

Landslides in Ireland

**Geological Survey of Ireland
Irish Landslides Working Group**



Department of Communications, Marine and Natural Resources
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Front Cover: Pollatomish Landslide

LANDSLIDES in IRELAND

**Editor
Ronnie Creighton**

**A Report of the Irish
Landslides Working Group**

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PREFACE

Until recently Ireland has been regarded as a comparatively benign environment as far as landslides are concerned. However, two widely publicized landslides in the autumn of 2003 that occurred near Pollatomish in Co. Mayo and Derrybrien in Co. Galway demonstrated the extent of property damage and social upheaval that can result from such events. The Mayo event was preceded by periods of heavy rainfall which are thought to have triggered ground failure; at Derrybrien site construction work for a windfarm is thought to have been a further contributory factor. Fortunately on this occasion there was no loss of life or serious injury, although historic events have done so, such as that at Castlegarde, Co. Limerick in 1708 which claimed 21 lives.

The events of late 2003 served to emphasize our paucity of knowledge and understanding of such landslides and bogslides in Ireland. To address this situation, GSI in early 2004 established the Irish Landslides Working Group with membership invited from other Government Departments, state agencies and the university sector. Those who volunteered to join the Group brought with them a wide range of expertise in geology (both bedrock and glacial deposits), geomorphology, geotechnical engineering, planning and GIS. Since its inception the Irish Landslides Working Group has worked well and in a focused manner to deliver this report of their deliberations and data gathering.

An important conclusion of the work to date is that the incidence of landslide events in upland areas in Ireland has been grossly underestimated. The Irish Landslides Database which has been created records just over 100 entries historic landslide events whereas in Britain the British Geological Survey inventory records over 10,000 events. A pilot survey carried out by GSI in the Breifne uplands, in the north-west of Ireland in 2005 recorded over 700 historic events over a "county size" area, pointing to the fact that nationwide there are probably many thousands of unrecorded events. There is an urgent need to document these events as the first step in delineating landslide-prone areas and in order to produce landslide susceptibility maps to better inform planning decisions, to mitigate future property loss and safeguard our communities. Equally we need to better understand these events and how they occur, through focused and applied research programmes.

As development expands in Ireland with increased population pressure, new housing construction coupled with expanded infrastructure and communications systems will be required that will inevitably encroach into potentially hazardous areas. Predictions of accelerated climate change may further exacerbate property loss and environmental degradation resulting from more frequent landslide events. We must act now to curb the cost of future landslide hazards through better understanding and mapping of these hazards and by improving our capability to mitigate and manage such natural disasters.

Dr. Peadar McArdle
Director
Geological Survey of Ireland

EXECUTIVE SUMMARY

1. Introduction

Landslides are a major cause of substantial damage to property and loss of life every year across the globe. They are a major geohazard and can be triggered by earthquakes, volcanic eruptions, heavy rainfall, or indeed by man-made activities. Ireland is not a high risk area for major landslide events and in fact is a relatively benign environment in this regard compared to other countries. However the historic record does contain a few serious events such as that at Castlegarde in Co. Limerick when twenty-one people died. The events at Pollatomish and Derrybrien in 2003 brought this issue to the fore, and it was clear that there was no collated body of data either on the historic record or the susceptibility of areas to landslides in the future.

In early 2004 the Geological Survey of Ireland (GSI) established a multi-disciplinary team, the Irish Landslides Working Group (ILWG), with expertise in geology, geomorphology, geotechnical engineering, planning, and GIS. The main objectives were:-

1. Build a national database of past landslide events.
2. Examine geotechnical parameters with regard to landslides.
3. Assess the potential for landslide susceptibility mapping in Ireland.
4. Make recommendations on the integration of landslide hazard issues into the planning process.
5. Promote landslide research in Ireland.
6. Raise public awareness about landslide hazard in Ireland.

The Group did not have the resources within its timeframe to document submarine slope failures or coastal landslides. Also it did not have the remit to do site-specific studies at landslide events.

The Group was also of the view that the work should be done on an all-Ireland basis and welcomed the participation of the Geological Survey of Northern Ireland in the project.

2. Landslide Classification

As with many natural phenomena landslides have proved difficult to classify because of their inherent complexity with regard to movement and material types. The classification used is based on that of the British Geological Survey (BGS) and Varnes, 1978. Movement types are listed as flows, slides (rotational and translational), falls, topples, spreads, and complex. Earth materials range from clay-size particles up through boulder-size to solid bedrock. This grading classification is also combined with water content to give a fuller description. The materials classification used is also that adopted by the BGS in their Geohazards Programme. There is one crucial addition to it for the Irish context and that is the inclusion of peat as a significant material. The main material types are therefore rock, debris, earth, mud, and peat, which are defined in detail. The causes of landsliding are also complex and are the subject of substantial research worldwide. The myriad of factors can be divided into two groups. Firstly there are the conditioning factors which relate to the inherent nature of the slope in question – rock/soil type and their geotechnical properties, slope gradient and profile, slope drainage and permeability, and land cover. Secondly there are the triggering factors which act on the slope to initiate the landslide. These include earthquakes, volcanic eruption, heavy rainfall, natural erosion, and man-made causes such as undercutting and land drainage.

3. The Irish Landslides Database

Crucial to the study of landslide hazard in Ireland is data on past landslide events through the creation of a landslides database for the island of Ireland. An exhaustive search has been made of a wide range of sources and an Access database has been developed in GSI. Using this baseline information and modern landscape datasets, areas which might be susceptible to landsliding can be identified. GIS has been a very useful tool in defining more accurately the location, and determining the conditioning factors at any site. Digital maps on geology, topography and drainage, and land cover among others, as well as digital aerial photography, have

been very important in populating the database fields for the events. The initial search of reference sources has identified 117 events. Many more events will be identified in future research, as has been found in the Breifne project. The preliminary analysis indicated that Co. Wicklow has the most events (14), followed by Co. Mayo (12), and Co. Antrim (10). The majority of events (63) involved peat as the main material, while some 31 were composed of coarse debris.

At Pollatomish in northwest Mayo over 40 catastrophic landslides occurred on the night of Friday 19th September 2003. This was due to exceptionally heavy rainfall in the area. Extensive damage was done to roads, bridges, and houses. The majority of failures involved the sliding and flowing of peat down the hillside. It was concluded that, due to the contraction of the peat after a very dry summer, the excessive rainwater could gain rapid access saturating the peat mass very quickly and making it buoyant. This process was aided by the presence of an impermeable hard pan at the peat-mineral soil interface.

The Derrybrien landslide occurred on 16th October 2003. It was located on a wind farm construction site on the Slieve Aughty Hills just to the north of Derrybrien village. The site is covered with blanket bog. From the failure site the peat flowed down into a local stream and then into the main river which eventually reached Lough Cutra, causing a major fish kill there. It was concluded that there were two contributory factors, a zone of weak peat and proximity of a natural drainage channel. Activity associated with the wind farm construction was also felt to be a contributory factor.

4. Geotechnics of Landslides

Geotechnics of landslides is concerned with the failure mechanisms of soil and rock through an analysis of their strength parameters and the effect of water on those parameters. The geotechnical factors are separated into those relating to “mineral” soils, those relating to organic soils such as peat, and those relating to rock. Strength at failure is expressed in terms of the shear strength parameters, cohesion and angle of shearing resistance. Many landslides occur during or after heavy rain. Water has two main detrimental effects – it reduces the force resisting instability and increases those causing the instability. Water can also destabilise slopes where water seeps from an exposed face, as is the case where there is a sand layer in an exposed face of glacial till.

In Ireland “Mineral” soils are predominately glacially-derived. Glacial tills (or boulder clays) have high angles of shearing resistance, typically 30° to 35°. Very steep slopes can be cut in these soils in the short term but they will eventually fail due to the dissipation of soil suction forces. They are also subject to internal erosion. Pure clay soils are rarely encountered in Ireland.

Landslides involving peat, in both raised and blanket bog, make up a significant number of events in the Irish Landslides Database. Blanket bog failures are more common in the wetter autumn and winter periods, while those in raised bogs can occur at any time in the year. Water can make up to 90% of the peat mass, thus tending it to flow when it fails. Excess water pressure at the base can result in uplift and then downslope failure can occur. Man’s activities such as turf cutting or land drainage can also cause failure. There is a strong correlation between high rainfall and peat slides, as occurred at Pollatomish. The fibre structure of peat is also important. Increased humification with depth can produce weak layers which can be the source of failure.

Landslides in rock are common in upland areas where steep rock faces occur. They can take the form of free falls through air, topples about a pivot point, or slides which may be rotational or translational in form. They can occur because of the weakening of the rock by chemical weathering, physical weathering due to frost shattering, or movement along discontinuities in the rock such as bedding planes, joints or faults.

The geotechnical properties of Irish earth materials, particularly peat, need to be investigated with special reference to slope instability. Fundamental research is needed on the behaviour of peat at low effective stresses, and methods are needed to more accurately measure the strength properties of peat which are relevant to peat slides. Mineral soils prone to landslides also need to be identified.

5. Landslide Susceptibility Mapping in Ireland

Even though Ireland is not a high-risk zone for major landslides, landslides do occur and it is thus important to undertake landslide hazard and risk assessment. Such assessments are the subject of much research internationally with regard to the methodologies used. The terminology can be confusing as risk, hazard, vulnerability, and susceptibility are defined differently by different workers. The terminology of the United States

Geological Survey (USGS) has been adopted here. The two main types of risk assessment are qualitative and quantitative. In Ireland rigorous quantitative assessment is not feasible at the moment as the large amounts of data required are just not available. The most pragmatic approach for Ireland would be a qualitative expression of probability combined with an estimation of potential costs arising from a landslide. Therefore it is recommended that landslide susceptibility mapping be undertaken in Ireland and this could be a powerful tool for decision makers in dealing with landslide hazard issues.

The spatial relationship between landslide occurrence and the pre-existing environmental or conditioning factors can lead to the identification of areas of landslide susceptibility. GIS can provide an integrated framework for analysis where different map datasets - geology, soils, vegetation, etc. can be superimposed one on another and the total character of a site or area can be identified. When combined with remote sensing datasets such as LANDSAT or LIDAR they provide a very powerful tool for susceptibility mapping. These datasets are now available for Ireland.

A pilot susceptibility mapping case study was done in Co. Mayo where landslides have occurred and where the necessary digital datasets are available. Two key criteria, devised by the geotechnical engineers, were used as the basis for the susceptibility modelling. These were – “peat is in excess of 0.5m thick or the peat slope is greater than 15°”. Three different runs of the susceptibility model were done. In the first run the key input maps were the EPA Soil and Subsoils Maps (prepared by the Spatial Analysis Group at Teagasc), and a Slope Map derived from the EPA-Teagasc DEM, which, when the two criteria were applied, produced the first run susceptibility map. This indicated a low percentage of occurrences of susceptible areas. In the second run the Subsoils Map and the Land Cover map were combined to give a Reclassified Peat Map. This was combined with the Slope Map (slope > 15°) to give a second run susceptibility map which showed a greater area of susceptibility. In the third run both criteria were used with all peat cover. The area of susceptibility increased again. The study only examined peat areas and did not consider mineral soils.

The study highlighted the challenges in incorporating highly resolved criteria such as those used into deterministic regional mapping. The modelling process can be greatly improved by evaluating these relationships. There needs to be comprehensive research on the issues raised by this study. Also, susceptibility rules for mineral soils and rock need to be devised, and the issue of run-out areas downslope needs to be considered in the modelling. This susceptibility mapping provides the potential for the development of planning guidance in the future.

A second susceptibility pilot project was undertaken in the Bréifne Area covering parts of Counties Sligo, Cavan, and Leitrim. Several thematic datasets were used including bedrock geology, Quaternary geology, rock outcrop, and Land Cover. This last, the Land Cover Map produced by Teagasc, was the most suitable. A 20m DEM, black and white orthophotography, and colour stereophotography were the main digital datasets used. The Landsat ETM was not used due to its poor spatial resolution. The two geotechnical criteria used in the Mayo project were used here. As a result of this image interpretation and fieldwork 706 landslide events were identified and subdivided into four groups – bedrock slides, peat slides, flows, and falls.

A full statistical analysis was done on these events in relation to their occurrence on the various thematic layers as well as the slope, elevation, and aspect parameters. The resultant weightings were then used to produce a series of landslide susceptibility maps for the region. An error assessment was then done to compare the distribution of the actual landslides with the predicted susceptibility zones. The correlation was a good one. This pilot project was important in that it identified the thematic and digital datasets which were of value. Fieldwork was an important component of the project, and the combination of image interpretation and fieldwork on an iterative basis proved to be a very effective method of study. Further research is needed to improve the classification systems used, and other thematic and digital datasets need to be added to the model to improve its robustness.

6. Landslides and Planning

The Planning and Development Acts 2000-2004 provide the legal framework for the Irish planning system. National guidelines relevant to the development of unstable land are “Guidelines on Quarrying and Ancillary Activities (2004)” and “Draft Wind Energy Development Guidelines (2004)”. Most Development Plans do not contain objectives with regard to unstable ground, except for coastal areas. The Building Control Act 1990, through the Building Regulations, imposes requirements on the design and construction of buildings to ensure they are safe. The Regulations make no specific reference to landslide risk.

Strategic Environmental Assessment (SEA) applies to certain Development Plans, Local Area Plans, and Special Development Zones (SDZ). It is a formal, systematic evaluation of the likely significant effects and

involves a report on the current state of the physical environment. The Irish Landslides Database could be a valuable baseline data input at the start of the SEA process. Environmental Impact Statements (EIS) have to be completed for specified projects. The topics to be covered in an EIS are set out in the Regulations pertaining to such statements. Geology is not specifically mentioned, but the EPA Guidelines for them do make reference to consideration of all the natural materials underlying a development so geology should be considered.

The United Kingdom (UK) has a lot more landslides than Ireland. England and Wales have specific guidance on landslides and planning. These are PPG 14 “Landslides and Planning” and PPG 20 “Coastal Planning”. The guidance aims to advise all interested parties about the exercise of planning controls on lands which are, or potentially are, unstable. It requires the carrying out of detailed identification and assessment of landslides.

Given that there may be a greater frequency of landslides in the future due to the impact of climate change and the increased pressure for development in remoter areas, it is important that the issue of land instability is addressed at all stages of the planning process. This will require up to date information on landslide occurrence in a readily accessible format. Before this can be achieved the Irish Landslides Database needs to be expanded, and research work on landslide susceptibility mapping and hazard assessment needs to be undertaken. This research would require an appropriate level of funding. The preparation of national guidance on this issue should be considered as part of the wider issue of natural hazards in general. Specific national guidance could then be formulated which could call upon a landslides database, require the identification of susceptible areas and the formulation of landslide risk assessments where relevant. The guidance would also ensure that the type of development is suitable for the ground in question, and recommend that landslide mitigation measures be taken to reduce the risks linked to developments.

7. Landslides in Northern Ireland

Landslides occur in a number of different geological settings in Northern Ireland and in some cases constitute significant geohazards. Landslides are common around the edge of the basalt plateau in Counties Antrim and Londonderry where large, deep-seated rotational slip blocks of basalt and chalk were activated as a result of glacial erosion of the underlying softer Jurassic mudstones. Mudflows and debris flows are also a significant hazard along the Antrim Coast Road. Catastrophic flows of mud, triggered by the ground saturation of the Jurassic mudstone after heavy rainfall, have blocked the road near Glenarm on many occasions. Rock falls are an ever present problem around the edge of the plateau in Counties Antrim and Londonderry, and the steep overhanging basalt cliffs require continuing management with the use of geotextiles or rock anchors and, in some cases, removal of sections of the rock face. In 1998 the British Geological Survey (BGS) undertook a geohazard research project on the Antrim coast which identified zones of landslide risk and described the constraints to development within the various hazard zones.

In Co. Fermanagh landslides and large block screes occur at the base of the steep mountain slopes and along the cliff lines at Magho, Belmore, and Cuilcagh. Glacial erosion produced oversteepening of the cliffs of limestone and mudstone and triggered rotational landslides. Although now mainly dormant, slope instability at Magho continues to affect the A46 road.

Peat slides and bog bursts are rapid mass movements in upland peat areas triggered by heavy rainfall. They have been recorded on the Antrim Plateau and on Cuilcagh Mountain in Co. Fermanagh. Peat failure is not fully understood but there are some common factors. The peat generally overlies a low permeability mineral soil layer and there is connectivity between the surface drainage and the peat/impermeable layer interface. They are found on a convex slope or a slope with a break of slope at its head, and in proximity to local drainage. Upland peat areas are under pressure from wind farm developments and developers are now routinely asked to assess the risk of landslides in their Environmental Impact Assessment submissions.

The Geological Survey of Northern Ireland (GSNI) is a statutory consultee to the Planning Service in Northern Ireland and provides advice on a range of geologically-related planning matters including landslide risk.

It is difficult to predict whether or not landslide risk will increase as a result of future climate change. The predicted increase in amounts and intensity of winter precipitation, accompanied by increasing severity of winter gales, could increase the risk of slope instability.

A landslides database for Northern Ireland would help raise awareness of landslide hazard and provide an improved capability to deliver geological information to key stakeholders. It is therefore recommended that landslides in Northern Ireland be fully documented in a database, and, where appropriate, research be undertaken into landslide risk assessment and landslide susceptibility mapping. Consideration should also be given to the development of a detailed Planning Policy Statement similar to PPG 14 “Development on Unstable Ground” already in operation in England and Wales.

8. Landslide Research in Ireland

This chapter attempts to document the landslide research which has been undertaken in Ireland. It is by no means an exhaustive review of the work that has been done. Prior to 2003, when the Pollatomish and Derrybrien landslides occurred, research work on landslides can be divided into two categories. The first was field based geomorphological study carried out by geology and geography academics, and the second was geotechnical and largely laboratory based research done in civil engineering departments of the universities. Tomlinson (Queens University, Belfast) worked on peat erosion and peat slides in the uplands of Northern Ireland. Coxon (Trinity College Dublin), with other colleagues, documented the peat slides in Co. Sligo during the 1980's. Dykes, Kirk, and Warburton examined peat failures on Cuilcagh Mountain on the Cavan/Fermanagh border. Hanrahan and others worked extensively on the geotechnical properties of peat.

Subsequent to the landslides of 2003 and the establishment of the Irish Landslides Working Group, a research workshop was held in Trinity College Dublin in October 2004. This brought together several university lecturers and postgraduate students who were working on various aspects of landslides research in Ireland. Abstracts of these and other research projects are included in this publication. There are two abstracts on the Pollatomish landslides. Dykes and Warburton documented the landslides and discussed the reasons for peat failure. Murphy conducted a geophysical investigation on one slide using ground penetrating radar (GPR) and a seismogram. The GPR successfully determined the failure plane of the peat. O'Loinsigh and Boylan examined the use of satellite imagery and digital elevation models (DEM) to identify landslide events in Co. Sligo and Co. Wicklow respectively. Colgan assessed the use of GIS techniques in mapping landslides and producing susceptibility maps. Boylan, Long, and Farrell looked at the geotechnical properties of peat and glacial till. Elliot described submarine slope failure in offshore Ireland using data derived from the GSI National Seabed Survey. McDonagh assessed the socio-economic significance of landslides, and Tonry addressed the issue of the integration of the landslide issue into the Irish planning process.

Much research still needs to be done on landslides in an Irish context. From a geotechnical standpoint, peat strength and behaviour, as well as the behaviour of Ireland's glacially-derived soils require more work. As the work of the Irish Landslides Working Group has identified, there is a need for multi-disciplinary studies on landslide phenomena involving geologists, geomorphologists, engineers, ecologists, climatologists, and planners. An important topic is the impact of climatic change on landslide susceptibility. With progress in these specific research themes, more informed research can be undertaken on the methodology of landslide susceptibility mapping and risk assessment. All of this research requires a dedicated funding stream with the Irish Landslides Working Group or its successor taking up a co-ordinating or advisory role.

9. Recommendations for Future Work

The Irish Landslides Working Group recommends that a large body of research be completed with regard to landslide hazard assessment in Ireland. The growing pressure for development in more marginal land areas, and the potential impacts of climate change, make such work an important imperative in the context of the sustainable development of the Irish landscape, and also on health and safety grounds.

Landslide hazard is a major geohazard and is included as a survey and research theme in the Geoscience Initiative recently prepared by the Geological Survey of Ireland, and currently being proposed to Government for funding. In addition landslides are being examined in an all-Ireland context. There has been extensive co-operation between the Geological Survey of Ireland and the Geological Survey of Northern Ireland on this and other geoscience themes. The work will require a multi-disciplinary team bringing together various types of expertise, and therefore a multi-agency approach. This landslides report lays the foundation of such research, in documenting the issues involved.

Several key recommendations for future work on landslides in Ireland have been made. For each project, the main objectives are set out and estimated costs given to reflect a three-year programme in all cases. The specific tasks for each of these objectives are also listed in the report. A strategic framework to implement this work programme is also outlined.

1. Public Awareness/Outreach

It is important that there is much greater public awareness of landslide hazard in Ireland so that the general public know of the potential for slope instability in certain areas and the possible consequences in terms of life and property.

Main Objectives

- Increase public/private sector awareness of landslide hazard in Ireland
- Provide practical support and guidance to developers/regulators

Cost:- €15,000

2. Landslide Susceptibility Mapping and Research on Geotechnical Properties of Landslides

Surveys of past landslide events and research into landslide materials and mechanisms underpin all future strategy on this geohazard in Ireland.

Landslide Susceptibility Mapping

Main objectives

- Expansion and enhancement of the National Landslides Database
- Production of landslide susceptibility maps on a phased regional basis
- Assessment of the feasibility of landslide hazard and risk mapping in Ireland
- Assessment of the impact of climatic change on slope instability in Ireland

Cost:- €490,000

Research on Geotechnical Properties of Landslides

These research projects on the geotechnical properties of landslide materials will be undertaken in University College Dublin and Trinity College Dublin under the supervision of geotechnical engineers, who are members of the Irish Landslides Working Group. The research is costed over a three-year period in each case.

- Priority 1 Peat slides and peat strength
- Priority 2 Stable slopes in glacial till
- Priority 3 Stable slopes in marine tills

Cost:- €430,000

3. Landslides and Public Policy

The most important benefit of all the proposed projects listed above would be the full integration of landslide hazard into public policies on planning guidelines and development control. Such integration can only be implemented when appropriate and readily accessible datasets on landslide susceptibility mapping and landslide risk assessment are available.

Main Objectives

- Increase an awareness of landslide hazard in Ireland
- Full integration of landslide hazard into public policies on planning guidelines and development control

Cost:- €50,000

Total Cost :- €985,000 over a three-year period

Strategic framework

- Future work on landslide hazard must be done within a well-funded strategic framework.
- The work already done by the Irish Landslides Working Group and reported in this publication should form the basis for the future work.

- The landslides hazard work should be continued within a multi-disciplinary framework led by the Geological Survey of Ireland.
- This multi-disciplinary approach would involve geologists, geomorphologists, geotechnical engineers, climatologists, planners, and those with GIS expertise
- The collaborators would include university researchers, local authorities, government departments and agencies such as Teagasc, and consulting geologists and engineers.
- The funding necessary for the proposed work programme should be sought.

1. INTRODUCTION

Ronnie Creighton

1.1 Background

Landslides are a major geohazard in many countries across the globe, along with earthquakes and volcanoes. Indeed many landslides are triggered by earthquakes or volcanic eruptions. These landslide events lead to massive losses in terms of human life and infrastructure. Landslides are a major area of scientific research by both geologists and engineers. At La Conchita, California (Plate 1.1) a landslide which was initiated in 1995 reactivated in heavy rain in 2005 killing ten people.



Plate 1.1 La Conchita, California 1995, 2005
(<http://landslides.usgs.gov/>)

Landslides have the potential to cause great havoc, and have done so all around the world. They have resulted in massive loss of life and damage to infrastructure. The landslides caused by the earthquake in Pakistan in October 2005 are a case in point. With regard to infrastructure, landslides can damage roads, railways, canal embankments, and cause dams to fail. They can destroy or severely damage buildings of all types – housing, commercial or industrial property. Rivers can be blocked or diverted by sediment or rock displaced by landslides. The consequences of this can include flooding, pollution of watercourses and the killing of fish stocks. This was the case at Derrybrien. Agricultural land can be sterilised in the short to medium term. It does not require spectacularly huge landslide events to cause serious disruption or loss of life. Relatively small landslides in terms of the volume of material displaced can damage bridges and roads, and also cause injury and death. These potential impacts of landslides, irrespective of their size, mean that the scale of the problem for Ireland in the past and into the future needs serious attention so that the susceptibility of the Irish landscape to slope instability can be properly assessed.

Ireland is fortunate not to be in a high risk area for these major geohazards. Indeed, in comparison to many other countries, Ireland may be regarded as a benign environment in terms of landslide hazard. Ireland has had many landslides over time but these have been mostly small scale failures or in remote areas where there has been little impact in terms of loss of life or damage to property. The potential for major destructive landslides is slight. However there have been instances of severe events in Ireland in the past. Twenty-one people died at Castlegarde in Co. Limerick in 1708. Consequently landslides in Ireland have not been the subject of any coordinated research in terms of assessment on a national scale of past events or failure mechanisms.

Events in late 2003 at Pollatomish in Co. Mayo (Plate 1.2), and Derrybrien in Co. Galway, where there was considerable damage done but thankfully no loss of life, have highlighted the paucity of information on landslides in Ireland. There is no collated body of data either at the regional or national scale. It was clear that much work needs to be done to assess the scale of the problem historically and also to assess the susceptibility of areas to landslide hazard in the future. This has direct relevance to the sustainable development of the landscape in terms of housing, infrastructure etc. and is therefore an important issue for the planning process.



Plate 1.2 Pollatomish Landslides, Co. Mayo

Predictions have been made about the impact of global warming on Ireland (Sweeney, 1997). In summary these predictions indicate a change to wetter winters and drier summers. In addition there may be an increase in frequency of high intensity rainfall events. Such precipitation changes could have serious implications for slope stability. Given this scenario it is important that an assessment of landslide hazard is undertaken and to this end the Geological Survey of Ireland (GSI) set up the Irish Landslides Working Group (ILWG) to examine the issue.

1.2 Irish Landslides Working Group

The Irish Landslides Group (ILWG) was established in early 2004 as a direct response to the landslides in the autumn of 2003. It was felt important that it should be a multi-disciplinary team, bringing together various types of expertise which are relevant to landslide studies. This point is often stressed in the international literature on the subject (Brunsden, 1993). The Group includes expertise on geology (Bedrock and Quaternary), geomorphology, geotechnical engineering, planning, and GIS. The participants were drawn from state and semi-state agencies, and also the universities (Appendix 1).

Main objectives:-

1. Build a national database of past landslide events
2. Examine geotechnical parameters with regard to landslides.
3. Assess the potential for landslide susceptibility mapping in Ireland.
4. Make recommendations on the integration of landslide hazard issues into the planning process.
5. Promotion of landslide research in Ireland.
6. Raise public awareness about landslide hazard in Ireland.

It is not within the remit of the ILWG to undertake site-specific studies at landslide events as they occur but to collate data on landslides at a national level in order to make recommendations for future mitigation of landslide risk.

The work of the Group was focused on landslide events inland on the island of Ireland and the group was also very keen that it should be an all-Ireland project. It did not consider submarine slope failures or coastal landslides caused by marine erosion. This latter is a very important category of slope failure in Ireland as indicated by the problems of marine erosion around our coasts. However it was decided that the ILWG could not cover this in any detail, as it was felt the group did not have the resources within its timeframe of operation to examine it adequately, and also because information on coastal instability is very poorly collated and there is very limited published data. It is certainly a topic for future study both at a national and regional level.

1.3 The Landslides Publication

This publication has been written by members of the ILWG and produced by the GSI. It is very difficult to tailor such a publication for a wide range of readership. It began as a short general report on landslides in Ireland. However as the project progressed a substantial body of work was assembled which had to be documented. The style of the publication was therefore revised substantially. The main objectives are to inform the wider public in Ireland about landslides in general, and also to provide technical data and discussion on some core issues for those who have a professional or academic interest, or indeed responsibility with regard to landslides.

It seeks to describe the various types of landslides that can occur, including the earth materials involved and the mechanisms of failure, and to illustrate the amount of information that is available about past landslide events. Consideration is also given to the geotechnical parameters involved in slope failure and landslide susceptibility mapping for Ireland. The integration of landslide issues into public planning policies is crucial to the future limitation of landslide hazard in the context of sustainable landscape development. It also documents landslides research to date and examines future strategies in this regard. Above all it aims to increase awareness about slope instability and landslide hazard in Ireland. This is addressed in one of main recommendations in Chapter 9:-

Public Awareness/Outreach

It is important that there is much greater public awareness of landslide hazard in Ireland so that the general public know of the potential for slope instability in certain areas and the possible consequences in terms of life and property.

Main Objectives

- Increase public/private sector awareness of landslide hazard in Ireland
- Provide practical support and guidance to developers/regulators

2. LANDSLIDE CLASSIFICATION

Ronnie Creighton

2.1 The Problem of Definition

Landslides come in a great variety of shapes and sizes. Some are very large and cause great devastation while others are very small and cause little or no damage at all. They can be single events of slope instability, or they can be complex in nature with multiple events at the one site. They can occur in a wide range of earth materials and be due to a variety of failure mechanisms. There is a virtual myriad of types and great efforts have been made over the years by researchers to order or classify these very significant natural phenomena.

The term “**Landslide**” is the internationally accepted term now for any downslope movement of earth materials under the force of gravity. It is thus a generic term which covers all types of downslope movement. Other such terms used generically in the past have included “landslip” and “mass movement”. There are several different mechanisms by which material is transferred downslope under the influence of gravity. In addition there are several styles of landslide and several different earth materials involved. The latter are discussed in more detail in Section 2.3 below.

2.2 Landslide Movement Types

The type of movement is dependent on many factors including the slope gradient, type of material, and the hydrological conditions. There are seven main types which are set out in Table 2.1 below.

Type of Movement	Description
Flow	Slow to rapid mass movement in saturated materials which advance by viscous flow, usually following initial sliding movement. Some flows may be bounded by basal and marginal shear surfaces but the dominant movement of the displaced mass is by flowage.
Rotational Slide	Sliding outwards on one or more concave-upward failure surfaces.
Planar Slide	Sliding on a planar failure surface running more or less parallel to the slope
Fall	Mass detached from steep slope/cliff along surface with little or no shear displacement, descends mostly through the air by free fall, bouncing or rolling.
Topple	Forward rotation about a pivot point.
Spread	Lateral extension of a rock or soil mass.
Complex	Slides involving two or more of the main movement types in combination.

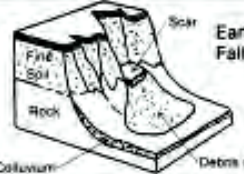
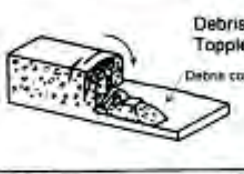
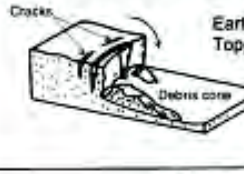
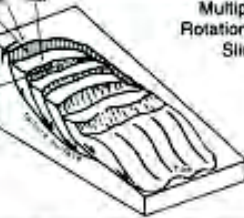
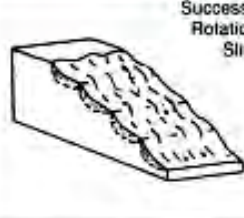
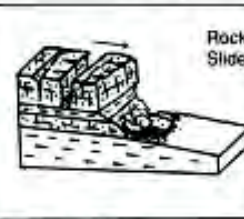
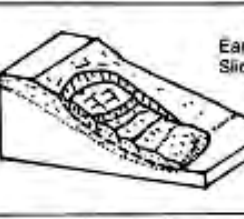
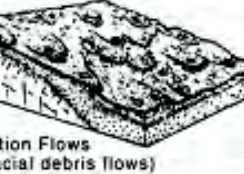
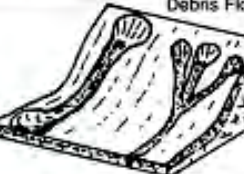
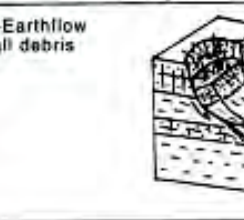
Table 2.1 Landslide Movement Types. Based upon Waters, 1996 (by permission of the British Geological Survey), and Varnes, 1978.

Nature is usually more complex than classifications can portray. As indicated in Table 2.1, for flows and falls there is often a combination of types of movement involved in any one event. As the failure progresses there is an evolution in the mechanisms of movement which is reflected in the landslide geometry. Such events are classified as complex. These types are set out graphically in Fig. 2.1.

Flows

Flows can occur in bedrock but they are extremely slow and occur in areas of high relief. They have rarely been documented in Ireland and will not be discussed further here.

Flows in unconsolidated materials are much more obvious and indeed do occur in Ireland. In terms of speed flows can range from slow to very fast, and in terms of moisture content, can range from totally saturated to dry. However generally the effect of water is important in initiating flow.

Material		ROCK	DEBRIS	EARTH
Movement type				
FALLS	Falls	 Rock Fall	 Debris Fall Scree Debris cone	 Earth Fall Scarp Colluvium Debris cone
	Topples	 Rock Topple	 Debris Topple Debris cone	 Earth Topple Cracks Debris cone
SLIDES	Rotational	 Single Rotational Slide (Slump)	 Multiple Rotational Slide Crown, Head, Tail, Toe	 Successive Rotational Slides
	Translational (Planar)	 Rock Slide	 Debris Slide	 Earth Slide
FLOWS		 Spillfluction Flows (Periglacial debris flows)	 Debris Flow	 Earth Flow (Mud Flow)
COMPLEX		 eg. Slump-Earthflow with rockfall debris	 eg. Composite, non-circular part rotational/part translational slide grading to earthflow at toe	

(IPR/65-17C British Geological Survey. © NERC. All rights reserved)

Fig. 2.1 Landslides Classification (After Waters, 1996)

Debris flows contain a high percentage of coarse fragments and often result from unusually high precipitation. The moving soil and rock debris quickly gains the capacity to move considerable amounts of material at faster and faster speeds. They often follow already existing stream channels and can extend for several kilometres before stopping and dropping their debris load in river valleys or at the base of steep slopes.

Mud flows on the other hand are made up of fine grained materials (> 50% sand-, silt-, clay – sized particles (Varnes, 1978). They are highly saturated and can propagate and move very quickly. In the international literature there are various classifications of mudflows, the detail of which are not of concern to us here. The best examples of mudflows in Ireland occur on the Co. Antrim coast north of Larne.

Falls

Falls involve the free fall through air of a detached rock or debris mass. There is little lateral displacement at the point of rupture but the material may roll or bounce for considerable distances downslope forming talus slopes and scree slopes. Falls can happen very rapidly with no prior indication. They are very common, both in rock and debris, on steep slopes below bedrock scarps in upland areas. The extensive development of talus and scree slopes is testament to this. Falls may be activated due to a loss of support because of basal erosion, to a loss of internal strength due to weathering, or to mechanical break-up by water freezing/thawing processes.

