survey location were identified. Species cover was not quantified; however, the dominant species and relevant characteristics of the floral assemblage were noted at each location. Additional details, such as the presence of bare peat and standing water, degree of grazing and disturbance were also noted. A total of 33 points were surveyed.

Full botanical survey results are included in Appendix C of the report for Task 2 and 3 of this project, which provides species lists, notes and overall vegetation cover estimates (%) for each survey location. The data collected were analysed to classify and indicate the condition of vegetation at each survey location and combined to provide a site-scale assessment.

Three main habitat types are present in the area around the head of the peat failure: upland blanket bog (PB2); cutover bog/upland blanket bog mosaic (PB5/PB2) and wet heath (HH3). The head of the second peat failure extends southwards into these habitats. Conifer plantation WD4 planted on blanket bog is present to the north, with the majority of the peat failure having occurred in this hydrologically and ecologically much altered, former blanket bog habitat. Remnant strips of upland blanket bog/wet heath in the form of firebreaks run though the conifer plantation. The upland blanket bog, cutover bog/upland blanket bog mosaic and wet heath habitats were surveyed in detail.

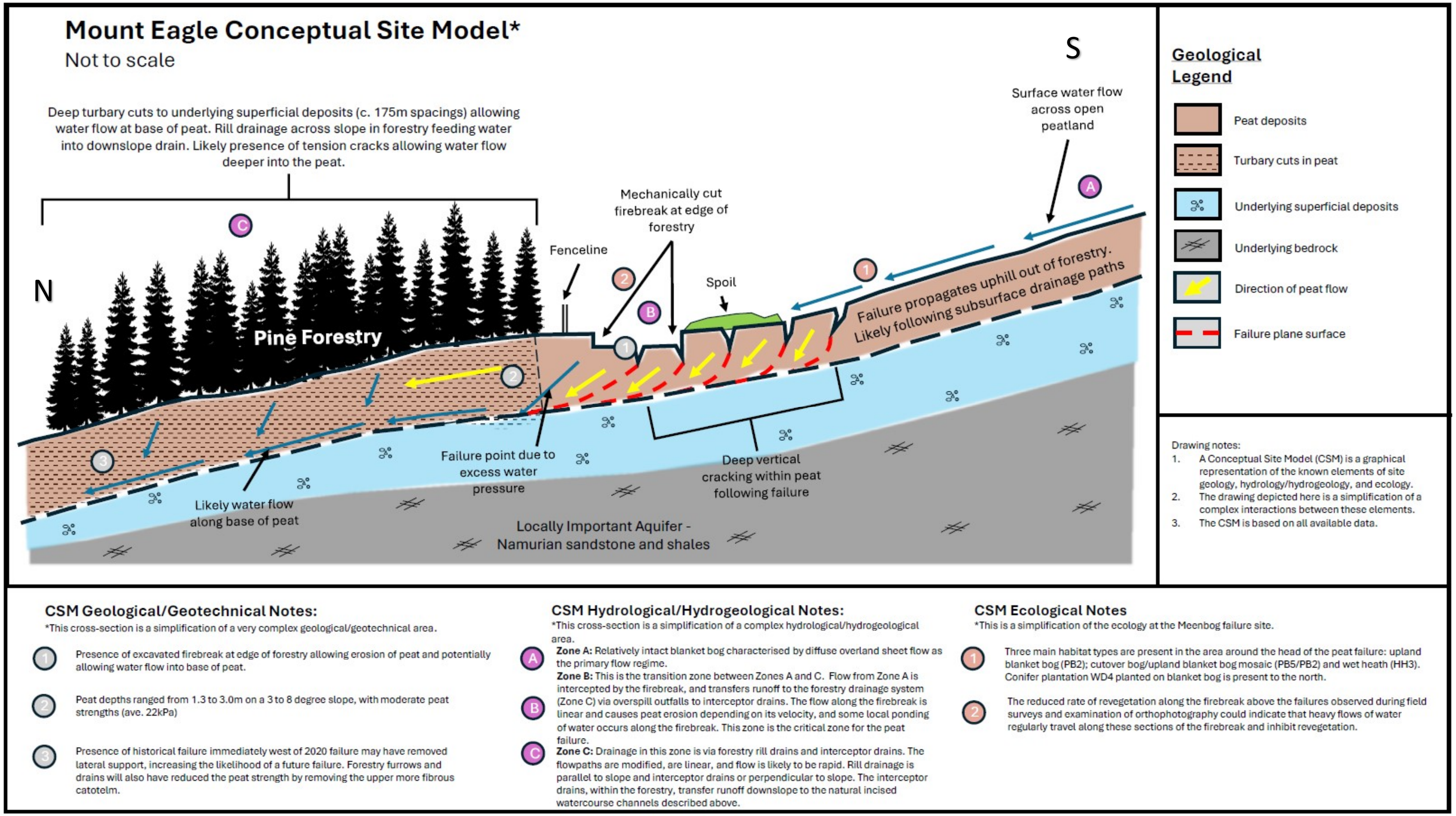


Figure 6.3: Mount Eagle Conceptual Site Model

7. Contributary Factors to Major Peatland Failures (Findings of Task 2/3)

The following section covers the key conditioning and triggering factors in each of the peat failures visited as part of Task 3 of the project.

