Landslide hazard assessment and characterisation for forestry asset management in Great Britain

C. Foster, H.J. Reeves, C. Pennington, P.R.N. Hobbs, M.G. Culshaw & J. Plim
British Geological Survey, UK

J.T. Smith
Golder Associates (UK) Ltd., formerly Transport Research Laboratory, UK

F. MacCulloch (FCS), G. Queen (FCW)
Forestry Commission, UK

M.G. Winter
Transport Research Laboratory, UK

ABSTRACT: Between 2008 and 2010, the British Geological Survey (BGS) carried out 2 separate studies to identify and quantify landslide hazards with the potential to affect third party assets (infrastructure, property and communities) in Scottish Forestry Commission managed land (with the Transport Research Laboratory) and in Wales. A desk-based investigation analysed a range of information, including: the BGS National Landslide Database, National Digital Geological Mapping (DiGMap50), landslide potential maps (GeoSure & DebrisFlow) plus information from published literature. These resources were used to score key landslide characteristics and, where necessary, estimate the magnitude and extent of the hazard. This was achieved using a custom geographical information system (GIS) combined with an established algorithm to assess the susceptibility to landslide hazards and the likelihood of their impact on third party assets. For areas where a high landslide potential was identified, proformas were completed, recording detailed information on the geological and geomorphological conditions, known or recorded landslides and assets at risk with a score for landslide hazard and likelihood. The outputs from this study are an attributed GIS with an accompanying inventory of detailed proformas. The study results are now contributing to the management & maintenance of Forestry Commission assets in Scotland and Wales.

1. INTRODUCTION

Compared with many countries in more geologically active areas, Great Britain (GB) has a low level of landslide hazard. Between 2005 and 2010, less than forty landslides a year were reported by the media and, excluding the 1966 Aberfan coal spoil debris flow (Anon. 1967), 'only' 16 people are recorded as having been killed by landslides in more than hundred years, most of these by coastal rock or debris falls (Gibson *et al.* 2012). The National Landslide Database contains information on between 15 000 and 16 000 landslides (Foster *et al.* 2012); this compares with nearly 500 000 landslides recorded in Italy (a country of similar size and population) (Trigila & Iadanza 2008) and a death rate of around 15 people per year (Guzzetti 2000).

However, despite this generally low level of risk from landslides in GB, land owners and managers are increasingly required to understand the risks associated with their land and how their activities may affect landsliding. This is particularly true where a landslide, initiated on a piece of land for which they are responsible, may impact on assets owned by others (3rd party assets). The Forestry Commission (FC) is a non-ministerial government department responsible for publicly-owned forest in GB. It has nearly 1 million hectares of land under its management, mostly in rural areas. The organisation has separate, but linked, management units for England, Scotland and Wales. 60% of its land is in Scotland, 26% in England and 14% in Wales. This land is divided into a series of forest blocks within larger forest districts for management purposes. Because much of its land, particularly in Scotland and Wales, is in areas of greater relief and higher levels of rainfall than elsewhere, the potential for landslides initiating from this land is such that the FC decided that it was necessary to better understand the level of landslide hazard and risk to 3rd party assets on land adjoining their forest blocks in the two countries.

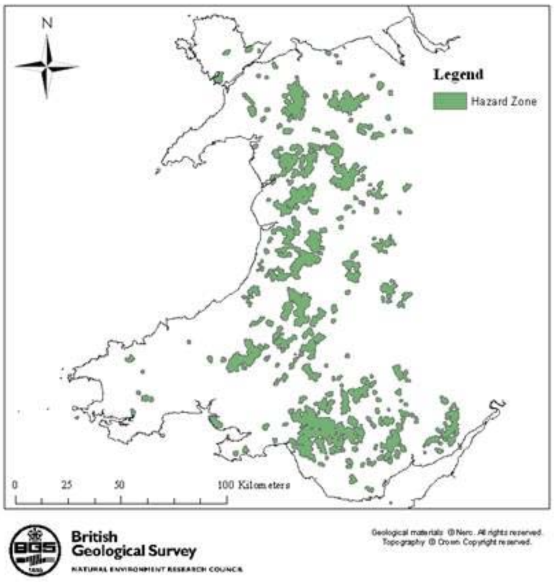
The FC in Scotland and Wales commissioned the British Geological Survey (with the Transport Research Laboratory, TRL) to carry out a study to identify and quantify landslide hazards that had the potential to affect 3rd party assets such as infrastructure, property and communities. This study, which was entirely desk-based using existing data sets, is described in this paper.