Topples

Toppling is a distinct type of movement which can be classified separately to falls. It involves the forward tilting of a rock mass about a pivot point under the force of gravity. The rock mass may stay in place in this position for a long time or it may fall away downslope due to further weakening or undercutting. This will depend on the rock type, the geometry of the rock mass, and the extent of the discontinuities.

Spreads

In contrast to flows the dominant movement in spreads is lateral extension due to shearing or tensional fractures. In bedrock there may be such extension without a controlling basal shear surface (Varnes, 1978). Alternatively this extension of coherent rock or soil may be due to plastic flow of a weaker subjacent layer. The coherent mass may subside into the lower layer or it may slide or flow. Spreads can therefore be very complex but are felt to be distinct enough to be classified separately.

Complex Landslides

Complex landslides involve more than one type of movement mechanism. There can be different types of movement in different parts of the moving mass at the same time or a change of movement type as the landslide develops and proceeds downslope. Classifications can often be quite artificial constructs and this is true in the case of landslides also. Though individual types can be identified in nature, as described above, two if not more types of movement are often involved. A common occurrence is where slides develop into flows in the lower parts of the slope. Large landslide zones usually have complex landslide types. Examples of this type of terrain occur on the Isle of Wight and the coast of Dorset in southern England (Conway, 1977). Landslide zones of this scale and complexity are rare in Ireland, the best example probably being on the coast of Co. Antrim north of Larne (Prior et al, 1968).

2.3 Landslide Materials

The classification of the earth materials involved in landslides is also very difficult. Earth materials range in a continuum from clay-size particles, up through boulder-size to solid bedrock. They are principally classified according to grade and water content. Further information, for example on texture and structure, can also be brought into the classification scheme if it is available. In addition more than one type of material may be involved in any one event. On any particular slope there is likely to be a stratigraphy or layering of various material types. The landslide may be initiated in one particular layer.

The following is a list of material types commonly used in landslide mapping:-

1. Bedrock Rock so lithified that it cannot be removed by digging.
2. Debris Coarse-grained soils dominated by material of gravel-size or greater – greater than 2mm in diameter.
3. Earth Fine-grained soils dominated by material of clay to sand-size, in a dry condition – less than 2mm in diameter.
4. Mud Fine-grained soils dominated by material of clay to sand-size, in a wet condition – less than 2mm in diameter.
5. Peat Organic material formed by the accumulation of dead plants in waterlogged conditions.

In Ireland the Quaternary or unconsolidated sediments over rock are mainly glacial tills, sands and gravels. Another important characteristic of the Irish landscape is that there are extensive tracts of peat bog, both raised bog in the midlands, and blanket bog in the uplands and along the western seaboard. Both of these have important ramifications for landslide susceptibility in Ireland.

2.4 Factors causing Landsliding

Slope failure can be due to a large number of factors. The engineering investigation of actual slope failure or the designation of areas of potential landslide hazard is highly complex. Landslides are a major area of research on a global scale with international conferences taking place on a regular basis at different venues around the world. This research has become more and more interdisciplinary in nature. As a starting point, in order to set up a simpler framework for further analysis, the myriad of factors can be classified into two main categories. These are the background or conditioning factors and secondly the external or triggering factors.

Conditioning Factors

Of fundamental importance are the physical characteristics of the slope which might make it prone to failure if triggered by other external factors. These physical factors are many and varied and need to be documented in any slope assessment. The major ones are listed below.

- Bedrock Geology – lithology, structure, texture, mineralogy, degree of weathering
- Quaternary Geology – lithology, thickness, extent of discontinuities, degree of weathering
- Geotechnical properties of bedrock and Quaternary sediments
- Geomorphology – slope elevation, slope gradient, slope aspect, downslope profile, cross-slope profile
- Hydrology – slope drainage pattern
- Hydrogeology – water table level, permeability
- Land Cover – vegetation type, land use

Triggering Factors

These are the external factors which can act on the slope to initiate landslides given the character of the slope as defined by the various parameters listed above.

- Earthquakes – not a major factor in Ireland
- Volcanoes – active volcanoes not present in Ireland
- Rainfall – total amount, intensity, time interval
- Natural erosion – slope surface, base of slope
- Man-made – undercutting of slopes, removal of retaining walls, land drainage

Many of these factors are considered further in the later chapters which follow on the geotechnical aspects of landslides and susceptibility mapping.

3. THE IRISH LANDSLIDES DATABASE

Ronnie Creighton

3.1 The Need for an Irish Landslides Database

Fundamental to the study of landslide hazard in Ireland is information on the extent of the problem in the past. This involves a listing of past events with data, where available, on location, landslide type, materials, causes, and impacts. This data can then be used to assess landslide hazard in the future by defining areas or zones which might be susceptible to landsliding. From this baseline information risk assessment may be undertaken and a strategy for mitigation put in place.

To date there has been no compiled dataset on slope instability in Ireland. This in part reflects the limited scale of the problem in the past which in turn impacts on resources availability to undertake such research. The aim of the database being developed in GSI is to assemble as much information as possible from whatever source to produce a national map of landslide events with key attribute data, where possible, for each.

3.2 Database Structure

The database is built in Microsoft Access. There are a total of nine related Tables, based on a one-to-one relationship throughout, the key primary field being "Landslide_ID". The tables are:-

1. Landslide_Event
2. Landslide_Weather
3. Landslide_Terrain
4. Landslide_Dimensions
5. Landslide_Reference
6. Landslide_Mechanism
7. Landslide_Location
8. Landslide_Impacts
9. Landslide_Land_Use

Each table contains a number of fields which are mostly text boxes while some are linked to Look-Up Lists. The database structure is set out in Appendix 4. Each table is linked to a Form for data entry and there are also full Query and Report facilities within the Access database. It should be said that as most of the entries in the database to date are historic events there is no data to populate many of the fields in the various tables. However this design has been adopted because of the expectation that future slope failures will be documented in a more detailed way so that the database can be used to the full. The exercise of populating the fields with the data available for past events is an ongoing process.

3.3 Data Sources

In the absence of any national compilation of landslide events, an extensive trawl of as many sources as possible has to be done to maximize the number of events recorded. Associated with this is a bibliography of landslide and related references for Ireland. This is included in Appendix 6. In the database a reference source is listed for each event, so that the original source can easily be retrieved.

The list of data source types includes the following:-

Field Guides – published and unpublished guides by geological and other associations.

Internet Search

Journal – published papers

Letter – communication from individuals or agencies

e-mail – communication from individuals or agencies

Newspaper – articles in national and regional papers

Textbook – a variety of books can contain information on past landslide events

Technical report – where these can be used in the public domain

On-site visit – where this has been done for recent events

Local Authorities – an important source of local information

GSI Webform – event reporting by the public.

Geological field maps

Digital colour aerial photography

The list of data sources will of course be added to as time goes on, but it is felt the main types are included in this list. The GSI Webform for the reporting of events by members of the public has met with only limited success but remains available online for people to use. A strict validation process is needed here.

A major source of events was the excellent textbook “The Bogs of Ireland” by Feehan and O'Donovan (1996) published by University College Dublin. It lists in excess of forty bog flows or bog slides and has a comprehensive bibliography relating to these. The database at this point in time does contain a lot of events involving peat materials, possibly reflecting the published data available. This preponderance of peat events is likely to decrease over time as more detailed field searching combined with remote sensing techniques is undertaken. The research will no doubt uncover more bog slides, but importantly, more events in other materials such as rock falls and debris flows which have not been documented in published literature to the same extent.

3.4 Data Quality

The amount of information available on past events is highly variable. Older records tend to have very limited information. The sources may contain adequate plans of the slides or flows, but often the data is poor in terms of generating a good grid reference of the location. A good grid reference with a stated accuracy figure in metres is a prerequisite for each event so that the conditioning factors for each can be determined. These would include bedrock and soil types, materials, and slope geometry parameters. Indeed the older records may have very limited information on these environmental conditions, and also on the impacts of the event in terms of damage to property or infrastructure.

Where the information in the source material is lacking it can be augmented by a search of other sources. Plan drawings can be related to 6” to 1 mile (1:10,560 scale) maps which can provide information on townland name, elevation, land cover, proximity to watercourses etc. Of considerable value nowadays are digital colour aerial photographs which can often show the remnant scars of earlier events. Grid references can be generated automatically from these images. These methods, very useful in verifying or adding further information to previously documented events, can also be used in detailed regional investigations for previously undocumented landslides. In addition to the above, satellite imagery can also be used, though this has been used with only limited success. This is discussed further in the chapter on susceptibility mapping.

The grid references and associated accuracies for the database events are felt to be the best that can be achieved given the available information and the quality of the map and photograph sources for the area in question. As work on the database proceeds and detailed examination is made of the various regions in Ireland, accuracy will improve considerably where events are initially defined by remote sensing methods and then verified by extensive field checking.

3.5 Use of GIS in Landslide Research

Charise McKeon

From GSI's earliest attempts at creating a landslide database, the value of implementing a Geographic Information System (GIS) has been recognised. From initial work by staff and research student Christine Colgan, this has now expanded to a vital part of the desk study and a solution in many cases to the variable amounts and quality of information collected on historic landslides. As already mentioned the need for a good quality grid reference with a stated accuracy is essential for each event and the use of a GIS augmented this requirement greatly giving ca. 80% of the events with an accuracy of 500m or less, 6 of the total having an exact accuracy.

In order to achieve the utmost from the GIS it was vital that there was a variety of both spatial and topographical datasets included. The majority of the datasets are either vector images or in shapefile format. The GIS consists of a series of layers built up according to coverage and scale as follows: Counties, Townlands, Map indices, Basemap (covering Ordnance Survey Maps from scales of 1:600,000 to 1:10,560 (6": 1 mile)) and OSi Colour Orthophotographs (1:40,000 scale).

Particularly useful was the 1:100,000 scale OSi basemaps, which display contour information and spot heights for upland regions. Having such a broad range of scales available means that previously available data can be verified, be it highly detailed (e.g. a landslide located within a bog that is visible from aerial photography, giving location and possible dimensions information) or less detailed (e.g. a landslide that is located along the R572 – road names displayed on the 1:250,000 scale OSi Maps).

To expand data obtained from these spatial and topographical datasets it is also possible to introduce digital geological data coverage such as Bedrock and Quaternary data. The GSI has produced a seamless 1:100,000 scale digital Bedrock Map and also a similar dataset at 1:500,000 scale.

The Irish Landslides Database consists of a look-up table based on the geological units at 1:500,000 scale. However, if a more detailed geological description is required for a specific area the 1:100,000 scale dataset can be used. The GSI also holds a full set of 19th Century georeferenced 6" to 1 mile (1:10,560) scale bedrock field sheets. These can provide additional data, especially more historic data on areas of bog land, forestry etc., when used as part of the GIS. Other datasets include the digital Quaternary (subsoil) data, Groundwater Aquifer data and Teagasc soils data.

In 2005 a new set of data within a GIS was made available to the GSI from the DCMNR/OSi web mapping service. This made it possible to view an entire set of oblique coastal colour photographs for the entire coast of Ireland. This is a result of a survey that was flown in September 2003 by the Engineering Division within DCMNR. It is possible to locate areas prone to coastal landslip and then relate the locations to the Colour Orthophotographs/basemaps within the GIS already created and vice versa.

With the now complete GIS in place the current Irish Landslides Database (117 events) was added and each event was examined in detail, beginning with the original information available and with the aim of expanding on this using the GIS. An example of this is event No. 110, Sheehan in Co. Mayo. The only piece of information available on this event was an email to say that there was a slide in the townland of Sheehan. By searching the area covered by the spatial and topographical datasets in the townland of Sheehan the landslide was found. This event was visible on the Colour Orthophotographs (Fig. 3.1). It was then possible to obtain an exact grid reference, approximate dimensions, terrain type, bedrock type and mechanism information; material, style, mechanism type etc. Having no information on an exact date for this event it can be assumed that it was pre 2000 (Orthophotographs date from 2000). Further information gathered for other events from the GIS includes vegetation type, aspect, slope, drainage and further dimensions information. For another event, photographs which were taken on a site visit, were referenced to the Orthophotographs thus making it possible to pinpoint the exact point of the rupture as no exact grid reference was taken in the field.

These instances are just a small example of the additional information that can be gathered on an event by using the GIS, thus showing that the desktop research on landslide events is a highly valuable step into the continuing research and understanding of landslide events in Ireland.



Fig. 3.1 Two images showing the use of GIS spatial and topographic datasets to locate a landslide event

3.6 General Analysis of Database Events

The expansion of a database is always an ongoing process. Therefore any description or discussion of the database contents can only be a snapshot in time. It is important to note at this point that the events discovered in the Breifne area pilot susceptibility mapping project (Chapter 5.2) have not been entered into the database yet. Many hundreds of events were discovered in that pilot study and large numbers will no doubt be found in other upland areas when similar research studies are undertaken in the future. These will all be added to the database in due course.

There are 117 landslide events recorded in the database at this time (Fig. 3.2). The majority of these are from historical published sources. There are also several more recent events which have been individually documented. In addition the results of a postgraduate project in Co. Wicklow have been included. This is described fully in Chapter 8 – Landslide Research in Ireland. The types of event recorded will naturally reflect the data sources available.

Of the total of 117 events, 100 are in the Republic of Ireland and 17 are in Northern Ireland. The events are listed in Appendix 5. Co. Wicklow has the most events with 14. Co. Mayo has 12, and Co. Antrim has 10. These reflect the upland blanket bog areas and also the serious instability along the edge of the basalt escarpment in Co. Antrim. After these come Co. Offaly with 8 events and Co. Limerick with 7 events. The following counties have no events recorded as yet – Monaghan, Meath, Carlow, Wexford and Armagh. The remainder of the counties have between 1 and 6 events each. The earliest event recorded is near Clogher, Co. Tyrone in 1488. There is little information available on this slippage of peat bog. The latest recorded is a topple in rock on the Hillhead Road in Newry in March 2005.

It was stated in the Introduction that Ireland has a relatively benign landscape in terms of geohazards. Ireland has indeed been spared the major catastrophes that have occurred in other parts of Europe due to landslides. However there have been fatalities in Ireland. The worst was at Castlegarde bog near Cappamore, Co. Limerick in 1708 when 21 people died. In 1896 at Knocknageesha, Co. Kerry 8 people died. There were 2 fatalities in the Owenmore Valley, Co. Mayo in 1819 and at Ballaghline, near Lisdoonvarna, Co. Clare in 1900. Fortunately there were no fatalities at the recent landslides at Pollatomish and Derrybrien.

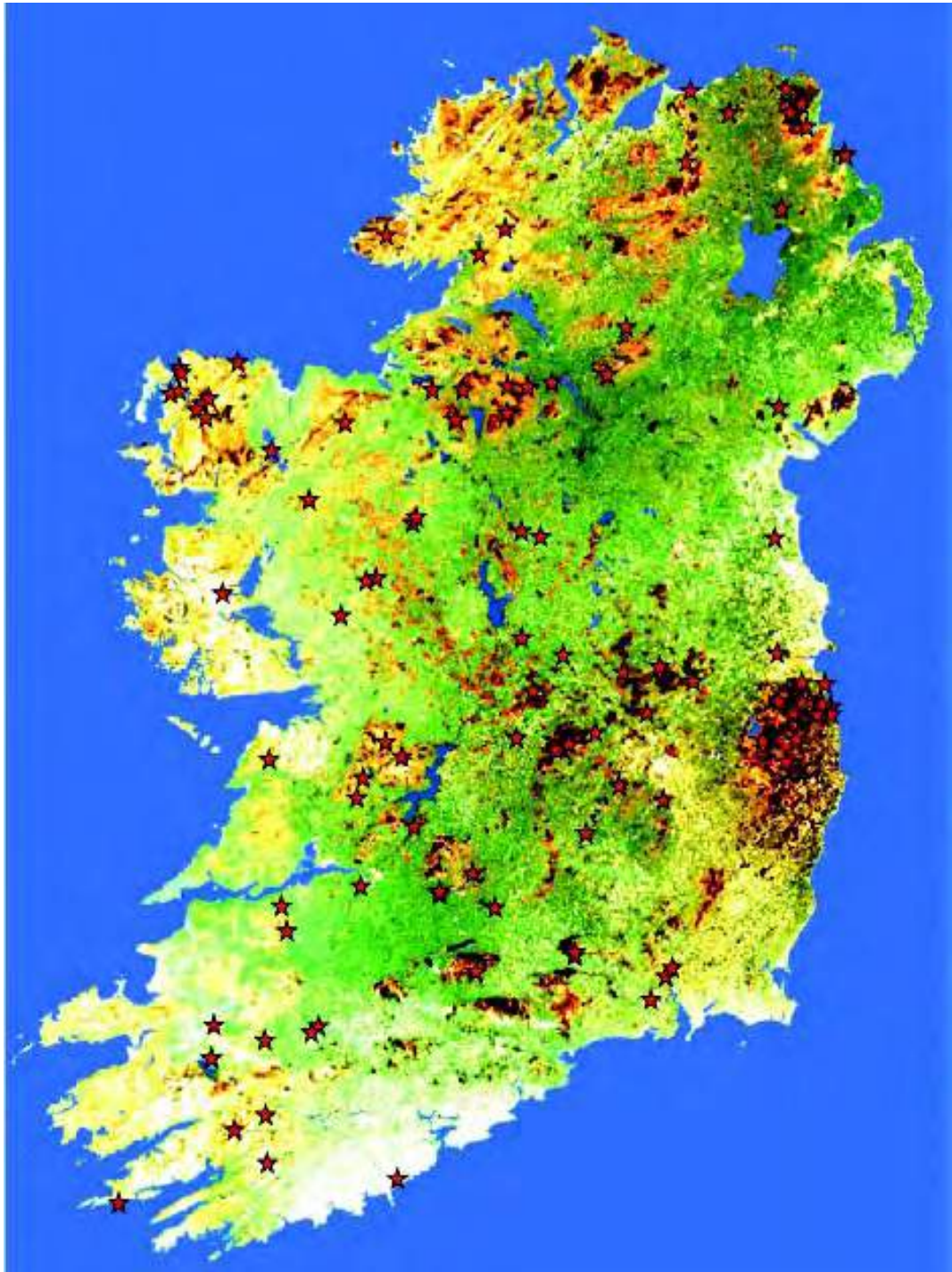


Fig. 3.2 Irish Landslides Map

An initial analysis of the events shows that the majority involved peat as the principal material (Table 3.2). There were 63 of these in total. The landslide mechanisms included both slides and flows. The published sources referred to them as bogslides, bog flows, or bog bursts. There is insufficient data to determine the precise mechanism involved in each individual event. However they are likely to have been sliding and flowing, and a combination of both. They occurred in two contrasting situations. Two-thirds (43 in total) were in blanket bog both in upland locations and the low-lying blanket bog of western Ireland. In the upland areas they occurred both on the relatively flat plateau surfaces and also on the steeper slopes surrounding them. One-third (20 in total) occurred on the raised bogs in the lowlands of Ireland where slope failure occurred on relatively low angle slopes around the edges of the bogs. Peat has particular geotechnical properties. This issue of slope gradient and failure in peat is dealt with fully in Chapter 4 – Geotechnics of Landslides. Peat slides on raised bogs can potentially cause more damage to life and property as more people were living close by, in contrast to the more remote blanket bog environments. The fatalities at Castlegarde near Cappamore in Co. Limerick are a good example of this.

15 Events						
14 Events	Wicklow					
13 Events						
12 Events	Mayo					
11 Events						
10 Events	Antrim					
9 Events						
8 Events	Offaly					
7 Events	Limerick	Laois				
6 Events	Galway	Cork				
5 Events	Kerry	Tipperary	Sligo			
4 Events	Dublin					
3 Events	Donegal	Fermanagh	Clare	Derry		
2 Events	Tyrone	Roscommon	Longford	Kilkenny	Leitrim	
1 Events	Westmeath	Cavan	Waterfor	Kildare	Louth	Down
0 Events	Monaghan	Meath	Wexford	Carlow	Armagh	

Table 3.1 Landslide Events Per County

DEBRIS	EARTH	TILL	MUD	PEAT	ROCK	UNSPECIFIED
31		4	2	63	9	8

Table 3.2 Landslide Events – Materials

The next biggest category is those involving mineral soils - debris – coarse-grained soils dominated by gravel grade or larger. There were 31 of these. For many there is little information as to the precise nature of the debris materials, but many would be derived from glacial tills, sands and gravels, or other diamicts which mantle the hillslopes in Ireland. In addition there are 4 events for which the material can be more precisely defined as glacial till rather than the more general term “debris”. Mud, that is wet, fine-grained soil, is found at 2 locations, both on the Coast Road in Co. Antrim. Other mudflows on this stretch of the Coast Road have yet to be documented in the database. There are 8 rockfalls or rock topples listed so far. The recent study in the Breifne area (see Chapter 5) has identified many rockfalls which have yet to be entered into the database. Of the total of 117 only 8 are left as yet unspecified with regard to the type of material or mechanism involved.

The historical record of the dates of occurrence is also interesting. This is shown in Fig. 3.3. The greater number shown in the 20th Century will to some extent reflect better record keeping and reporting. It probably also indicates a real increase in the frequency of landslide events. There have been 14 events recorded in the current century so far.

CENTURY	NUMBER	YEARS
15 th Century	1	1488
16 th Century	0	
17 th Century	1	1697
18 th Century	6	1708, 1712, 1745, 1786, 1788 x 2
19 th Century	16	1809, 1819, 1821 x 2, 1824, 1832, 1835, 1840, 1867, 1870, 1873, 1883 x 2, 1890, 1895, 1896
20 th Century	48	1900, 1909, 1916, 1931, 1934, 1937, 1938, 1945 x 2, 1946, 1947, 1948, 1954 x 2, 1963 x 2, 1965 x 2, 1973, 1974, 1975, 1979, 1980 x 4, 1984 x 2, 1985, 1986 x 5, 1987, 1988 x 4, 1992, 1995, 1997, 1998 x 2, 1999 x 4, 1980 x 4, 1984 x 2, 1985, 1986 x 5, 1987, 1988 x 3, 1992, 1995, 1997, 1998 x 2, 1999 x 4
21 st Century	14	2000 x 2, 2001, 2002 x 2, 2003 x 5, 2004 x 2, 2005 x 2

Table 3.3 Landslide Events per Century

It must be stressed that research into these past events listed in the database is at an early stage, therefore little more can be added by way of analysis at this time. Ongoing research will be reported on at a later time. However the next two sections concern two events for which information is available. These are the landslides at Pollatomish and Derrybrien which were the stimulus for the landslides initiative by the GSI.

3.7 The Pollatomish Landslides – 2003

3.7.1 Introduction

A major landslide event occurred in the Pollatomish area of North Mayo (Fig. 3.3) on the night of Friday 19th September, 2003, during a period of very heavy rainfall. The landslides resulted in considerable damage to roads, bridges and property and the evacuation of over 40 families from their homes, although fortunately there was no loss of life. There were about 40 individual slides of peat and weathered rock. The size of these varied between 15m³ and 20,000m³ (Long and Jennings, 2006).

This section is based on the GSI report on the landslides (Creighton and Verbruggen, 2003). It also makes reference to the consultants' report to Mayo County Council (Tobin, 2003) and the above mentioned geotechnical paper by Long and Jennings (2006).

3.7.2 Topography

The Pollatomish area of north Mayo is dominated by the upland area of Dooncarton Mountain and Barnacuille Mountain whose summit heights are 260m and 242m respectively. A radar mast, a principal local landmark, is located on Dooncarton Mountain. The ridge extends further to the west towards Gortbrack with summit heights here of 250m and 233m. The land drops steeply on all sides, towards the coast on the east and north sides, and to the interior river valley on the south side of the Dooncarton and Barnacuille summits.

To the north of Pollatomish, the mountain slope drops steeply almost to the coast on the west side of Sruwaddacon Bay, there being only a narrow coastal strip, where the road is located, at an elevation of 10m to 15m above sea level. To the north of the mountain at Glengad there is a wider coastal strip at elevations of 10m to 20m above sea level. Bedrock outcrops all around the coastline with the exception of the area at the mouth of Sruwaddacon Bay.

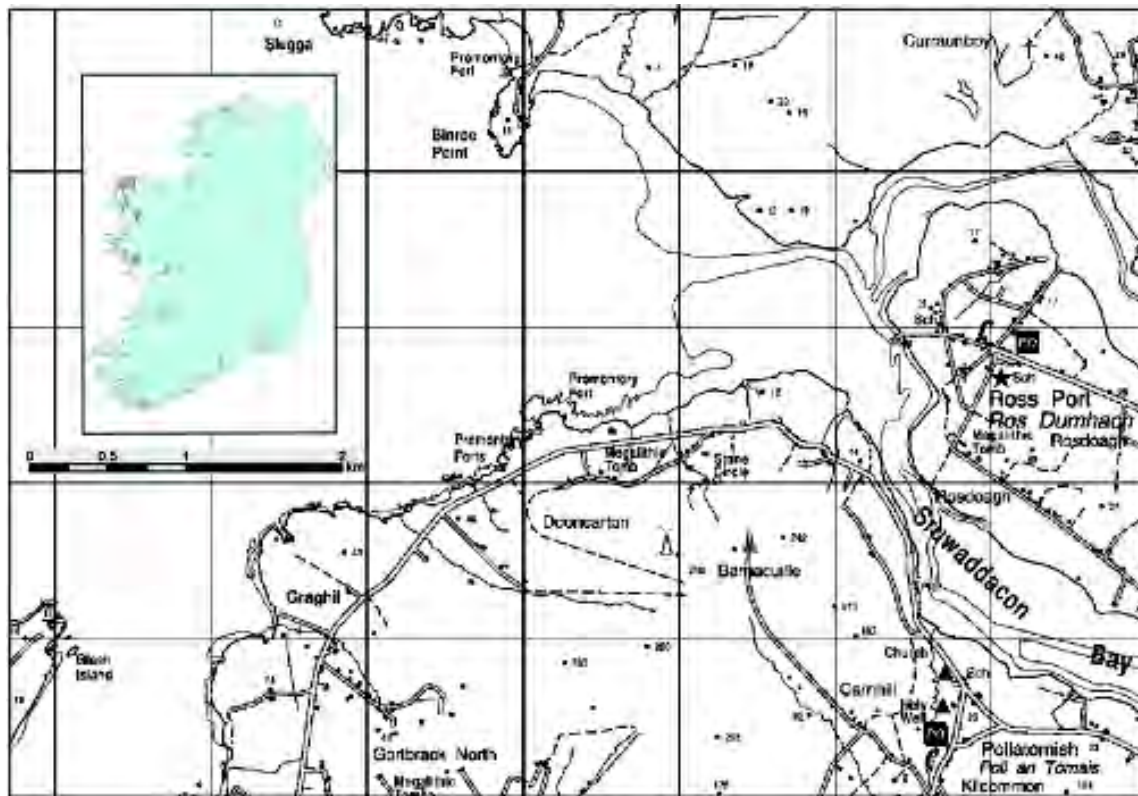


Fig. 3.3 Location map of the Pollatomish Area

The steeper, very rocky slope on the north side of the mountain below the summit may represent an old corrie backwall where there has been accentuated erosion by ice during the Ice Age. The slope profiles vary along the mountainside as determined from the 10m contours on the aerial photograph, but for much of the length there is a relatively even slope between the 50m and 150m contours. Above the 150m contour the slopes steepen considerably - 30° to 60° - (Long and Jennings, 2006) towards the ridge crest. It was in this area that the landslides were initiated. Also, above the cemetery and some distance to the north and south of it, the slope steepens between approximately 40m and 100m above sea level.

Five main streams drain the mountain area, as defined on 1:50,000 Sheet 22. The principal one is the river which rises on the south side of the summits (the interior river valley) and enters the sea at Pollatomish beside the cemetery. Moving north from Pollatomish a stream enters the sea at the mouth of Sruwaddacon bay. Another stream flows north to the sea at Glengad. Two further streams drain the mountain to the west and southwest. In addition several other gullies drain the mountain between these more major watercourses. Much of the rainfall and the resultant landslide material was channelled into these streams and caused considerable damage to property, the roads, and bridges. The erosive power of this water is well seen in the overdeepened gorges in the streams north of the cemetery where they cross the road.

3.7.3 Bedrock Geology

The bedrock or solid geology of the Dooncarton area is described in the Geological Survey of Ireland publication "Geology of North Mayo" (Long et al., 1992), which includes a geological map of the area at 1:100,000 scale. The local geology consists of metamorphic rocks over 400 million years old, belonging to the "Dalradian Supergroup", and dominantly made up of altered sedimentary rocks, schists and sandstones with some thin marbles (Fig. 3.4). A number of geological faults occur in the area, including within the steep Dooncarton Mountain. However the area is tectonically stable and there is no evidence for any recent movement on any of these structures, which are likely to have last moved over 200 million years ago. These faults and all of the geology is best exposed in coastal sections west and north of Dooncarton Mountain, and has been extrapolated across the hillier ground where exposure is poor. In more detail the local geology consists of the following rock types, grouped into a number of formations (Table 3.4). Dooncarton Mountain also contains an igneous intrusive rock, which is metamorphosed to metadolerite.

Group	Formation	Rocktypes	Location
Inver Group	Inver Schist	Graphitic, semi-pelitic schists and marbles	Upper Slopes Dooncarton, Barnacuilie, Gortbrack
Inver Group	Ballybeg Park Limestone	Calcareous schists & marble.	Upper Slopes Dooncarton, Barnacuilie, Gortbrack
Inver Group	Doon-na-Dell Schist	Semi-pelitic (silty) schists	Upper Slopes Dooncarton, Barnacuilie, Gortbrack
Appin Group	Pollacappul Fmn.	Calcareous, graphitic and semi-pelitic schists	Middle Slopes Dooncarton Hill
Erri Group	Srahlaghy Quartzite Fmn.	Massive pale coloured quartzites	Middle Slopes Dooncarton Hill
Erri Group	Benmore Fmn.	Psammites (Metamorphic sandstones)	Lower Slopes of Dooncarton Hill, Pollatomish
Erri Group	Broadhaven Fmn.	Psammites (Metamorphic sandstones)	Lower Slopes of Dooncarton Hill, Pollatomish

Table 3.4 Bedrock Types in the Pollatomish area

The faults in the area are low-angle reverse faults or thrusts, which have emplaced younger rocks onto the older rocks. The movement on these faults is interpreted as having occurred during a series of mountain building events, called the Caledonian-Appalachian orogeny, over a 200 million year period, but which ended 400 million years before present. While there is some evidence for reactivation of these earlier structures during the Hercynian Orogeny (c.200 million years ago) elsewhere in Ireland, there is no evidence for any more recent fault reactivation in this area. Faults are orientated at a low angle, less than 40°, to the northerly and easterly facing slopes that have failed, and dip towards the south and south west. As such they are at close to right angles with the failed slope and thus far less likely to fail than a fracture at a low angle or sub-parallel to the slope surface.

The role of the bedrock geology in the landslide event is critical but indirect. The presence of the high ground and the slope profile is controlled by the underlying geology, the folding and faulting of which has resulted in the current relief. The different hardness of adjoining formations, such as hard metamorphosed sandstones and more easily weathered schists, has resulted in the stepped profile of the hillside. A north-south fault line, which may contain material which is easier to erode than the surrounding rocks, forms part of the course of the stream flowing into the bay at Pollatomish. Another important factor is that these rock types are all highly impermeable, being tightly cemented and compact, thus have a high run off rate during rainfall compared to more permeable rocks such as younger limestones or sandstones.

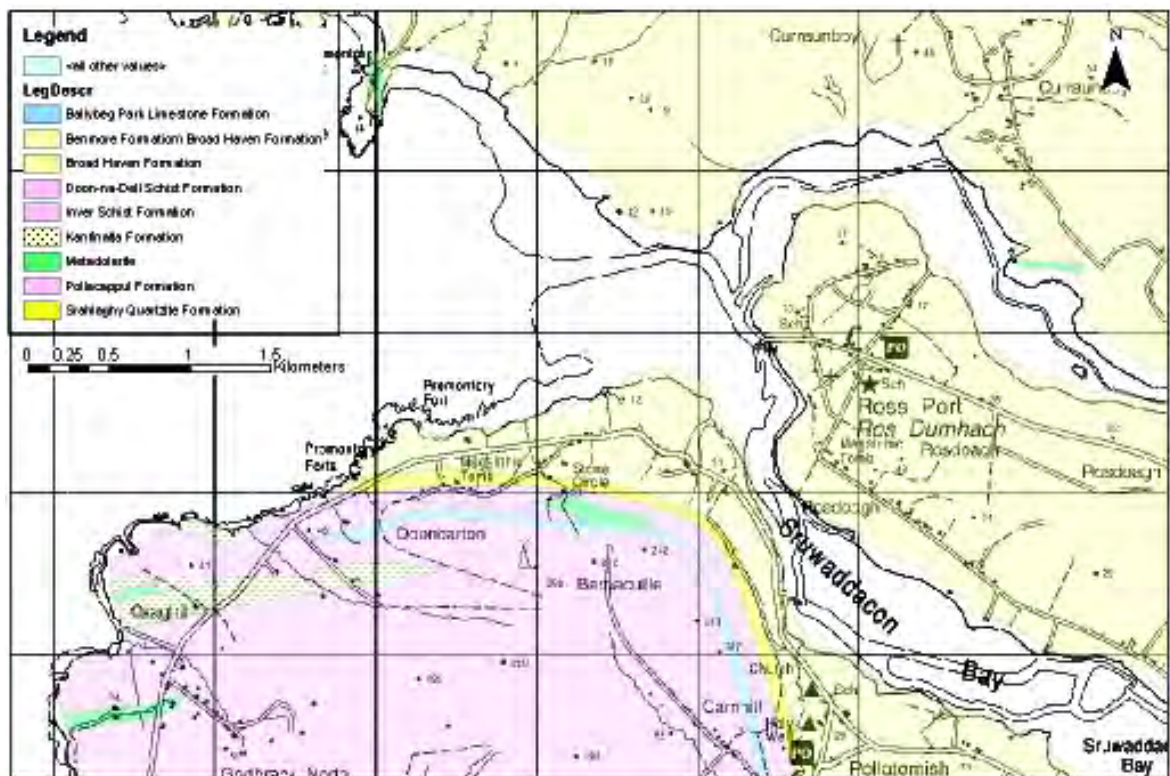


Fig. 3.4 Bedrock Geology of the Pollatomish Area

3.7.4 Quaternary Geology

Quaternary Geology is concerned with the superficial unconsolidated sediments (clays, sands, gravels, etc.) overlying the bedrock, and their morphology on the landscape. These sediments and the landscape are the result of depositional and erosional processes taking place during the Glacial (Ice Age) and Postglacial Periods up until the present day. The superficial deposits of this part of County Mayo have not yet been mapped in detail. Therefore there are only very general maps available of the distribution of sediments overlying the rockhead.