7.1 Meenbog

The following are considered to be the key conditioning and triggering factors of the bog flow/peat failure of 12 November 2020.

One or a few of these factors in combination are highly unlikely to cause the scale of the peat failure that occurred. It is likely that the combination of all of the identified factors created the conditions for the peat failure.

FT visited the failure site and carried out testing and observations, the following is based on the site visits and aerial imagery.

- **Construction of floating road (Triggering factor).** The construction works for the floating road triggered a localised initial peat failure within the underlying *in situ* peat. It would not be uncommon for discrete sections of floating road to undergo excessive movement due to localised weakening within the underlying peat, however at this location a number of other contributory factors caused an escalation of the initial localised failure.

- **Low Peat Shear Strength (Conditioning factor).** It is considered that a zone of unforeseen weaker peat was present below the floating road that resulted in localised bearing failure within the underlying peat. Where there were drains passing below the floating road, which occurred at about the location of the failure, the drains would have severed the acrotelm layer (upper fibrous layer) of the peat where most of the intrinsic strength of the peat lies.

- **Interceptor Drain (Conditioning Factor).** A forestry interceptor drain is noted to flow towards the failure area, but the main drainage outfall from the open blanket bog area occurs approx. 80m south of the failure inception point.

- **Area of deep, wet, blanket bog comprising weak peat immediately upslope (Conditioning factor).** Upslope of the location where the floating road was being constructed was a flat plateau that was a blanket bog area formed of a large body of notably saturated and very weak peat. For lateral stability, this body of saturated and very weak peat relied on the peat slope upon which the floating road was being constructed. Hand vane results indicated undrained shear strengths in the range 2 to 9kPa, with an average value of slightly less than about 5kPa. These low recorded peat strengths represent a body of very weak peat.

- **Rainfall pattern (Conditioning factor).** A combination of preceding heavy rainfall and the pattern of weather recorded over the preceding months likely contributed to the failure. However, the failure was not triggered by an intense rainfall event. There was, however, a 28mm rainfall event recorded at

Lough Mourne ASC on 11 November 2020, so the site was likely to be wet, but likely no wetter than normal. Several similar daily totals were recorded at Lough Mourne ASC in the weeks and months preceding the failure. There was no clear significant peak rainfall duration period immediately prior to the peat failure. There was a significant dry spell (April and May 2020) followed by relatively high daily rainfall amounts (from June 2020 onwards).

- **Cracks in the peat under the forestry plantations (Conditioning Factor).** The significant and sustained dry spell may have caused drying of the already altered peat within the forestry, leading to cracking of the near surface peat particularly along forestry furrows and drainage lines, or widening/deepening of existing cracking within the forestry. Subsequent run-off from rainfall may then have gained ingress to the peat at depth via these cracks, potentially eroding the base of peat or increasing the porewater pressure at the peat/overburden interface.

- **Drainage and surface water ingress into peat (Conditioning factor).** Pre-failure topography indicates that drainage from the open blanket bog occurred to a low point approx. 80m south of the failure inception point. The west-east forestry interceptor drain present along the southern edge of the forestry block to the north of the open bogland directed drainage towards the failure area. However, not all of this forestry block (approx. 4Ha) drained to the failure point as there is an offshoot drain noted roughly 40m from the eastern end of the forestry that likely directed some of the forestry drainage to the southwest towards the natural low point.

  Drone footage from the area on the morning of the failure indicate some water in the west-east interceptor drain, and some minor ponding upstream and downstream of the floating road. Such ponding is not uncommon when constructing floating roads, but this is noteworthy all the same considering the location of the failure. However, the open blanket bog did not drain via the forestry interceptor, and it is possible that not all the forestry drained via this interceptor either, given the location of the offshoot drain.

- **Topography/ Convex break in slope (Conditioning factor).** The initiation of the failure occurred at a convex break in the peat slope. A convex break in slope is commonly cited as the location for peat failures for a number of reasons. In this particular case, the convex break in slope marks the transition from an upgradient plateau area containing deeper and very weak and saturated peat compared to downslope where the peat is not as deep and has relatively greater strength. At the convex break in slope, it is likely that in many cases there is a zone of relatively higher strength peat, due to a greater degree of drainage, that acts to support the very weak and saturated peak present in the plateau area upslope. If this zone is removed or damaged it can lead to the type of retrogressive failure noted at Meenbog.