2. METHODOLOGY

The aim of the study was to determine the level of hazard posed by landslides originating on FC managed land in Scotland and Wales, which could impact upon 3rd party assets. The potentially affected areas were referred to as the *hazard zone* and included the FC managed land with a 500 m buffer area around it. A 500 m buffer zone was chosen because experience showed that this was the likely maximum extent of landsliding from the source to the toe in the areas being studied. However, in Scotland debris flow hazard is more significant and it was decided that a buffer of 800m would be used. The study methodology was determined and applied first in Wales and then in Scotland. Figures 1 and 2 show the extent of FC land (including the 500 m buffer zone) in Wales and Scotland respectively.

The objectives were to provide an assessment of the nature, distribution and extent of landslides that affect the hazard zone and then to characterise the potential hazard and likelihood of impact. The study was undertaken in two distinct phases. Phase 1 involved *landslide screening* – using existing datasets to identify those areas where further detail was required and where resources in Phase 2 should be concentrated. For those forest blocks where no landslides or indications of landslide susceptibility were identified, no further assessment was undertaken. Phase 2 consisted of *landslide characterization* – the use of available resources to identify and, where necessary, estimate key landslide characteristics.

Figure 1. Spatial extent of Forestry Commission Wales land including the 500 m buffer (*hazard zone*).



2.1 *Landslide screening - data sources*

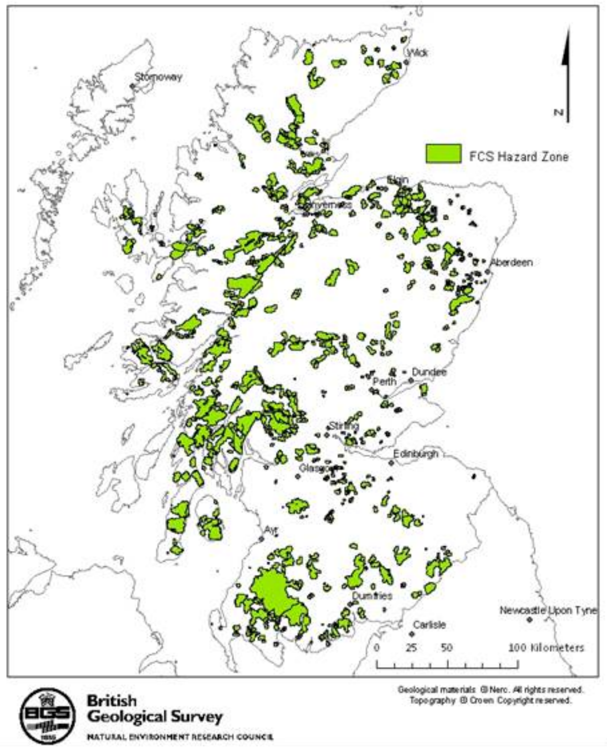
A number of data sources, held by the BGS were used during the first phase of work:

- BGS National Landslide Database (NLD).
- BGS Digital Geological Map of Great Britain (DiGMapGB50).
- BGS GeoSure National Hazard Assessment GIS (Slope Instability) (Walsby 2007, 2008).
- BGS GeoSure DebrisFlow.
- Landslides recorded by Smith (1984) (Scotland only).
- Information from the Scottish Road Networks Landslide Study described by Winter *et al*. (2005, 2008).

In addition, the FC provided digital files of the legal boundaries of FC managed land.

These data were interrogated by expert geologists to determine those areas of known landslides or known landslide susceptibility that may impinge upon or affect managed FC land and assets.

