Peatslide hazard rating system for wind farm development purposes

Douglas Nichol
Enviros Consulting Ltd, 61 The Shore, Leith, Edinburgh, EH6 6RA

Introduction

Wind farm developments in peatland terrain are often susceptible to peatslide hazards. In 2002, a major peatslide associated with construction of a wind farm at Derrybrien, Ireland damaged two bridges, obstructed two roads and polluted watercourses and all work on the wind farm site ceased while engineers devised emergency measures to stem the flow of the slide (Fleming 2003). Following the events at Derrybren and because of the perception that increased human encroachment onto peatland has created an increase in the incidence of peatslides the need has arisen for a procedure to assess the hazard. Moreover, the interests of wind farm developers are also best served by addressing peatslide potential at an early stage because failure to deal with the matter may give rise to very expensive delays during the design, planning approval and construction phases.

The Peatslide Hazard Rating System (PHRS) is intended to be a proactive tool to rationally address peatslide hazards and provide a defensible, standardised way to assess priority by numerically differentiating the apparent risk at potential peatslide sites.

Hazard rating systems are used extensively for the engineering assessment of landslips, debris flows and rockfall along transportation corridors and internationally they have received wide acclaim (e.g. Miller, 2003; McMillan & Matheson, 1998; Winters et al, 2005). However, the existing systems appear unsuited to the assessment of peatslide potential on wind farm projects and so a new procedure was required. For example, much shallower slopes are required for peatslides than for other types of landslide and other contributory factors have different parts to play. After considering the range of options available, the hazard rating system developed by Pierson (1992) for the USA Federal Highway Administration (FHWA) for assessments of rockfall was adopted as the prototype for a Peatslide Hazard Rating System (PHRS). We simply modified, tailored and customised the original FHWA system into a peatslide hazard assessment protocol (Nichol, 2006).

Development of the PHRS system has included testing and validation at 3 sites to confirm a realistic set of values for each category. As far as the system has been developed and applied to date, several of the categories have been modified on the basis of the experience gained. In particular, the design of field survey forms have undergone extensive revision based on the field experience gained at different wind farm projects. Hopefully, it can now be implemented at a far greater number of sites to ensure a consistent approach to the problem that exists.

Description of System

The PHRS is a two-step process that provides a rational way to make informed decisions about peatslide risk across a site and to develop programmes aimed at reducing the peatslide risk at the worst sites.

The first step involves a walkover survey that allows a properly trained and experienced geo-engineer to gain an appreciation of the site and consider the best way to approach its subdivision into zones of similar levels of PHRS interest. Whereas grouping too many separate site segments into one long PHRS zone will diminish the value and the flexibility of the resulting database, too many PHRS zones may become cumbersome and difficult to manage. Some localities may have been previously subdivided into segments for other purposes and these may be appropriate to adopt as PHRS zones. It is important during this stage to also take account of the aim of the PHRS survey and the proposed end-use at the site. Since it is essentially a subjective evaluation of the peatslide potential, geo-engineering judgements need to be made by experienced and insightful personnel.

The PHRS is primarily concerned with the peatslide potential at sites such as turbine positions and access track routes and so the second step involves detailed rating of each PHRS zone. The criterion of the estimated potential for peatslides is therefore the controlling element of this rating. These hazard factors are summarised in Table 1 and described in detail in the subsequent sections.

Table 1: Peatslide Hazard Rating System (PHRS) – Summary of hazard factors.