- **Forestry related activities (Conditioning factor).** The area downslope of the floating road comprised a forestry plantation that had been felled a few years in advance of the wind farm construction. The extraction route from this forestry block appears to follow an alignment consistent with the route of the floating road, with a slight skew to the northeast close to where the failure inception occurred. Previous forestry extraction routes may have weakened the underlying peat especially at a turning point. This area comprised forestry furrows and drains aligned downslope on peat slopes with a peat depth of about 1.8m and a slope angle of 4-6 degrees. This area is not unique, nor would it represent an increased stability risk. However, the presence of furrows and drains aligned downslope on peat slopes, which have severed the acrotelm layer and the likely blockage of drainage following felling operations allowed the slope to readily fail once localised failure was initiated upslope. The failure through this area exploited the existing forestry furrows which are lines of weakness.

7.2 Shass Mountain

The following are considered to be the key conditioning and triggering factors of the peat failure of 28 June 2020. One or a few of these factors in combination are unlikely to cause the scale of the peat failure that occurred but the combination of all of the factors was sufficient to cause the failure.

It is considered that preceding heavy rainfall and the pattern of weather recorded over the preceding months contributed significantly to the failure. FT visited the failure site and carried out testing and observations, the following is based on the site visit and aerial imagery.

- There is no evidence to suggest there were mechanical works (drainage or forestry related) ongoing at the site at the time of the failure.
- Rainfall intensity and pattern (Triggering factor). The trigger for the failure is related to run-off/water flow from preceding heavy rainfall following a prolonged dry spell.

Site-specific Conditioning Factors

- **Potentially Low Peat Shear Strength (Conditioning Factor).** Hand-held shear vane strength testing was carried out at selected locations around the head of the failure within the forestry and in the open peat land during the site visit. The hand vane results indicated undrained shear strengths (c_u) in the range 6 to 29kPa, with an average value of about 18kPa. The peat depth was on average about 2.5m (max. of 5m). In general, the recorded undrained shear strength of the peat was not significantly low at the test locations. Unfortunately, the peat strength in the central part of the failure is not known. Given the type of failure, it is conjectured that there must have been a significant body of saturated and weak peat (c_u<5kPa) within the upper scar area. The above suggests that saturation of an already weak peat area by rainfall and the additional volumes of surface water directed to the failure location by the forestry drains were likely significant contributory factors in the failure.
- **Forestry drains alignment with slope (Conditioning Factor).** The forestry drains are shallow rill drains and run north-south in general alignment with the slope and therefore direct water towards the location of the failure initiation point.
- **Forestry and associated subsurface peat cracks (Conditioning Factor).** The forestry drains will also have caused significant change to the natural in-situ hydrological conditions of the blanket bog.

  Additionally, the tree root systems will have altered the properties of the catotelm and acrotelm peat. In some cases, this may provide additional strength, but where there is weaker peat or groundwater influence (such as upwelling groundwater pressures), or where cracking of the peat occurs (tree growth is known to cause can cracking and fissuring of the peat), the addition of extreme rainfall onto such weaker conditions could cause the initiation of a failure.

  Some cracking was observed in existing drainage along the edge of the forestry, but it was not clear whether this occurred during/after the failure, or whether it was present before the failure. While there is no direct evidence that the forestry drainage contributed to the failure, it is likely to have played a significant role. For example, all the rill drains run north-south, and these transfer water to the east-west interceptor, and then to the south via overspills where gaps in the perimeter soil berms occurred. This drainage system thereby focused runoff to specific locations rather than diffusely, which would have been the natural condition. Given that there was no maintenance of the interceptor drain (it was observed to be heavily vegetated and closed in), nor was there likely any maintenance at the overspills, it is possible that during an extreme rainfall event the overspills were flooded and likely overloaded. There is also evidence from the drone footage of the failure event at Shass that forestry run-off water was ponding on the firebreak downslope of the interceptor drain.

The proximity of the head of the failure to the upslope margin of the open blanket bog and forestry plantation would strongly suggest that run-off from the forestry which had drainage furrows directed downslope towards the failure, possibly in combination with run-off flowing within the downslope perimeter interceptor drain of the forestry plantation, was directed towards the site of the head of the failure.

Considering the likely volume of water that would have been concentrated in this area, and at ponding and overspill areas, where the water penetrated into the base of the peat through cracks in the peat surface under existing drains or in combination with natural processes, this is considered likely to be sufficient to initiate localised failure within the weaker more decomposed peat (catotelm peat) at depth. The localised failure would then have destabilised the adjacent intact peat causing the larger peat failure. Following the initial failure, the head of the failure retrogressed upslope into the forestry plantation following the lines of weakness in the blanket peat created by the forestry drainage furrows.