The Pollatomish area was glaciated at some stage during the last glacial period in Ireland, termed the Midlandian, which ended some 10,000 years ago. It is not known at what stage of the Midlandian Cold Period (ca. 100,000 to 10,000 years ago) the icesheet advance over the northwest part of Co. Mayo occurred. The ice advanced northwest from the Irish Midlands, breached through the Nephin mountain range and spread out across the lower ground west of the mountains. In general the drift deposits in this part of Co. Mayo are fairly thin and mainly consist of a weathered glacial till or boulder clay containing stones of the underlying Dalradian rocks, quartzites and schists. There is little glacial sand and gravel in the region. In the postglacial period an extensive cover of blanket peat developed over the Erris region.

In the area of Dooncarton Mountain and the villages of Pollatomish and Glengad there is a thin cover of glacial sediments and indeed many areas which are drift-free. As stated above, the area has not been mapped in detail so the exact extent of drift cover cannot be confirmed with any certainty. Peat bog lies directly on the bedrock in many places particularly on the higher slopes.

It is possible that the upper parts of Dooncarton Mountain were never glaciated (Synge, 1969), the icesheet only reaching a certain height on the slopes of the mountain which is defined by the "drift limit" or the elevation above which no glacial sediments occur. A walkover on the slopes above the cemetery suggests that the drift limit in this area is somewhere between 50m and 100m above sea level.

An exposure on the side of the high road to Barnacuille directly above the cemetery shows a very sandy glacial deposit with small angular to sub-rounded stones. The high sand content probably reflects the lithology of the underlying quartzites and schists, ie. dominated by sand grade particles. This sandy deposit is suggestive of an ice-marginal location for deposition where there has been some degree of sorting by water underneath the ice. On top of this sandy facies there is a layer of head or a colluvial slope deposit which contains stones of the underlying schistose bedrock set in a sandy clay matrix. The deposit is very stony and the stones have a preferred orientation or fabric pointing downslope, indicating that sediment has moved downslope. This may have happened towards the end of the Ice Age when periglacial conditions prevailed. There was no ice cover but a very cold Arctic-type climate with extensive permafrost conditions. Alternate freezing and thawing would result in considerable movement of sediment downslope.

No other exposures in the Pollatomish or Glengad area were examined. Reconnaissance mapping by Synge (Synge, 1968) suggested that the steeper mountain slope behind Glengad may have been the backwall of a very old corrie where there had been a local build-up of snow and ice. Remnant hummocks or moraines of this local ice flow were identified downslope near the coast.

3.7.5 The Slope Deposits

Below the ridge line four different slope elements have been identified (Tobin, 2003). There is a very steep upper slope of 30° to 60° inclination, covered by a thin layer of blanket peat (0.2m to 1.2m in thickness). The peat cover either lies directly on the bedrock surface or on a thin weathered rock layer or mineral soil. The middle or intermediate slope has inclinations of 10° to 30° and shows the same profile of peat on a weathered stony soil, the latter being a colluvial deposit due to mass movement downslope. The lower slope steepens again to 45° to 60°, and the peat and the weathered soil are thinner than above. The bedrock is therefore nearer the surface here. The coastal strip where the road is located has lower slope angles and a covering of till or colluvium (head).

The blanket peat layer is thin and the thicknesses are typical of steep mountain slopes in western Ireland. It does show a stratification with a humified facies at the base. The glacial till, seen on the lower slopes, is a weathered unit with a silty sandy matrix and containing a variable percentage of clasts from gravel up to boulder size. The matrix reflects the underlying schistose bedrock. Exposures indicate that it is often not an in situ till but in fact a colluvial or head deposit. The contained stones often show a preferred downslope orientation or fabric. The weathered regolith shows an internal zonation which in many places has been critical in the development of the slides. About 200mm to 300mm (Long and Jennings, 2006) below the top of this facies is a thin hard pan layer, a precipitate of iron and manganese leached down from above. It is highly impermeable. Above it are thin layers of compacted organic silt/clay.

3.7.6 The Landslide Events

There were more than 40 individual landslides on the night of 19 September 2003 (Tobin, 2003). The landslides occurred on almost all the slopes around Dooncarton Mountain. These included the slopes extending from Pollatomish to Glengad facing the sea, the valley head and western slopes of the river valley south of the summit, and on the slopes of the valley to the west of the summit. In these last two locations there was no immediate threat to any houses or farm buildings. The severe havoc was caused between Pollatomish and Glengad.

On the night of 19 September 2003 the Pollatomish area was subjected to a very extreme and localised weather event. Upwards of 80mm of rain fell in a two hour period. This intensity of rainfall was not recorded at the Belmullet weather station. A similar intense rainfall event occurred on the Shetland Islands earlier on the same day causing a series of peat slides.

This extreme rainfall event was the prime cause of the Pollatomish slides. However the scale of the disaster was exacerbated by the condition of the peat and underlying weathered rock which was due to the antecedent dry weather conditions during the summer period. The effect of this was the drying and shrinkage of the peat, and the development of new cracks and reactivation of old ones. The intense rainfall percolated quickly through the peat to the top of the mineral soil, where its movement downwards was impeded by the impermeable hard pan and the bedrock. Pore pressures increased and the peat mass became buoyant, making it subject to sliding due to gravitational forces.

Several different failure mechanisms have been identified (Tobin, 2003). On the upper steep slopes there was shallow translational sliding of peat and weathered mineral soil, resulting in the exposure of very smooth or polished failure surfaces composed of peat and a clayey soil. Further downslope there was shallow rotational sliding of the weathered rock and soil. In addition the huge volumes of water cascading down the slopes created debris flows of peat blocks and weathered rock. This may have equated to sheet flow at the height of the storm. The resultant scatter of debris all across the slopes was very visible from higher elevations. A lot of the debris was eventually channelled into the pre-existing drainage channels causing extensive deepening of these on the lower slopes near the road.



Plate 3.1 Pollatomish Slide

In the area of walkover (Creighton and Verbruggen, 2003), the backwall of the slides showed a typical crescentic shape in plan and had a vertical scarp of 0.5m to 1.5m of peat and weathered rock. Tears in the peat were seen on the margins of some slides. The slip surface had developed at or close to the interface between the peat and the underlying weathered rock. This surface was extremely smooth and difficult to walk on, the peat having been smeared and moulded on the bedrock surface (Plate 3.1). It also exhibited striations or scratches in the downslope direction where coarser material has scored the peat. On a number of the failure surfaces the hard pan was exposed at the base of the peat. At the lower end of the slip surfaces there were frequently dumps of the eroded peat and rock. These were overtopped by the rush of water carrying the eroded peat hags and boulders further downslope in debris flows.

3.8 The Derrybrien Landslide – 2003

3.8.1 Introduction

A landslide occurred in the Slieve Aughty Hills of Co. Galway, close to the village of Derrybrien on October 16th 2003, with further movement after heavy rain on October 29th. The head of the failure was located within the construction site of a new wind farm. The failure occurred on the southern slopes of Cashlaundrumlahan Mountain, approximately 11 km south of Loughrea and 15 km east of Gort in County Galway (Fig. 3.5). It is an area of hills, covered in blanket bog and forestry, with little good farmland and sparsely populated. A major wind farm was being developed on the top of the hill, which reaches an elevation of 352 m, involving the construction of 71 turbines, half of which had their concrete bases completed, and 15 km of roads, almost all of which had been completed.



Fig. 3.5 Location of the Derrybrien landslide

3.8.2 Geology

Geological outcrop in the area is very limited due to the extensive bog development, but has been mapped previously from stream sections and old quarries. The majority of the area is underlain by red and yellow sandstones and siltstones of the Ayle River Formation, which are Upper Devonian/Lower Carboniferous in age, with the higher ground consisting of inliers of green to grey silicified sandstones and conglomerates of the Derryfadda Formation, which are Silurian in age (Fig. 3.5). Based on existing mapping, the development occurs partly in each formation. A good exposure of Silurian sediments occurs in the borrow pit on the wind farm site. Both formations are classified within the GSI's Aquifer Classification Scheme as "poor aquifers which are generally unproductive except for local zones (PI)". This indicates rocks of low permeability and consequently high run-off. The unconsolidated Quaternary sediments are also poorly exposed in the area, but appear to consist of fine sandy to silty clays. There are no significant fault structures mapped in the area.

3.8.3 The Landslide Event

The landslide first occurred on the afternoon of Thursday 16th October 2003 and was initiated at an approximate elevation of 350m and continued downslope in a south/south-easterly trend. At an elevation of ca.270m the slide was diverted in an east-southeast direction into the river gorge, where it continued to progress downslope

in the river valley. The initial landslide continued until October 19th where it stopped at an elevation of 195m upslope of the locally named “Black Road”. On October 29th following heavy rain the slide was reactivated and continued down slope for another 1.5km blocking two roads, including the “Black Road”.

The area where the failure began, or “head” of the slide, is adjacent to the construction site for one of the turbines – No. T68. The area slopes very gently to the south at less than 10°. In this area the peat has been excavated over an area of approximately 30m sq. The depth of the excavation was not apparent as it was water filled, but it certainly exceeds 2m in depth. Also the nature of the subsoil or bedrock in the area could not be ascertained. Adjacent to the southern side of this excavation is an access road, which is one of several parallel roads that run approximately east/west. These roads are constructed as “floating roads” on the peat, consisting of a layer of felled logs, covered with a membrane and hardcore. At the failure the road had been displaced downslope by up to approximately 3m and had subsided by approximately 1m. Downslope of the road the bog surface had failed and all the trees had collapsed and been moved downslope from an area initially ca.30m wide.

Below the upper area where the bog initially failed the displaced mass became a bog flow, where the liquefied peat flowed, and was confined for the most part within the steep-sided stream channel lower down. The area damaged by the peat is confined almost entirely to the forestry and within the stream banks, only over-topping the bank at the dammed bridge areas (Plate 3.2). No occupied houses were directly affected by the flow, although an abandoned farmhouse was in the path of the flow. Two bridges were closed for several days.



Plate 3.2 Derrybrien Landslide

The material displaced consisted almost entirely of peat and the vegetative cover. There was little bedrock or subsoil material moved in the failure. Weather at the time of the initial failure was quite dry, although the second phase of the movement of the bog appears to have been triggered by heavy rainfall. Specialist consultants were employed by the developers to investigate the peat slide. The conclusion reached was that there were two contributory physical factors, a zone of weak peat and proximity of a natural drainage channel. It was also concluded that activity associated with the construction of the wind farm was also a contributory factor. Their report also made recommendations for improvements in construction methods.

3.9 Irish Landslides Database - Recommendations

- The Irish Landslides Database should continue to be expanded on an ongoing basis
- Liaison should be established with other agencies in both the public and private sectors to progress the acquisition of data on past events

- The classification scheme should be further refined to specifically relate to Irish conditions in terms of landslide mechanisms and materials
- Further analysis should be done of the current list of past events
- The events identified in the Breifne Project (Chapter 5.2) should be added to the database as soon as possible
- The methodology for landslide susceptibility mapping should be assessed further in the light of the experience of its use in the Breifne Project
- Landslide susceptibility mapping should then be extended to the rest of Ireland on a staged basis, focusing initially on upland areas
- The use of GIS techniques in landslide identification should be significantly extended through the use of high quality thematic datasets and the acquisition of high resolution digital terrain models (DEMs)

4. GEOTECHNICS OF LANDSLIDES

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4.1 Introduction

The geotechnics of landslides covers the different ways (mechanisms) in which soils and rocks can fail and give rise to landslides, the factors that cause these failures, and the soil/rock strength properties that are related to these failures. In a geotechnical analysis of a landslide, or of a potential landslide, the forces of the mass of soil or rock contributing to instability are identified and are compared with those forces which are available to resist this instability. Such an analysis must include the strength parameters of the soils and rocks, and the effect of water on these parameters and on the overall destabilising forces. The assessment of the strength parameters considers the geological and geomorphological processes that were involved in the formation of the soil or rock slopes, the nature of the soil particles or fractures in rock and, most importantly, the local hydrogeology and hydrology as water plays an important role in triggering landslides.

The discussion of the geotechnical factors relating to landslides in Ireland is necessarily separated into those relating to landslides in 'mineral' soils, those relating to organic soils, and those involving slides in rock. Mineral soils in this context comprise all soils with the exception of highly organic soils such as peats. Highly organic soils are considered separately because of the way they are formed. With their very high moisture content and low bulk density, these soils are particularly prone to major landslide events. Broadly speaking, major landslides in the mineral soils in Ireland are relatively infrequent as are major rock slides, however there is a long history of major landslide events in raised and blanket bogs. Notwithstanding this, major landslides do occur in this country in 'mineral' soils and in rocks.

4.2 Strength parameters of soils and rocks

The strength of a soil or a rock at failure can be expressed in term of the fundamental shear strength parameters c' and ϕ' which are the cohesion and angle of shearing resistance in terms of effective stress. With reference to Equation 4.1, the shearing resistance (τ_f) in terms of stress (force/unit area) represents the available strength of the soil and this is made up of the 'cohesion' and also a component that depends on the normal stress (σ_n) less the water pressures (u) acting on the failure plane as illustrated below.

$$\tau_f = c' + (\sigma_n - u) \tan \phi' \quad \text{Equation 4.1}$$

The significance of the various terms can best be appreciated by considering the stability of a wedge of soil or rock as shown on Fig. 4.1 and by assuming that the c' term is small and can be ignored, which is true of most soils. This wedge type model is one of many failure mechanisms, for example circular, translational, and others, and is used here for illustration purposes only.



Fig. 4.1 Stability of wedge of soil or rock a) dry slope b) with water pressures

The force causing the block to slide is the component of the weight force acting parallel to the failure surface $W \sin \psi_p$. If there is no water pressure on the failure plane then the resisting force is $W \cos \psi_p \tan \phi'$. The term $\tan \phi'$ is analogous to a coefficient of friction term μ which may be more familiar to some. If the water on the failure plane is under pressure, then this will result in a force U perpendicular to the plane which will reduce the resisting force to $(W \cos \psi_p - U) \tan \phi'$. As will be discussed later, most of the Irish glacial soils have a relatively high value of ϕ' when compared with some other soils and this results in some relatively steep natural slopes.

The fact that subtraction of the water pressure from the normal stress (or force) on the failure plane reduces the effective stress and hence the frictional component of the shear strength is an important characteristic of soil behaviour and is the main cause for landslides occurring in rainy periods as will be discussed later.

With reference to Fig. 4.2, the stress/strain curves of some soils, principally clays, typically show a peak value of τ_p with the strength decreasing as the soil suffers further displacement. At large deformations, for example on slickensided shear planes, the clay particles are aligned parallel to the direction of shear and offer the least resistance to shear, and the soil is at its residual shear strength, τ_R . Under this condition, $c' = 0$ and $\phi' = \phi'_R$ so that

$$\tau_R = (\sigma_n - u) \tan \phi'_R \quad \text{Equation 4.2}$$

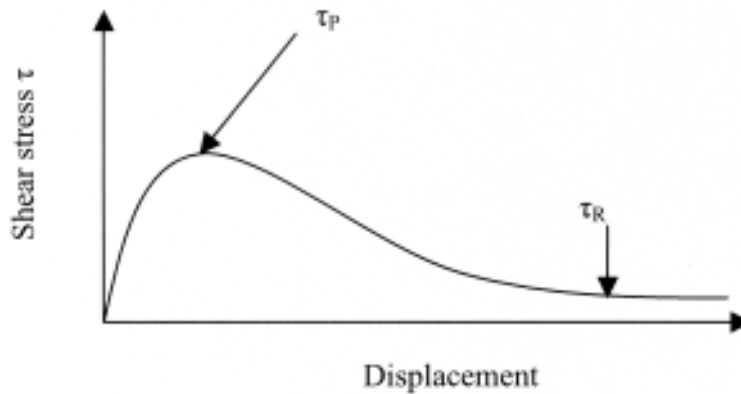


Fig. 4.2 Stress/strain behaviour of a clay soil.

The stability of landslides is normally assessed on the basis of the strength parameters of the ground, c' and ϕ' (determined at peak shear strength values) if the ground has not suffered significant movement, or on the basis of the residual strength parameter ϕ'_R if there are indications that previous movements may have reduced its shear strength to the residual value. It is also necessary to know the water pressures (u) along the failure plane being considered or make reasonable assumptions about its value.

There is a particular loading condition which is sometimes relevant to landslides, namely the undrained condition. The undrained condition applies when the loading is so rapid that no water can drain from the failure surfaces. This condition can be replicated in the laboratory to allow the shear strength to be determined (for saturated soils) in terms of its undrained shear strength which is given the symbol c_u .

4.3 Role of water in landslides

Intuitively it is well known that many landslides generally occur during or soon after a heavy downpour of rain, however the way that water affects the stability of the ground or rock may not be fully appreciated. The concept of water 'lubricating' a soil or rock in the sense that it makes the particles 'slippy' is generally technically incorrect. With reference to Equations 4.1 and 4.2 above, the values of ϕ' and ϕ'_R of the soil and rock are generally the same whether the soil is dry or wet, although there may be some long term reduction in ϕ' in very weak rocks. However, as can be seen from Equation 4.1, the shear strength reduces as ' u ', the pore water pressure increases. Furthermore, as is illustrated in Fig. 4.3, water pressures in vertical cracks in the soil or rocks exert forces which further destabilise the mass. Thus water has two detrimental effects, it reduces the force resisting the instability and increases those causing the instability.

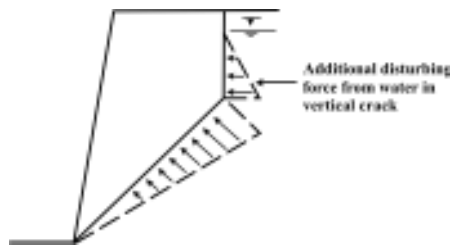


Fig. 4.3 Forces caused by water in vertical cracks.

Water plays another important role in destabilising slopes in Irish soils when it seeps from an exposed face, as is illustrated in Fig. 4.4. The forces between the flowing water and the soil particles result in a face in a granular material being stable at a slope of approximately half of that at which it would be stable if there were no flow.

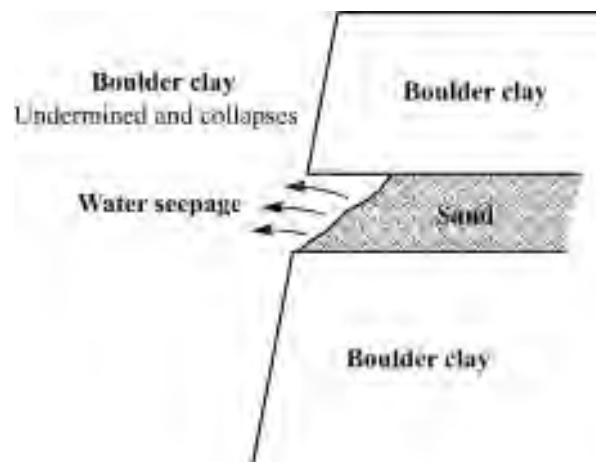


Fig. 4.4 Effect of water seepage in granular soils

For example, it can be shown that the stable angle of a granular material is equal to ϕ' , which for a typical sand would be about 30° (about 1.75 horizontal to 1 vertical). This reduces to about 15° (about 3.7 horizontal to 1 vertical) with horizontal flow. Many of our Irish soils are of glacial origin and, because of this, their stratification can be very variable with sand layers within typical boulder clays. The boulder clay slopes would typically be stable at a slope of 2 horizontal to 1 vertical, however where there is water flowing from sand layers these form flatter slopes, undermining the upper clays which leads to a slope failure. This process is called internal erosion and is a common cause for instability in slopes of Irish glacial soils. Because of this, herringbone drains (Plate 4.1) are frequently used in the slopes formed by road cuttings to intercept this water flow before it reaches the slope face and hence prevent this type of failure.



Plate 4.1 Herringbone drainage system being installed in cut slope of glacial till.

4.4 Geotechnics of landslides in 'mineral' soils

The overburden deposits in Ireland are predominantly glacially derived soils which have been deposited in complex geological conditions. There are also areas of recent fluvial deposits in our rivers and estuaries, and soft lacustrine soils in our lakes. The recent alluvial and lacustrine soils are deposited in low lying areas and do not in themselves give rise to landslides unless fill is placed on the surface or material dredged or excavated.

There are local areas of overconsolidated clay soils which were laid down in interglacial conditions. These clay soils would typically have significantly lower angles of shearing resistance than the more typical glacial tills and, where encountered, may require special attention.

Glacial soils can be deposited in a number of ways, generally in a complex depositional environment, and their method of deposition and the variability of the deposits can have an important bearing on the risk of landslides occurring. Glacial deposits include, for example:-

- lodgement tills
- englacial tills
- glaciofluvial deposits
- glaciolacustrine deposits.

Lodgement and englacial tills

Irish lodgement and englacial tills generally have relatively high angles of shearing resistance (ϕ') and low if any effective cohesion intercept (c'), and are generally well graded with sufficient fines to make them appear to be a 'cohesive' soil in the short term. These tills are colloquially called boulder clays, although boulders may not always be present. Typically the angle of shearing resistance of Irish lodgement and englacial tills would be between 30° and 35° (Hanrahan 1977, Farrell & Wall, 1990) and have residual shear strength parameters close to the peak ϕ' values (Loughman, 1979). A survey of 150 year old railway slopes on the southwest region of the Irish rail network recorded an average slope inclination of 38° for slopes with an average height of about 5m (Jennings, 2003). About 90% of all cut slopes surveyed were at a slope angle greater than 30° . Very steep slopes can be cut into these soils in the short term, however this short term stability arises from soil suction forces which will dissipate with time and give rise to slope failure. There is little evidence of cementation between particles which would give a cohesion intercept. Glacial soils are formed in very complex geological conditions and this does result in significant variations within deposits. As a consequence of this, free draining sand and gravel layers frequently occur within what would otherwise be considered boulder clay, giving rise to the risk of internal erosion as discussed previously. The normal long term stable slope angles adopted in practice in these lodgement and englacial tills is 2H to 1V, with herringbone drains used to intercept water flow as required to prevent internal erosion as discussed above.

Glaciolacustrine deposits

Glaciofluvial and glaciolacustrine deposits are formed by water flowing around the ice margins and into ponds and lakes which were sometimes of considerable extent. In some circumstances these have given rise to layered or laminated silts, clays and sands which can be stiff/compact if the ice subsequently readvanced over these deposits. Instabilities have arisen in slopes formed within these deposits due to the low strength parameters of some of the clay layers, together with water pressures that build up within some of the sand layers. For example, angles of shearing resistance of the order of 24° have been recorded in these soils, with residual angles of shearing resistance of the order of 10° . An example of a rotational/translational failure in glaciolacustrine soil is shown on Plate 4.2.



Plate 4.2 Slope failure in a glaciolacustrine deposit.

Clay deposits

Pure clay layers are not commonly encountered in Ireland but do occur in parts of the country. These soils can typically have a low effective stress angle of shearing resistance and can have fissures, some of which may be slickensided such that the residual strength parameters would apply. Slopes in such soils would require particular attention and typically slope angles of 3H to 1V or flatter may be required for stability.

4.5 Geotechnics of landslides in organic soils

Landslides in organic soils, particularly peat, form a very significant portion of the total number of slides recorded in the Irish Landslides Database. A significant number of slides have occurred both in raised and blanket bogs. Although slides in upland blanket bogs are the more common, an analysis of 48 landslide events by IQUA (1985) showed that about 23% of the slides occurred in raised bogs (Fig. 4.5). The failures in blanket bogs tend to be more common in the wetter autumn and winter months, whereas incidents in raised bogs do occur more randomly throughout the year.

Undoubtedly the two most important contributing factors to peat instability are:

- its very low unit weight,
- the influence of water.

The unit weight of peat is typically 10 kN/m^3 to 11 kN/m^3 , i.e. more or less identical to that of water which is 9.81 kN/m^3 . The mass of water can account for 90% of the mass of peat. Consequently it is not surprising then that many of the failures in peat have been described as “bursts” or “flows”. Naturally occurring excess water pressure in or close to the base of the peat can cause simple buoyancy or uplift. Occasionally man induced activities, such as turf cutting, can release the basal near-liquid peat. This was the cause of the largest peat slide which occurred in Ireland, at Knocknageesha in 1896.

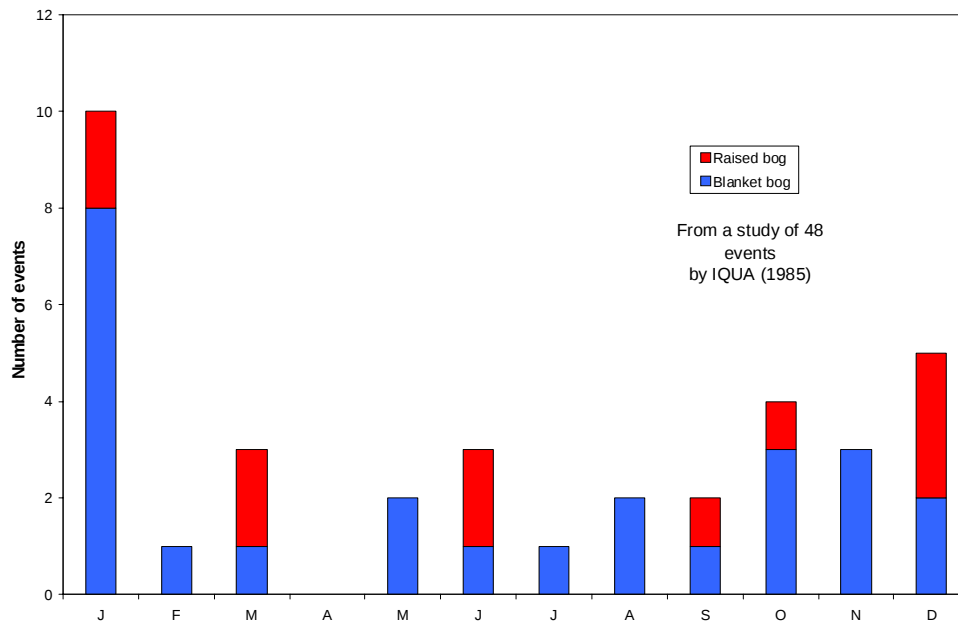


Fig. 4.5. Number of peat slides per month (based on Alexander et al., 1985)

Drying of the peat during prolonged warm weather can reduce its unit weight and increase the risk of uplift. This was likely to have been a contributory factor to the slides at Pollatomish in September 2003. Long periods of dry weather will also induce cracking in the peat, thus providing a flow path for water to reach the weaker zones. It is also likely that such a scenario contributed to the failure of the Grand Canal near Edenderry in 1989 (Pigott et al, 1992). As can be seen in Plate 4.3, the slide resembles a classic shear failure. Lateral water pressure from the canal displaced somewhat buoyant peat. Witnesses to the slides describe a tearing sound as the embankment material separated from its foundation.



Plate 4.3 Slide on the Grand Canal, near Edenderry (Pigott et al., 1992)

There is a strong correlation between high rainfall and peat slides. Again the events at Pollatomish are a good example. About 80 mm of rain fell in 2 hours at the time of the slides. Alexander et al. (1986) analysed the slides which occurred at Straduff townland, Co. Sligo in May 1985. As can be seen in Fig. 4.6 the months of January and February 1985 were unusually dry. However rainfall in April and May was almost twice the normal. On the 26th May, the day of the slide, there was more than 50 mm of rain.

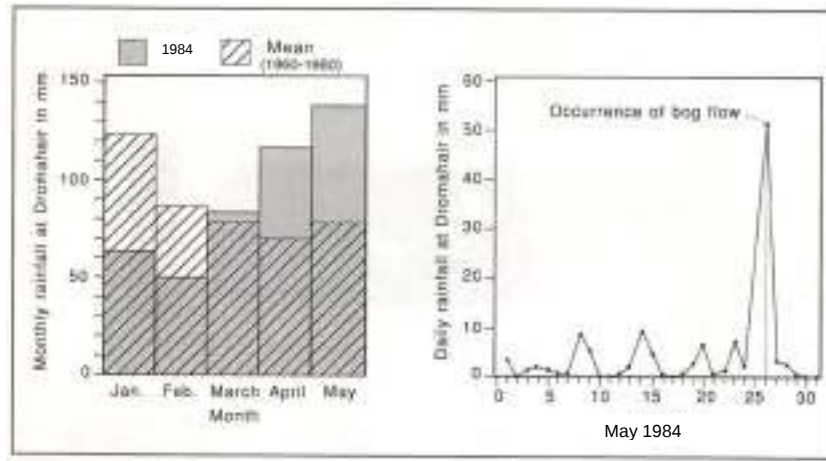


Fig. 4.6 Rainfall data for Dromahair, Co. Leitrim (Alexander et al., 1985)

A complicating factor in the understanding of landslides in peat is the presence of fibres and the natural heterogeneity of the material. The reinforcing effect of fibres, particularly in the upper less humified layers can sometimes increase stability. However the nature of peat can vary significantly with depth and between different points. The natural development of peat can result in significantly decomposed or weak layers being present at depth, and such occurrences as ancient peat fires, former slides, or a change in the environment at a particular time during its formation can also result in weak layers or discontinuities in the peat. Such a weak layer is thought to have contributed to the major slide that occurred at Derrybrien in October 2003.

Peat slides in upland blanket bogs often resemble translational planar slides which can be analysed using a relatively simple infinite slope analysis. As discussed previously, shear resistance can be considered in terms of effective stress parameters (c' and ϕ') or in terms of total stress (c_u). According to Haefli (1948) and subsequently Skempton and DeLory (1957), the factor of safety (FoS) for a planar translation slide for the total stress case is given by:

$$FOS = \frac{c_u}{\gamma z \sin \beta \cos \beta} \quad \text{Equation 4.3}$$

where:

c_u = undrained shear strength of peat

γ = bulk unit weight

β = slope angle on base of sliding

In other words FOS increases with increasing peat strength and with increasing depth of peat but decreases with increasing unit weight and slope angle.

For effective stress analysis, and assuming steady seepage of groundwater parallel to ground level:

$$FoS = \frac{c'}{\gamma z \cos \beta \sin \beta} + \frac{(\gamma - \gamma_w m) \tan \phi'}{\gamma \tan \beta} \quad \text{Equation 4.4}$$

where:

c' = effective cohesion of peat

ϕ' = effective friction angle

γ_w = bulk unit weight of water

m = depth to groundwater measured upwards from slip surface

Of course the most significant (and so far unanswered question) is does conventional soil mechanics apply to peat soils ?. For example, conventional methods for determining undrained shear strength, e.g. the field vane test, have been called into question when used in peat (Landva, 1980) as different values of c_u are obtained with different size vanes. Determination of c_u or c' in the laboratory is difficult due to problems with sampling the peat, due to its near liquid state and due to its low strength which is at the limit of much of the current methods of strength determination.

It is well known by research at University College Dublin (Hanrahan, 1954, Hanrahan et al., 1967) and Trinity College Dublin (McGeever, 1987, Farrell and Hebib, 1998) that, due to the influence of the fibres, peat has unusually high angles of friction. Values greater than 40° to 50° have frequently been reported. It has also been shown that the friction angle varies more significantly than for mineral soils depending on the test type (i.e. triaxial compression, extension, simple shear etc.). However, in the case of bogslides, the effective stresses are generally very low, consequently the contribution to shear strength from the angle of shearing resistance can be very low. For example, peat essentially floats if there is a high water table. Taking the example of a translational slide which can be represented by Equations 4.3 and 4.4, peat is unusual compared with mineral soils in that the water table is generally near the surface, consequently 'm' in Equation 4.4 is near unity and also $\gamma \approx \gamma_w$, consequently the last term in Equation 4.4 is approximately zero. This means that in many instances, the friction angle may not play an important stabilising role. Also, comparing the two equations, it can be seen that the role of c_u and c' are very similar when the effective normal stress on the sliding plane is low.

Undrained shear strengths of 2kPa have been backfigured from some slides when using total stress analyses. The effect of fibres, anisotropy and other factors also may play an important role in stabilising bogs. Long and Jennings (2006) have used an infinite slope analysis with effective stress strength parameters with an assessment of the effect of fibres to successfully model the failures which occurred at Pollatomish. The circumstantial evidence that many bog slides occurred during extreme rainfall events following a period of dry weather is also of relevance. Further research is required to study stable and unstable areas of peat in order to develop methods of reliably determining the stability of such slopes under extreme environmental conditions. Extensive peat slides have occurred at basal slopes of as low as 2° , consequently a flat slope in peat does not necessarily represent a stable slope. The predicted climate changes (Sweeney et al, 2003) may have significant implications on the stability of the peat slopes in Ireland.

The discussion above shows that peat deposits can present a significant hazard which requires a risk assessment in many practical situations. For example, the Pollatomish landslides have shown that peat thickness of 0.5m to 1m can be a major hazard if these occur on steep slopes. Both effective stress and total stress analyses indicate that the margin of safety of slopes with peat 0.5m or thicker may be unsatisfactory on slopes of 15° or greater. It is therefore considered that peat may present a hazard if it is greater than 0.5m thick or if it is less than 0.5m and on a slope steeper than 15° .

4.6 Geotechnics of landslides in rock

Landslides in rock may typically be classified into falls, topples, slides and complex movements. Falls would involve falling blocks of different sizes which are detached from a steep rock wall or cliff. Movements include bouncing, rolling and sliding with rock block fragmentation on impact.

Topples involve overturning forces that cause blocks of rock to topple about a pivot point below the centre of gravity. Slides involve similar mechanisms to those discussed previously in this chapter where disturbing forces/moments are greater than the restoring forces/moments on one or more surfaces. The failure surface can be planar (translational slides), or circular (rotational, sometimes called slumps by geologists). Complex movements can be a combination of one or more of the above.

Falls are local failures of slopes which are due to weathering of rock, ice pressures or water pressures. These do occur on rock faces from time to time. Topples arise either from water or wind pressures or from a bearing capacity failure of the toe. Slides arise from the same mechanism as for soil except along discrete weak planes in the rock and can be triggered by increases in water pressures along these surfaces during rain as was discussed previously in Section 2 in relation to soil. Rock slides do occur in Ireland, generally related to manmade excavations or on the higher mountain areas where environmental factors are impacting on steep faces. Falls and topples are clearly evident where steep rock faces occur and an example of a potential toppling failure can be seen in Plate 4.4.



Plate 4.4 Potential toppling failure at Monesk on the Cavan/Leitrim border, also known as Englishman's Mountain. (Photo – Xavier Pellicer, GSI)

4.7 Recommendations

The Geotechnical Properties of Irish earth materials, particularly peats, with specific reference to slope instability, be investigated

Peat

- Carry out fundamental research into the behaviour of peat at low effective stresses with particular reference to its shear strength
- Develop methods of measuring the strength properties of peat relevant to peat slides
- Observe the behaviour of critical peat bogs over time, including the surface movements in relation to variations in moisture contents, water pressures, and density

Mineral Soils

- Identify areas of mineral soils in Ireland which may be prone to landslides
- Develop slope protection methods which may be used in areas which are identified as particularly prone to landslides.