Category	Rating criteria and score			
	Points 3	**Points 9**	**Points 27**	**Points 81**
Rainfall and climate	Low to moderate precipitation	Moderate precipitation	High precipitation	Very high precipitation
Presence of water on slope	No water on slope; Few water bodies	Intermittent water on slope; Occasional water bodies	Continual water on slope Many water bodies	Continual water on slope Major water bodies
Rockhead or subsoil	Rough and irregular rockhead or granular subsoil of sand and gravel	Undulating rockhead or granular subsoil	Planar and regular rockhead or cohesive subsoil	Smooth, polished and regular rockhead or cohesive subsoil of clay
Peat profile and depth	Single layer profile less than 1 m deep	Double layer profile less than 2 m deep	Triple layer profile greater than 2 m deep	Complex profile greater than 4 m deep
Peat strength (vane shear test)	40 kPa	30 kPa	20 kPa	10 kPa
Slope and slope regularity	2^o ; even	5^o ; uneven	10^o ; irregular	15^o ; very irregular
Geomorphology and site history	Few differential erosion features	Occasional erosion features	Many erosion features	Major erosion features
Sub-profile drainage	Few pipes	Occasional pipes	Many pipes	Many pipes and sinkholes
Peatslide history	Few slides	Occasional slides	Many slides	Major peatslide events
Potential peatslide severity	Few consequences; small impacted area	Minor consequences; minor impacted area	Many consequences; large impacted area	Major consequences; large impacted area

The Detailed Rating System

The detailed rating includes 10 categories that when evaluated, scored and totalled, allow one to numerically differentiate sites from the least to the most hazardous. Sites with higher scores present the highest risk. These 10 categories represent the significant elements of a peatslide prone location that contribute to the overall hazard.

In Table 1, the four columns of criteria on the right correspond to logical breaks in the increasing risk associated with each category. Accordingly, the benchmark scores above each column increase from left to right exponentially from 3 to 81. An exponential system provides a rapid increase in score that distinguishes the more hazardous sites. The set scores are representative of a continuum of points ranging from 1 to 100. Using a continuum of points instead of only the benchmark points listed at the top of each column allows the rater flexibility in evaluating the relative impact of conditions that are extremely variable.

To assist with scoring, the users manual includes a scoring graph for each category. The curve on the graph defines the cubic exponential scoring system used for all categories. The graph relates the category evaluation to an appropriate score (e.g. Fig. 1). Even with subjective categories such as peatslide history, the graph is quite useful in assigning a score to a condition that falls somewhere between the described benchmarks. A final hazard score for a given site is then obtained by summing the scores from each contributory factor.

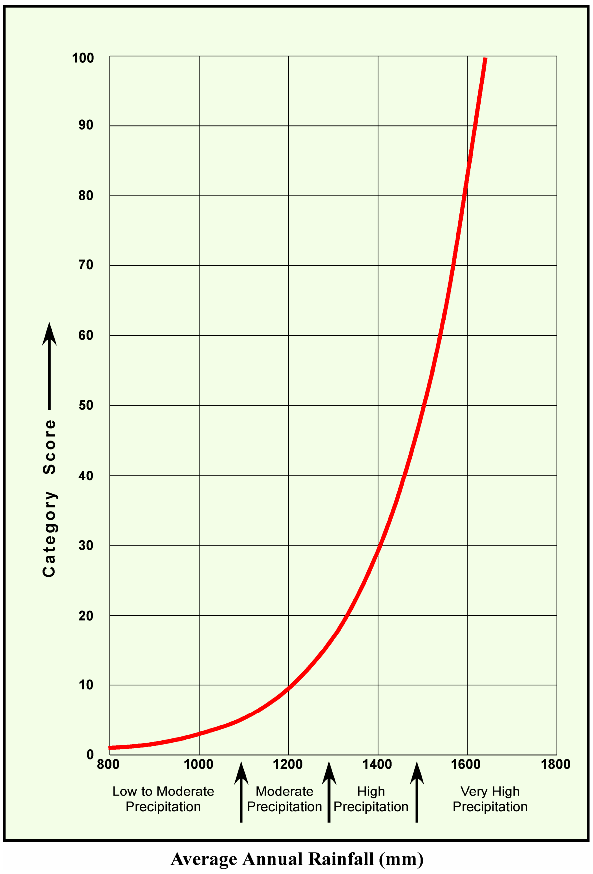

Fig. 1. Example of graph from users manual for rainfall and climate.