- **Role of Flush Zones (Conditioning Factor).** Prior to afforestation, there was a large funnelling collection flush zone at this site. This flush zone encompasses the majority of the study area and the failure footprint. Remnants of this flush zone and potential new flushes created by discharge from the boundary interceptor drain were mapped by FT in 2022. The spatial extent of these recently mapped flush zones is limited by the destructive impact of the peat failure.

  The pre-afforestation original collector flush zone is considered to be an important indicator of the volume of surface water that collected and funnelled through this area before it reached the stream in the eastern boundary of the site. The fact that this area coincides with the failure inception zone supports the interpretation that changes to the flow regime arising from the forestry plantation and associated drainage impact (direct and indirect), is likely a primary conditioning factor to slope instability in this area. The only issue here is that the flush zone existed in this form for many years alongside the forestry drainage, and as such it is not clear why, when there were previous similar rainfall events, it contributed to the 2020 failure.

7.3 Mount Eagle

The following are considered to be the key conditioning and triggering factors of the peat failure of November 2020.

It is considered likely that the combination of all of the identified factors created the conditions for the peat failure as one or a few of these factors in combination are highly unlikely to cause the scale of the peat failure that occurred.

There is no evidence to suggest there were mechanical works (drainage related or forestry related) ongoing at the site at the time of the failure.

- **Rainfall (Triggering Factor).** The trigger for the failure is likely related to run-off/water flow from preceding rainfall following a prolonged dry spell. The proximity of the head of the failure to the upslope margin of the forestry plantation and the open blanket bog would strongly suggest that run-off from the open peatland, possibly in combination with run-off flowing along the firebreak, was concentrated at the head of the failure.

Site Conditioning Factors (November 2020 failure)

- **Previous failure (Conditioning factor).** There is a previous adjacent failure that likely occurred for the same reasons as the 2020 failure. The presence of this previous failure is, however, considered to be a conditioning factor in the 2020 failure, as it is likely to have removed some lateral support of the peat on the edge of the 2020 failure, increasing the likelihood of a future failure.

- **Drainage (Conditioning Factor).** The forestry plantation that is located downslope within the failure catchment has caused significant changes to the natural drainage conditions, both along the firebreaks and also within the forested area. Drains within the conifer plantation and in open bog to the south-west of the failure are also likely to contribute to some drying of the blanket bog upslope of the failure. The east-west orientated interceptor drains within the forestry may also have held water on the slope if they were not properly maintained, leading to saturation of the peat.

  Considering the volume of water that would have been concentrated in this area, where the water penetrated into the base of the peat through cracks in the peat surface under existing drains or through natural processes this would likely be sufficient to initiate localised failure within any weaker peat at depth. The localised failure would then destabilise the adjacent intact peat causing the larger peat failure. Following initial failure, the head of the failure retrogressed upslope out of the forestry.

  It is also noteworthy that the pre-2018 and the November 2020 failures both occurred in the headwaters of a tributary stream, which is one of a number of headwaters in the area. Such areas may be areas of more focused flow than other areas. This is similar to the conditions at the Shass Mountain failure.

- **Topography (Conditioning Factor).** A slight convex break in slope has been noted at the assumed failure point within the forestry. This type of feature has been found at a significant number of peat failures across Ireland and the UK and is considered to be a key conditioning factor in peat slides.

- **Forestry Firebreak (Conditioning Factor).** The firebreak is an excavation on the upslope side of the forestry, with the attendant effect of draining and potentially peat drying the blanket bog upslope. Drains within the conifer plantation and in open bog to the south-west of the failure are also likely to contribute to some drying of the blanket bog upslope of the failure. The proximity of the head of the failure to the upslope margin of the forestry plantation and the blanket bog would strongly suggest that run-off from the blanket bog, possibly in combination with run-off flowing along the firebreak, was concentrated, and potentially ponding, both within the firebreak and possible further down the slope at the initiation point of the failure.

This perimeter firebreak has, over time, been eroded, denuded, desiccated and cracking has developed due to oxidation of the peat surface. Over time, these cracks have widened and propagated vertically into the peat substrate. Water coming off as sheet flow from the open blanket bog, will therefore also have infiltrated as subsurface flow into these linear cracks which ultimately can cause instability by lubrication and buoyancy of the weaker catotelm peat at the base of the peat profile. The slip layer is considered to be at the base of peat contact with underlying mineral subsoils / bedrock.

- **Peat Strength (Conditioning Factor).** Shear vane strength testing (hand-held) was carried out at selected locations around the head of the failure within the forestry and in the open blanket bog during the site visit. The hand vane results indicated undrained shear strengths in the range 12 to 44kPa, with an average value of about 22kPa. The peat depth was on average about 2.3m. In general, the recorded undrained shear strength of the peat was not significantly low at the test locations. The peat strength in the central part of the failure is not known.