Figure 2. Spatial extent of Forestry Commission Scotland land including the 500 m buffer (*hazard zone).*



2.1.1 *The National Landslide Database*

The BGS National Landslide Database (NLD) contains over 16,000 records of landslides throughout Great Britain. It incorporates information from a nationwide database that was initially provided to BGS by the UK Government's then Department of the Environment, but this dataset has been considerably improved, expanded and quality assured, though some entries are still being checked. The BGS database stores information in 124 different fields including name, dimensions, landslide type, level of activity and recorded damage (Foster *et al.* in press). The NLD includes additional information about the mapped landslides and landslides reported in other sources. Sources of information outside of the activities of the BGS include textbooks, PhD theses, MSc dissertations and scientific papers in journals and conference proceedings. Other data are collected through media reports, site investigations and new mapping in the field. Data are stored within an ORACLE database, which can be queried through Microsoft Access and displayed spatially as an Arc GIS layer. Although the database represents the largest single resource of information about landslides in GB, it does not yet contain a complete record of all landslides across the country. Many records are not fully populated and a long-term process of populating the database more fully is underway by BGS.

2.1.2 *Digital Geological Map of Great Britain (DiGMapGB50)*

The BGS has a range of geological maps produced digitally at scales of 1:625,000, 1:250,000 and 1:50,000. For this study the most appropriate scale was the more detailed 1:50,000 model DiGMapGB50. This has a number of fully attributed layers, which include bedrock geology, superficial deposits and mass movement deposits. The latter was used in this study.

2.1.3 *GeoSure National Hazard Assessment GIS*

GeoSure is the national hazard assessment of geohazards (including slope instability) that is generated for the whole country using an algorithm within a GIS (Walsby 2007, 2008). The factors considered within GeoSure to assess slope instability include lithology, material strength, discontinuities and slope angle; it also incorporates information about mapped landslides. Although the system is essentially based upon interpreted data and experience, it provides a practical method of collating and interpreting complex information that would otherwise have been very difficult to use. For most purposes, the model is output as a GIS layer attributed with 'hazard' ratings A-E (Table 1). The GeoSure dataset was designed for assessment of the potential for geological hazards to cause damage to buildings. As such, it was used in this study only as a guide to where there were areas of greater susceptibility to landslide activity. The GeoSure dataset was clipped to the FC *hazard zone* and those areas with a rating of D or E were included in the output. The FC agreed that ratings A, B and C represented landslide susceptibilities that would not be significant for the purposes of this study and, therefore, would not be shown.

Table 1. Descriptions for the five ratings of slope instability within GeoSure

Rating	GeoSure Slope Instability Layer
A	No indicators for slope instability identified.
B	Slope instability problems are unlikely to be present.
C	Slope instability problems may be present or anticipated.
D	Slope instability problems are probably present or have occurred in the past.
E	Slope instability problems almost certainly present.

2.1.4 *GeoSure DebrisFlow*

A GIS method, modified from GeoSure, was also undertaken to assess the potential for debris flows. Compared with other landslides in the *hazard zone*, these types of landslides have a different set of criteria that can lead to their initiation. The methodology was developed by a separate research project that investigated the debris flow hazard posed to the transport network in Scotland (Winter *et al*. 2005). The factors taken into account when assessing the debris flow potential were: availability of debris material, hydrogeological conditions, land use, proximity of stream channels and slope angle. This analysis has mainly been carried out through an iterative process of attributing or manipulating each of these datasets to represent as many of the factors as possible that contribute to debris flow hazards (Harrison *et al.* 2008). Thus, expertise has been applied to DiGMap to change the standard attribution of polygons (age and type of rock) to numerical codes that estimate bedrock permeability and the degree to which source material for debris flows can be formed. Only the two most significant categories of debris flow potential (D and E) of this revised GeoSure methodology, like that of GeoSure itself, were used.