Before decisions can be made on how to score a peatslide section, the criteria for each category must be well understood and carefully considered and based on sound engineering judgement. This is crucial in relation to border-line cases to make sure the overall scores provide a fair and balanced representation of the site in question.

<u>Rainfall and climate</u>

The role of rainfall is the most important contributory factor for peatslides. Areas receiving high rainfall have more potential for peatslides than areas of low rainfall. Measurement is based on the average annual rainfall in mm for the nearest weather station and generally within the range 800-1800 mm per year. For higher levels of rainfall the maximum score of 100 applies. The rater may adjust the score within a discretionary maximum of 10 points to take account of elevation, slope aspect, exposure to winds, etc.

Water on slope

The wetness conditions of the ground are evaluated with this category. If water is known to flow continually or intermittently from the site, it is rated accordingly. This is combined with observations on the presence of streams, rivers, pools, lochs or other bodies of water that affect the wetness of the site. Comparisons are also made with the terrain conditions found at established sites of peatslides elsewhere. The following guidance applies :-

3 points	No water on slope – Dry ground.
9 points	Intermittent water on slope – Occasional pools and streamlets.
27 points	Continual water on slopes – Streams and ponds. Wet ground
81 points	Continual water on slopes – Rivers and lochs. Saturated ground

Rockhead or subsoil

The geologic conditions of the surface at engineering rockhead are evaluated with this category. The first case applies to solid rock and distinguishes between a smooth, polished and even rockhead surface and one that is rough and irregular. The second case applies where engineering rockhead consists of unconsolidated surficial or drift deposits and the distinction is made between cohesive subsoils of clay and granular subsoils of sand and gravel (Fig. 2).

This parameter directly relates to the potential for a block of peat to move relative to the rockhead surface. Friction along the surface is governed by the macro and micro roughness. Macro roughness is the degree of undulation on the surface whereas micro roughness is the texture of the surface itself. In addition, the presence of a impervious clay or rock at engineering rockhead may give rise to perched water tables and an increase in the peatslide potential. Peatslide potential is also greater in areas where the engineering rockhead surface contains highly weathered or hydrothermally altered products or where previous movements have given rise to slickensides.

Fig. 2. Initiation point of a shallow peatslide on a rockhead of coarse gravel and smooth rock.

Peat profile and depth

The characteristics of the peat profile are considered in this category and the distinction is made between complex profiles of deep peat that receive high scores and thin, simple, single-layer profiles that receive low ones. As far as possible, scoring should be consistent with the following scheme :-

3 points	Single layer profile of peat less than 1 m deep
9 points	Double layer profile of peat less than 2 m deep
27 points	Triple layer profile of peat greater than 2 m deep
81 points	Complex profile of peat greater than 4 m deep

The rater needs to consider several factors in estimating peat profile characteristics and not overstate the significance of peat depths obtained by probing. Other factors include von Post classification (after Hobbs, 1986) and particularly H-values (humification), M-values (moisture content) and F- and R-values (fibre content).

Peat strength (vane shear test)

Peat strength is notoriously difficult to measure. However, the hand vane provides an approximate indication and can be used to collect readings in cuttings, stream banks and shallow hand-dug pits. Lowest strength values should be used for scoring purposes. Scores are allocated based on results in the range 0-50 kPa.

Slope and slope regularity

Peat profiles resting on steep slopes have more potential energy than those on gentle slopes; thus they present a greater hazard and receive a higher rating (Fig. 3). Measurement is on the steepest slope in the section, preferably determined in the field using a clinometer or the results of a theodolite survey of the site. However, a good approximation of slope angle can also be obtained using the contour lines on a topographic map.

The rater may adjust the score by a discretionary maximum of 10 points to take account of slope regularity, outcrops of rock, presence of tracks, etc.