7.4 Summary

The following provides a summary of the triggering and conditioning factors for the three major peat failures:

Table 7-1: Triggering and Conditioning Factors for Three Peat Failures

Site	Triggering Factors	Conditioning Factors (site-specific characteristics)
Meenbog County Donegal (12 November 2020)	Construction activity causing excess loading on blanket bog (during construction of floating road across blanket bog)	Convex break in slope at site of construction activity. Area of poorly drained, deep, weak peat (blanket bog) directly upslope of route of access road. Presence of forestry drainage altering the ecohydrological functioning of the blanket bog and focussing water flow.
Shass (Boleybrack Mountain) County Leitrim (28 June 2020)	Localised very heavy rainfall event on June 28^{th} 2020.	Blanket bog with altered ecohydrological functioning. Forestry drainage upslope of the failure location is diverting additional volumes of run-off water into localised areas of the deep open blanket bog. Pre-existing flush zones that converge on the failure points and that may facilitate surface run-off water access to the weaker peat base peat. Convex break in slope close to the point of the failure. Presence of soft clay layer at the base of the peat.
Mount Eagle County Kerry (15 November 2020)	Rainfall pattern during the earlier year (dry Spring and wet Summer) combined with run-off from the open blanket bog being focussed within forestry drains	Drained and afforested blanket bog hence with severely altered ecohydrological functioning. Forestry drainage focusing surface run-off water into localised area of afforested blanket bog; erosion of blanket bog along a firebreak at upper edge of the forestry; and peat drying/cracking due to lack of vegetation cover along the firebreak. Convex break in slope close to the point of the failure. Presence of older failure adjacent to 2020 failure has removed lateral support to the area that failed in 2020.

These Conditioning and Triggering factors are similar to those found in other historical peat failures across Ireland and the UK, involving rainfall, head loading of peat during construction activity (both triggering factors), convex breaks in slope and the impact of forestry drainage on surface water flow and the ecohydrological functioning of blanket bog (conditioning factors). Each of these factors is important when considering the potential susceptibility of a site to peat failure.

8. Potential to Update the National Landslide Susceptibility Map (Task 4)

The purpose of Task 4 was to review and assess whether areas of peatland within the study areas of this project, currently mapped as low to moderate susceptibility on the National Landslide Susceptibility Map, are likely to have a higher classification of susceptibility to landslides due to factors not previously included in the analyses, and to produce a technical note to cover this. A number of options were considered, and these are summarised below.

The most straightforward option may be to add an additional layer (or note) to the existing susceptibility mapping for areas that can be identified as having the following characteristics:

- Presence of an upland blanket bog or active raised bog setting
- Slopes of 3-10 degrees (as an example)

The additional layer/note would inform that these areas may be at higher risk from peat instability, and that an appropriate peat stability assessment should be undertaken for any works proposed in these areas, irrespective of the current landslide susceptibility rating. The peat stability assessment should include the gathering of site-specific data on the condition and extent of peat and drainage (hydrology and hydrogeology) on the site.

An alternative to the above would be to apply a filter layer to the existing susceptibility mapping, effectively "greying-out" all areas of upland blanket bog. A note would be added to the legend stating "Areas of upland blanket bog should be considered at higher risk of peat failure. Any development in these areas should include an appropriate site-specific peat stability assessment undertaken by multidisciplinary teams of suitably qualified and experienced scientific and technical professionals".

As the susceptibility mapping was undertaken using a 20m DEM, another option would be to look to update the mapping based on more detailed topographic data (such as LiDAR), which would allow for a refinement in the calculation of the TFI, which may alter the landslide susceptibility classification of certain areas. It may also allow for the identification of concave and convex breaks in slope, which are a known conditioning factor in peat failures.

In order to be relevant specifically to peat failures, it is considered that additional factors would have to be included to create a specific assessment of the landslide susceptibility of peat deposits. This would involve the collation of a series of datasets, such as blanket bog/wet heath areas, forestry plantations, drainage systems, topographic data, catchment data, peatland condition data and others. However, any such assessment would require the application of suitable weighting factors to datasets, as not all datasets have an equal impact on peat stability.

As an example,

- The slope characteristics, such as areas of concave/convex breaks in slope would have to be identified, as these areas are considered to be at higher risk of failure. In all of these cases, the surface slope angle is assumed to reflect the slope angle of the base of the peat, unless evidence to suggest otherwise is available.

- Slightly different slope bands to the originals would need to be selected, providing more bands at lower slope angles (<15 degrees) with only a couple of bands above this, as peat typically does not accumulate in significant quantities on steep slopes. Such steeper slopes are already classified as 'High' susceptibility.
- Additional factors, such as areas within the headwaters of watercourses would also have to be considered, as well as drainage patterns, (natural/man-made) such as flushes. Rainfall levels and patterns would also be a part of this assessment.
- The condition (level of decomposition), thickness of a peat deposit and water level/hydrogeological conditions within the peat deposit should also be considered. The shear strength of peat is also important, although there are issues around the accuracy of field measurements of this parameter.
- The land use of an area, and specifically any change in land use (such as peat extraction or forestry, for example), would also have to be considered. Degradation of peat areas can also be a conditioning factor in peat failures, and these areas would also have to be identified, likely from high quality satellite imagery/aerial photography and other available data. This would require significant time and effort if applied to all upland peatlands across the country. The National Land Cover and Habitat Map (NLCHM), provides a more detailed dataset of land types nationally and would likely be very useful for this though it will need some prior validation against existing peatland ground truth data.