5. LANDSLIDE SUSCEPTIBILITY MAPPING IN IRELAND

5.1 Landslide Susceptibility Mapping Réamonn Fealy

5.1.1 Introduction

One of the first reactions that people may have to the notion of undertaking landslide risk assessment or hazard mapping Ireland might well be “Why?”. In Ireland we are not used to dealing with natural hazards or considering ourselves to be at risk from such hazards. In the main we are fortunate relative to other regions of the world in this regard. We see events like the South East Asian Tsunami of December 2004 or the devastation wrought by Hurricane Katrina in New Orleans and Hurricane Stan in South America in 2005 as being far removed from us. Reports of the loss of life resulting from landslide activity in South America due to Hurricane Stan reach us and our reactions, while sympathetic, are generally grounded in a sense of it could never happen to us.

It has been estimated in the literature that landslides are thought to result in the deaths of 600 people annually around the globe (Aleotti and Chowdhury, 1999). Most people in Ireland will feel lucky that this hazard is geographically removed from us. Most however will not be aware that 21 people died in such an event in 1708 near Cappamore in Co. Limerick or that 8 people died in an event at Knocknageesha in Co. Kerry. The event at Pollatomish in September 2003 was remarkable in that no injuries or loss of life resulted. The dramatic descriptions of the experiences of those people who were fortunate enough to escape the torrent of water, peat, rock and soil that flowed down the mountain that night should be sufficient to cause most people to stop and think more carefully about the potential danger posed by landslides in Ireland.

While generally not considered to be frequently occurring events it should be borne in mind that our knowledge of landslides in Ireland is limited. The database established by the Irish Landslides Working Group (ILWG) is in the main formed only from the recent historical record. The earliest record in the database extends back only as far as 1488. Given such a short record, relative to geological timescales, the extent and frequency of occurrence that can be inferred is limited.

The perception that landslides are too rare to cause concern is misguided and the apparent infrequency should not be relied on as an excuse not to take the potential dangers posed by landslides very seriously. Society would generally agree that one life lost would be too high a price to pay. As the death of a woman in a Welsh seaside car park in Nefyn in 2001 shows, we as a society would be very unwise to underestimate the dangers posed by landslide events. Like many natural hazards, although the frequency may be low, the potential to do extreme damage and to result in human injury or death must always be considered.

5.1.2 Hazard and risk assessment

One of the most important actions in seeking to mitigate the potential damage caused by natural events is to identify as precisely as possible the areas that are most likely to be affected by such events. Given the complexity of the factors involved in landslides this task is best dealt with in a multidisciplinary framework. The emerging work in this area, which is well developed in those regions of the world most prone to landslide hazard, has generally proceeded within the framework of risk assessment.

Risk assessment, although once the primary area of interest for the financial sector and high risk industries, has greatly expanded into the area of natural sciences. The methods and terminology employed in risk assessment provide a convenient structure to study and assess the potential of natural events to impact on society. However there are limitations to the application of the methodology not least of which is the fact that it is a human constructed framework for assessment and response. Nature has proved countless times in the past and will continue to do so in the future that we must not become over-reliant on human systems of understanding. Events in nature are often extremely complex and it is vitally important that we seek to understand the limitations in our approaches. By doing so we will ultimately benefit from improved responses to the hazards posed, resulting in improved protection from loss of property and life.

Terminology

It is apparent in the literature that, internationally, multiple definitions and cross-applications of terminology are common. Key terms, such as risk, hazard, vulnerability, and susceptibility are used in different ways by various authors and it is not uncommon to find these terms used interchangeably even within the same publication. This can lead to confusion amongst the stakeholders in landslide hazard and risk assessment, from the public through to engineers and the authorities that are charged with protecting society from such hazards. Consensus would appear to be forming on the use of these terms. For the purposes of the work described here the terminology used by the United States Geological Survey (USGS) has been used as a guide and where modified this has been highlighted.

Included here is a description of some of the basic terms used by the USGS in describing the map outputs delivered as part of their national landslide hazard mitigation strategy (Spiker and Gori, 2000).

Landslide inventory map shows the locations and outlines of landslides. A landslide inventory is a dataset that may represent a single event or multiple events. Small-scale maps may show only landslide locations whereas large-scale maps may distinguish landslide sources from deposits and classify different kinds of landslides and show other pertinent data.

Landslide susceptibility map ranks slope stability of an area into categories that range from stable to unstable. Susceptibility maps show where landslides may form. Many susceptibility maps use a colour scheme that relates warm colours (red, orange, and yellow) to unstable and marginally unstable areas and cool colours (blue and green) to more stable areas.

Landslide hazard map indicates the annual probability (likelihood) of landslides occurring throughout an area. An ideal landslide hazard map shows not only the chances that a landslide may form at a particular place, but also the chances that a landslide from further upslope may strike that place.

Landslide risk map shows the expected annual cost of landslide damage throughout an area. Risk maps combine the probability information from a landslide hazard map with an analysis of all possible consequences (property damage, casualties and loss of services).

Hazard and Risk

For the purposes of the general discussion concerning impacts from landslide events, the term hazard is used to describe an event with potential to impact on humans. It is clear from this definition that it is possible for a large magnitude landslide to occur and not necessarily constitute a hazard. This situation could arise if the event were to take place where no negative impact was caused to humans. It will immediately become clear however that the possibility of such a situation occurring in Ireland is low. This is in no way due to the unlikelihood of a large magnitude event occurring. It is to do primarily with the fact that there is very little land area in Ireland that is not owned or utilised by humans. As such, any event will have a human impact and therefore can be considered a hazard.

The human impact of landslide events may be negligible in areas of low habitation or low utility but they remain a hazard under the above definition nonetheless. It could be argued that changes in society such as the increased demand for rural housing and an increase in recreational use of more natural areas have increased human exposure to the adverse affects from landslide events and therefore increased the hazard of landslides in Ireland.

It is at this point that the more formal definition of risk becomes important. In common terms risk is often used to describe the probability of an event occurring. In terms of risk assessment however, risk is both a measure of the likelihood of an event and the extent of its adverse consequences. It is an assessment of the probability of a landslide occurring in combination with a full estimation of all possible outcomes. These outcomes will generally be expressed in cost terms such as damage costs or the loss of life or injury. In simplified terms, by this definition very large landslides that occurred very frequently in areas that are both inaccessible and not used for economic gain by humans would represent a low risk. This is because the costs in terms of property loss or casualties will be low despite the frequency and size of the event. Perhaps more importantly from a human perspective the converse holds true. Landslide events with a perceived low frequency should be considered as posing significant risk if their potential cost is high. Fig. 5.1 shows this notion of risk expressed qualitatively in a matrix.

Two simplified hypothetical examples serve to mark the extremes of high and low risk. An overhanging cliff face that is considered to be active, in the sense that rock falls are a frequent occurrence, situated in a remote and inaccessible mountain valley, will have a negligible risk associated with it. However to build a school under a cliff face even if the cliff has been stable for as long as records have been maintained would pose an unacceptably high risk because of the adverse impacts on human life and property that would follow a failure in the cliff face. The upper right cell in Fig. 5.1 represents the first case while the latter case of the school would be situated towards the lower left corner.

	<u>Consequence or Cost of outcome</u>			
	Extreme	Moderate	Mild	Negligible
Probability				
High	High	High	Medium	Near Zero
Medium	High	Medium	Medium/Low	Near Zero
Low	High/Medium	Medium/Low	Low	Near Zero
Negligible	High/Medium/Low	Medium/Low	Low	Near Zero

Fig. 5.1 Example of qualitative risk matrix (after Lee and Jones, 2004)

The extent of risk occurring between these two extremes is harder to determine and yet is arguably much more important to fully understand. Low to medium magnitude events will often attract less attention than high magnitude events, and the probability of occurrence of all magnitude events is often not well understood. Put another way, just because we have no record of damaging landslides in an area does not mean that they cannot occur. The situation can therefore arise that human development and activity will occur in areas of high landslide risk, primarily because the hazard has not been identified and consequently the risk not assessed.

Types of Risk assessment

There are two main approaches to presenting an assessment of risk. These are:

Qualitative risk assessment. This involves the expression of the likelihood of an event occurring and the extent of its adverse consequences being expressed qualitatively. The most common representation of qualitative risk assessment is in the form of risk matrices as shown in Fig. 5.1.

Quantitative risk assessment. This involves quantifying the probability of an event occurring and expressing in real terms the losses that would arise from such an event.

It might be possible to include a third broad category here which would span these two approaches. This form of risk assessment might include an expression of the probability of an event occurring with a qualitative representation of the adverse costs, or a qualitative expression of the likelihood of an event with a quantification of resulting costs.

While at first glance, quantitative risk assessment would appear to be the most desirable, in practice the attainment of an accurate estimation of risk in this form is extremely challenging, if not impossible in an Irish context. The requirement of extensive amounts of data to estimate the probability factor alone most likely excludes its use in this country. Fundamentally as a method it is extremely vulnerable to the criticism of false precision, where the expression of risk in numerical terms makes it appear more accurate than it actually is.

On the other hand the benefit of qualitative risk assessment is that it is simply expressed and therefore perhaps more easily understood. This too has its weakness in that it could be argued that the method is grossly over-simplistic as an approach to dealing with landslide hazard. It may be the case that in Ireland the most appropriate, and importantly, the most pragmatic approach would aim towards a semi-quantitative method where a qualitative expression of likelihood is combined with a detailed estimation of the potential costs arising from a landslide.

Such a method would potentially result in a very powerful tool to assist the appropriate authorities in dealing with landslide hazard in Ireland. In areas where a strong case for the potential of landslide hazard is identified, local authorities could adjust planning guidance as necessary. Similarly, infrastructure providers could take account of the estimated potential loss in real terms when deciding on the location of assets such as power lines. Even agencies charged with matters such as the management of natural resources would have valuable information to aid in their management strategy and to guide them in a cost-benefit analysis of implementing mitigation measures to the potential damage caused by landslides. The peat landslide in Derrybrien in 2003 is estimated to have killed over 50,000 fish (SRFB, 2003).

Due to the difficulty of estimating probabilities of landslides in Ireland, the estimation of the likelihood of an event can at best be only qualitative. As alluded to by Aleotti and Chowdbury (1999) the challenges posed by the probabilistic component of hazard assessment, coupled with assessing both vulnerability and the uncertainties associated with both of these aspects, frequently the best that can be achieved is an assessment of susceptibility. They define susceptibility as the *possibility* that a landslide will occur in a particular area on the basis of the local environmental conditions. In Ireland susceptibility assessment based on what can be termed an “environmental pre-condition” approach offers the best way forward for engaging with the hazard posed by landslide.

5.1.3 Landslide susceptibility assessment

Procedure

Irrespective of the form of hazard and risk assessment employed, whether quantitative, qualitative or a combination of both, a number of steps are required for the successful implementation of a national strategy for landslide hazard assessment and mitigation. These are:

- the development of a national inventory of landslide events.
- the development of maps to show areas where the potential for landslides exists
- the development of appropriate guidance and standards arising from the above

Inventory

The development of a national inventory is vitally important as part of the initial investigation of landslides in an Irish context. It is generally accepted that landslides are more likely to occur in areas of previous occurrence. This is based on the fact that there are a number of key factors that are important in determining the occurrence of landslides. These include geology - type and structure, soil type, topography and slope angle and form. These factors will generally occur in zones and the previous occurrence of a landslide event in such a zone must be recognised as significant in indicating the potential of future occurrence, given a similar triggering mechanism.

Susceptibility Mapping

A key use of a landslide inventory map is the location of landslide events relative to these factors, which facilitates the analysis of potential causative factors. By determining the spatial relationships between landslide occurrence and pre-existing environmental conditions the complex interaction of these factors in the causative sequence of slope failure can be better understood. The recognition of these environmental factors also means that their occurrence elsewhere can be determined, leading to the development of maps of potential future landslide occurrence. As such the susceptibility of other areas to landsliding can be established. The development of landslide susceptibility mapping is a key component in landslide hazard assessment.

Susceptibility mapping also allows the incorporation of the knowledge and experience gained by the geotechnical engineering community into landslide hazard assessment. A substantial body of work exists in the area of slope stability analysis. While the results of such analysis, e.g. Factor of Safety indices etc., are often driven by site-specific investigation or laboratory experimentation, incorporation of these elements into a broader mapping framework allows assessment at a regional level. While exposed to the potential criticism that these studies are developed on a local scale and should not be used outside of the scale of their development, in the absence of raw data to drive an empirical approach, their inclusion gives hazard assessment a defensible starting point for the spatial allocation of susceptibility outside the local scale.

Appropriate guidance and standards

The ultimate aim of any inventory and mapping effort is to ensure the reduction of risk to human life and property. It is essential therefore that the results of the inventory and susceptibility mapping be taken account of in both the planning and regulatory frameworks and by individual citizens. The provision of information to the general public facilitates informed decision making and the incorporation into the planning system ensures that the recognition of risk is formalised and acknowledged in the planning process with the aim of mitigating risk. The issue of planning is dealt with in Chapter 6.

5.1.4 Mapping and GIS

By definition, landslide hazard will be determined by where the potential for landslides occurs, and similarly risk will be estimated based on the location of people or assets in geographic proximity to such hazard. This points to the extreme significance of mapping in any deployment and implementation of a landslide hazard mitigation strategy. Essentially, the successful management of landslide hazard will be predicated on knowing where such hazards are likely to occur. It is only within a spatial framework that landslide hazard can be optimally understood and dealt with. Map products are therefore a very important part of landslide hazard management, and the availability of map outputs are of huge benefit to government departments, state agencies, local authorities, engineers, and the public in general.

GIS

The development of Geographic Information System (GIS) technology has greatly facilitated spatial analysis and the creation of useful map outputs. Although the term GIS is often thought of as being a particular type of software, GIS is more correctly defined as a system of computer software, hardware and data, and personnel, to help manipulate, analyze and present information that is tied to a spatial location. GIS is a systematic method to visualize, manipulate, analyze, and display spatial data. Simply put, a GIS combines layers of information about a place to give a better understanding of that place.

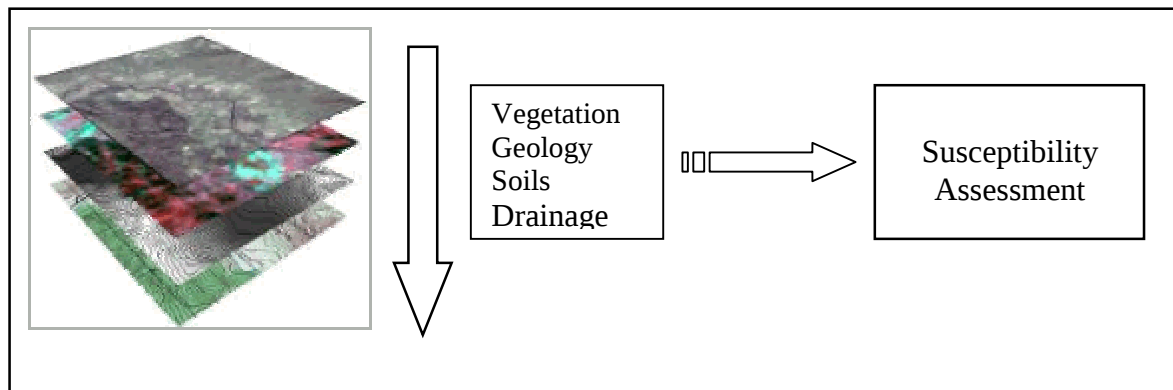


Fig. 5.2 The concept of overlay analysis in GIS

Fig. 5.2 is a simple graphic representation of how spatial data layers can be combined in an overlay analysis thus yielding new information about a location. In this figure data layers such as vegetation, geology, soils and drainage networks are shown in overlay fashion, correctly located with respect to each other. These layers can be analysed in association with the occurrence of landslide events to develop a model of the co-occurrence of landslide causative factors. The output can be used either statistically or deterministically to develop a landslide susceptibility map.

The use of GIS is extremely important in both investigating and helping to establish the spatial relationships between causative factors and landslide events, and also in preparing map products of susceptibility, hazard and risk. For the first purpose, the development of spatial relationships, the GIS acts as an integrating framework for the analysis. By providing a management system for the variety of input spatial datasets and the tools for investigating their interrelationships, the GIS can greatly improve the efficiency of such analysis. Table 5.1 lists some of the datasets relevant to landslide investigation that are available in Ireland.

Data Theme	Dataset	Scale/Resolution	Coverage
Soil	General Soil Map of Ireland	1:575,000	Whole Country
	AFT county soil maps	1:126,720	Partial (44%)
	AFT soil survey field maps	1:10,560 scale	Partial (44%)
	IFS County Soil Maps	1:50,000-1:100,000	National
	IFS County Parent Material Maps	1:50,000 Nominal	National
Geology	GSI bedrock geology	1:100,000	National
	GSI groundwater mapping/Aquifer		
	GSI geotechnical data		
	GSI quaternary mapping		
Elevation	EPA/Teagasc DEM	20m	National
	OSI Contour (Vector)	10m interval	National
	OSI DEM	Mixed	National
	GeoTOPO DTM	1000m	Whole Country
	Synoptics DTM	50m	Whole Country
Land cover	CORINE 1990	25Ha	Whole Country
	CORINE 2000	25Ha	Whole Country
	IFS County Land cover Maps	1Ha	National
Climate	ICARUS (NUIM) 1961-90 Baseline Climatologies	1000m	Whole Country
	Met Eireann observed data network		
Air photo	1973 National Stereophotography	1:30,000	National
	1995 National Stereophotography	1:40,000	National
	1995 National Orthophotography	1:40,000	National
	2000 National Stereophotography	1:40,000	National
	2000 National Orthophotography	1:40,000	National

Table 5.1 Digital datasets of relevance to landslide hazard assessment

Remote Sensing

GIS can be used to map the location of recorded landslide events, but importantly, it can also be used to investigate the occurrence of events which have not previously been recorded. This investigation can use a number of methods including aerial photo interpretation, satellite image interpretation, satellite image classification and terrain analysis. To date the use of these approaches, which are broadly termed remote sensing methods, has been somewhat hampered by the resolution of the available data (with the exception of aerial photo interpretation). However the increasing development and availability of commercial high resolution satellite imagery with resolutions of 1 metre and less suggests that this area will become increasingly important in the future. The development of high resolution terrain models, particularly by acquisition technology such as LIDAR, will also potentially yield significant gains in efforts to map previous unknown landslide events. Table 5.2 lists sensor data which can be of use for landslide hazard assessment.

Platform / sensor	pixel resolution(m)	spectral resolution	spectral range
AVHRR	1100	5	VNIR-TIR
SPOT veg	1150	4	VNIR-SWIR
TERRA/MODIS	250/500/1000	36	VNIR-SWIR-TIR
TERRA/ASTER	15,30,90	16	VNIR-SWIR-TIR
TERRA/MSIR	275/1150	4	VNIR
LANDSAT /TM	30,120	7	VNIR-SWIR-TIR
LANDSAT / ETM	30,60,15	8	PAN +TM
SPOT HRV	10,20	4	PAN, VNIR
SPOTHRVIR	10,20	5	SWIR-HRV
QUICKBIRD	0.61, 2.44	5	PAN, VNIR
IKONOS	1, 4	5	PAN, VNIR
<i>AVIRIS HYMAP</i>	4,20	168-224	VNIR, SWIR
<i>CASI-2</i>	5	48-288	VNIR
<i>ADAR 5500</i>	0.5	4	VNIR
<u>RADARSAT</u>	25	*	*
<u>ENVISAT/ASAR</u>	30		DUAL POLARIZATION
<u>ERS1/2</u>	25		
LIDAR	<1		LASER

Table 5.2 Digital Sensor Data of relevance to landslide hazard assessment

bold - stereo images available

italics – airborne

Underline – radar

5.1.5 Landslide Susceptibility Mapping Case Study: County Mayo

This section presents a brief case study to investigate the use of GIS in the production of landslide susceptibility maps for a large area of the country. County Mayo was chosen as the focus of this case study due to the recent occurrence of landslide activity in the area and because of the existence of the small-scale, large-area datasets necessary for extensive hazard assessment. The focus for this case study is on the potential for landslides in organic soils.

Susceptibility criteria

One of the key challenges in developing a susceptibility map for landslides in Ireland is the basic lack of recorded data on landslide occurrence. The inventory compiled by the ILWG is an essential first step in the collection of data to help in assessing the relative susceptibility of locations in Ireland to landslides. However it is most likely that there will not be sufficient data in the inventory to drive either a quantitative or statistical approach to determining susceptibility.

A pragmatic approach to susceptibility mapping should therefore be guided by best available information, supported by the information derived from the national inventory. For the current case study and as a starting point for mapping susceptibility, the geotechnical sub-group of the ILWG developed criteria which could form the basis of an initial susceptibility mapping exercise. A more detailed examination of the geotechnical engineering issues relating to landslides can be found in Chapter 4.

After consideration the sub-group proposed that there is the potential of an unacceptable risk of a landslide which could give rise to a hazard where:

- peat is in excess of 0.5m or where the peat slope angle is greater than 15 degrees.

These criteria were then used to specify the development of a GIS based susceptibility map for organic soils in Co. Mayo.

Available datasets

The first task in developing a susceptibility map involves an assessment of the available data. The following datasets were available for the case study:

Theme	Source	Scale	Extent
Soil	An Foras Taluntais	1:127,560	Western half of Mayo
	EPA Soil & Subsoil Mapping Project	1:50,000-1:100,000 (Nominal)	Entire county
Landcover	EPA Soil & Subsoil Mapping Project	1 Ha grid cell resolution	Entire county
Slope	EPA-Teagasc DEM	20m grid cell resolution	Entire county

Table 5.3 Datasets available for Co. Mayo case study

Dataset background information

At the outset of the EPA Soil & Subsoil Mapping Project (initially established as the FIPS-IFS project), less than half of the country's soils had been surveyed and published at a detailed reconnaissance (1:126,720) scale (Fealy et al., 2004). This necessitated the development of soil mapping for the remainder of the country at a similar scale. Due to the short project time frame, remote sensing and GIS techniques were incorporated into the project methodology.

The EPA Soil & Subsoil Mapping Project developed a methodology for the creation of a first-approximation soil classification for those areas not previously surveyed by the National Soil Survey. This also involved the production of a subsoils map for the entire country using stereo-photogrammetric interpretation supported by field work.

The use of stereo-photogrammetric image pairs facilitated viewing of the landscape in a simulated 3-dimensional environment. This technique is well established in soil survey methodology and is widely used internationally. Map units are discriminated using visual signals from the imagery such as texture, tone and appearance along with contextual information provided by 3D viewing. Vegetation overlying peat is generally very easily discriminated from the imagery, facilitating generally high accuracy levels for the classification of peat.

Within the same project, a landcover map of Ireland has been developed using supervised classification of satellite imagery acquired by the Thematic Mapper (TM) sensor on board Landsat 5. The resulting land cover thematic map illustrates the distribution of land cover classes. These classes represent groupings of vegetation types, developed from aerial photographic training data, and are indicative of vegetation type in a broad sense.

The EPA-Teagasc DEM was developed using ANUDEM software and the Ordnance Survey of Ireland 1:50,000 data as input. (Preston and Mills, 2002).

The National Soil Survey (NSS) was initiated in 1959, shortly after the establishment of An Foras Taluntais (AFT), the precursor organisation to Teagasc. During the period of operation of the NSS, a number of soil survey outputs were produced at varying scales. Chief amongst these was the publication of 1:127,560 scale mapping for approximately 44% of the country.

The NSS Soil Map of West Mayo was developed using the established methods of soil survey used in other counties in Ireland. This involved mapping soils in the field and the production of a reduced scale soil map for publication at 1:127,560 scale. Although available for only half of Co. Mayo, the map provided a very useful dataset to assess the other datasets used in this case study.

Methodology and results

The production of the susceptibility map based on the criteria supplied by the geotechnical sub-group is relatively straightforward in the sense of the GIS methodology used. In simple terms, it requires the input of a slope map, a peat map, and the application of the criteria thresholds.

The development of a slope map for Co. Mayo for this case study was straightforward. The slope map was produced in ESRI Grid format using ESRI ArcView software. Conceptually, the slope request fits a plane to a 3x3 cell neighbourhood of height values from the DEM around the processing or centre cell. The slope for the cell is calculated from the 3x3 neighbourhood using an average maximum technique.

The development of a peat map suitable for use in mapping susceptibility, although theoretically straightforward, is a somewhat more difficult task. This is illustrated by the results of the first run of the susceptibility model.

For this initial run, the criteria addressing peat slope angle $> 15^\circ$ was modelled. All peat mapped in the subsoils map was used in the classification process as shown in Fig. 5.3. The input maps to the classification process are shown in Fig. 5.4. The data was combined in the GIS using established map algebra techniques.



Fig 5.3 Model schematic for first susceptibility map

The output of this first run susceptibility map production is shown in Fig. 5.6. The susceptible areas in this first run have been enlarged by a factor of 5 for display purposes. With this exaggeration factor taken into account, examination of the output shows that there is a relatively low percentage occurrence of susceptible areas as defined by the modelling process.

Further examination of the inputs shows a low occurrence of peat areas in the subsoils map on slopes $> 15^\circ$. This situation results directly from the nature of the classification scheme employed in the production of the subsoil maps. The category referring to rock was mapped based on the general classification criteria of rock being at or close (within 1 metre) to the surface. For soil classification purposes in traditional soil survey, peat soils are characterised by being at least 30cm in depth in a drained state, and 40cms in depth in an undrained state. The situation therefore arises where areas mapped correctly as rock in the subsoils map of Mayo would appear equally correctly as peat on the published NSS soil map. Both maps are essentially correct in these areas in terms of the classification schemes employed in the mapping efforts.

While initially appearing problematic, this situation can be used to improve the use of the data available for this case study. This results from the fact that the published soil survey map, if considered to be more resolved in the sense that survey was primarily field based, can be used to assess the other data inputs. A revised combination of data can then be employed in the production of a landslide susceptibility map. Fig. 5.5 shows the NSS soil map of West Mayo and peat landcover classes from the EPA Soil and Subsoil landcover map.

Each of the subsoil classes was examined in relation to the landcover map and the published NSS soil map of West Mayo. Subsoil classes were reselected on the basis of their spatial co-occurrence with peat landcover types. This subset of subsoil types was tabulated according to the spatial overlap on mapped soil types from the NSS soil map.

		Subsoil class co-occurring with peat type landcover			
		Rck	TQz	TGr	TMp
NSS Soil Map	Peat	56	77	58	64
	Peaty Podzol	37	17	23	30
	Total	93%	94%	81%	94%

Table 5.4 Relative percentages of particular subsoil categories and their associated mapped NSS soil classes.

The subsoil classes are:

Rck = rock at or near the surface

TQz, TGr, TMp = Tills predominantly composed of Quartzitic, Granitic and Metamorphic materials respectively

From this analysis it is clear that the use of the peat category from the landcover map in conjunction with the additional classes from the subsoils map as detailed above could provide an enhanced predictive map of peat

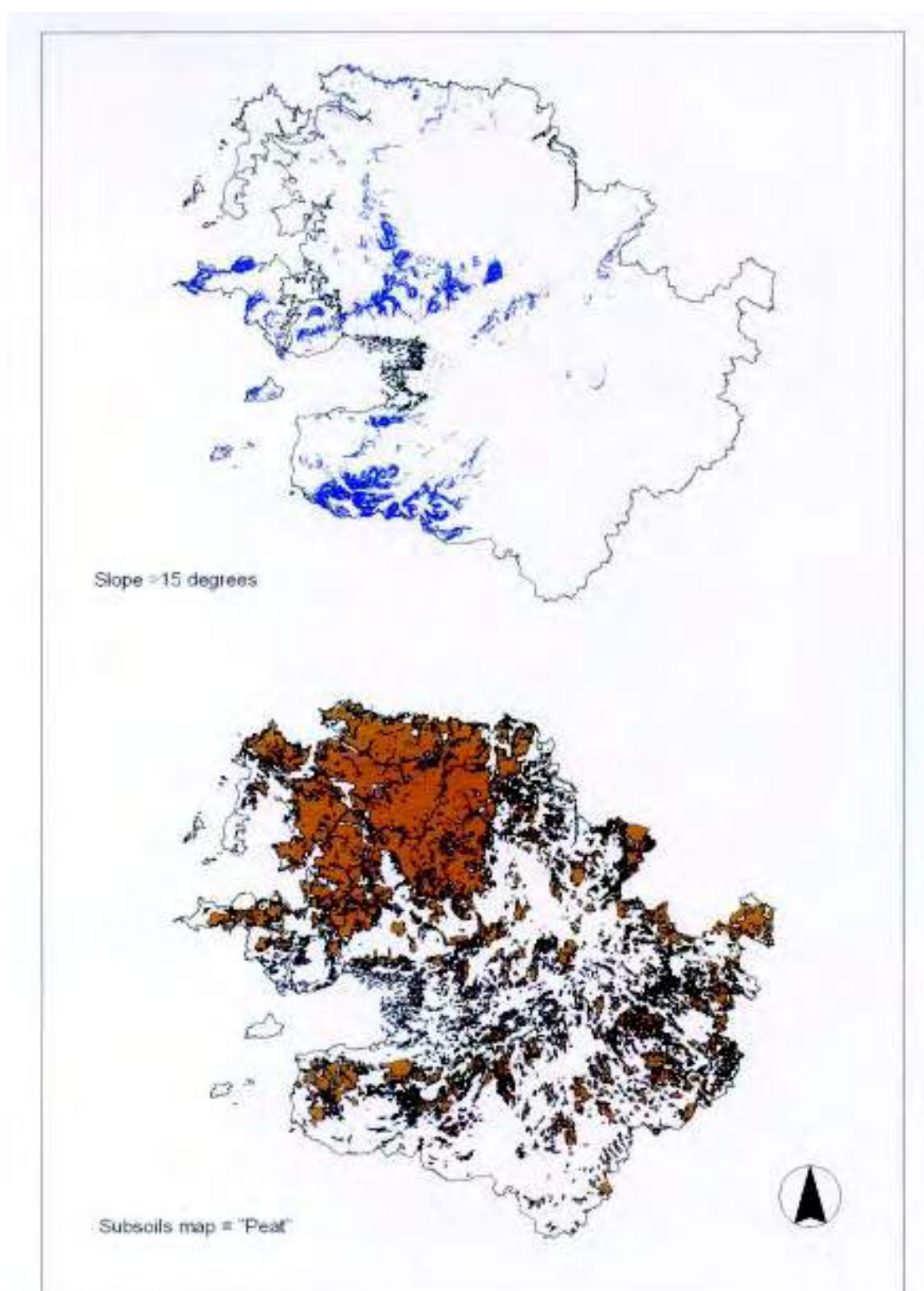


Fig. 5.4 Slope and Peat inputs to first run of susceptibility map

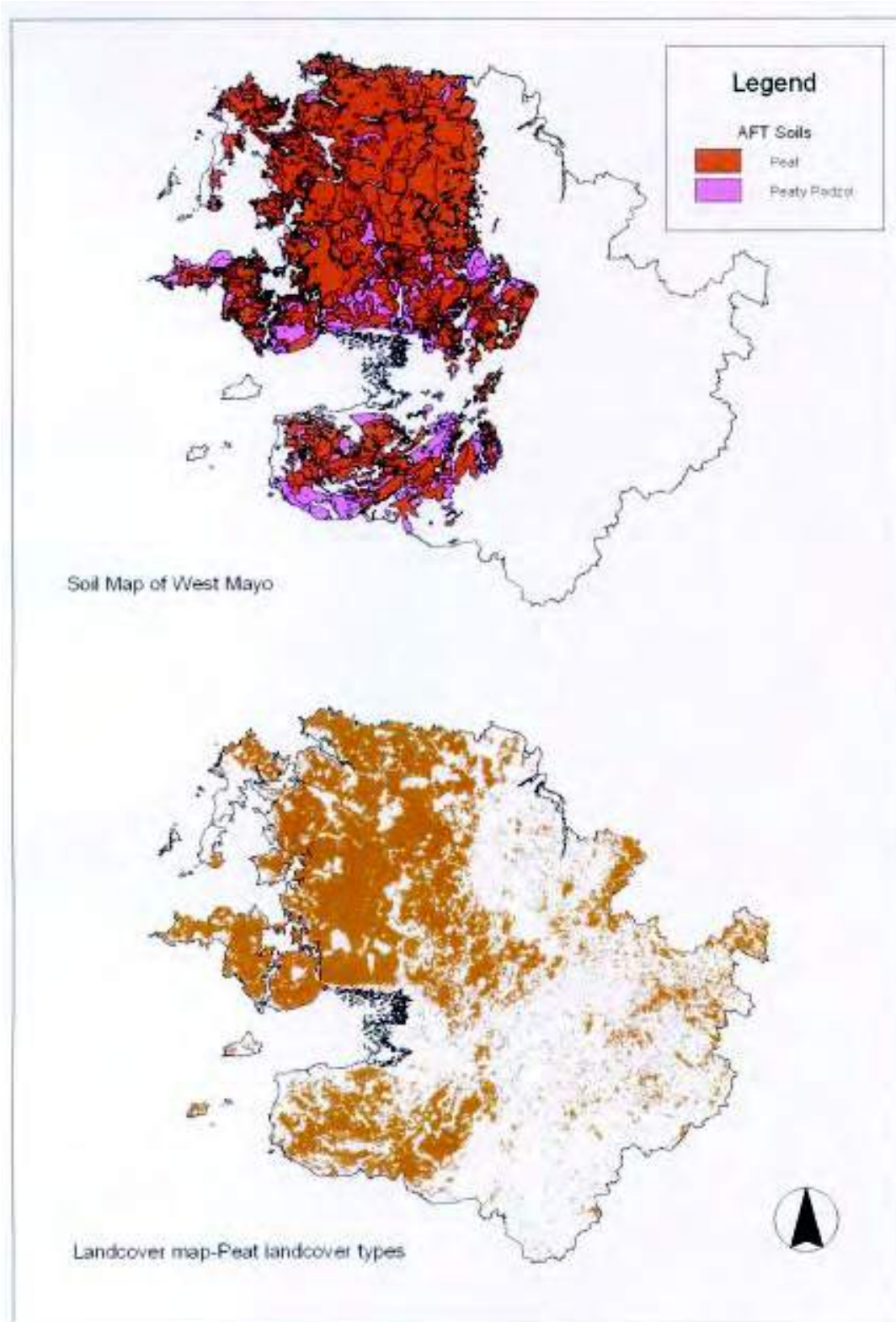


Fig. 5.5 Peat and peaty podzols from NSS Soil Map of West Mayo and peat landcover types

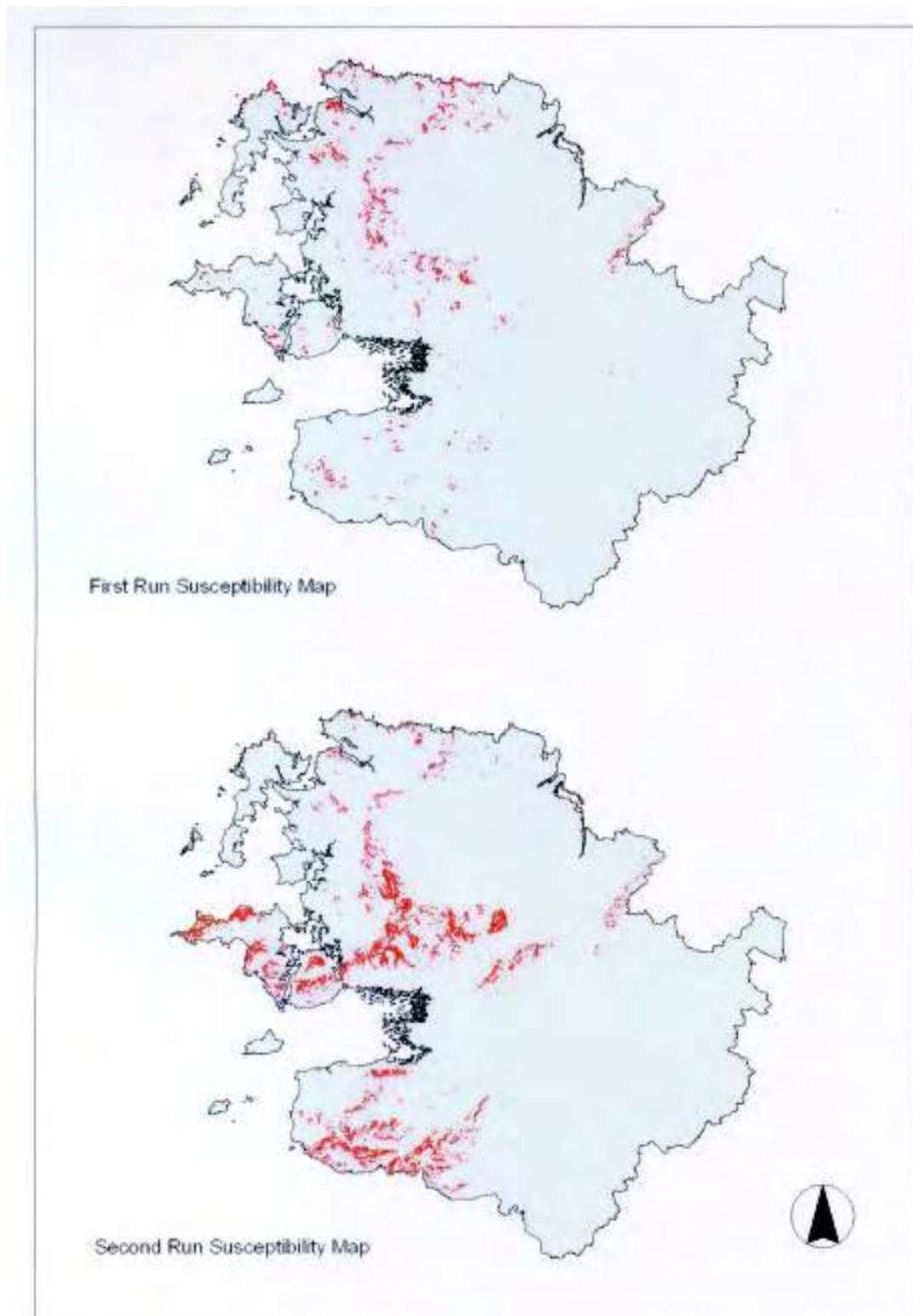


Fig. 5.6 Results of both susceptibility runs. Susceptible areas shown in red

for susceptibility mapping purposes. The table shows that the newly defined peat class for input to the susceptibility modelling process would potentially include some peaty podzol categories which are a mineral soil with a peaty surface horizon. This is primarily due to the fact that these classes mapped by soil survey include both peaty podzols and peat which, in hill and mountain environments, often intergrade into each other over short distances.