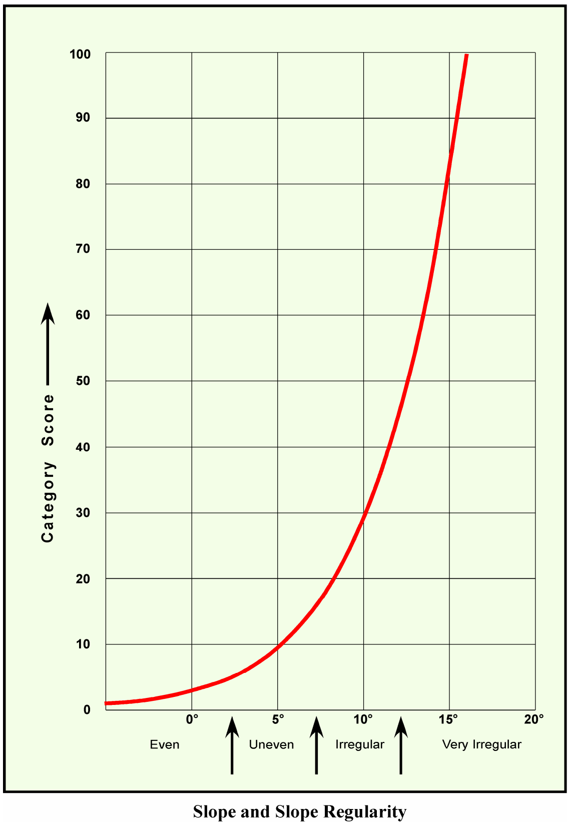

Fig. 3. Example of graph from users manual for angle and regularity of slope.

Geomorphology and site history

Natural erosion features such as hags, mounds, ridges, pools, incised streams as well as disruption of the ground surface by grazing, burning, forestry, drainage ditches, tracks, fence-lines and man-made cuttings for fuel, all affect the integrity of the near surface layers of peat and particularly the tensile strength of the root-mat. In addition, they may create localised oversteepening of slopes or unsupported blocks of peat.
The degree of hazard caused by erosion and degradation and thus the score given in this category should reflect how quickly erosion and degradation are taking place, the size of blocks or units being exposed and the amount of material being released.

Sub-profile drainage

Natural soil pipe networks are a localized feature in most peatland areas. The pipes comprise smooth walled approximately circular conduits or tunnels typically about 10-50 mm diameter; some pipes are over 150 m long. Since the presence of subterranean water courses may lead to the saturation of the local areas of peat, they give rise to an increase in the chance of peatsliding. The pipes can form throughout the peat profile, at the peat-substrate interface, or entirely within the subsoil but they usually occur at the contact between two layers of contrasting engineering properties. Large pipes may collapse and become open gullies. However, since the may underlie as much as 5 % of an area of peatland, the initial problem is to determine the location and distribution of piping. In most instances they may be discerned based on surface observation such as seepage points, sinkholes, grass lanes and lines of reeds.

According to Jones (1978) it seems clear that pipes, whilst not restricted to upland regions do occur more frequently in the uplands. In addition, based on a study of 180 catchments, Holden (2004) noted significantly higher soil pipe densities in catchments with peats dominated by Calluna species and also in catchments that are artificially drained.

Table 2. Soil pipe networks – type localities and typical pipe frequency counts.

Locality	Reference	Type	No of pipes per km of transect
Burbage Brook, Hathersage, Peak District	Jones (1978)	steep upland	100
Afon Cerist, Dinas Mawddwy, Gwynedd	Jones (1978)	upland	80
Cerrig yr Wyn, Cambria	Holden et al (2002)	upland	56
Nant Gerig, Cambria	Holden et al (2002)	upland	36
Maesnant, Plynlimon (mid-Wales)	Jones (1978)	intermediate	16
Little Dodgen Pot Sike, North Pennines	Holden et al (2002)	upland moor	10
Bourn Brook, Cambridge	Jones (1978)	lowland	7
New Forest	Jones (1978)	lowland	0

Simple frequency counts of the occurrence of pipe outlets in stream banks are available for a wide range of geomorphologies and a selection of typical values is given in Table 2 that can be used on a comparative basis to estimate pipe density at other sites. The actual fall-off in pipe frequency from uplands to lowlands is probably even greater than these counts suggest.