2.1.5 *Landslides from Smith (1984) (Scotland only)*

In 1984 an investigation was carried out into the location of landslides within the Scottish Highlands, particularly ones affecting infrastructure and development projects (Smith 1984). For this study, any landslides on Smiths's maps not shown on DiGMap but contained within the hazard zone were digitally captured and supplied as a separate layer. 28 such landslides were identified.

2.2 *Landslide characterisation*

Landslide characterisation involved using a custom Geographical Information System (GIS) combined with a hazard and likelihood scoring scheme suited to the potential and known landslide hazards.

For each area of landsliding or potential landsliding identified within a forestry block, which could affect a third party asset, an area (polygon) was drawn around the affected location using ArcGIS 9.2 GIS. For each identified area a proforma was completed describing geology, geomorphology, known and potential hazards, assets at risk and the results of the hazard and likelihood scoring.

In many cases landslide polygons contained information from more than one set of hazard data. The full set of data sources used in the GIS is listed below

- Forest areas (FC)
- Elements at risk (FC/Ordnance Survey)
- GeoSure, classes D & E (BGS)
- DebrisFlow, classes D & E (BGS/TRL)

- National Landslide Database: NLD (BGS)
- Smith Scottish Highlands landslides (1984) (Scotland only) (BGS)
- Instability points & areas (FC)
- Geology: DiGMap50 (BGS)
- Topography (OS)
- Spring locations (BGS)
- Digital Elevation Model, 5 m (NEXTMap)

2.2.1 *Hazard score*

For each polygon a score is given for 'hazard.' . Guzzetti *et al* (1999) define intensity of a landslide as a measure of its destructiveness which is a function of volume and velocity. It was felt this was a good way to define hazard with regard the assessment of the impact of landslides on third party assets. Therefore the hazard score reflects the likely speed of movement of the landslide and its size (length and depth). One score for each polygon is given, reflecting both the known and potential hazards within the defined polygon. In the case of multiple landslide types being present, the most hazardous landslide is scored giving a worst case scenario. There are three numbers given for hazard: one is the total score and the others, in brackets, are the scores for speed and size. Tables 2 and 3 and Figure 4 show how the different scores were determined. In the Glen Croe example, speed is scored '4' and size '5.' The product of these scores is '20' giving a hazard matrix score of '4.'

Table 2. Ratings and descriptions of landslide speed

Score	Speed	Landslide type
1	Extremely slow	Creep
2	Very Slow-Slow	Reactivated landslide
3	Moderate	Rotational landslide, Translational slide (low angle)
4	Rapid	Flow, Translational slide, (increasing slope angle, decreasing clay content). Bedrock translational slide.
5	Very rapid-Extremely rapid	Flow and rock fall

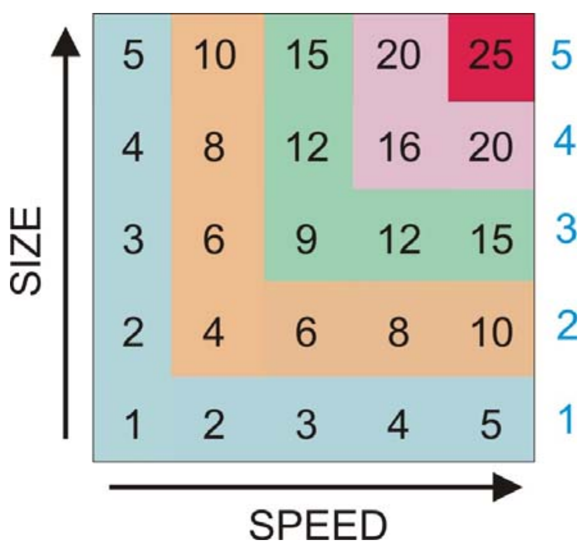
2.2.2 *Likelihood score*

For each 3rd party asset a score is given for 'likelihood.' This is the likelihood of any landsliding within the FC managed land reaching the asset at risk and not the likelihood of a slide actually occurring. It takes into account the distance that could be travelled by that landslide and includes a rating for any impediments that might obstruct travel such as rivers or places where the landslide would have to travel upslope. The likely distance travelled by landslides within the identified susceptible area will be dependent on the types of landsliding occuring. On the proforma there are three numbers given for 'likelihood;' one is the total score and the other two, shown in brackets, represent the scores for distance to the asset (from the landslide) and the impediment factor. Tables 4 and 5 and Figure 5 show how the different scores were determined. In the Glen Croe example, speed is scored '4' and size '4.' The product of these scores is '16' giving a likelihood matrix score of '4.'