Each of the bullet points above would require the collation of a series of existing datasets (such as locations of blanket bog/wet heath, forestry plantations, drainage systems and habitats), refinements of some existing datasets, and possibly the creation of new datasets to allow these factors to be included in a landslide susceptibility assessment.

An example of a "peat specific" qualitative risk assessment is provided for the three failures, based on peat depth, peat strength, slope shape and the presence of artificial drains. It shows that this type of assessment would increase the landslide susceptibility classification of the three sites, to "Moderately High" for the area around the Meenbog failure, "High" for Shass Mountain and "High" for Mount Eagle.

The above can be seen to potentially increase the landslide susceptibility assessment of the three areas to a point where there would be an increased risk of failure following a suitable trigger event. However, the exact location and extent of any potential failure would be significantly harder to determine. This highlights the difficulties in attempting to identify specific areas of high risk. The Meenbog failure was triggered by activity associated with the construction of a wind turbine access road across blanket bog. In the case of Shass Mountain, rainfall is considered to be the trigger for the peat failure however heavy rainfall does not always lead to a peat failure therefore it is clear that there are predisposing factors operating at Shass. The Mount Eagle failure appears to have been mostly related to the drainage of the site along with the volume of surface water runoff from an excavated firebreak over time. The blanket bog at this site is also highly compromised in terms of normal ecosytem functioning by forestry drainage and a previous landslide also occurred close to the site of the current study landslide site which may have destabilised the latter.

As different triggers and conditioning factors are associated with each failure, producing a single assessment which can accurately reflect all of these failures is not considered feasible.

9. Identify Data Gaps Related to Peat Stability in Impact Assessments (Task 5)

The purpose of Task 5 was to produce a short technical note to identify any potential data gaps (with respect to peatland failures and peat stability) related to impact assessments and planning associated with infrastructural developments and other land uses/land use changes that have the potential to affect blanket bog and allied peatland habitats. The findings of the technical note are summarised below.

There are a significant number of publicly available datasets (GSI, NPWS, EPA, TE, etc.) that are of use for impact assessments, and these should be the starting point for any assessment. This should always be supplemented by site specific data, gathered either from high resolution aerial photography, LiDAR surveys and importantly also from site investigations by appropriate individual specialist disciplines. The recommendations of the Scottish Guidelines (2nd Edition) in terms of data gathering and assessment in relation to peat stability should be followed as a useful starting point for any development on blanket bog but should also be adapted to take into account conditions specific to Ireland's peatlands as many of the Scottish sites may occur in areas of lower rainfall than many of the Irish bog sites.

Remote sensing monitoring can be used to identify land movement which can be measured at a very high temporal resolution (e.g. inSAR).

It is recommended that specialists should work on site together at an early stage in assessments as their combined expertise can gain more insight than each working alone. A hydrologist (or geotechnical engineer) and peatland ecologist working together for example will have a greater understanding of the susceptibility to peat failure of a site than each working alone.

Peatland stability is influenced by multiple factors, such as changes in drainage patterns, land use practices, and alterations in peatland hydrology and ecological functioning. These changes, often associated with activities including forestry, infrastructure development, drainage and peat extraction, agriculture etc., can lead to alterations in vegetation and ecosystem functioning and result in desiccation and erosion which may impact on peat stability. Land use changes, particularly the conversion of undisturbed peatlands to plantation forests, can result in the loss of natural vegetation and lead to hydrological disruption and to peat subsidence, affecting peatland ecosystem structure and functioning and peat stability. Habitat fragmentation due to construction also plays a role in ecosystem functioning impacts and ecological and biodiversity impacts and peat stability impacts.

Site specific detailed information is important for a comprehensive understanding of how these factors affect peatland ecology, ecosystem functioning, biodiversity and peat stability. Depending on the general site characteristics, the following may require more detailed studies, both desk and field based:

- Water Table Position;
- Water Inflow and Outflow;
- Rainfall and Climate;
- Groundwater Flow;
- Vegetation;
- Ecosystem functioning including connectivity/fragmentation;
- Permeability;
- Compression and Settlement;

- Human Activities;
- Peat Thickness;
- Climate Change;
- Erosion Control.