Peatslide history

Since the pre-existence of peatslides is considered to be a good predictor of future instability, this category directly represents the known peatslide activity at the site. It is best obtained during walkover surveys and also by reference to air photos and discussions with local landowners (Fig. 4). However, there may be no history available and so as far as possible, the following guidance should be followed: -

3 points — Few slides – Small peatslides have occurred several times according to historical information but it is not a persistent problem. If peatslides occur rarely or only during severe storms this category should be used. This category is also used if no peatslide history data is available.

9 points — Occasional slides – Small peatslides occur regularly and can be expected during most storms.

27 points — Many slides – Large slides are also present as a noteworthy feature of the site.

81 points — Major peatslide events –Peatslide events occur frequently throughout the year and severe events are common.

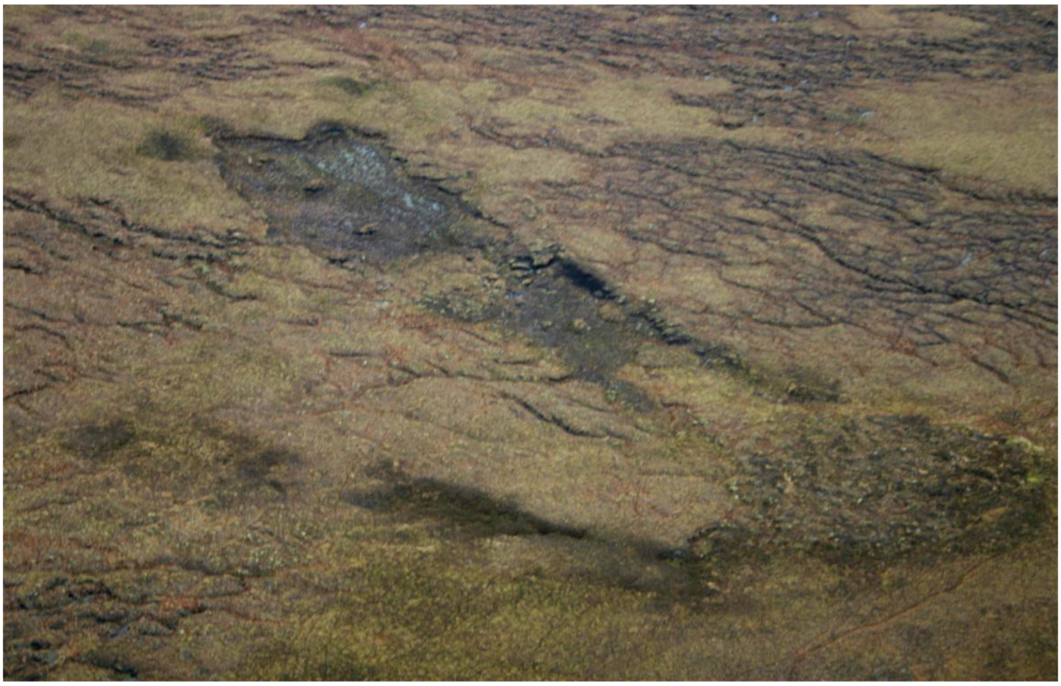

Fig. 4. Major peatslide on hillside showing head, track and run-out zones.

Potential peatslide severity

This is perhaps the most non-technical and subjective category to score because the potential consequences of a peatslide are difficult to surmise. Consideration should be given to potential impacts on (a) people, cattle and sheep, (b) physical assets such as roads, bridges, houses, fences etc, (c) environmental assets such as flora, fauna, landscape, water bodies, etc. It is also important to consider the size of an impacted area and distinguish large from small by using an appropriate score. Another consideration involves potential costs and delays to development projects and also the costs involved in any clean-up and subsequent site maintenance. And most difficult of all, potential recovery times that may apply for example in relation to fish stocks or revegetation etc.