Similarly it was decided to include all peat derived from this selection process despite the criteria suggesting use of peat greater than 50cm in depth. This was again deemed justifiable on the basis of the inherent variability of soil/peat classes in the field. Combined with the established field mapping specification for peats which requires them to be >40cm in depth in an undrained state it was considered that for conservative purposes in susceptibility mapping all peat classes derived from this modelling process would be included.

The model process for the second run susceptibility map is described in Fig. 5.7. The second susceptibility map is shown in Fig. 5.6. Here the susceptible areas have not been adjusted for display purposes. It is apparent that there is a significantly greater area classified as susceptible in this output.

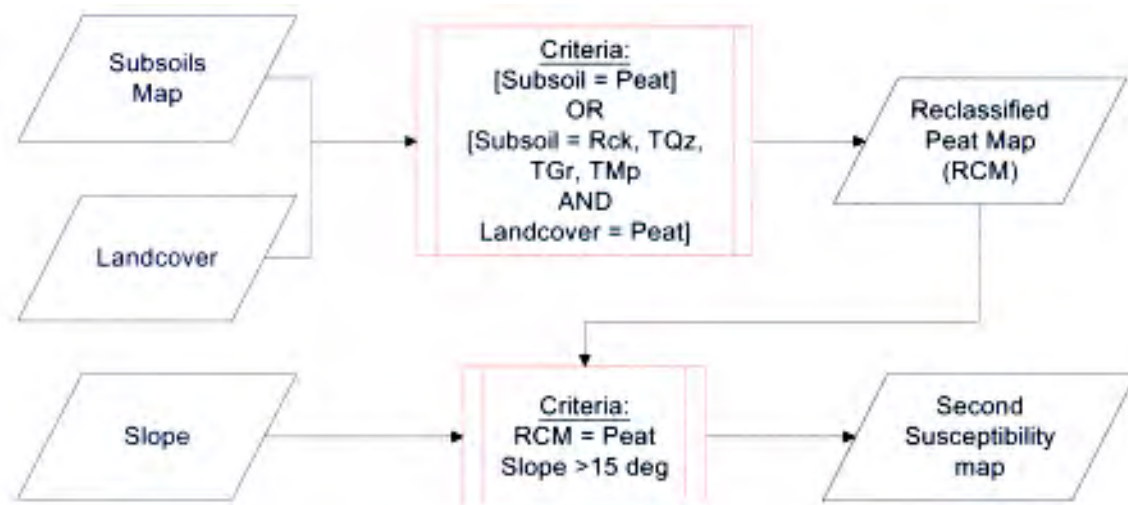


Fig. 5.7 Model schematic for second susceptibility map

For the final model run both criteria for landslide hazard assessment were included in the map process. In this final run of the susceptibility map, the output of the second run susceptibility map was combined with all subsoils mapped as peat. Once again, all peat mapped in the subsoils map was included on the basis that in the majority of cases most mapped peat will approach or be greater than the 50cm depth limit specified by the hazard criteria. The results of this model run are shown in Fig. 5.8.

Once again there is a significant increase in the area mapped as susceptible to landslide. Fig. 5.9 shows the areas mapped as susceptible by all three approaches as percentages of the total land area of Co. Mayo.

Whereas previously the areas mapped as susceptible were confined to predominantly upland areas, where slopes would be expected to be in excess of 15°, the inclusion of the criteria relating to peat greatly extends the area and range of susceptible areas, accounting for 42% of the total land area in Co. Mayo. While appearing large, this figure is not necessarily an incorrect or exaggerated result. When viewed in light of the events recorded in the landslide database and their coincidence with susceptible-mapped areas, the results suggest that there is merit to the development of susceptibility mapping in the manner described here. This is further supported by the fact that in all three model runs the Pollatomish area is identified as being susceptible to landslide hazard. However, uncertainties inherent in the model output should be investigated fully.

It is important to note that this case study focuses only on organic soils and their susceptibility to landslide. Mineral soils and rock areas have not been evaluated. Furthermore, the issue of run-out zones, which are areas occurring in landslide fall-lines, has not been examined here and such areas have not been incorporated into the map. It could be argued that the investigation and mapping of run-out zones should be deemed a very important area for future research.

Susceptibility maps tend towards mapping landslide initiation sites only, which are those sites where the environmental conditions prevailing suggest the possibility of a landslide hazard. However those areas downslope of the initiation site will not be mapped in many susceptibility efforts as these will not exhibit conditions known to be associated with landslide initiation. These areas in the fall-zone are more likely to be inhabited or developed and therefore where the proper assessment of risk of landslide events should be targeted.

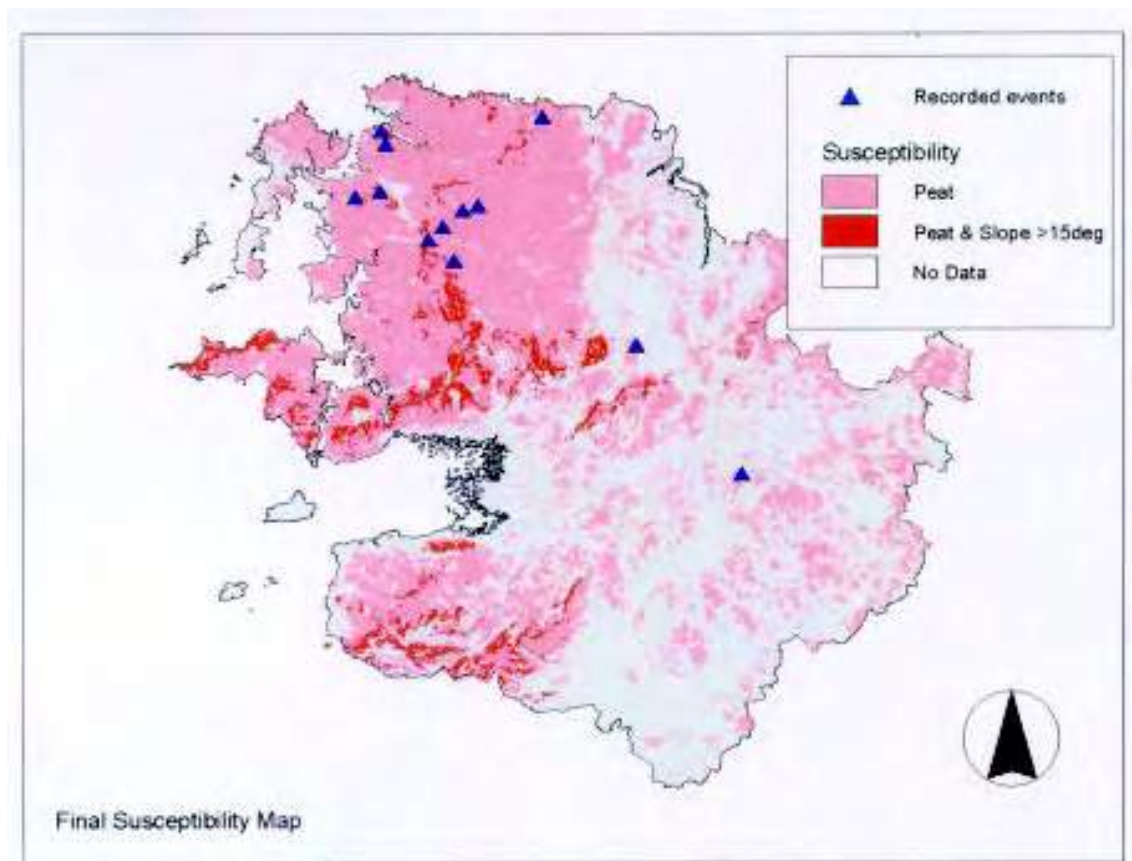


Fig. 5.8 Final susceptibility map and recorded landslide events

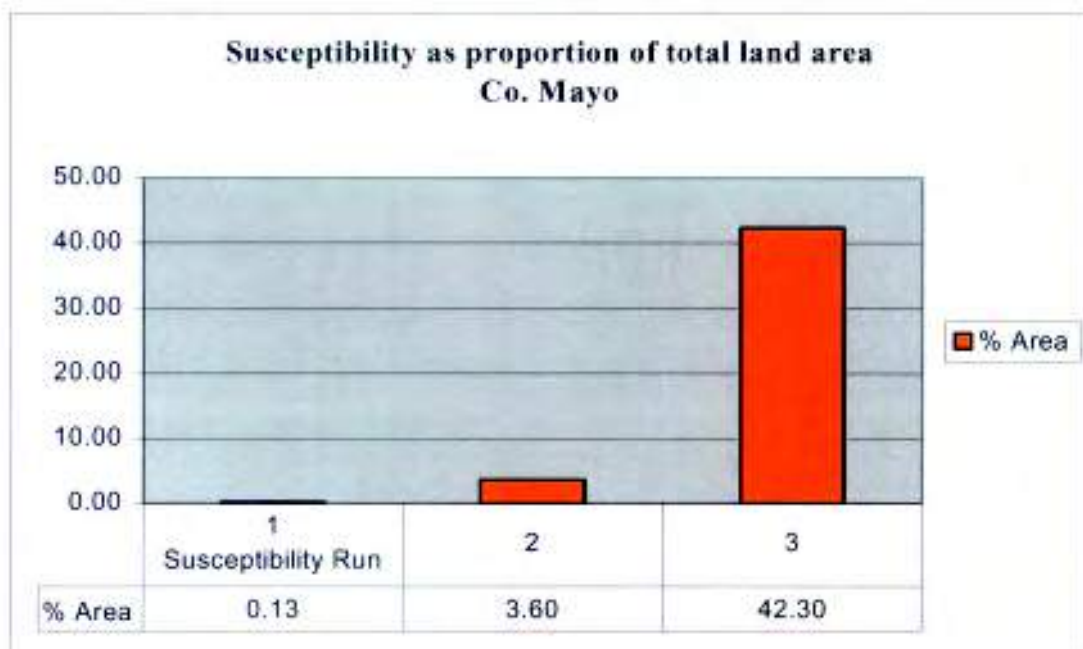


Fig. 5.9 Proportions of susceptibility by three approaches

5.1.6 Conclusion

This case study highlights some of the challenges involved in developing regional scale mapping relating to landslide hazard. It shows that preliminary results can be obtained based on the data available but that these results need careful and thorough evaluation. The challenge of incorporating relatively highly resolved criteria (i.e. those derived from geotechnical analysis) into deterministic regional mapping has been highlighted. The

relationships between developed susceptibility criteria and available data, and between available data and reality on the ground, need to be examined fully. By evaluating these relationships the modelling process can be better understood and any uncertainties in the modelling framework can be documented and communicated to all parties with an interest in assessing the hazard posed by landslides in Ireland.

The results clearly highlight the necessity for a comprehensive analysis of the issues involved in susceptibility mapping raised in this case study. This is particularly relevant in light of the expected role of planning authorities and the potential for the development of planning guidance on this matter in the future. Future research in this area will be essential in determining the role of regional susceptibility mapping in the development and implementation of such planning guidance.

5.1.7 Recommendations

- A full assessment of available national maps and the interrelationships between the classifications used and those required for susceptibility mapping
- Particular focus should be paid to the classification “Peat” as used by the various national maps. The relationship between the mapped peat categories and their depths should be examined.
- On completion of susceptibility rules for mineral soils and rock, these should be incorporated into the susceptibility mapping effort
- Further investigation should consider the issue of run-out areas and how these are accounted for in assessing potential risk due to landslide hazards.

5.2. Bréifne Area Landslides Susceptibility Mapping

Xavier Pellicer



Plate 5.1 Rotational landslide and subsequent rock falls occurring in Cuilcagh Mountains, County Leitrim.

5.2.1 Introduction

The aims of this project were to identify and map landslide occurrences in the Bréifne Area in north-west Ireland; to produce a landslide susceptibility map using GIS; and to test a first approach for a methodology for systematic landslide mapping for the whole of Ireland.

The Bréifne Area is located in North West Ireland covering parts of County Sligo, County Cavan and County Leitrim in the Republic, and County Fermanagh in Northern Ireland (Fig. 5.10). It covers an area of 3082 km². Due to the lack of readily available datasets such as a DEM and air photographs for County Fermanagh it was decided to exclude it from the study area. The final study area therefore covers a total area of 2129.7 km².

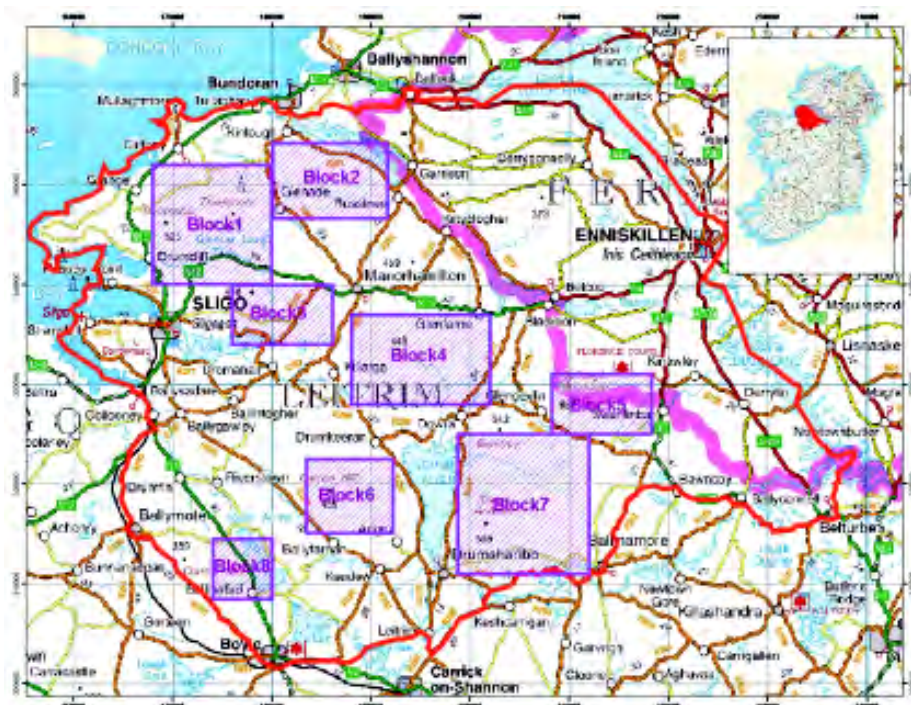


Fig. 5.10. Bréifne area outlined in red. Location of areas where landslide mapping has been focused outlined in purple.

The methodology used to derive the final susceptibility maps was compiled from several literature examples (Santacana et al. 2003, Tangestani 2003, Morton et al. 2003). Due to the large extent of the study area (2129.7 Km²) and the short length of time available for fieldwork (less than one month), mapping was mainly based on remote sensing techniques such as satellite imagery, aerial photography and orthophotography analysis. All these datasets were combined with digital elevation models (DEM) to facilitate identification and classification of landslide events.

5.2.2 Datasets

The datasets used during the landslide mapping and analysis are displayed in Tables 5.1 and 5.2. All datasets have been tested and a selection was finally made for this project. This decision was based on the scale or resolution of the dataset. High spatial resolution datasets (>1:20,000) have been found to be more efficient for landslide mapping.

Several **thematic datasets** were viewed and compared to assess which ones would be used during the final analysis. Landcover, Bedrock Geology, Quaternary Geology and rock outcrop maps were available for the project and details of these datasets are displayed in Table 5.1. Several landcover maps were available for this project. The Landcover Thematic map supplied by Teagasc was considered the most suitable. Some areas of this dataset were characterized as “Unclassified” and in those areas the Corine landcover map was used to input the class instead. Other thematic datasets used were a Bedrock Geology map at 1:100,000 scale from the Geological Survey of Ireland (GSI) and the Irish Forestry Soil (IFS) parent material maps (available only for Co. Sligo and Co. Cavan) produced by the Spatial Analysis Group in Teagasc.

With regard to **digital datasets**, satellite images were analysed following the methodology used by O’Loingsigh (2005). Landsat ETM+ imagery was not selected as the landslide mapping dataset due to its poor spatial resolution. The EPA/Teagasc DEM with a spatial resolution of 20m was used to generate aspect and slope maps for the area. The combination of black and white orthophotography from 1995 with the DEM using © Fledermaus software, for 3D visualisation, was utilized to map and classify most of the occurrences. This method was compared to digital stereophotography, which was employed in areas where no other elevation data was available.

5.2.3 Methodology

The methodology used is based on a literature review and fieldwork experience. The large number of events mapped dictated which method would be used to produce a landslide susceptibility map. It was decided to use statistical analysis on the data acquired. Fig. 5.12 shows a schematic representation of the methodology employed.

Dataset processing

Following the approach used by O’Loingsigh (2005) Landsat ETM+ imagery was analysed using ERDAS software. The image was pre-processed in order to improve the spatial resolution using the following steps:

1. 6 multispectral bands and panchromatic image were re-projected to Irish GRID using Nearest Neighbour as the resampling method.
2. Image was resampled to 15 metres resolution using a resolution merge method where the panchromatic image was the high-resolution input file. Principal component analysis was the method utilized, and Cubic Convolution was the resampling technique.
3. Image was projected with RGB 542.

Large landslide scars can be observed in Image 1 (Fig 5.11) displayed in magenta and outlined in green. Comparing this to Image 2 (colour orthophoto for the same area), it can be observed how some smaller features cannot be identified in the Landsat image due to pixel size or shadow effect (area outlined in blue). Changes in vegetation in Image 1 gives the same response – magenta area outlined in red – as landslide scars. This could lead to misinterpretation.

Use of Landsat imagery can be useful when no other imagery at a higher resolution is available. Due to availability of colour and black and white orthophotography data with a 1 metre spatial resolution for the study area, Landsat imagery was discarded as a mapping tool.

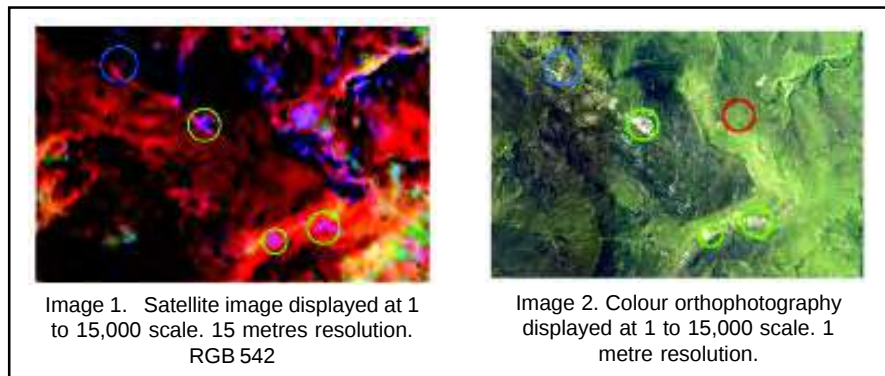


Fig. 5.11. Satellite image and aerial photography for same area.

Three main types of aerial photography were used for landslide mapping and classification:

- 1995 black and white national digital stereophotography at 1:40,000 scale.
- 1995 black and white national digital orthophotography at 1:40,000 scale.
- 2000 colour national digital orthophotography at 1:40,000 scale.

Digital Elevation Models at 20m resolution for the area were generated from the EPA DEM in the Republic. The ERA Maptec DEM (50m spatial resolution) for the area in Northern Ireland was resampled to 20m resolution. Datasets for the Republic of Ireland and Northern Ireland were merged to create a unique DEM for the Bréifne Area at 20m spatial resolution.

Slope analysis was evaluated on the 20m resolution EPA DEM and the resampled (20m resolution) ERA Maptec DEM. There was no variation between the two datasets.

Slope analysis was evaluated between 20m EPA DEM and the original 50m resolution ERA Maptec DEM. Differences were spotted in this case. A larger area is covered in the EPA DEM when selecting areas with slope greater than 15°.

The dataset produced from merging the EPA DEM at 20m resolution for the Republic of Ireland, and the ERA Maptec DEM resampled at 20m resolution for Co. Fermanagh, was selected as suitable for further analysis.

The criteria outlined in Chapter 5.1 - "Peat is in excess of 0.5m thick or where the peat slope angle is greater than 15°" - were used to identify potentially vulnerable areas. Peat covered areas were selected from the Teagasc Land Cover map 2004 for the whole area, and from the IFS parent material maps for Counties Sligo and Cavan. Areas with slopes greater than 15° were selected from the slope map derived from the DEM.

Landslide Mapping by Image Analysis

The area of study was reduced to 8 sub-areas (Fig 5.10), named Blocks 1 to 8. These blocks were selected using the following parameters:

- Areas covered by peat.
- Areas with slope gradient >15°

The block areas were created to enable the use of Fledermaus software. The 8 blocks were located based on the number of landslides discovered during a preliminary scanning of the areas defined by the two criteria above using aerial photography. The area covered and the number of events occurring in each block is shown in Table 5.5.

Block Number	Area (sq. km)	Number of events mapped
1	143.4	269
2	90.4	92
3	60.8	22
4	12.6	82
5	60.6	83
6	59.9	38
7	151.7	98
8	35.8	0
Total	615.2	684

Table 5.5 Area and number of events identified in each block.

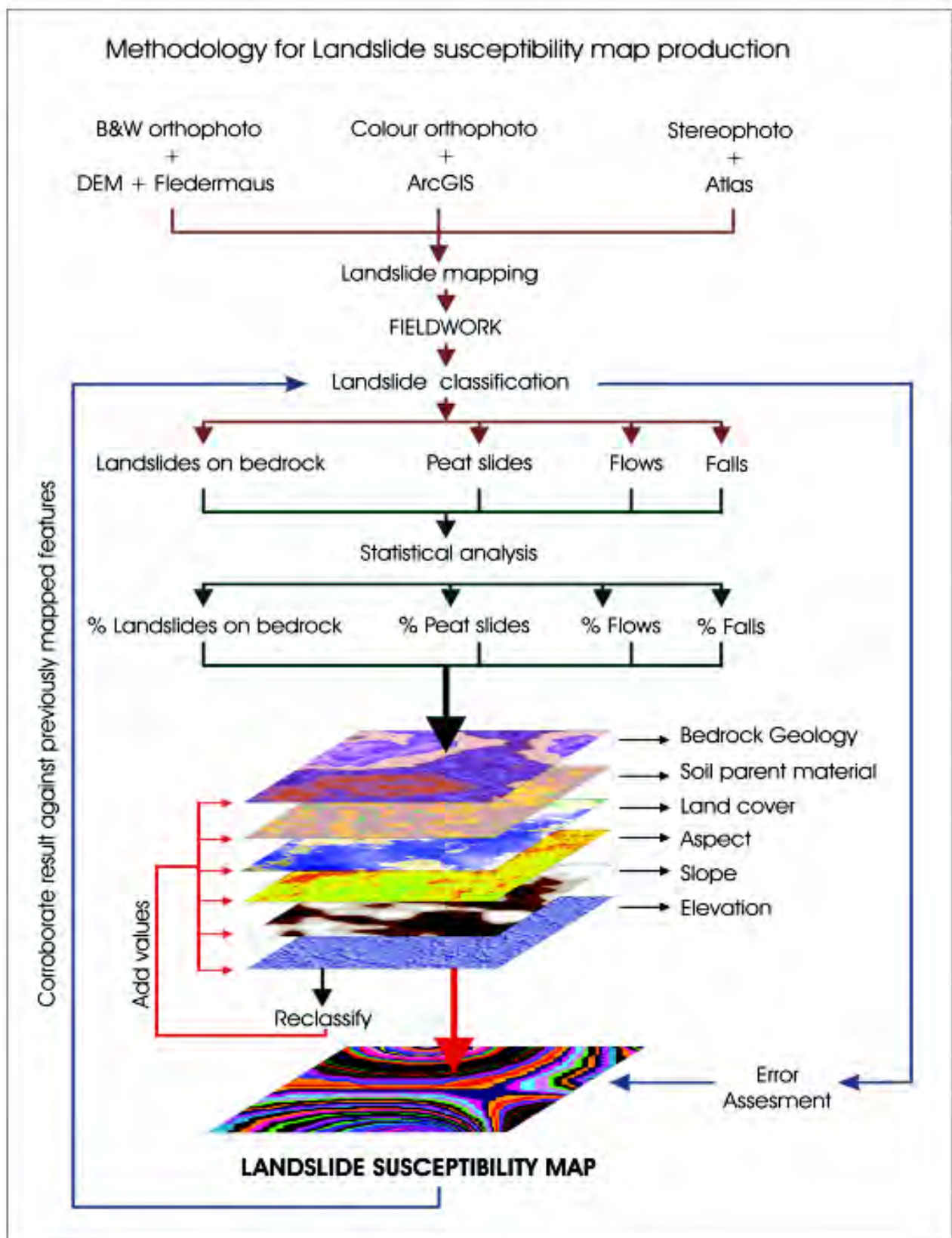


Fig. 5.12. Landslide susceptibility mapping methodology

Black and white orthophotography was merged for each block separately. It was subsequently processed using ArcGIS software in order to obtain an image with superior contrast and quality. Block areas were draped on a 20m spatial resolution DEM and displayed with Fledermaus software. Due to problems arising during the resolution merge in ArcGIS, the orthophotography had to be resampled to 2m spatial resolution. Use of Fledermaus software greatly improved the display and understanding of the landslide mechanism operating in each slide. This greatly enhanced identification of landslide occurrences and this was the key software for landslide identification and classification. Events were simultaneously digitised using ArcGIS 8.3.

170 events were mapped with the Teagasc digital stereophotography using Atlas software. Its more accurate elevation values permitted the detection of events not recognized by other methods. In addition, areas outside the blocks were also surveyed using this method. A total of 23 events were located outside the blocks.

The following parameters were recorded and digitised during landslide identification:

Location of landslide crown.

Landslide length and orientation.

Landslide class based on type of movement and mechanism. A list of codes used for classification is shown in Table 5.6.

The classification obtained was checked, corroborated, and refined during subsequent fieldwork.

A total of 694 events were identified, digitised, classified and stored in an Access database, prior to field investigation.

Fieldwork

The first stage of the short fieldwork programme involved visiting sites where good examples of landslides had been recorded during image analysis. The second stage of the fieldwork was focused on visiting sites where the landslide classification using aerial photography required further investigation.

A total of 52 landslides were recorded. There were 17 peat slides. There were 18 rotational bedrock slides with associated rock falls and debris flows. 5 events were classified as falls and topples occurring in both bedrock and earth; rock falls were recorded on limestone or sandstone bedrock while rock topples occur on strongly jointed sandstone bedrock. A single earth flow and a debris flow were recorded on shale bedrock. 10 events were classified as complex in that they involved more than one mechanism.

98 digital photographs were taken and their orientation and location was recorded. They are stored in the Bréifne landslide database.

Landslide dimensions were difficult to record during fieldwork, especially for large-scale landslides. Use of the DEM and aerial photography was found more suitable for this purpose.

About 30% of the 52 landslides recorded during fieldwork were incorrectly or insufficiently classified during the previous image interpretation. 50% of the peat slides classified during image interpretation had been erroneously categorized. Several events classified as bog bursts had to be reclassified as peat erosion features. Conversely, some areas classified as peat erosion or peat creep during image interpretation, were in fact found to be bog bursts. Events classified prior to the fieldwork were revised using the imagery and reclassified where necessary.

Fieldwork was essential to properly categorize and catalogue land movements previously identified and classified using the aerial photography images.

Landslide Classification.

Landslides were classified using a coding system (Table 5.6) especially created for this project. The final classification was based on the classification of landslides types used by the British Geological Survey (Northmore, 1996). The peat classification used was that of Boylan (Personal communication, 2005).

In total 694 events were classified from the image interpretation. They were divided into four groups:

- Peat slides
- Bedrock slides
- Flows
- Falls*

CODE	NAME	DESCRIPTION
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FALLS		
FA_FR	Rock Fall	Mass detached from steep slope/cliff.
FA_FD	Debris Fall	Mass of coarse material detached from steep slope/cliff.
FA_FE	Earth Fall	Mass of fine material detached from steep slope/cliff.
FA_TR	Rock Topple	Mass detached from steep slope/cliff with forward rotation about a pivot point.
FA_TD	Debris Topple	Mass of coarse material detached from steep slope/cliff with forward rotation about a pivot point.
FA_TE	Earth Topple	Mass of fine material detached from steep slope/Cliff with forward rotation about a pivot point.
FA_U	Undifferentiated Fall	Undifferentiated mass detached from steep slope/cliff.

SLIDES		
SL_RSI	Single Rotational Slide	Sliding outwards on one concave failure surface.
SL_RM	Multiple Rotational Slide	Sliding outwards on more than one concave failure surfaces converging on main surface.
SL_RSC	Successive Rotational Slide	Sliding outwards on more than one successive concave failure surfaces.
SL_RU	Undifferentiated Rotational Slide	Undifferentiated rotational movement sliding outwards on one or more concave failure surfaces.
SL_TR	Translational Rock Slide	Rock sliding on a planar failure surface running more or less parallel to the slope.
SL_TD	Translational Debris Slide	Debris sliding on a planar failure surface running more or less parallel to the slope.
SL_TE	Translational Earth Slide	Earth sliding on a planar failure surface running more or less parallel to the slope.
SL_TU	Undifferentiated Translational Slide	Undifferentiated material sliding on a planar failure surface running more or less parallel to the slope.
SL_MADE	Slide caused by human activity	
SL_U	Undifferentiated Slide	Undifferentiated Bedrock Slide.
SL_PT_B	Bog Burst	Catastrophic failure of structural and hydrological integrity of a peat bog causing peat flow
SL_PT_U	Undifferentiated Peat Slide	Peat slide, unknown mechanism

FLOWS		
FW_D	Debris Flow	Flow of saturated mass of coarse material (gravel or coarser)
FW_E	Earth Flow	Flow of saturated mass of fine material (clay, silt, sand)
FW_S	Solifluction Flow	

COMPLEX		
CX_RT	Complex Rotational /Translational Slide	Composite non-circular part rotational/part translational slide grading to earth flow at toe
CX_FRD	Complex Continuous Rock Fall	Continuous process generating scree deposits.
CX_SFWEFR	Complex Slump-Earthflow with Rock fall debris	Slide involving rotational movement, simple or multiple, and earth flow and rock fall debris on the surface
CX_UND	Complex Undifferentiated Slide	Slide involving two or more of the main movement types in combination
CX_DE	Complex Debris flow	Debris flow involving two or more mechanisms and materials.

Table 5.6. Landslide classification (Northmore, 1996) modified. Peat classification by Boylan (Personal communication, 2005).

*14 Topples were mapped during the project, statistical analysis with this small sample may be misrepresentative. It was decided to categorize them as falls.

Landslide classification figures for the 694 events are shown in Table 5.7. It was decided to omit the man-made slides from the analysis, therefore, a total of 691 events were used for the statistical analysis.

Statistical Analysis

Landslides mapped during image interpretation and fieldwork were coded as seen in Table 5.6. Landslide classes were treated separately during the statistical analysis. The literature review and the fieldwork observations reveal that factors triggering landslides differ depending on the landslide type. The division of the landslides into the four groups described above was considered the best approach to get an adequate number of slides for statistical analysis, and to group slides where triggering and conditioning factors are be similar.