In relation to peat stability, stability assessments should not be limited to the development footprint, it should also assess areas upslope and downslope of any development as these can either be impacted or have an impact on a development. Areas of deep, soft peat and areas of waterlogged ground within a site should be identified during site visits and should be avoided, as these would be considered to be more at risk of peat failure. Any change in land use that includes the potential to reduce the water table or cause significant settlement within the peat should include an appropriate assessment of this particular risk. Bog restoration projects should also include such an assessment due to the potential impact on peat stability from an increase in the groundwater table following the blockage of drains. Areas of historical failure should be examined to assess the risk of future movement.

An accurate assessment of the strength of peat should be included in any assessment, however the limitations and difficulties in accurately measuring peat strength and covering all areas of a blanket bog site should be stated clearly and the associated risks for peat stability detailed in the assessment. Peat decomposition should also be described, according to the von Post classification (von Post and Granlund, 1926), although it is noted that a suitably experienced practitioner is required to ensure an accurate consistent description (Long, 1994).

Any slope stability assessment should also be accompanied by an appropriate risk assessment of qualitative factors, as detailed in the Scottish Guidelines. Any such risk assessment should include consideration of the effect of a change in drainage conditions, or groundwater level, on peat stability.

Appropriate geomorphological and topographical surveys (such as LiDAR) should be undertaken to allow for identification of higher risk areas on a site with respect to peat stability. These are typically found at sharp breaks in slope, either concave or convex.

Appropriate hydrological assessments should be undertaken to determine any areas on the site where there is an existing boundary between natural and man-made drainage flows on any development site. Where these are present the hydrological impact of any proposed development on these areas should be assessed. In terms of peat stability, peat failures have been associated with the headwaters of streams. As such, an assessment of any drainage outfalls, either point flows or diffuse flow should be included to ensure that the risk of a sudden discharge into sensitive headwaters is negligible or low. An appropriate buffer zone should be included between any excavations and adjacent watercourses.

Ecological and ecosystem functioning assessments should include suitably detailed habitat and vegetation mapping across the entire site and including the sub-catchment or hydrological unit encompassing the site, with surveys of ecological receptors and an assessment and valuation of ecological resources. Any ecological survey should clearly identify, map, and assess areas of deep, wet, quaking, pool-patterned bog for example as these areas are considered susceptible to failure.

The impacts of both higher summer temperatures, along with more frequent heavy precipitation events, should be assessed in terms of the impact on the hydrology, ecology, and the peat stability of a particular site. Historic and up to date site specific data on rainfall amounts are important data to help inform on peat properties, peatland types and subtypes; current climatic conditions etc and thus provide valuable information on peat failure susceptibility.

An appropriate peat management plan should be included in any assessment, providing an assessment of peat excavation volumes, peat storage locations, details of how peat disturbance will be minimised, details of peat monitoring requirements and a stability assessment of any permanent peat storage locations.

10. Assessment of Impacts of Land Use Change on Peat Stability (Task 6)

The aim of Task 6 was to produce a technical note that will be of assistance to planning authorities and government agencies relating to the assessments of potential impacts of proposed land use changes (e.g. infrastructural developments, peat extraction, forestry operations etc.) on blanket bog and peatland habitats.

The technical note focuses on land uses and land use changes that may directly or indirectly impact on key blanket bog features and properties including geology, geomorphology, stratigraphy, structure, ecology, ecohydrological functioning and directly or indirectly on peat stability. Land use impacts blanket bog ecohydrology and the geotechnical properties of the peat. An assessment of peat stability should be undertaken where the depth of peat exceeds 0.5m, or justification provided for sites where a peat stability assessment is not undertaken.

Depending on the general site characteristics, the following may require more detailed studies:

- Water Table Position;
- Natural and artificial drainage systems
- Rainfall and Climate;
- Groundwater Flow;
- Surface water flow pattern and impacts on these
- Habitat Vegetation patterns of variation;
- Topography
- Substrate topography
- Areas such as wet or quaking bog area, pool systems etc
- Ecosystem functioning including hydrological functioning, connectivity/fragmentation;
- Peat Permeability;
- Compression and Subsidence;
- Human Activities (past and recent/current;
- Peat Thickness and condition;
- Climate Change factors;
- Erosion Control.

Impact Assessments should cover not just the development footprint, but also any area downslope of the development that may be impacted from peat instability, or any area upslope (such as occurred at Shass, Meenbog and Mount Eagle) that has the potential to impact on the proposed development. It is also important that Impact Assessments consider direct or indirect impacts, or combination of impacts that may reduce the stability of peat through a change in land use. A non-exhaustive checklist is included in Appendix A of the Technical Note for Task 6 containing items/reports to be considered when reviewing planning applications.