Rated section length

Although the rated section length is not used for scoring purposes, it provides a useful measure in the scoring table as another means of attaching relative weight or significance to each PHRS zone. The heading itself is also useful for recording landmarks such as turbine positions.

Other considerations

In addition to scoring the above categories, the rating team should take photographs of significant features that influence the scores. They should also gather enough field information to recommend the most appropriate or suitable mitigation and/or remedial measures. Both total fix and hazard reduction strategies should be considered.

PHRS scores are intended as a means of comparing different sites and as a tool for prioritising risk reduction measures and mitigation works. The PHRS system itself does not attach any particular significance to the total score for each site and leaves it to the professional project engineers to draw their own conclusions based on an understanding of the local conditions that apply. However, as rule of thumb, sites with a rating of less than 200 are assigned a low priority while those with a rating of more than 400 are identified for urgent attention.

Total PHRS scores of 373, 482 and 434 apply in relation to the well-established peatslide localities at Morsgail, Isle of Lewis, Scotland (Bowes, 1960), Derrybrien, Galway, Republic of Ireland (Fleming 2003) and Hart Hope, North Pennines, England (Warburton et al, 2003) respectively (see Table 3).

Table 3. Peatslide Hazard Rating System (PHRS) results for established peatslide localities.

Zone / Site	Morsgail,	Lewis	Derrybrien,	Galway	Hart Hope,	Pennines
	Value	Score	Value	Score	Value	Score
Rainfall and climate	1600	81	1750	100	1100	6
Presence of water on slope		29		9		40
Rockhead or subsoil		55		75		80
Zone length (m)	220		180		550	
Peat profile and depth (m)	2.2	18	2.0	15	0.8	6
Peat strength – vane shear (kPa)	20	27	9	90	14	53
Slope and slope regularity	15°	81	8°	22	9°	26
Geomorphology and site history		36		30		55
Sub-profile drainage		25		27		42
Peatslide history		11		34		88
Potential peatslide severity		10		80		38
Total		373		482		434

To illustrate the variation in PHRS scores, total scores for 3 typical wind farm projects prior to peatslide risk reduction measures (A, B & C) are plotted on Figure 5 together with those for the peatslide localities listed in Table 3. Interestingly, this scattergram also demonstrates how the PHRS system was validated. Although Figure 5 shows single spot identifiers for total scores, results for say, turbine positions may be plotted as a cluster of points or as a bar showing the range of results obtained.

In addition, PHRS scores are extremely useful for project design purposes and for recognising opportunities for peatslide hazard mitigation. Appropriate engineering responses include deleting or repositioning turbine positions and access road routes, supplementary drainage works, slope engineering or ground stabilization.