The conditioning factors treated during the statistical analysis are listed below. Other conditioning factors such as rainfall or structural geology were not included as the available datasets were not suitable for this exercise:

Bedrock type
Soil parent material
Land cover
Slope
Aspect
Elevation

Type	Mechanism type - code	Number of events
Bedrock Slides	Multiple Rotational Slide - SL_RM	5
	Single Rotational Slide - SL_RSI	2
	Undifferentiated Rotational Slide - SL_RU	85
	Translational Debris Slide - SL_TD	2
	Translational Rock Slide - SL_TR	4
	Complex Slump-Earthflow with Rock fall debris - CX_SFWEFR	4
	Total	102
Peat Slides	Bog Burst - SL_PT_B	131
	Undifferentiated Peat Slide - SL_PT_U	99
Total		230
Flows	Debris Flow - FW_D	41
	Earth Flow - FW_E	14
	Complex Debris flow - CX_DE	23
Total		78
Falls	Rock Fall - FA_FR	108
	Debris Fall - FA_FD	9
	Earth Fall - FA_FE	6
	Rock Topple - FA_TR	14
	Complex Continuous Rock Fall - CX_FRD	144
Total		281
Other	Slide caused by human activity - SL_MADE	3
TOTAL		694

Table 5.7. Number and type of landslides mapped.

The percentage of events occurring on each of these six conditioning factors was computed. This percentage was subsequently applied to measure the weight of each conditioning factor for the susceptibility map production (e.g. 27% of Bedrock Slides occur on Shale. A weight of 27 was given to areas underlain by Shale bedrock). The same principle was applied to each landslide type combined with each conditioning factor.

Bedrock

The bedrock geology of the Bréifne area is rather complex. Numerous bedrock formations are present in the area and bedrock type is a very important factor in susceptibility to landsliding. The percentage of events occurring on each formation was calculated. A simplified bedrock geology map, containing nine bedrock types was selected for the analysis. The reasons for using a simplified map of nine bedrock types are listed below:

- The bedrock formations are regionally distributed and would give higher weights in areas where events are concentrated.
- A smaller number of bedrock types in the analysis will give a better distribution of weights.
- Simplified bedrock geology types have similar structural, petrological and lithological characteristics.

The percentages calculated for each landslide type are shown in Fig. 5.13. It should be noted that Limestone, Sandstone and Shale comprise the highest percentages of events.

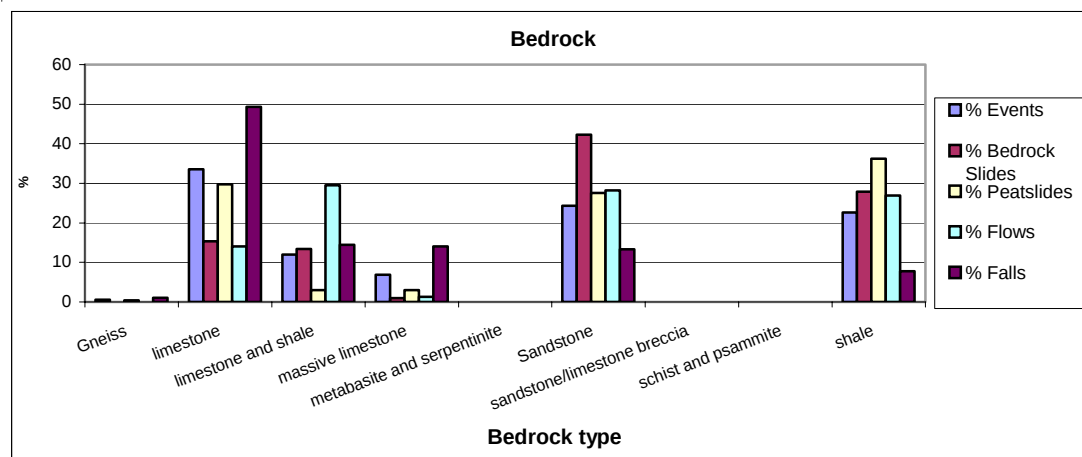


Fig. 5.13 Percentage of Landslides by Bedrock type.

Soil parent material (Subsoil)

Not all of the study area is covered by this thematic dataset. The Co. Leitrim dataset was not available for this study. A total of 399 events are within the areas covered by Co. Sligo and Co. Cavan. These were categorized as follows.

- 66 Bedrock slides
- 128 Peat slides
- 55 Flow
- 144 Falls

Only five soil parent material types were involved in the slide events in the area. Final calculations (Fig. 5.14) show bedrock slides and falls occurring mostly on areas where rock is at or close to the surface. Peat slides take place in peat-covered areas, but, according to the IFS parent material map, some occurrences are happening in non-peat covered areas. This may be explained by the fact that only those areas with peat of 1m+ in depth are mapped as peat covered, and slides may occur in areas of thin peat. Flows chiefly occur on rock at or near surface. This is attributable to the fact that 60% of the flows occur in areas dominated by shale, or limestone and shale, and these are bedrock types susceptible to flowing when water saturated.

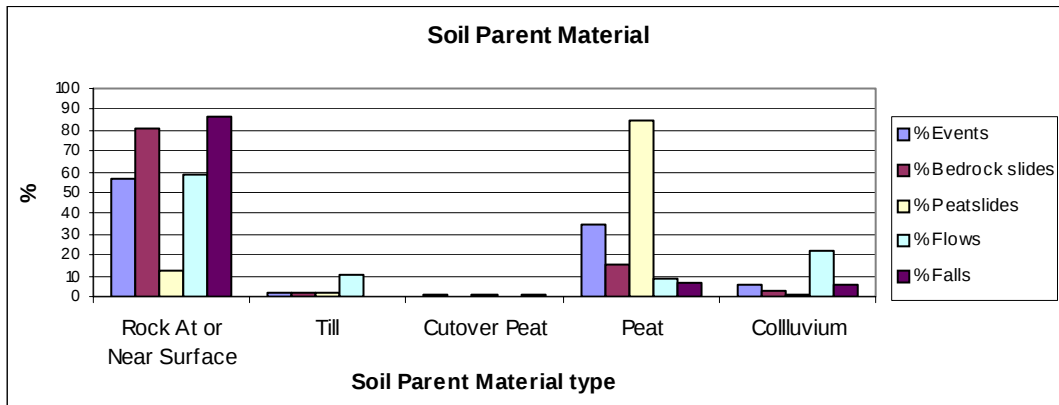


Fig. 5.14 Percentage of Landslides by Soil parent material type.

Landcover Map

The landcover map covers the whole area within the Republic of Ireland. The map has 15 different landcover types. Landslide events occur in 10 of these classes. All events mapped have been used to compute statistics. Final results are shown in Fig. 5.15.

Most of the land and peat slides occur on Bog and Heath. Peat cover was one of the factors used to decide where to focus the survey and this may have influenced the distribution of the data. It also has to be noted that very few events are occurring on bare rock or rocky complex. This is due to the small area (0.2% of the total) covered by these two landcover types. A similar situation is shown in bog, this landcover type covers only 0.8% of the map.

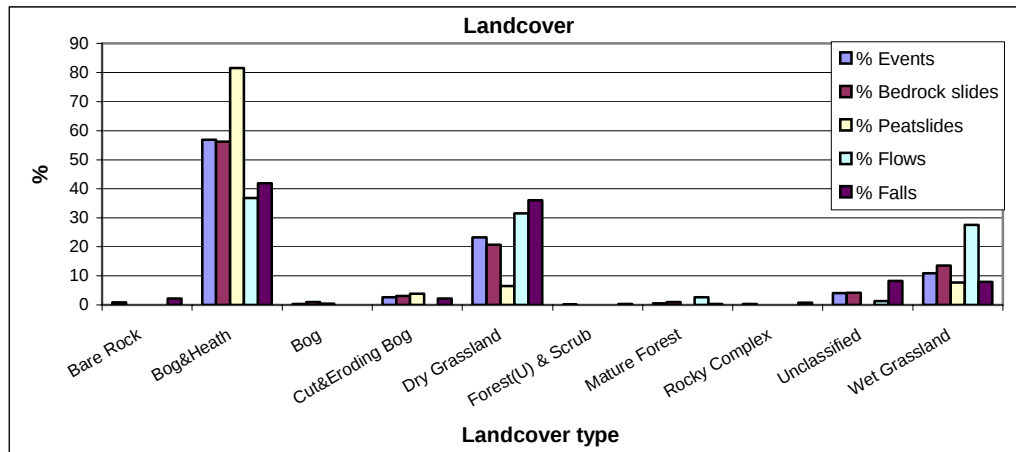


Fig. 5.15 Percentage of Landslides by land cover type.

Slope

The slope map was generated from the DEM for Bréifne, using Spatial Analyst Extension in ArcGIS 8.3 software. Slope is considered a major conditioning factor for landslide occurrence, although while landslide type varied

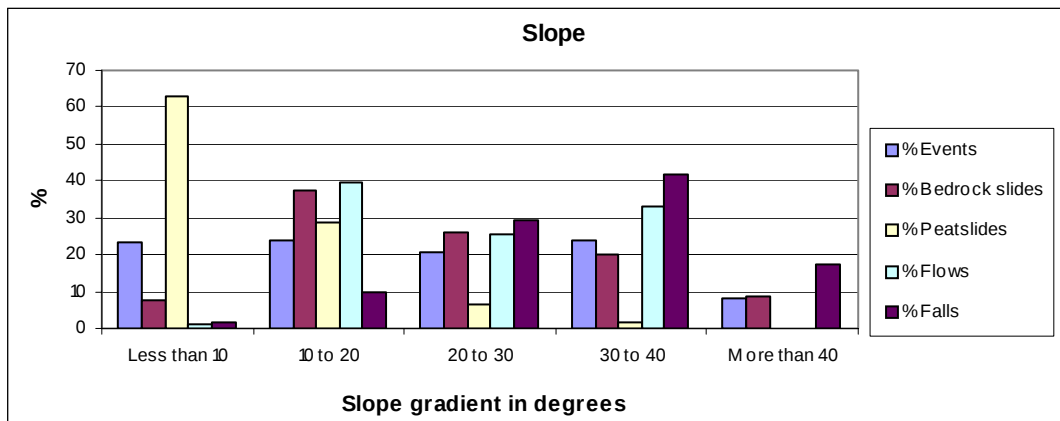


Fig. 5.16 Percentage of Landslides by slope gradient

with slope, overall 20-25% of all events occurred in each of the intervals from less than 10° to 30-40°. Slope data was divided in ranges of 10° and the percentage of slides occurring in each range calculated (Fig. 5.16).

Bedrock slides and falls predominantly occur on slopes steeper than 20°. Flows are likely to occur on slopes steeper than 10° and peat slides are more predominant on slopes from 0° to 20°.

Aspect

A directional aspect map was also generated from the DEM for the Bréifne Area using Spatial Analyst Extension in ArcGIS 8.3 software. It was divided into ranges of 22.5° and the percentage of slides occurring in each range computed (Fig. 5.17).

Landslides occur in all directions. Directional aspect does not appear to have an important role as a conditioning factor as percentage values are very similar to each other, therefore weight for this conditioning factor will tend to be evenly distributed.

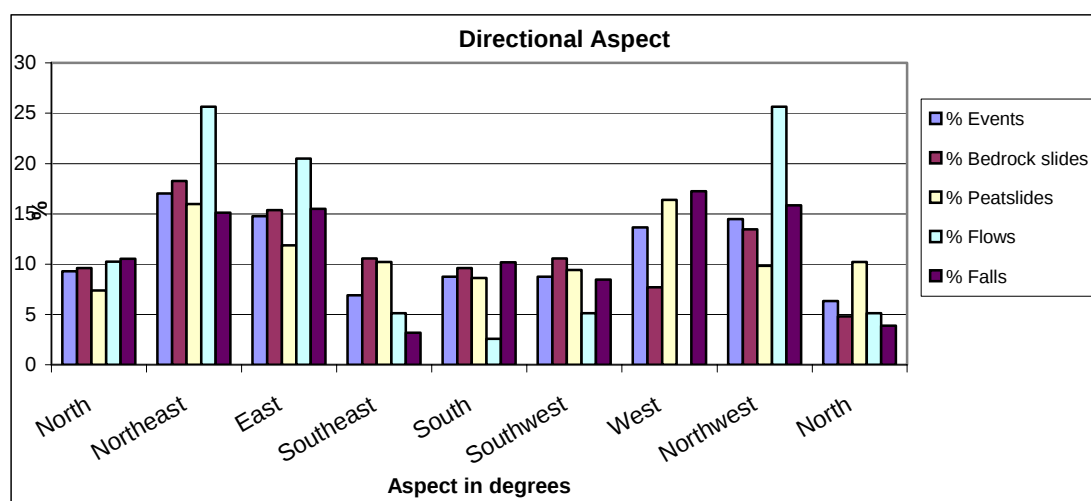


Fig. 5.17 Percentage of Landslides by aspect range.

Elevation

The DEM was analysed to obtain the number of slides occurring at each elevation. It was found to be a major landslide conditioning factor. Very few slides occur under an elevation of 200m. The dataset was divided into ranges of 100m and the number of events occurring in each computed (Fig. 5.18).

Bedrock slides usually take place between 200 and 500 metres O.D. Flows are the only type of event occurring below 200m. Peat slides and falls happen mainly between 300m and 500m. A rainfall dataset for the area with a suitable spatial resolution was not available. It is likely that elevation would be partly related to this triggering factor, which was not examined during this study.

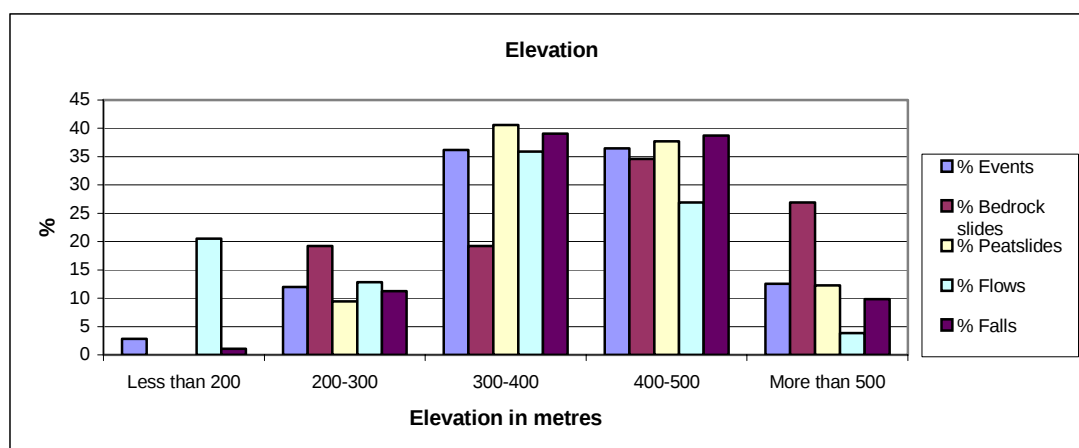


Fig. 5.18 Percentage of Landslides by elevation range.

Statistical Data Processing

As mentioned above weight values were extracted from the percentage of events occurring in each class within a conditioning factor. Datasets previously used were transformed to raster format at 25m resolution. The final landslide susceptibility maps were released at this resolution.

Raster datasets were reclassified using different values for each landslide type (e.g. *Shale was reclassified to 27 for bedrock slides, to 36 for peat slides, to 27 for flows, and to 8 for falls (Fig.5.12). Elevation from 400m to 500m was reclassified to 35 bedrock slides, to 38 for peat slides, to 27 for flow, and to 39 for fall (Fig. 5.17).*

Lack of data for soil parent material. Due to the fact that Co. Leitrim had no soil parent material data available at the time of the study, this area was reclassified with a value of **20** (average of values). As data for this area becomes available, reclassification for soil parent material should be performed to obtain a more accurate final classification.

Reclassification was performed on each layer (conditioning factor) for each landslide type. 24 layers (6 for each landslide type) were reclassified and used to produce the susceptibility map.

As a final step, reclassified layers for each landslide type were summed using Spatial Analyst. On the resulting susceptibility maps high pixel values indicate high susceptibility to landsliding and low pixel values represent low susceptibility. Maximum and minimum values of susceptibility vary depending on the type of landslide (Table 5.8 – see Table Appendix).

Landslide susceptibility was divided into 7 levels indicating high to low susceptibility. Manual method and Equal interval breaks were used to make divisions between levels of susceptibility (Table 5.9 – see Table Appendix).

Knowledge gained from fieldwork suggested the employment of the manual method as a more realistic approach (Maps 1, 3, 5 and 7 – see Map Appendix). Using this approach, areas with extremely high susceptibility to landsliding are represented by very high values, whereas low susceptibility areas are represented by a wide range of lower values. Nevertheless, a landslide susceptibility map using equal interval breaks is presented (Maps 2, 4, 6 and 8 – see Map Appendix).

Landslide susceptibility maps for landslides in bedrock, peat slides, flows and falls at 1 to 500,000 scale can be viewed in the Map Appendix. See list of maps below:

Map 1 – Landslide susceptibility map for bedrock slides using manual method breaks.

Map 2 – Landslide susceptibility map for bedrock slides using equal intervals breaks.

Map 3 – Landslide susceptibility map for rock, debris, earth fall and toppling using manual method breaks.

Map 4 – Landslide susceptibility map for rock, debris, earth fall and toppling using equal intervals breaks.

Map 5 – Landslide susceptibility map for debris and earth flow using manual method breaks.

Map 6 – Landslide susceptibility map for debris and earth flow using equal intervals breaks.

Map 7 – Landslide susceptibility map for peat slides using manual method breaks.

Map 8 – Landslide susceptibility map for peat slides using equal intervals breaks.

Error Assessment

As a final exercise, susceptibility map results were compared to previously mapped landslides. The aim of this exercise is to statistically analyse the number of landslides mapped within each susceptibility range. The manual method of classification was used for this assessment.

The first analysis showed the following results;- 20% of bedrock slides, 10% of peat slides, 20% of flows and 15% of falls were contained within areas of low susceptibility values. These events were individually reviewed and it was noted that most of the events occurring in low susceptible areas are within Co. Leitrim or at the outskirts of the study area. The area covered by Co. Leitrim has soil parent material weight values of 20 (averaged) due to the lack of data (See Statistical Data Processing) and this was subsequently identified as the reason for such low susceptibility results in areas with landslide occurrences. The analysis should be undertaken once more when a soil parent material map for the area is available and error assessment results computed again using its outcome.

As the dataset was not available at the time, manual corrections were applied to the slides occurring in areas affected by low susceptibility values. Rock outcrop data, Teagasc land cover map and Corine land cover map were used for this purpose. Table 5.10 illustrates the percentage of events within each susceptibility category after applying the manual corrections. Note how more than 90% of the events are confined to areas with medium or higher susceptibility values. 58% of bedrock slides, 70% of peat slides, 52% of flows and 50% of falls occur within high, very high and extremely high susceptibility values.

Susceptibility	% Bedrock Slides	% Peatslides	% Flows	% Falls
Extremely High	8.82	19.01	8.97	9.22
Very High	18.63	15.29	19.23	4.96
High	32.35	36.36	23.08	35.46
Medium	36.27	29.34	41.03	47.52
Low	3.92	0	7.69	2.48
Very Low	0	0	0	0
Extremely Low	0	0	0	0.35

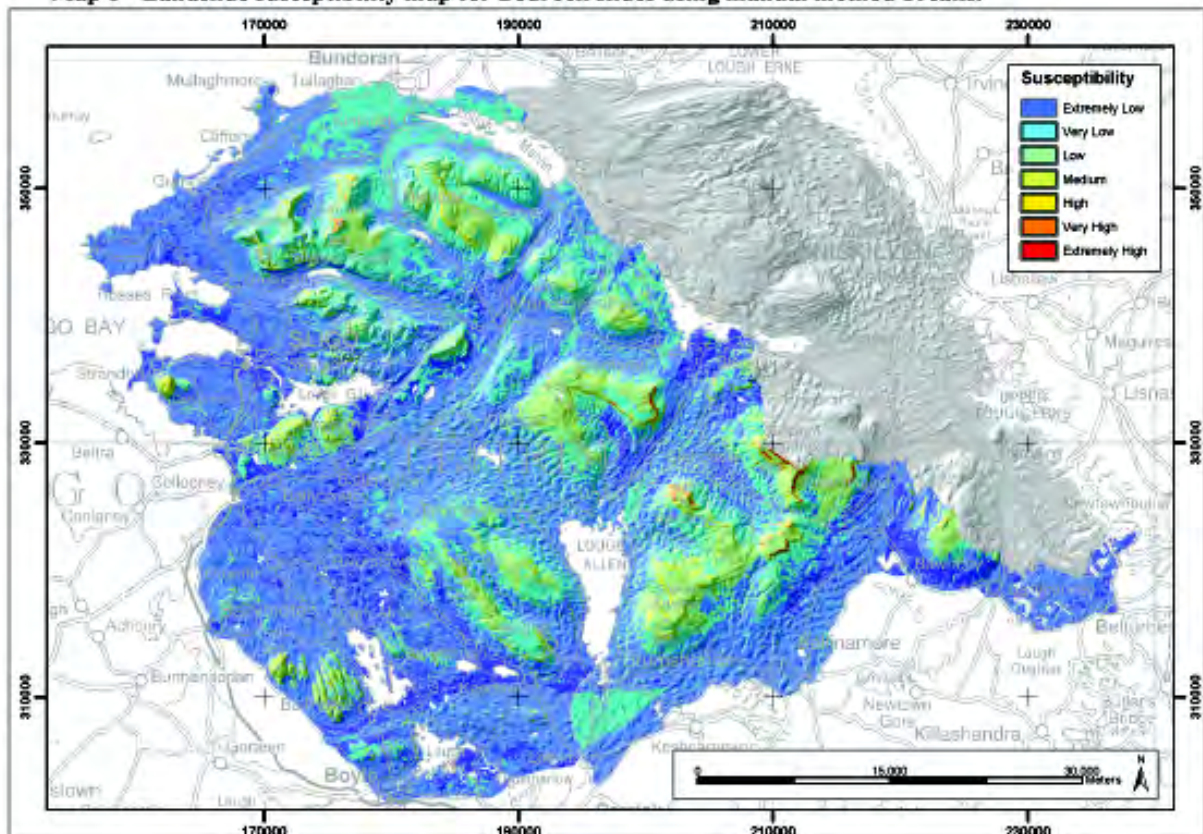
Table 5.10 Percentage of events mapped contained within each susceptibility category.

5.2.4. Conclusions and Recommendations

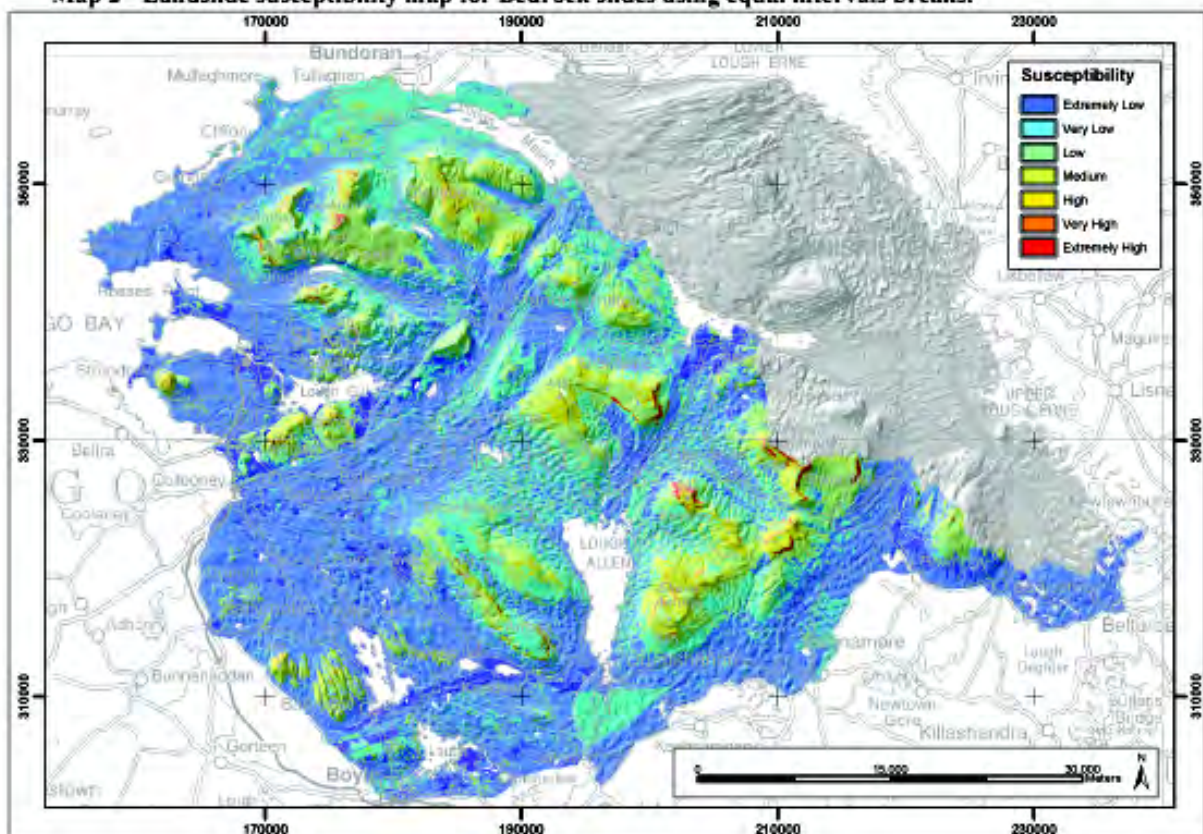
- Landsat ETM+ imagery (RGB 542) can be used as a first approach to locate scars produced during landsliding. It has to be noted that the response of these scars is often similar to the response of other features in the image. The low resolution of this data makes it unsuitable for landslide mapping and classification.
- The combination of colour, and black and white, aerial photography analysis was the most suitable method for landslide mapping. The use of Fledermaus software and digital stereophotography to display 3-D aerial photography greatly improved the identification and classification of events.
- Fieldwork was found to be of major importance in landslide mapping and classification. Accurate classification can be only performed after field assessment.
- Accuracy of classification is fundamental in the methodology used in this project. A large number of events were mapped. However, it was not possible to achieve a highly accurate classification due to the short timeframe of the project (less than 2 months). More fieldwork and image analysis would be needed, and is recommended for future work.
- The thematic datasets used as conditioning factors seem to be appropriate. Use of other data such as rainfall data, distance from crown to watershed and accurate structural geology data (bed jointing, fault distribution and bed dipping) would have enhanced the classification and the resultant susceptibility mapping.
- The error assessment has shown a high correlation between the landslide susceptibility map and the actual mapped events. The final result can be considered very satisfactory. Integration of additional conditioning factors as mentioned above would greatly improve the landslide susceptibility maps produced. The methodology used during this project allows the integration of new datasets to derive the final landslide susceptibility map outputs.
- Existing spatial datasets can be used to produce a robust landslide susceptibility map in the Irish context. The study demonstrates the applicability of international practices in this area and usefulness of such mapping, particularly when carried out in conjunction with follow up field investigation and ground truthing.

CHAPTER 5.2 - MAP APPENDIX

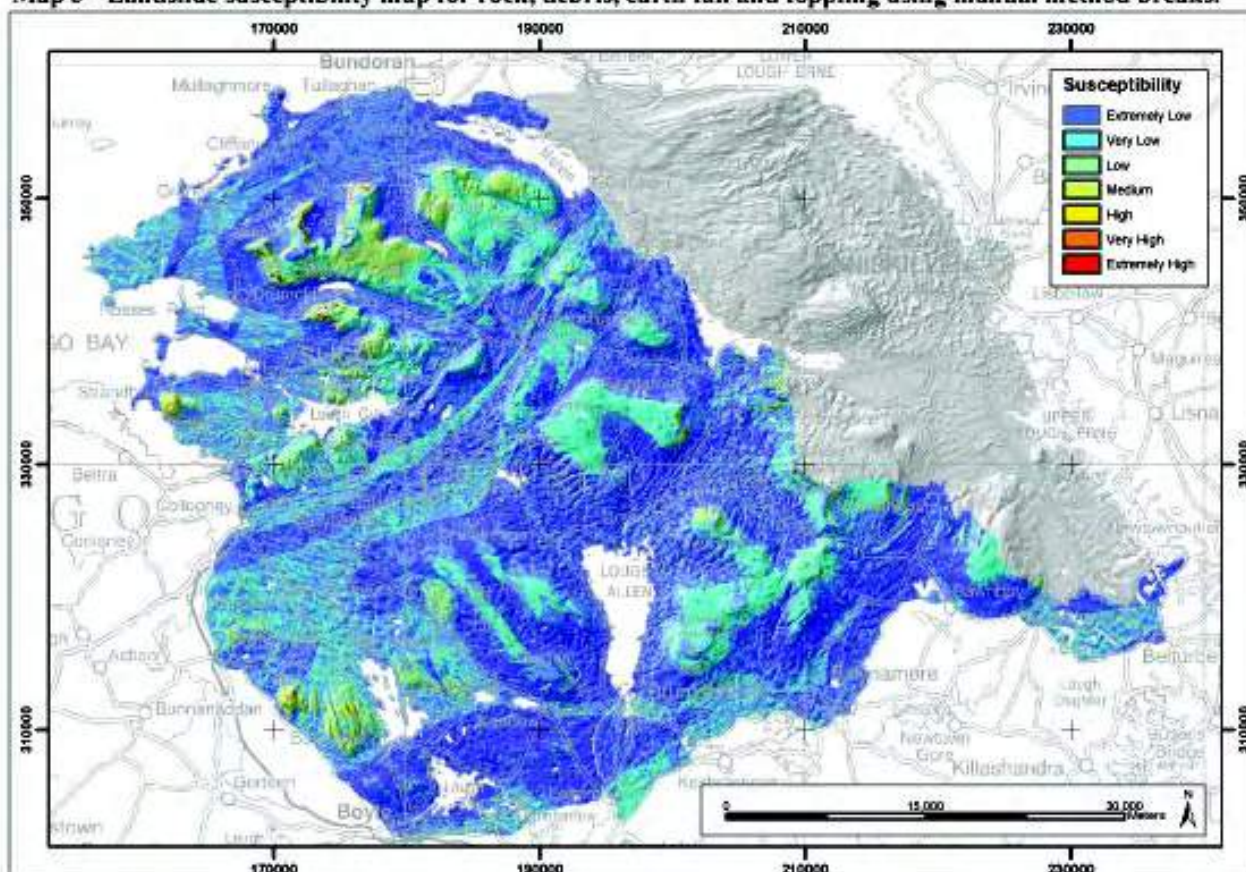
Map 1 - Landslide susceptibility map for Bedrock slides using manual method breaks.



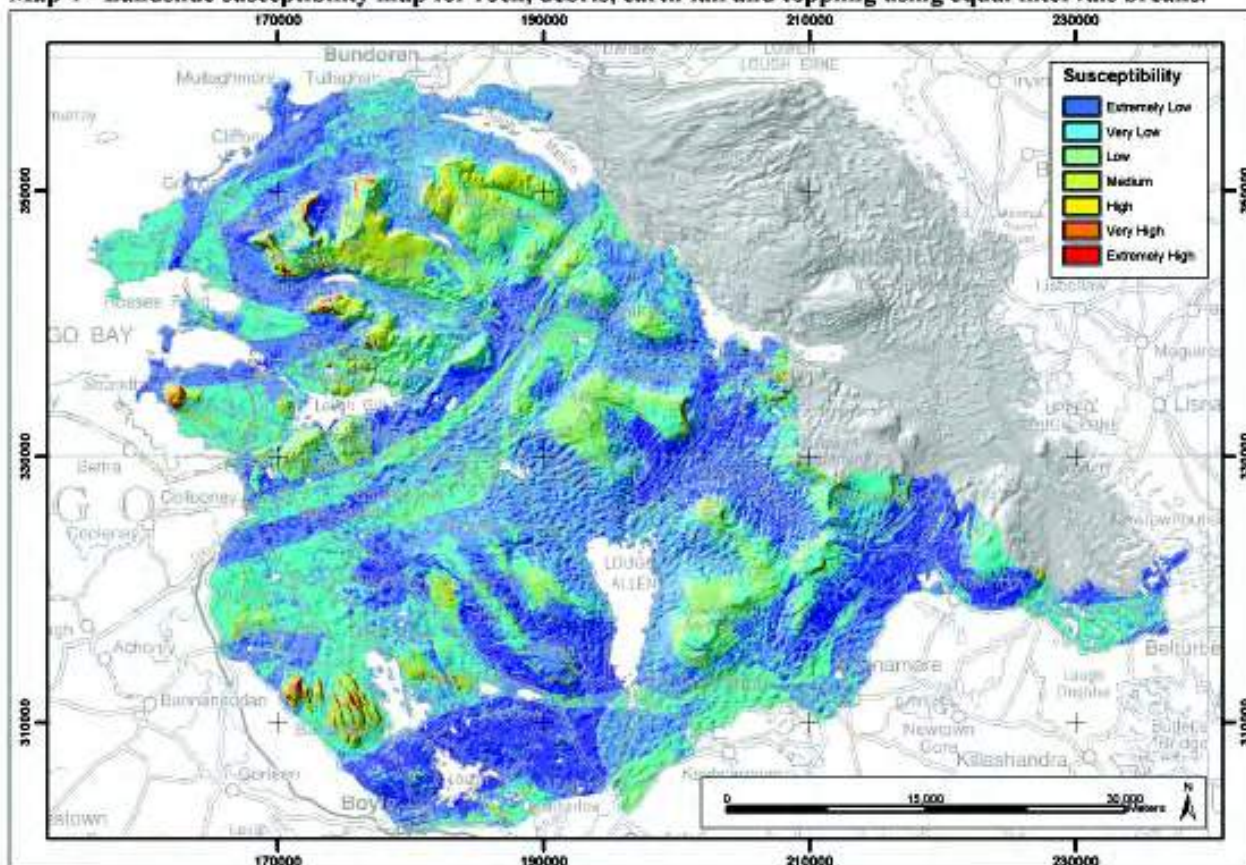
Map 2 - Landslide susceptibility map for Bedrock slides using equal intervals breaks.