Table 3. Scores and criteria for size ratings

Score	Size (m)	Example
1	10+	Small landslide into a river, slide at base of slope (confined).
2	<100	Shallow landslide (Rotational, translational, flow in superficial material)
3	<200	Translational and rotational landslides in bedrock. (Shallow, <3 m). Or larger superficial landslides.
4	<300	Debris flow. (Open slope, less steep slopes). Translational or rotational bedrock landslides (Moderately deep-seated, 3-5 m)
5	>300	Debris flow (channelised, steeper slopes). Translational and rotational slides (Deep-seated, >5 m)

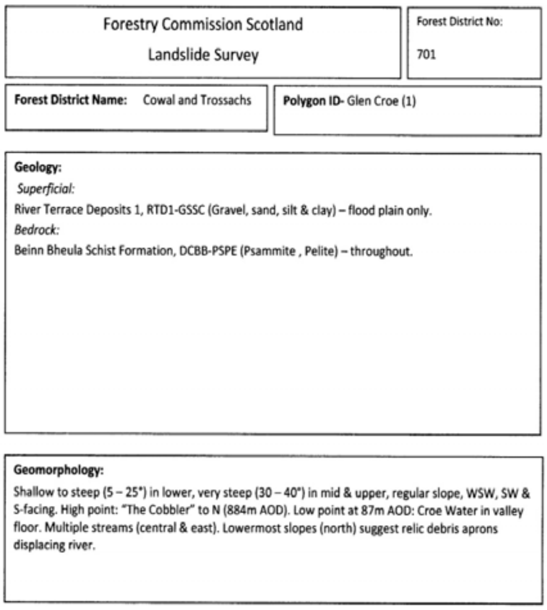
Figure 4. Score matrix for 'hazard.' The overall score (1-5), given as the first number in the proforma, is shown on the right of the diagram



2.2.2 *The proforma*

The proformas represent a written account of the information behind the hazard and likelihood scores. The end user is able to refer back to the proforma in order to determine how the scores have been derived. An example of a proforma produced for an area in the Cowal and Trossach district is given in Figures 3a and b:

Figure 3a. Landslide characterisation proforma (page 1) for the Glen Croe polygon in the Cowal-Trossachs Forest District, Scotland.



Forestry Commission Scotland
Landslide Survey

Forest District No: 701

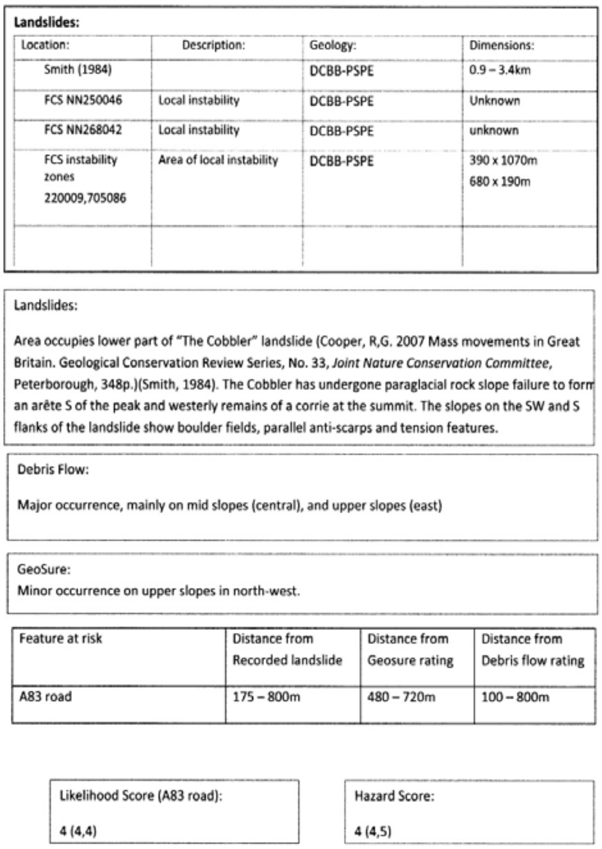
Forest District Name: Cowal and Trossachs