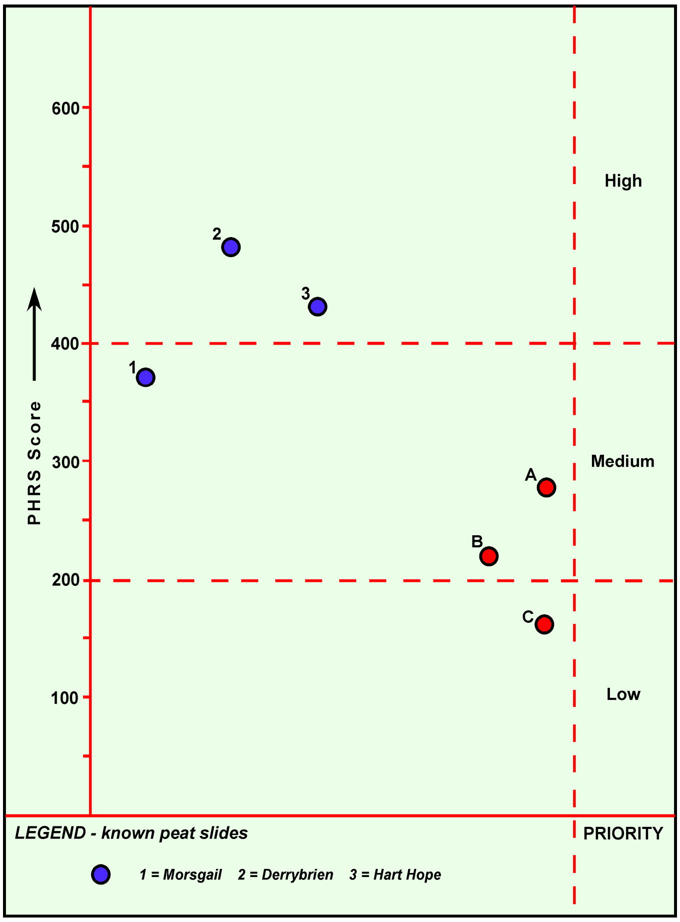

Fig. 5. Scattergram of PHRS scores for peatlide localities and 3 wind farm sites.

Conclusions

In this study, a Peatslide Hazard Rating System (PHRS) has been developed as a useful tool to rationally address peatslide hazards and provide a defensible, standardised way to assess priority by numerically differentiating the apparent risk at potential peatslide sites. As a screening tool it identifies high and low risk segments of a site so that high risk segments may be identified for further investigations.

The main factors affecting peatslide potential are rainfall, water on slope, rockhead, peat profile and depth, peat strength, slope, geomorphology, sub-profile drainage, peatslide history and severity. These factors are evaluated using a scoring matrix and the findings used as a means of comparing different sites and estimating the significance of the peatslide hazard.

Three case histories were considered to verify the appropriateness of the system and initial findings appear very promising for predicting the levels of risk associated with peatslides on peatland sites being considered for wind farm development projects.

Acknowledgements

The contributions and feedback from various colleagues at Enviros Ltd including Beverley Walker are appreciated.

References

Bowes, D.R., 1960. A bog-burst in the Isle of Lewis. *The Scottish Geographical Magazine*, **76**(1), 21-23.

Fleming, D., 2003a. Irish engineers battle huge landslide. *New Civil Engineer*, (6 November 2003), 6.

Fleming, D., 2003b. Check dams halt Galway wind farm landslide. *Ground engineering*, (December 2003), 4.

Hobbs, N.B., 1986. Mire morphology and the properties and behaviour of some British and foreign peats. Quarterly Journal of Engineering Geology, London, **19**, 7-80.

Holden, J., 2004. Controls on piping in peatlands; understanding subsurface-surface landform development. Paper 254-7, 32nd International Geological Congress, Florence 2004 – Scientific Sessions: abstracts (part 2), 1142.

Holden, J. & Burt, T.P., 2002. Piping and pipeflow in a deep peat catchment. *Catena*, **48**, 163-199.

Jones, A.A.A., 1978. Soil pipe networks: distribution and discharge. *Cambria*, **5**, 1-21.

McMillan, P. & Matheson, G.D., 1998. Rock slope hazard assessment: a new approach. *In:* Maund, J.G. & Eddleston, M. (eds) *Geohazards in Engineering Geology*. Geological Society, London, Engineering Geology Special Publication, **15**, 177-183.

Miller, S.M., 2003. Development and implementation of the Idaho Highway Slope Instability and Management System (HiSIMS). *University of Idaho, National Institute for Advanced Transportation Technology, NIATT Report No NO3-07*. (http://www.webs1.uidaho.edu/niatt)

Nichol, D., 2006. Users manual for the peatslide hazard rating system. *Enviros Ltd, internal* report (unpublished).

Pierson, L.A., 1992. Rockfall hazard rating system. *Transportation Research Record*, **1343**, 6-13.

Warburton, J., Higgitt, D. & Mills, A., 2003. Anatomy of a Pennine peat slide, northern England. Earth Surface Processes and Landforms, **28**, 457-473.

Winters, M.G., MacGregor, F. & Shackman, L., 2005. *Scottish Road Network Landslide Study*. The Scottish Executive, Edinburgh.