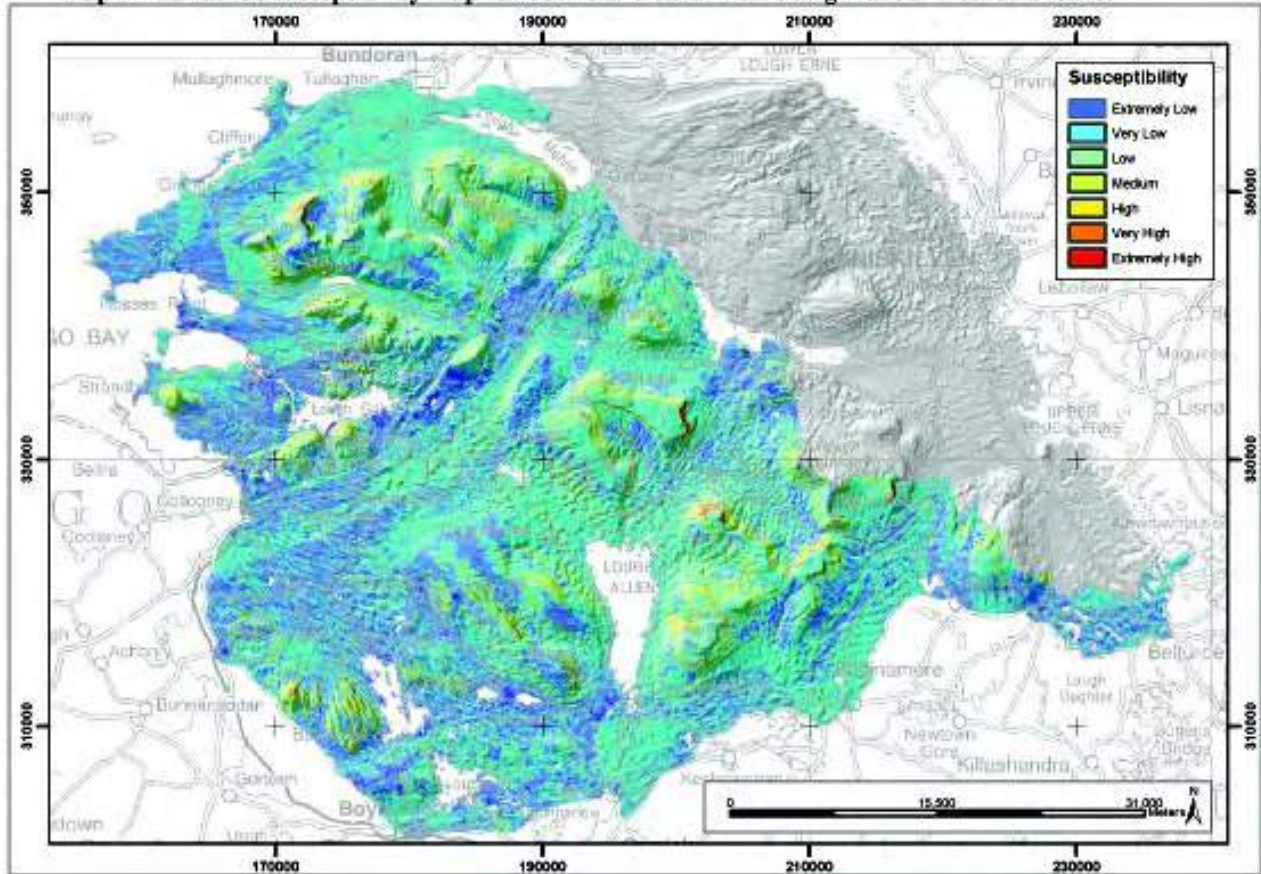
Map 3 - Landslide susceptibility map for rock, debris, earth fall and toppling using manual method breaks.



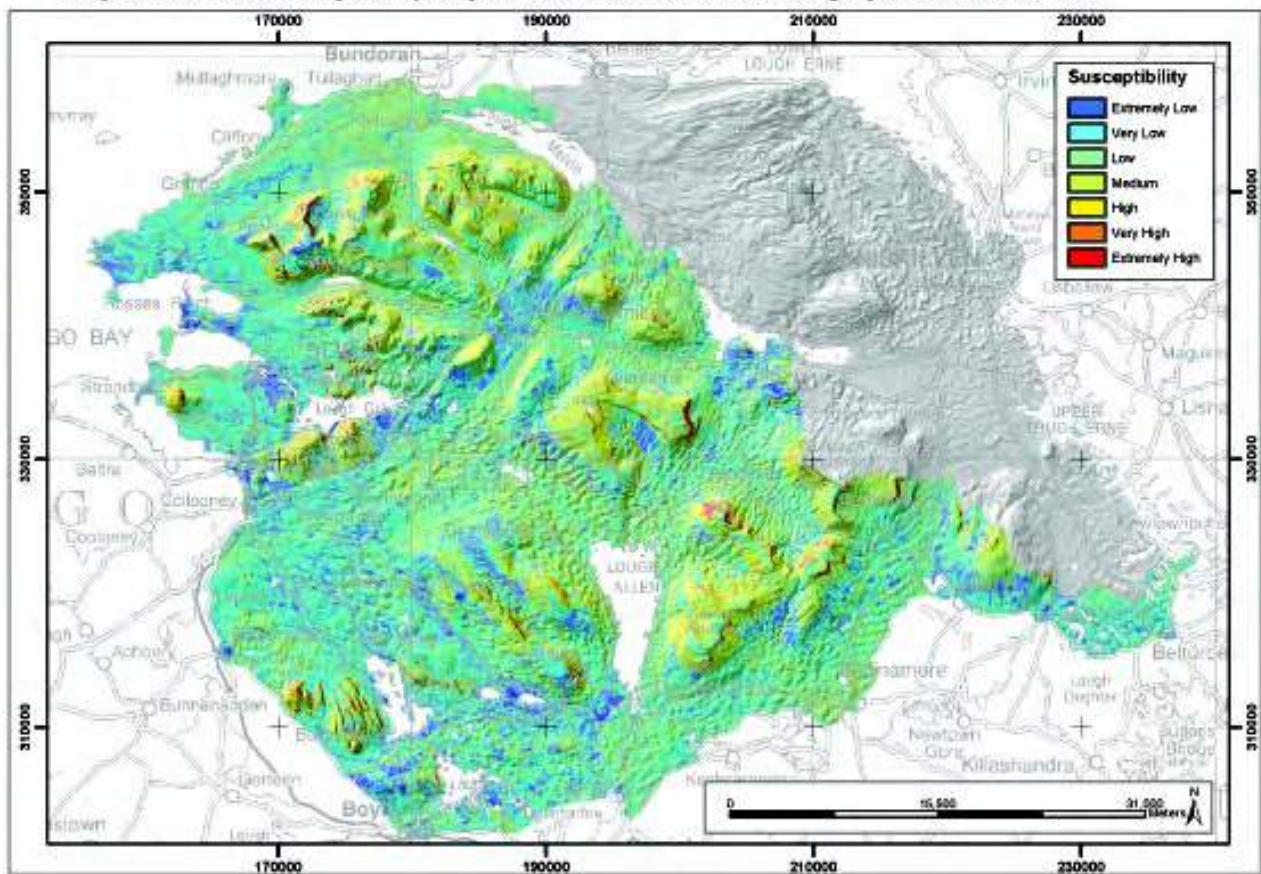
Map 4 - Landslide susceptibility map for rock, debris, earth fall and toppling using equal intervals breaks.



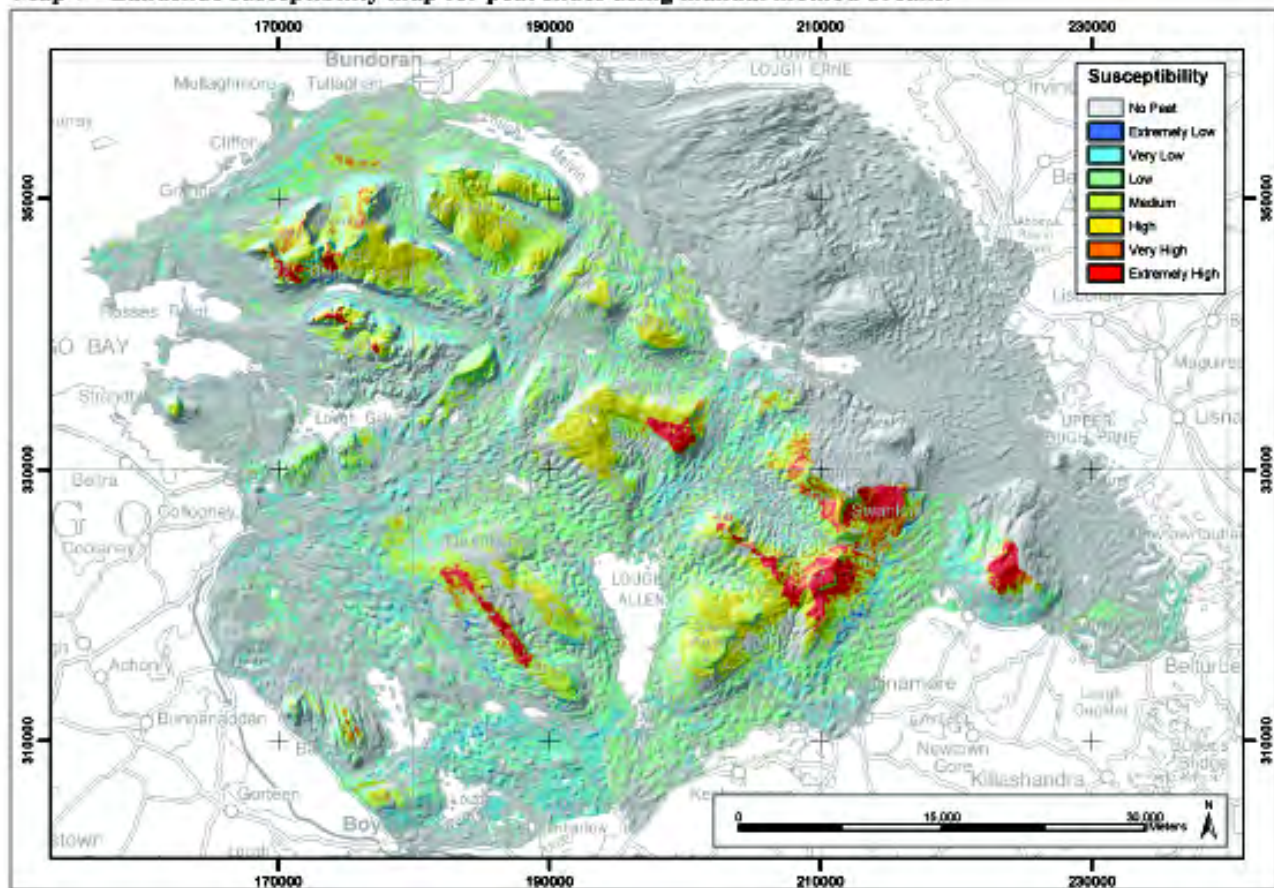
Map 5 - Landslide susceptibility map for debris and earth flow using manual method breaks.



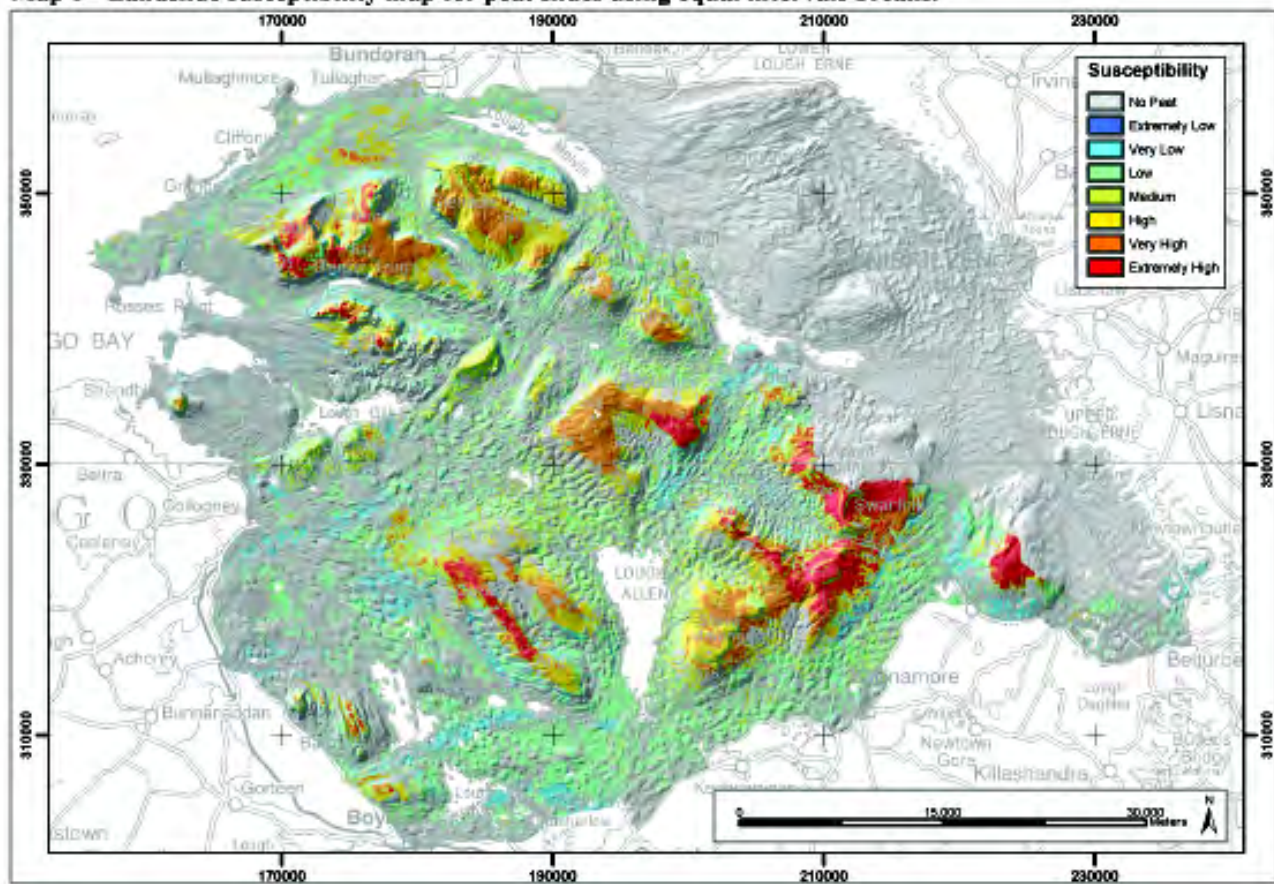
Map 6 - Landslide susceptibility map for debris and earth flow using equal intervals breaks.



Map 7 - Landslide susceptibility map for peat slides using manual method breaks.



Map 8 - Landslide susceptibility map for peat slides using equal intervals breaks.



CHAPTER 5.2 – TABLE APPENDIX

Bedrock slides	Maximum	Minimum	Type Maximum	Type Minimum
Bedrock	42	0	Sandstone	Various
Soil parent material	80	0	Rock at or near surface	Cutover Peat
Landcover	56	0	Bog & Heath	Various
Slope	38	8	10 to 20	Less than 10
Altitude	35	0	400-500	Less than 200
Aspect	18	5	Northeast (22.5-67.5)	North (337.5-360)
Total	269	13		

Table 5.8a. Maximum and minimum weights and class affected for Bedrock slides.

Peat Slide	Maximum	Minimum	Type Maximum	Type Minimum
Bedrock	36	0	Shale	Various
Soil parent material	84	1	Peat	Various
Landcover	82	0	Bog & Heath	Various
Slope	63	0	Less than 10	More than 40
Altitude	41	0	300-400	Less than 200
Aspect	16	7	West(247.5-292.5)	North (0-22.5)
Total	322	8		

Table 5.8b. Maximum and minimum weights and class affected for Peat slides.

Flows	Maximum	Minimum	Type Maximum	Type Minimum
Bedrock	29	0	limestone and shale	Various
Soil parent material	58	0	Rock at or near surface	Cutover Peat
Landcover	37	0	Bog & Heath	Various
Slope	40	0	10 to 20	More than 40
Altitude	36	4	300-400	More than 500
Aspect	26	3	Northeast (22.5-67.5)	South (157.5-202.5)
Total	226	7		

Table 5.8c. Maximum and minimum weights and class affected for Flows.

Falls	Maximum	Minimum	Type Maximum	Type Minimum
Bedrock	49	0	limestone	Various
Soil parent material	87	0	Rock at or near surface	Till
Landcover	42	0	Bog & Heath	Various
Slope	42	1	30 to 40	Less than 10
Altitude	39	1	300-400/400-500	Less than 200
Aspect	17	3	West (247.5-292.5)	Southeast (112.5-157.5)
Total	276	5		

Table 5.8d. Maximum and minimum weights and class affected for Falls.

Susceptibility	Equal interval		Manual method	
	From	to	From	to
Extremely high	230	269	250	269
Very high	192	230	220	250
High	154	192	180	220
Medium	115	154	140	180
Low	77	115	90	140
Very low	38	77	50	90
Extremely low	0	38	0	50

Table 5.9a. Equal interval and manual method divisions applied to Bedrock slides.

Susceptibility	Equal interval		Manual method	
	From	to	From	to
Extremely high	276	322	300	322
Very high	230	276	270	300
High	184	230	230	270
Medium	138	184	170	230
Low	92	138	110	170
Very low	46	92	60	110
Extremely low	0	46	0	60

Table 5.9b. Equal interval and manual method divisions applied to Peat slides

Susceptibility	Equal interval		Manual method	
	From	to	From	to
Extremely high	194	226	210	226
Very high	161	194	190	210
High	129	161	160	190
Medium	97	129	130	160
Low	65	97	90	130
Very low	32	65	50	90
Extremely low	0	32	0	50

Table 5.9c. Equal interval and manual method divisions applied to Flows.

Susceptibility	Equal interval		Manual method	
	From	to	From	to
Extremely high	237	276	255	276
Very high	197	237	230	255
High	157	197	200	230
Medium	118	157	150	200
Low	79	118	100	150
Very low	39	79	60	100
Extremely low	0	39	0	60

Table 5.9d. Equal interval and manual method divisions applied to Falls.

6. LANDSLIDES AND PLANNING

Aileen Doyle

6.1 Introduction

The focus of this chapter is landslide hazard and the planning process. It will look at current practice in dealing with development on unstable or potentially unstable land in Ireland and the UK, and will focus on those parts of the planning system which interface directly with the issue of landslides such as the preparation of development plans and the development management system. It will also briefly look at building control both in Ireland and the UK. Current practice on landslides and planning in Northern Ireland will be dealt with in Chapter 7- Landslides in Northern Ireland.

There are other areas of human activity which may impact on landslide risk such as agriculture or forestry but which are exempt from the requirements for planning permission. These may however be subject to other consent procedures such as Natural Heritage Areas (NHA) which are subject to separate conservation measures. An awareness of ground instability or the potential for instability by persons carrying out such activities would also be important.

The chapter will also highlight the type of information needed to aid in the integration of landslide hazard assessment into land use planning and will conclude with a number of recommendations on the steps which need to be taken to promote awareness of the issue of landslide hazard and the planning process.

The chapter should be read in the context that the primary responsibility for dealing with the potential hazard of landslides in relation to particular developments lies with the developer.

6.2 Current Practice on Landslides and Planning in Ireland

The Planning and Development Acts 2000-2004 provide the legal framework for the Irish planning system. The system operates through a hierarchy of plans which include at National level, Ministerial Guidelines and the National Spatial Strategy (NSS), at Regional Level, the Regional Planning Guidelines (RPGs) and at local authority level, the development plan and development management process.

6.2.1 Ministerial Guidelines

Under Section 28 of the Planning and Development Act 2000, the Minister for the Environment, Heritage and Local Government may at any time issue guidelines to planning authorities regarding any of their functions under the Act. Planning authorities and, where applicable, An Bord Pleanála, are obliged to have regard to such guidelines in the performance of their functions. National guidelines which contain advice of relevance to development on unstable ground are:

“Guidelines on Quarrying and Ancillary Activities (2004)” and

“Draft Wind Energy Development Guidelines (2004)”

These documents provide guidance to planning authorities on how to deal with quarrying activities and wind energy development at development plan and planning application stages. Land instability is addressed in both these documents but more particularly in the Wind Energy Development Guidelines, currently in draft form, which contains strengthened guidance in relation to the geotechnical aspects of wind energy developments.

To date however, there is no national planning guidance on the specific issue of landslides. The question of whether or not there is a need for such national guidance will be addressed in the recommendations at the end of this chapter.

6.2.2 Regional Planning Guidelines

Regional Planning Guidelines (RPGs) to support the implementation of the National Spatial Strategy were adopted by all the Regional Authorities at the end of May 2004. The RPGs work within the overall approach

taken in the NSS and provide a regional framework to strengthen local authority development plans and other planning strategies at county, city and local level. The RPGs are intended to cover the period up to 2020 with periodic reviews, the first to take place in 2010.

As the issue of landslide susceptibility can extend beyond county boundaries it is an appropriate topic to be addressed at the regional level. The implementation of the regional guidelines may offer an opportunity to identify areas where landslide hazard is an issue of regional significance and to develop appropriate regional policies for land use planning in such areas.

6.2.3 Development Plans

Under the Planning and Development Act 2000, each planning authority is required to make a development plan every six years which sets out the sustainable planning and development objectives for its area. The Act also specifies which development objectives are mandatory and which are discretionary. The planning authority is under a statutory obligation to take such steps as are necessary to secure the objectives of the development plan.

Most development plans do not contain objectives in regard to either the identification of unstable ground or for regulating development on such land where identified (or known), apart from in coastal areas. This may be due to a number of reasons including the relatively low occurrence of landslides to date, the lack of information on landslide hazard, and the low intensity of development pressure in areas of potential instability. However increasing development pressure, often in remote uncultivated and undeveloped areas, from e.g. wind energy, residential and recreational activity, and also the possibility of an increase in storms and other dramatic weather events (Plate 6.1) due to climate change, may result in an increase in landslide occurrences.



Plate 6.1 Damaged House at Pollatomish

In this developing scenario, it is important to know as far as possible where and why landslides may occur and the likelihood and potential severity of further occurrences. The identification of the extent of the problem in advance will allow appropriate strategies to be adopted within the planning system both at the strategic development plan stage and also at the local level in individual planning applications.

In this regard there is provision under the Planning and Development Act 2000 to include objectives in development plans for regulating, restricting or controlling development in coastal areas or inland areas at risk of flooding, erosion and other natural hazards. The critical consideration must be to ensure that landslide risk is firstly identified by the GSI and that new development does not individually or cumulatively suffer from or give rise to landslide risks.

6.2.4 Development Management

The physical planning system in Ireland is run by 88 local planning authorities: 29 County Councils, 5 County Borough Corporations, 5 Borough Corporations and 49 Town Councils. An Bord Pleanála provides an appeal mechanism in relation to development control decisions made by a planning authority.

Applications for development that require planning permission under the Planning and Development Acts 2002-2004 are determined by planning authorities having regard to the provisions of the Development Plan, Local Area Plan where relevant, the National Spatial Strategy, Regional Planning Guidelines and any other relevant Government policy documents such as Ministerial guidelines.

The planning authority is required to give notice of valid applications to certain prescribed bodies where, in their opinion, the development would be relevant to the functions of that body. The Department of Communications, Marine and Natural Resources is currently a prescribed body in relation to development on the foreshore, afforestation, breeding and rearing of salmonid fish and quarries. Unlike the position in Northern Ireland the Geological Survey of Ireland (GSI), a line division of the Department of Communications, Marine and Natural Resources, is not yet a prescribed body for planning applications which would be relevant to its functions in regard to natural/geological hazards.

At the present time, the control on development on unstable ground relies heavily on accurate information being submitted by a developer and compliance with the Part A (Structures) of the national Building Regulations.

6.3 Building Control

The Building Control Act 1990 imposes particular requirements on the design and construction of buildings so as to ensure that they are safe to occupy and use. The planning and building codes are separate, each with their own enabling legislation and enforcement mechanisms, and each should take account of all material considerations, including ground stability and the risk of landslides.

6.3.1 Building Regulations

The Building Regulations relate to the design and construction of individual buildings and are not relevant to other forms of development. The specific requirements imposed by the Regulations on a building developer are set out in the various Parts of the Regulations (Part A – Part M). Each Part of the Regulations is backed up by a Technical Guidance Document (TGD) which gives general guidance on compliance with that Part, including detailed guidance for simple building types which, if complied with, can be taken as *prima facie* evidence of compliance with that Part of the Regulations. TGDs do not purport to be comprehensive nor do they provide explicit guidance on all issues that may be relevant to the Regulations.

Part A (Structures) of the Building Regulations deals with the structural design and construction of buildings, and contains the following requirements:-

- A1 (1): A building shall be designed and constructed with due regard to the theory and practice of structural engineering, so as to ensure that the combined dead, imposed, and wind loads are sustained and transmitted to the ground –
 - (a) safely, and
 - (b) without causing such deflection or deformation of any part of the building, or such movement of the ground, as will impair the stability of any part of another building.
- A2: A building shall be designed and constructed with due regard to the theory and practice of structural engineering, so as to ensure that movement of the subsoil caused by subsidence, swelling, shrinkage, or freezing will not impair the stability of any part of the building.

Thus, the Building Regulations require that buildings, regardless of the ground conditions, are designed and constructed so that they can be used safely and that they will not cause ground movements that would affect the stability of the building or another building. In addition, the Regulations require that buildings are designed and constructed so that their stability is not affected by subsoil movements caused by subsidence, swelling, shrinkage or freezing.

There is no specific reference to risk of landslides in either the Part A of Building Regulations or Technical Guidance Document A. However, the requirements for safety in use and for the prevention of ground movements that would affect the stability of another building may be deemed to require assessment of the risk of landslide, where appropriate.

6.4 Environmental Assessment

Environmental assessment is part of the planning process both at strategic level and local level. At the strategic level Strategic Environmental Assessment (SEA) applies to particular plans or programmes and at the local level Environmental Impact Assessment (EIA) applies to specified individual projects.

6.4.1 Strategic Environmental Assessment

The Strategic Environmental Assessment (SEA) Directive (2001/42/EC) applies to specified plans and programmes, forming the framework for consent to projects which must be subjected to EIA. The SEA Directive (SEAD) was transposed into Irish Law through the European Communities (Environmental Assessment of certain plans and programmes) Regulations 2004 (S.I. 435 of 2004) and Planning and Development (Strategic Environmental Assessment) Regulations 2004 (S.I. 436 of 2004).

The requirement under the SEAD applies to certain Development Plans, Local Area Plans and Special Development Zones (SDZ) (and variations of such plans), where the first formal preparatory action is taken on or after 21 July 2004 and which meet the criteria specified in the Directive.

The SEA process involves a formal, systematic evaluation of the likely significant environmental effects. It involves an analysis, in the form of an Environmental Report, of the current state of the physical environment, including environmental problems. This may include potential impacts such as flood risk and landslide risk (where known).

The landslide database currently being compiled by GSI should prove a valuable input into the baseline data on the current state of the environment at the outset of the SEA process. Such data would be critical to an assessment of any potential significant environmental impacts of implementing a Development Plan; and could also help in establishing measures to mitigate any potential negative impacts.

6.4.2 Environmental Impact Assessment (EIA)

The Environmental Impact Assessment (EIA) Directive (85/337/EEC as amended by Directive 97/11/EEC) requires the EIA of specified projects likely to have significant impact on the environment. When submitting a planning application for such a development, the applicant must also submit an Environmental Impact Statement (EIS). Projects needing environmental impact assessment are listed in Schedule 5 of the Planning and Development Regulations 2001.

In the case of development which is under the relevant EIA threshold, planning authorities are required under Article 103 of the 2001 Regulations to request an EIS where it considers that the proposed development is likely to have significant environmental effects.

The Planning and Development Regulations 2001 Schedule 6 sets out the information to be contained in an EIS, and lists those aspects of the environment likely to be significantly affected by the proposed development which must be examined including, inter alia, human beings, fauna, flora, soil, water, air, climatic factors, and the landscape.

In regard to this list the Institute of Geologists of Ireland (IGI) in 2002 (www.igi.ie) published a Guide to Geology in Environmental Impact Statements which highlighted the fact that geological factors may not be dealt with satisfactorily in Environmental Impact Statements, due partly to the fact that geology is not listed specifically as an issue to be dealt with in existing legislation, and because the relevant information is not readily available or easily accessible.

However, the EPA Guidelines on the Information to be contained in Environmental Impact Statements (2002) and subsequent Advice Notes on Current Practice in the preparation of Environmental Impact Statements (2003) do interpret the section on soils as including all natural materials underlying a development from the ground surface to an appropriate depth underground. Referral to these Guidelines and Advice Notes should ensure that the issue of geology and ground conditions are adequately considered.

6.5 Current Practice on Landslides and Planning in the United Kingdom

The incidence of landslides is more common in the UK. The British Geological Survey (BGS) has an extensive national database on landslide hazard. As a consequence there is comprehensive government guidance on landslides and planning:-

PPG 14. Landslides and Planning
(Updated in 2000 with the inclusion of two annexes)

Annex 1. Landslides and planning
Annex 2. Subsidence and planning

PPG 20. Coastal Planning (1992)

The purpose of the UK Planning Policy Guidance Notes guidelines is “to advise local authorities, landowners and developers on the exercise of planning controls over land use and development on or adjacent to slopes which are actually or potentially unstable”. These guidance notes recommend that a considered assessment of landslides, both at development plan stage and in determining planning applications, will help reduce the impact of the undesirable consequences of landslides.

The guidelines are intended to help ensure that:-

- The occurrence of and potential for slope instability is recognised at the earliest possible stage.
- Appropriate strategies are adopted for dealing with the problems arising thus preventing the unnecessary sterilisation of land.
- Due account is taken of the constraints imposed by slope instability at all stages of the planning process.
- Development does not proceed in certain areas of instability or where the treatment proposed is ineffectual.
- Development is suitable and will not be threatened by landslides or cause instability of surrounding slopes.
- Expensive protection or remedial works, which may be publicly funded, are not needed after a site has been developed.

The strategy recommended for managing the issue of land instability in PPG 14, Annex 1 involves separate and complementary roles for both the planning system and the building control system.

6.5.1 Development Plans

Where relevant information is available it is suggested that the development plan may use a constraints map or otherwise identify areas where particular consideration of landslides or the potential for landslides will be needed.

6.5.2 Development Control

General guidance for the handling of individual applications for development on land which is known or suspected to be unstable or potentially unstable is given in PPG 14. The advice requires the carrying out of detailed identification and assessment of landslides. The implementation of the suggested good practice has significant resource implications and this is referred to in the document.

Appendix 1A of PPG 14 Annex 1 contains a step by step approach to landslide assessment including guidance on how to establish:-

- Landslide extent and distribution
- Hazard and risk – and how to assess it

6.6 Recommendations for the inclusion of landslide hazard issues in the planning process.

The previous chapters have highlighted the fact that landslides do occur in Ireland although infrequently and that the most frequent occurrences appear to be in coastal, upland and peat bog areas. This infrequency of occurrence may change, as also referred to in previous chapters, with the impact of climate change and the increased pressure for development in hitherto undeveloped upland and peat bog areas. It is therefore opportune to review current practice to ensure that, where relevant, the issue of instability is addressed at all stages of the planning process.

To be able to identify, with a degree of certainty, areas which are subject to landslides or have the potential for landslides will require up to date information to be compiled and be readily accessible on landslide susceptibility maps and hazard risk assessment. The use of this information in the planning process should contribute to maximising the opportunities for sustainable development while minimising increases in landslide hazard risk and consequential economic loss and human suffering.

6.6.1 Recommendations for future action

Accordingly the Irish Landslides Working Group has proposed recommendations for future action in the context of land use planning and landslides. These recommendations are not meant to be definitive but to provide a platform for discussion and policy making, in consultation with all stakeholders including local authorities. These recommendations suggest two phases of action for the integration of landslide hazard issues into the planning process, one following on from the other.

Phase 1 – Research

- Research work to be carried out into the area of landslide susceptibility mapping and hazard risk assessment to identify areas which are subject to landslides or have the potential for landslides. This analysis of landslide hazard risk should give a clear picture of the extent of the problem in Ireland and would be helpful in considering if and to what extent national guidance on the issue of development on unstable land is required.
- It may be appropriate to consider the preparation of national guidance under Section 28 of the Planning and Development Act 2000 (para 6.2.1), on landslides as part of the wider issue of natural hazards in general to complement work already in progress on flood risk.
- Appropriate funding for such research would need to be put in place.
- Pending the outcome of this research it would be important that, where appropriate, future Ministerial Guidelines include the topic of known landslide hazard or the potential for such hazard as an issue to be addressed.

Phase 2 – National Guidance

If Phase 1 indicates the need for national guidance under Section 28 on the issue of landslide risk and the planning process, such guidance could:-

- Call up any available landslide database of past landslide events which is reliable and readily accessible.
- Recommend consideration of the causes and extent of the landslide problem, and the feasibility of identifying on the relevant development plan maps areas inherently unstable (or areas of potential instability) and the formulation of a landslide risk assessment methodology to facilitate land use planning in such areas.
- Include guidance to planning authorities, landowners and developers in these areas on how to ensure that the type of development proposed is suitable for the ground conditions and that the physical constraints on the land are taken into consideration at all stages of planning process.
- Recommend applicants/developers to examine the scope for remedial, preventative or precautionary measures including slope stabilisation measures on unstable or potentially unstable ground to avoid sterilising land unnecessarily and a requirement for landslide hazard assessment to be included for planning applications for development in the risk areas identified.

List of Relevant Planning Documents

Planning and Development Acts 2000-2004

Planning and Development Regulations 2001

Department of the Environment and Local Government (2002)

National Spatial Strategy 2002-2020

Department of the Environment Heritage and Local Government 2004

Quarries and Ancillary Activities – Guidelines for Planning Authorities

Building Control Act 1990

Building Regulations 1997-2002

Department of the Environment Heritage and Local Government 2003

Environmental Impact Assessment (EIA) - Guidance for Consent Authorities regarding Sub-Threshold Development

Department of the Environment Heritage and Local Government 2004

Implementation of the SEA Directive (2001/42/EC):

Assessment of the Effects of Certain Plans and Programmes on the Environment.

Guidelines for Regional Authorities and Planning Authorities

Department of the Environment – Welsh Office 1990

Planning Policy Guidance (PPG) 14: Development on Unstable Land

Department of Environment, Transport and the Regions, London 2000

Planning Policy Guidance PPG 14 - updated to include:-

Annex 1 Landslides and Planning

Annex 2 Subsidence and Planning

Department of the Environment – Welsh Office 1992

Planning Policy Guidance (PPG) 20: Coastal Planning

Environmental Protection Agency (EPA) (2002)

Guidelines on the Information to be contained in Environmental Impact Statements

Environmental Protection Agency (EPA) (2003)

Advice Notes on Current Practice in the preparation of Environmental Impact Statements

The Institute of Geologists of Ireland (2002)

Geology in Environmental Impact Statements – A Guide

7. LANDSLIDES IN NORTHERN IRELAND

Terence Johnston

Landslides occur in a number of different geological settings in Northern Ireland, and, in certain situations, constitute significant geohazards. The principal areas at risk are identified on the 1:50,000 and 1:250,000 scale geological maps published by the Geological Survey of Northern Ireland (GSNI).

7.1 Antrim Plateau Escarpment Instability (Counties Antrim and Londonderry)

Landslips and associated ground instability are common features around the edge of the basalt plateau in Counties Antrim and Londonderry where they contribute in a large part to the landscape character (Fig. 7.1).



Fig. 7.1 Principal Areas of Landslides Around the Basalt Plateau (Counties Antrim & Londonderry)

Three principal categories of slope instability can be recognised:

1. Rotational Landslips
2. Mudflows and Debris Flows
3. Rock Falls

1. Rotational Landslips

At a number of locations (Fig. 7.1) the edge of the Antrim Basalt Plateau consists of large scale, deep-seated, multiple rotational landslide features. The mechanisms behind this instability are directly related to the geological succession and the geomorphological processes that subsequently sculpted the landscape. The plateau edge is capped by hard “competent” rocks: basalt lavas (Antrim Lava Group, Tertiary) and chalk (Ulster White Limestone Formation, Cretaceous). These rocks overlie softer, less competent, impermeable mudstone: (Waterloo Mudstone Formation, Jurassic and the Penarth Group & Mercia Mudstone Groups, Triassic) (Fig. 7.2 and Plate 7.1).