Impacts on peat stability can result from several factors including: effects of land uses/land use changes that can alter peat structure and properties and impair the ecohydrological functioning of the peatland such as loading of peat (construction loading or stockpiling or loading from timber weight of plantation trees); erosion due to changes in the vegetation cover or the natural drainage regime; changes in the peatland's surface water flow patterns; focusing of water flow that increase water pressure at susceptible locations; excavations in peat (temporary or permanent); and the impacts of changes in the water levels in peat from artificial drainage or the blocking of existing drains and many more factors.

Lowering the groundwater table in peatlands through the use of artificial drainage, such as is associated with forestry plantations and infrastructure developments, can lead to desiccation within the acotelm and may lead to decomposition of the peat. This decomposition, may, in turn, lead to issues with peat stability as a more decomposed peat typically has a lower strength. Drainage can also lead to shrinkage of the peat, and subsidence of the surface of the peat.

Consideration needs to be given to the impact of the alteration of existing natural drainage on upland blanket bogs. Peat failures have been noted at the interface between natural and artificial drainage. An appropriate assessment of the impact of the change in land use on the hydrology of a blanket or raised bog should include an accurate conceptual model of the site, which includes any potential impact on the existing peat hydrology.

Should a change in land use or proposed development require the installation of new drainage or modification of existing drainage, new drainage should seek to minimise and mitigate the following:

- Water level drawdown, shrinkage, and decomposition of in-situ peat.
- Creation of preferential pathways and unidentified cracking of the peat mass
- Compaction of the in-situ peat
- Excessive drying out/desiccation of the peat mass
- Movement or change to existing peat workings

While each of the above aspects of a site (soils & geology, hydrogeology, hydrology, ecology) are typically considered individually, when considering peat stability all of the above also need to be considered in terms of their interaction with each other in order to accurately assess the potential impact of the change in land use on areas such as upland blanket bogs.

11. Conclusions and Recommendations

In undertaking this Project a wide range of issues have been explored and there are a series of reports dealing with specific topics in detail. The purpose of this report is to summarise that work and describe the findings.

The literature review provided a wide range of conditioning and trigger factors (Table 4.2) for peat failures that have occurred across Ireland and the UK. The most commonly reported trigger factors for failures were direct human activity (such as construction) and rainfall events. This rainfall can either be an intense, short term rainfall event or a prolonged period of higher than average rainfall. However, such rainfall requires a range of conditioning factors, several specifically linked to peatland ecohydrology, to be present to trigger a failure.

A summary of the conditioning and triggering factors associated with the different types of failures has also been provided. It should be noted that based on the publications reviewed, it is rare that one individual factor alone is reported to initiate a peat failure. This suggests that it requires a combination of two or more factors at the same location to initiate a peat failure, irrespective of the type of failure. Commonly reported factors are topography; peat properties; human activity or land use at the site; and rainfall.

The three major peat failures that occurred in 2020 were triggered by a mix of rainfall (Shass Mountain), construction activity (Meenbog) and water flow/run-off (Mount Eagle). Each of these three sites had a range of conditioning factors, as detailed below. These are broadly similar to the conditioning and triggering factors recorded in the literature review. However, further study would be recommended at both Mount Eagle and Shass Mountain to determine the risk of future peat failure in the lands adjacent to the 2020 failures.

Table 11-1: Triggering and Conditioning Factors for Reviewed Peat Failures

Site	Triggering Factors	Conditioning Factors (site-specific characteristics)
Meenbog County Donegal (12 November 2020)	Construction activity causing excess loading on blanket bog (during construction of floating road across blanket bog)	Convex break in slope at site of construction activity. Area of poorly drained, deep, weak peat (blanket bog) directly upslope of route of access road. Presence of forestry drainage altering the ecohydrological functioning of the blanket bog and focussing water flow.
Shass (Boleybrack Mountain) County Leitrim (28 June 2020)	Localised very heavy rainfall event on June 28th 2020.	Blanket bog with altered ecohydrological functioning. Forestry drainage upslope of the failure location is diverting additional volumes of run-off water into localised areas of the deep open blanket bog. Pre-existing flush zones that converge on the failure points and that may facilitate surface run-off water access to the weaker peat base peat. Convex break in slope close to the point of the failure. Presence of soft clay layer at the base of the peat.

Mount Eagle County Kerry (15 November 2020)	Rainfall pattern during the earlier year (dry Spring and wet Summer) combined with run-off from the open blanket bog being focussed within forestry drains	Drained and afforested blanket bog hence with severely altered ecohydrological functioning: Forestry drainage focusing surface run-off water into localised area of afforested blanket bog; erosion of blanket bog along a firebreak at upper edge of the forestry; and peat drying/cracking due to lack of vegetation cover along the firebreak. Convex break in slope close to the point of the failure. Presence of older failure adjacent to 2020 failure has removed lateral support to the area that failed in 2020.

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APPENDIX A

Potential to Update National Landslide Susceptibility Map

APPENDIX B

Data Gaps in Impact Assessments

APPENDIX C

Impact Assessment of Land Use Change on Blanket Bog