Polygon ID- Glen Croe (1)

Geology:
Superficial:
River Terrace Deposits 1, RTD1-GSSC (Gravel, sand, silt & clay) – flood plain only.
Bedrock:
Beinn Bheula Schist Formation, DCBB-PSPE (Psammite , Pelite) – throughout.

Geomorphology:
Shallow to steep (5 – 25°) in lower, very steep (30 – 40°) in mid & upper, regular slope, WSW, SW & S-facing. High point: "The Cobbler" to N (884m AOD). Low point at 87m AOD: Croe Water in valley floor. Multiple streams (central & east). Lowermost slopes (north) suggest relic debris aprons displacing river.

Figure 3b. Landslide characterisation proforma (page 2) for the Glen Croe polygon in the Cowal-Trossachs Forest District, Scotland



Landslides:

Location:	Description:	Geology:	Dimensions:
Smith (1984)		DCBB-PSPE	0.9 – 3.4km
FCS NN250046	Local instability	DCBB-PSPE	Unknown
FCS NN268042	Local instability	DCBB-PSPE	unknown
FCS instability zones 220009,705086	Area of local instability	DCBB-PSPE	390 x 1070m 680 x 190m

Landslides:

Area occupies lower part of "The Cobbler" landslide (Cooper, R,G. 2007 Mass movements in Great Britain. Geological Conservation Review Series, No. 33, *Joint Nature Conservation Committee*, Peterborough, 348p.)(Smith, 1984). The Cobbler has undergone paraglacial rock slope failure to form an arête S of the peak and westerly remains of a corrie at the summit. The slopes on the SW and S flanks of the landslide show boulder fields, parallel anti-scarps and tension features.

Debris Flow:

Major occurrence, mainly on mid slopes (central), and upper slopes (east)

GeoSure:
Minor occurrence on upper slopes in north-west.

Feature at risk	Distance from Recorded landslide	Distance from Geosure rating	Distance from Debris flow rating
A83 road	175 – 800m	480 – 720m	100 – 800m

Likelihood Score (A83 road):
4 (4,4)

Hazard Score:
4 (4,5)

3. DISCUSSION AND CONCLUSIONS

A methodology has been developed to enable the managers of Great Britain's public forests to assess the risk to 3rd party assets from landslides. This methodology is desk-based utilising a range of national datasets that are publicly available. For each forest block the presence of landslides and/or the potential for landsliding are identified. For each forest block within each forest district, where landsliding might occur, the nature of the landslide hazard is determined in terms of the speed and size of the landslide. Then, for each 3rd party asset (such as buildings or roads) the likelihood of a landslide impacting on the asset is determined by assessing the runout distance from the landslide source to the asset and the nature of any impediments to travel

Table 4. Rating system for likelihood incorporating run-out

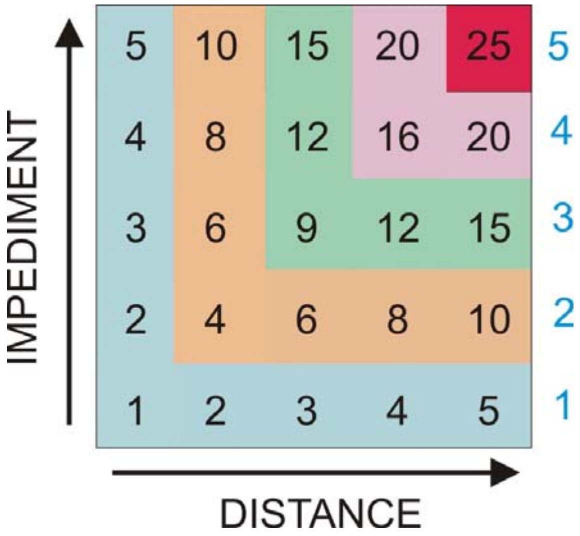
Score	Run-out (L)
1	Outside likely run-out distance
2	Outside of distance for any new slides but within run-out distance for reactivations
3	Within run-out distance (extremes/first time failures)
4	Within run-out distance (most cases)
5	0m to asset

Table 5. Impediment factor for inclusion in likelihood score

Score	Impediment Factor	Example
1	Landslide must cross a river	
2	Adverse topography	Slide needs to go up hill to reach asset.
3	Slide path goes against topography	Generally down slope but asset may be out of the direct path of a landslide or obstacles intervene.
4	Way is clear but slope is shallow	Low slope angles between landslide and asset.
5	Way is clear but slope is steep	Steep slope, run out more likely to reach asset.

Figure 4. Score matrix for 'likelihood.' The overall score (1-5) given as the first number in proforma, is shown on the right of the diagram

For each forest block, a proforma is produced that provides locational information, comments on the geology, geomorphology and landsliding, topographical information and the 'hazard' and 'likelihood' scores. It is recommended that the identified areas (polygons) that have been assessed as having a landslide hazard scores of 3, 4 or 5 and a likelihood of 3, 4 or 5, have a more detailed field-based slope stability assessment undertaken by a suitably experienced engineering geologist or geotechnical engineer.



Acknowledgements: This paper is published with the permission of the Executive Director of the British Geological Survey (NERC).

4. REFERENCES

Anon. 1967. *Report of the Tribunal appointed to inquire into the disaster at Aberfan on October 21st 1966.* London: Her Majesty's Stationery Office.

Foster, C., Pennington, C.V.L., Culshaw, M.G. & Lawrie, K. 2012. The National Landslide Database of Great Britain: development, evolution and applications. *Environmental Earth Sciences* (in press).

Gibson, A.D., Culshaw, M.G. Foster, C & Pennington, C.V.L. 2012. Landslide management in the UK, – the problem of managing hazards in a 'low risk' environment. *Landslides* (in press).

Guzzetti, F., A. Carrara, A., Cardinali, M and Reichenbach, P. (1999). "Landslide hazard evaluation: an aid to a sustainable development." *Geomorphology* 31: 181-216.

Guzzetti, F. 2000. Landslide fatalities and the evaluation of landslide risk in Italy. *Engineering Geology*, 58, 2, 89-107.

Harrison, M., Gibson, A., Forster, A., Entwisle, D. & Wildman, G. 2008. GIS-based assessment. In: Winter, M.G., Macgregor, F. & Shackman, L. (eds), *Scottish Road Network Landslides Study: Implementation*, 47-64. Edinburgh: Transport Scotland.

Smith, D.I. 1984. *The landslips of the Scottish Highlands in relation to major engineering projects*. Project Report 09/LS. Edinburgh: British Geological Survey.

Trigila, A. & Iadanza, C. 2008. Landslides in Italy. Report 83/2008. Rome: Italian National Institute for Environmental Protection and Research.

Walsby, J.C. 2007. Geohazard information to meet the needs of the British public and governmental policy. *Quaternary International*, 171/172, 179-185.

Walsby, J.C. 2008. GeoSure; a bridge between geology and decision-makers. In: Liverman, D.G.E., Pereira, C.P.G. & Marker, B. (eds.) *Communicating environmental geoscience*. London: Geological Society, Special Publications, 305, 81-87.

Winter, M.G., MacGregor, F. & Shackman, L. 2005. *Scottish Road Network Landslide Study Summary Report*. Edinburgh: The Scottish Executive.

Winter, M.G., Macgregor, F. & Shackman, L. (eds.) 2008. *Scottish Road Network Landslides Study – Implementation*. Edinburgh: Transport Scotland.