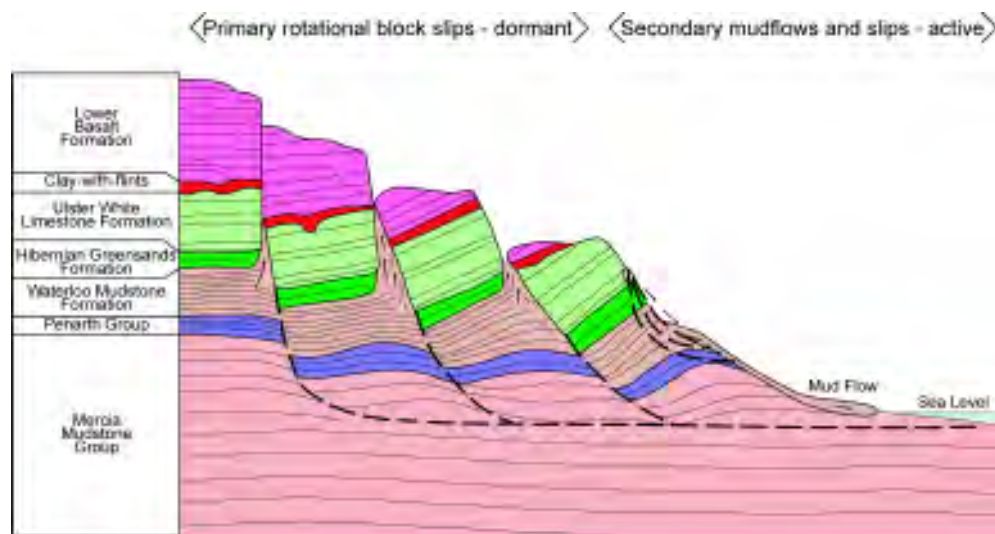


Fig. 7.2 Generalised Landslip Model Co Antrim (Crown Copyright)

During the last ice age, ice sheets flowed along the edge of the plateau eroding the soft mudstones rocks at its base. This undercut and oversteepened slope became inherently unstable. Along the plateau edge, failures took place on the vertical and steeply inclined surfaces within the chalk and basalt and along more shallowly inclined surfaces within the underlying more plastic mudstones (Fig. 7.2).

The large, older rotational landslide blocks have, through time, reached a state of equilibrium. These areas do however remain susceptible to ground movement and remain at risk of rock falls, shallow slumps and translational slides. In north and west Belfast an extensive area of palaeo-landslips continues to be a significant constraint on development. Where previous development has taken place on landslipped ground, dwellings and infrastructure frequently suffer from cracking and disruption of foundations as a result of continuing ground movements.

Stephens (1964) linked the large scale slip features at Benevenagh, County Londonderry and at Glenarm, Co Antrim to glacial action. Carney (1974) carried out a study of the landslide complexes along the Antrim coast using aerial photographs and applied his interpretation of the geomorphological history of the area as follows: “In late Tertiary times the lava plateau was affected by a series of erosion cycles seen as bench levels at 600m, 310m and 250m. Formation of the landslide escarpment may have occurred towards the end of this period after the junction between the Ulster White Limestone Formation and Waterloo Mudstone Formation had been exposed to marine erosion”.

During the early stages of glaciation in Northern Ireland, ice spread across Antrim from centres in Scotland and Ireland. The “Irish” ice spread eastwards across the Antrim Plateau and “Scottish” ice moved southwards across parts of Co. Antrim and Co. Down. A combination of the eastwards moving Irish ice and topography restricted the spread of the Scottish ice to the northern and eastern coastal fringes of Antrim (Bazley, 2004). Glacial erosion removed much of the pre-glacial landslide debris along the edge of the Antrim escarpment. By the time the ice had melted and retreated, the edge of the escarpment had been oversteepened and unconstrained thus precipitating a new phase of landslipping.



Plate 7.1 Rotational Landslide (Basalt over Chalk) at Garron Point, Coast Road, Co Antrim.
(Crown Copyright)

2. Mudflows

Mudflows and debris flows constitute another distinct and significant hazard along parts of the Antrim Coast Road (A2). The mudflows take the form of often catastrophic flows of liquified mud (Waterloo Mudstone Formation, Jurassic) and other debris. These flows have periodically blocked the road at Minnis North [D339 137] south of Glenarm (Plate 7.2) and are commonly triggered by ground saturation following periods of heavy rainfall.

Prior et al (1968) describe the principal active mudflows at Minnis North [D339 137], McAuley's Head [D332 147], Straidkilly Point [D300 168] and Garron Point [D286 252]. The flows are composite, each consisting of a "bowl slide", "flow track", and a composite depositional area. Detailed measurements of the flow movement indicated a significant time lag between rainfall and flow movement. The work concluded that the chief factor in initiating the mudflow was the seasonal accumulation of rainfall leading to saturation of the Jurassic mudstone. Rainfall beyond this saturation was then likely to trigger a mudflow.



Plate 7.2 Mudslide at Minnis North, Co Antrim. (Crown Copyright)

3. Rock Falls

Rock falls are an ever present hazard along many parts of the Co. Antrim and Co. Londonderry coasts especially where principal road and rail routes run along the narrow strip of land between the shore and the edge of the basalt plateau. Rock falls have been a regular occurrence on the Antrim coast road where steep and overhanging basalt faces require ongoing management and often have to be removed or secured using geotextile netting and rock anchors.

Along the north coast, the Belfast to Londonderry rail track, which runs on a narrow coastal strip between Castlerock and Downhill Strand, has proven particularly vulnerable to rock falls. A recent event (June 2002) resulted in derailment of the Londonderry to Belfast passenger train. (<http://www.niassembly.gov.uk/record/reports/020610.htm#2>).

Landslide Hazard Assessment on the Antrim Coast

The overall landslide hazard along the east Antrim coast was assessed in research carried out by the British Geological Survey (Forster, 1998) on behalf of the Geological Survey of Northern Ireland.

Geological and engineering geomorphological mapping techniques were used together with aerial photographic interpretation and an understanding of landslide processes to categorise the landslide types. Land with similar landslide hazard levels was then zoned on the basis of estimated landslide risk (low, medium, high, and very high levels). The research described constraints to land use and development within the various hazard zones and could potentially be developed to provide a decision support tool for land use planners.

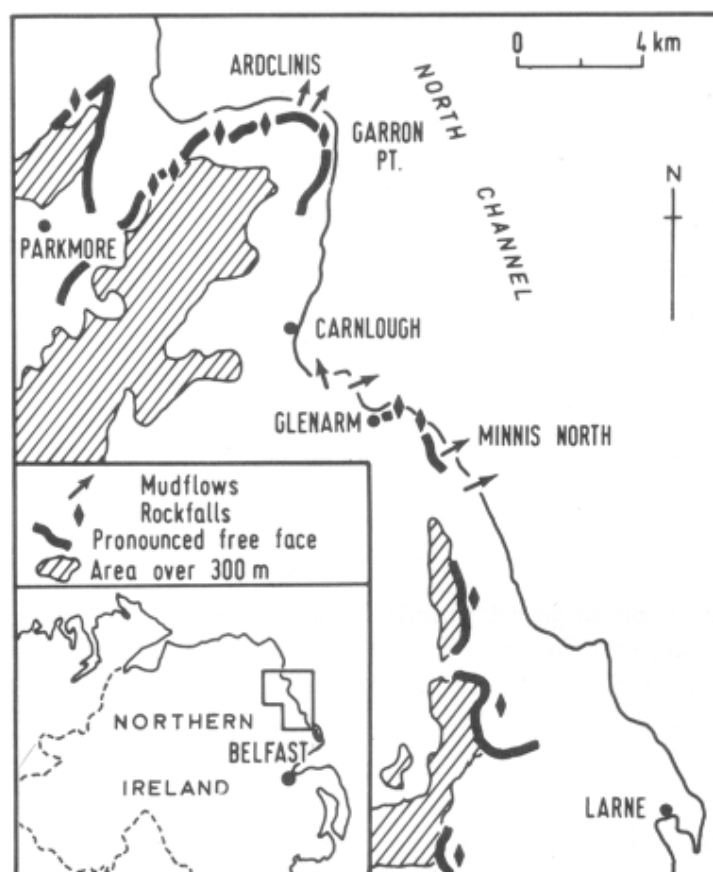


Fig. 7.3 Mudflow and Rock Fall Localities on the east Antrim Coast (from Prior et al., 1971).

7.2 Carboniferous Cliff Lines (Co Fermanagh)

Landslides occur along the cliff lines at Magho [H075 580], Belmore Mountain [H154 415], and Cuilcagh Mountain [H110 293]. In most cases these cliffs are capped by hard limestone strata (Dartry Limestone Formation, Carboniferous) and interbedded limestones/mudstones (Glencar Limestone Formation), which overlie less competent mudstone-dominant formations (Benbulbin Mudstone Formation and Bundoran Shale Formation).

Glacial erosion caused oversteepening of the Fermanagh cliff resulting in rotational landsliding and the accumulation of block screes. The major rotational landslips are now mainly dormant although smaller scale secondary slips still occur. At Magho, for example, large rotational slips and secondary slumps continue to cause instability problems and affect the Enniskillen to Belleek road (A46) close to the southern shore of Lower Lough Erne. At Cuilcagh Mountain, on the Co. Fermanagh/Co. Leitrim border, where massive blocky sandstone (Lackagh Sandstone Formation & Briscloonagh Sandstone Formation) overlies a mudstone-dominated succession (Dergvone Shale Formation), erosion and oversteepening of the cliff-face has resulted in landslips and toppling leading to an accumulation of a large block scree.

7.3 Peat Failure (Bog Bursts and Peat Slides)

Peat slides and bog bursts are characteristically rapid mass movements that occur in areas of upland peat and are triggered by heavy and/or prolonged rain.

Bog bursts usually involve rupture or tearing of the peat layer with liquefied peat often being expelled along the margin of the peat mass or through tears on the peat surface (Warburton et al., 2004).

Peat slides by contrast occur as slab-like shallow translational failures that involve shearing at or just above the interface between the peat and an underlying low permeability mineral substrate.

In Northern Ireland, bog failures have been documented in several areas:

Co. Antrim: Slieve-an-Orra Hills (Tomlinson et al., 1982).
Glendun (Colhoun et al., 1965).
Sherry Hill (Wilson et al., 1993).

Co. Fermanagh: Cuilcagh Area (Dykes and Kirk, 2001).
Carrowmaculla (Tomlinson, 1981).

On Cuilcagh Mountain, where relatively thin peat rests on modest slope angles, bog bursts appear to have been triggered by a combination of man-made alterations to the drainage regime induced by peat cutting and heavy rainfall.

Peat Failure Mechanisms

The mechanisms that lead to mass movement of peat are not yet fully understood, however a series of common factors have been identified (Tomlinson et al., 1982):

1. The peat overlies a low permeability or impervious clay-rich mineral substrate.
2. There is a convex slope or a slope with a break of slope at its head.
3. Proximity to local drainage (seeps, groundwater flow, pipes, streams)
4. Connectivity between surface drainage and the peat/impervious layer interface.

Much of the upland peat cover in Northern Ireland has been drained and removed either completely or partially for use as fuel, horticultural growing medium, or as part of general land improvements and reclamation. The remaining intact areas of peat are increasingly valued as habitats worthy of conservation and, in some cases, have been designated by the Environment & Heritage Service of Northern Ireland as Areas of Special Scientific Interest (ASSI) eg. Cuilcagh Mountain, Co Fermanagh (ASSI 069).

Reported bog burst and peat slide events in Northern Ireland have, to date, generally been of modest proportions and have occurred in relatively remote locations away from human habitation. The recent catastrophic bog slide events at Derrybrien (Co. Galway) and Pollatomish (Co. Mayo) have however heightened awareness of the potential for bog failure in Northern Ireland.

Coincidentally Northern Ireland has also recently experienced a growth in development of upland wind farms (with several more in the pipeline). In most cases these developments have been located in areas where full or partial peat cover, moderate to steep slopes, and high average annual rainfall can potentially increase the risk

of peat slides. To avoid this, GSNI now routinely advises the Planning Service to ensure that the Environmental Impact Assessments required to accompany applications for such developments consider peat slide risk and include information regarding peat depth and slope stability assessments.

7.4 Land Use Planning and Development Control in Landslide Susceptible Areas

The system for land use planning in Northern Ireland differs from those currently operating elsewhere in the United Kingdom and the Republic of Ireland.

In Northern Ireland, planning and development control is a centralised function and is primarily the responsibility of the Planning Service, an agency of the Department of the Environment. The Planning Service develops and implements Government planning policies and development plans in Northern Ireland.

The Planning Service's website (<http://www.planningni.gov.uk/>) summarises the role of the agency as follows:-

“The planning system exists to regulate the development and the use of land in the public interest. The Department's functions, in relation to planning, are set out in the Planning (Northern Ireland) Order 1991. The role of the Agency is to administer most of these functions. All planning decisions up until 14 October 2002 were taken under the authority of the Minister of the Department of Environment. Following the suspension of the Northern Ireland Assembly the Parliamentary Under Secretary of State at the Northern Ireland Office has exercised that authority.”

The GSNI acts as one of the Planning Service's statutory consultees and provides advice on a range of geologically related planning matters. Consultation takes place at various stages in the planning process, including planning policy development, regional and area planning, and development control.

GSNI maps landslides and areas of ground instability in the course of its systematic geological resurvey programme in Northern Ireland, and landslides are represented on the published 1:50,000 scale geological map series. GSNI is therefore uniquely placed to advise the Planning Service and identify potential landslide hazards which are potentially areas of planning constraint.

The Planning (Environmental Impact Assessment) Regulations (Northern Ireland) 1999 require applications for certain categories of development to undergo Environmental Impact Assessment and be accompanied by an Environmental Statement. GSNI provides the Planning Service and the developer with generic, (or sometimes site specific) advice on geological factors, including landslide risks that are likely to impact on or be impacted by a particular development.

Many of the landslides in Northern Ireland occur in remote areas or are of such minor extent that they pose no significant risk to the safety of humans, livestock, or infrastructure. Where landslides or ground instability do constitute a significant constraint to surface land use they need to be brought to the attention of developers and planning authorities alike.

The biggest threat to the stability of a landslide prone site arises through ignorance of the risks of unregulated development that may undermine the toe of a landslide, overload unstable ground, or radically alter existing ground drainage patterns. Detailed knowledge of the risk associated with landslides coupled with careful management of drainage, use of retaining walls, slope-grading etc., can often minimise the effects of further movement on existing dwellings and infrastructure.

“A Planning Strategy for Rural Northern Ireland” (Department of the Environment for Northern Ireland, 1993) outlines a policy for restricting development in unstable areas (PSU10). A more detailed Planning Policy Statement along the lines of PPG 14 “Development on Unstable Ground”, currently in operation in England and Wales, could be a useful resource to support planners and developers in Northern Ireland.

7.5 Some Thoughts about the Future

It is difficult to predict if and how the current levels and types of landslides and slope instability experienced in Northern Ireland will be affected by predicted changes in global climate. Existing slopes, both natural and artificial, (eg. railway and road embankments/cuttings) may also be vulnerable to future climatic changes.

Current predictions for climate change in Northern Ireland include: overall warming with rises in precipitation and potential evapotranspiration. Winter gales are predicted to decrease in frequency but increase in severity.

In addition, as a consequence of global climate changes, it is predicted that by the 2050s sea level around the Northern Ireland coastline will rise by between 13cm and 74cm.

It is also predicted that the increase in overall precipitation, particularly winter precipitation and its intensity, will have effects on river basins: in particular flooding, and the stability of exposed slopes in upland areas and in the coastal zone. (Whalley et al., 2002).

7.6 Conclusions and Recommendations

Conclusions

GSNI considers the key benefits of a landslide database for Northern Ireland to be:

- Raised awareness of the potential hazards posed by landslides and unstable ground
- Improved visualisation of actual and potential landslide areas
- An improved capability to deliver geological information services and technical decision-making support to key stakeholders (planners, engineers, developers).

Recommendations

1. The landslides database should be extended to include known events in Northern Ireland.
2. Landslide data should be incorporated as a theme (possibly part of a broader “geohazards” theme) in the GSNI – Geographical Information System.
3. Further research should be considered into the methodology, implications and practicality of landslide risk assessment and landslide susceptibility mapping.
4. In conjunction with the Planning Service, consideration should be given to developing a detailed Planning Policy Statement for Northern Ireland similar to PPG 14 “Development on Unstable Ground”, already in operation in England and Wales.

List of Relevant Planning Legislation & Guidance Documents for Northern Ireland

The Planning (Northern Ireland) Order 1991

Department of the Environment for Northern Ireland 1993

A Planning Strategy for Rural Northern Ireland. The Stationary Office, Belfast.

The Planning (Environmental Impact Assessment) Regulations (Northern Ireland) 1999

Planning Service, 1999. Development and Control Advice Note (DCAD) 10
“Environmental Impact Assessment”.

8. RESEARCH ON IRISH LANDSLIDES

Koenraad Verbruggen

8.1 Introduction

Given the relative rareness of their occurrence it is not surprising that research on Irish landslides has been limited to date. However past events have often led to academic investigations and this was also the case for the 2003 failures at Pollatomish and Derrybrien. Whilst the Irish Landslides Working Group (ILWG) cannot be certain that it is aware of all researchers that have looked at landslides in Ireland, particularly those who have made brief visits from overseas, a comprehensive databank of published material, has been collated. This chapter provides a brief overview of research on Irish landslides prior to 2003 and a summary of the projects carried out as a result of the more recent events.

8.2 Research pre-2003

Earlier work carried out on Irish Landslides can be broadly divided into:-

1. That conducted on specific failures and generally of a field and geomorphological nature, being descriptive and carried out by geography/geology academics, some of which are reviewed below.
2. The more geotechnical and laboratory based research into stability and behaviour of landslide materials, mainly glacial soils and peats, conducted by Civil Engineering Departments, some of which were referred to in Chapter 4 on the Geotechnics of Landslides in Ireland. A summary of current programmes is included.

Early Irish landslide accounts have been used to populate the Irish Landslides Database event listings (Appendix 5), but the majority are merely descriptive and the investigations do not really constitute research.

Tomlinson (1979, 1981) of Queens University, Belfast, working on peat erosion and failures in Northern Ireland in the 1970's and 1980's, not only described events but also investigated their likely cause and possibly important preconditioning factors. He believed an important factor in these failures, mostly of upland peat, was the presence of significant human disturbance such as the construction of townland boundary ditches, drainage channels and peat cutting.

Alexander, Coxon and Thorn, all then at Trinity College, Dublin (TCD), carried out research on peat failures in the Geevagh area of County Sligo in the mid 1980's (Alexander et al, 1986) and also documented failures across a wider area for a field guide of the Irish Quaternary Association (IQUA) (Alexander et al, 1985). The Geevagh study area, which has been further worked on by O'Loinsigh at TCD proved the existence of previous failures at the same location, in 1831 and 1945, all originating on the same upland ridge and being channelled into the same catchment. Proof of this came from cores taken in the valley area, where each event could be recognised as a thin peat deposit within the soil profile and scars at different stages of regrowth, visible on the hillside. Approximations of flow velocity and strength were also made from the size of some of the boulders that were moved by the event.

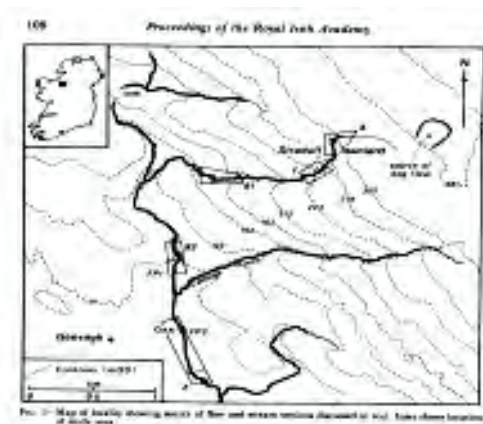


Fig. 8.1 Map of locality showing source of flow and stream sections, A Bog flow at Straduff Townland, Co Sligo, (Alexander, et al., 1986).

More recently Dykes, Kirk and Warburton of Huddersfield and Durham Universities respectively, examined peat failures on Cuilcagh Mountain on the Cavan/Fermanagh border, after an event in 1998 (Dykes and Kirk, 2001). More than 30 failures were mapped, some of which were estimated to have travelled over a kilometre. It was suggested that both digging of drainage ditches and possibly burning of peat might have been preconditioning factors in this case, and previous failures were mapped on the same mountain.



Fig. 8.2 (a) Location of the study site at Cuilcagh. (b) Location of the peat slide on Cuilcagh Mountain (1km grid squares; contours in metres). (Dykes and Kirk, 2001).

An important and recurring feature of these studies outlined above is that where an event was investigated, in almost all cases it was found that previous events of a similar nature had occurred in the same area, but may not have been recorded. This finding underlines the usefulness of a database of past events when it comes to future planning.

8.3 Research Workshop TCD 2004

In an attempt to stimulate cross discipline research in this area, the Irish Landslide Working Group held a half-day workshop of talks in TCD in October 2004. Speakers are listed in Table 8.1, and the event proved highly useful in gaining a measure of the information in existence and those areas that required greater investigation. In particular all researchers shared fully their data and thinking on the various aspects they were investigating. Unfortunately some researchers were unable to make it on the day, however they along with those who took part in the workshop have provided abstracts summarising their work, or presentations which have been summarised here.

Koen Verbruggen (GSI)	Opening Address
Shane Murphy (Leeds Univ.)	A geophysical investigation of a large scale peat slide on Dooncarton Mountain
Dr Mike Long (UCD)	Research at UCD on Peat Strength
Noel Boylan (UCD)	Proposed M.Sc Project on Peat failures in Wicklow Mountains
Dr Mike Long	
Tadhg O'Loinsigh (Presented by Steve Mc Carron) TCD	Identifying, recognizing, and predicting sites of mass movement in Irish uplands: A case study based on bog flows
Dr Alan Dykes, Univ Huddersfield (Presented by Paul Jennings (AGEC))	Geotechnical investigations of recent Irish Landslide events
Dr Eric Farrell, TCD	The Contribution of Geotechnics to Landslide Risk Assessment
Christine Colgan, NUIG/GSI	Landslides and Arc GIS
Gavin Elliott (Pat Shannon, Peter Haughton, Daniel Praeg (UCD) & Brian O'Reilly (DIAS))	Submarine landslides: Processes and Products, West of Ireland
Ken Gavin & Xue Jianfeng, UCD	Stability of man made glacial till slopes in southwest Ireland
Dr Ronnie Creighton (Irish Landslides Working Group)	Landslides in Ireland

Table 8.1 Participants in Landslide Workshop, TCD, 2004

8.4 Research. Post -2003 Abstracts

Table 8.2 lists the researchers who have recently, or who are currently working on Irish landslides. Abstracts submitted by the different project leaders are then included in their entirety.

Research on Landslides in Ireland (Post 2003)				
College	Department	Researcher/student	Qualification	Topic
NUIG (GSI)	Geography-GIS	<i>Christine Colgan</i>	MSc. GIS	Landslide Database development using GIS & Web
Univ of Huddersfield Univ of Durham	Geography	Alan Dykes Jeff Warburton		Joint Project - Pollatomish peat slides
Sligo IT	Environment	<i>Steve Torney</i>	Msc. Envl Health	Incorporate Risk of Landslides into the Irish Planning Process
Limerick IT	Quantity Surv.	<i>Daragh McDonagh (Tobin Eng.)</i>	Bsc Construction Economics	Landslides. A problem for the future?
UCD	Geology	<i>Gavin Elliott</i>	PhD.	Cainozoic evolution of the E. Rockall Slope System
				(Incl. Landslide evidence offshore from Nat. Seabed Survey data)
UCD (Irish Rail)	Civil Eng.	Ken Gavin	MSc.	Assessing the effects of rainfall on the stability of man made slopes in glacial till
UCD	Civil Eng.	<i>Mike Long/ Noel Boylan</i>	PhD.	A system for Peat stability analyses?
Leeds Univ.	Geophysics	<i>Shane Murphy</i>	MSc Geophysics	Geophysical investigation of peat failures
TCD	Civil Engineering	Dr Eric Farrell		Geotechnical Properties

Table 8.2 Table of Researchers

The Landslides on Dooncarton Mountain, Co. Mayo, 19 September 2003

Alan Dykes and Jeff Warburton

Catastrophic failures of peat deposits and peat-covered hillslopes have occurred in many parts of the world. Approximately 60% of all recorded peat failures are in Ireland (the Republic of Ireland and Northern Ireland), with a further 20% in the rest of the UK (Dykes and Kirk, in press). The serious impacts of these events were well known by the end of the 19th century, particularly following the disaster in Co. Kerry in 1896 that killed a family of eight people and involved 5-6 million m³ of peat (Sollas et al., 1897; Cole, 1897; Latimer, 1897). The landslides on Dooncarton Mountain, although of a much smaller scale and involving blanket bog rather than raised bog peat, constituted an event similar to others in recent years, e.g. July 1983 in southern Scotland (> 41 landslides and peat slides caused by > 65 mm of rainfall within 1¼ hours: Acreman, 1991) and on the same day as Dooncarton, 19 September 2003, in Shetland, northern Scotland (20 large peat slides caused by c.100 mm of rainfall within 3 hours).

The UK's Natural Environment Research Council (NERC) funded a research project to investigate in detail how and why so many landslides were triggered by the rainfall on Dooncarton Mountain in 2003, and what happened to the sediment generated from the landslides. The latter issue constitutes the main hazard from these slope failures, but has not previously been explicitly studied in this context in Ireland or the UK. However, understanding the factors that determine the susceptibility of (peat-covered) mountain slopes to failure in response to 'extreme' rainfall is the first critical stage of any assessment of the possible hazard from similar events in the future. This is becoming increasingly important given the consistent climate change predictions that emphasise the increasing frequency of severe high intensity rainstorms.

Preliminary conclusions from this research are:

1. The landslides were caused by high intensity rainfall resulting in high water pressures within the hillslopes.
2. The nature of slope failure was controlled by position on any given hillslope and the presence of subsurface water drainage and an extensive iron pan in the subsoil.
3. Drainage ditches do not appear to have been a significant contributing factor in failure.
4. Approximately 177,000 m³ of peat and soil were removed by the landslides. Some of this material was left on the lower mountain slopes but much of it entered streams, rivers and the sea.
5. These events are consistent with observations of peat landslides across Ireland and elsewhere in the world.

Further laboratory analysis of the slope materials, detailed computer modelling of stability conditions of the slopes, and quantification of the sediment run-outs using GIS techniques, are continuing to resolve these issues. This research has also highlighted a number of other key factors that require future research. These include the precise hydrological and geotechnical role of the subsurface iron pan in the soil profile, and the nature and distribution of subsurface pipes and other hydrological and structural discontinuities in the stability of intact mountain slopes.

A geophysical investigation of a large scale peat slide on Dooncarton Mountain

Shane Murphy (Project assisted by GSI)

A geophysical and engineering investigation was carried out on a discrete peat slide on Dooncarton Mountain, Co. Mayo, where 41 separate peat slides occurred on the 19th September 2003.

Geophysical fieldwork was carried out between the 19th to 28th June, and the 4th to 6th July 2004 using a Sensors and Software pulseEKKO 100 ground penetrating radar (GPR) unit and an ABEM Mark 6 seismogram. The collected GPR and seismic data was processed using ReflexW3.5 software developed by Sandmeier Scientific Software.

In the field, the refraction survey proved to be inappropriate for investigating the thickness of peat and was not subsequently processed. S-surveys however, provided Poisson's ratios of 0.442 and 0.431 with Young's modulus of 8.65 ± 0.05 MPa and 39.25 ± 0.25 MPa for the respective peat and weathered layers were calculated.

All processed GPR profiles displayed a strong, continuous reflector that corresponded to the peat-weathered rock layer boundary. A possible discontinuous iron pan reflector was located just below the top of the weathered layer. Naturally occurring pipes and sub terrain cracks were imaged in the peat using 100 and 200MHz antennae, although truthing or prior knowledge is generally required for interpretation of these features.

Laboratory tests performed on peat cores taken in the field showed the peat to have a density of 0.92 ± 0.02 g/cm³ while a rough index test proved that the peat had a low permeability. A simple two layer model with the peat sitting on top of the bedrock was back analysed using Janbu's Simplified Method for three cross sections provided by the GPR survey. By constraining the back analysis results with index shear strength results the cohesion of the peat was determined to be 8kPa and the internal angle of friction to range between 30° and 40°.

The GPR, as a tool of investigation, proved successful in determining the failure plane in the peat where the seismic surveys were ineffective in determining the cause of the failure. The GPR and engineering analysis combined to prove that water flowed through the cracks of the impermeable peat and caused the peat to become buoyant and susceptible to failure resulting in the peat slides.

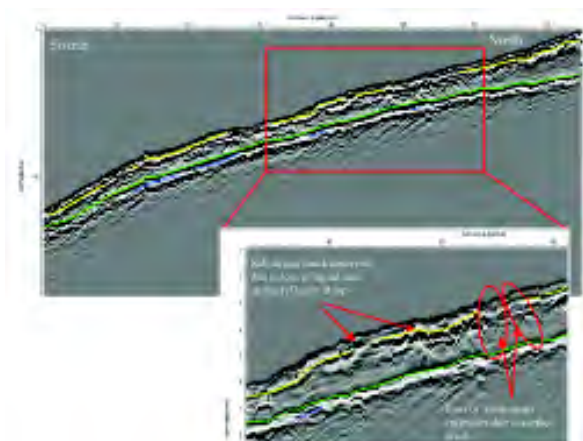


Fig. 8.3 A GPR profile along a survey line above the scar that is located to the south of the survey. Yellow represents the acrotelm-catotelm boundary, green the start of the weathered layer, and blue a possible hard pan in the weathered layer. Shane Murphy

Identifying, recognizing, and prediction sites of mass movement in Irish uplands: A case study based on bog flows

Tadhg O'Loinsigh

The original area of study for this project was Geevagh, Co Sligo where a documented bog burst occurred in 1984 (Alexander et al., 1986). Aerial photographs taken in 2000 with 1m resolution in conjunction with 1m digital ortho-pair imagery from the Ordnance Survey of Ireland (OSi) were used to identify the flow and drainage features in the peat comparing the results with free satellite data collected in 2002 from Landsat.

From the colour aerial photographs, the healing 1984 bogflow scar could be clearly defined as well as two scars that probably occurred in 1945 and 1831. Correlating features on the aerial photographs with observations in the field and ortho-pair imagery proved that drainage features in the peat could be delineated as well as ridges of peat in the scars indicating flow direction. While this technique provides a definitive process of identifying previous bogflows and drainage features, the cost of acquiring the aerial images is expensive if used over large areas.

In comparison, the Landsat 7 ETM+ images of Geevagh, viewed using the False Colour Composite (FCC) bands 542 (which displays disturbed ground as purple in colour), was too coarse to define the relic scars. Therefore higher resolution satellite imagery needs to be evaluated (i.e. IKONOS or Quickbird datasets) in order to properly assess the benefits of this technique.

Following the detailed investigation at Geevagh, a larger investigation (encompassing Eagles Rock Mountain, Truskmore Mountain and King's Mountain) was undertaken with the aim of identifying bog flows using Landsat imagery. This survey incorporated Landsat ETM+ sharpened to 15m resolution and draped on a 90m digital elevation model (DEM) from the Shuttle Radar Topographic Mission (SRTM) to produce a 3D map of the area.

The use of 3D maps at the bandwidth GRB 432 provided locations of disturbed ground (denoted by the colour purple) that could then be distinguished from roads and settlements by their topographical location. Correlating the purple upland zones from the principle component analysis (PCA) on the 4,3,2 bands were applied over the same area as the 3D map but without being overlaid on the DEM. This method illustrated relic scars as black linear features and is recommended as a preliminary survey technique.

In conclusion, aerial photographs and ortho-pair imagery provide the best data to identify old bogflows but expensive to use over large areas. Satellite images from Landsat ETM+, whilst free, had too coarse a resolution for detailed scar analysis, however PCA using bands 4,3,2 provide the best method for distinguishing large scale healing scars. Combining Landsat GRB432 with DEMs was also found to be productive in delineating roads and settlements from old scars by topographical location.

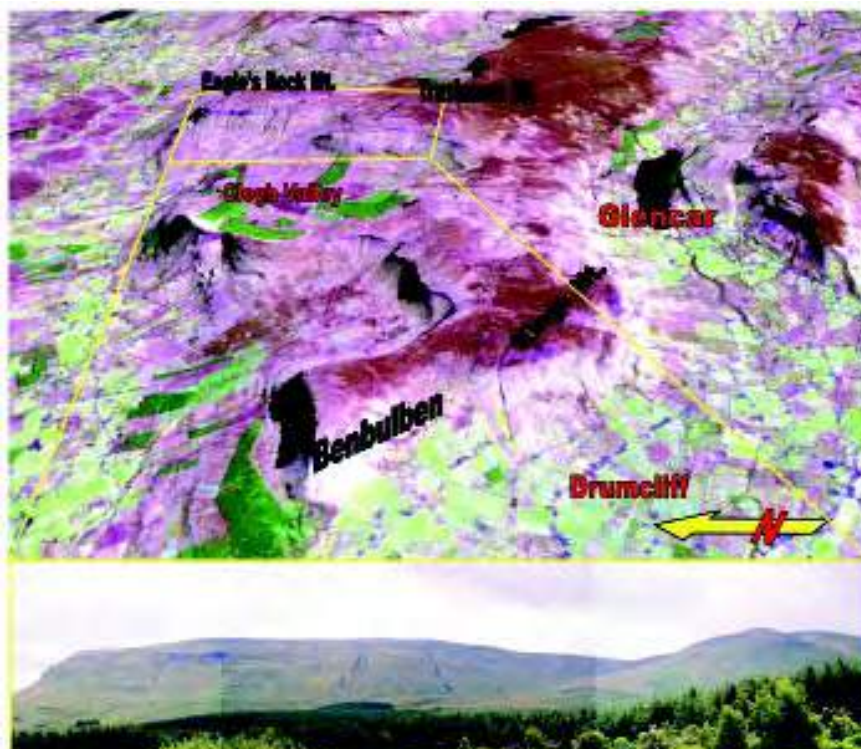


Fig. 8.4 Landsat image draped over Digital Elevation Model (DEM) used in relic bog burst detection. The adjoining photograph is of Eagle's Rock Mountain where the purple colour in the satellite image relates to the scars seen in the photograph. The dark patches on the northern sides of the mountains (e.g. to the north of Benbulbin) are shadow zones caused by the direction the image was taken in relation to the aspect of the mountain.

Peat Landslides in Co. Wicklow

Noel Boylan and Michael Long

The aim of this project is to investigate geotechnical behaviour of peat susceptible to landsliding. Remote sensing techniques such as satellite imagery, aerial photography and Digital Elevation Models (DEM) were used to detect slides in a study area of Co. Wicklow. Recently developed techniques (O'Lionsigh, 2004) were used to assist the detection and further techniques were developed. This study has shown that the occurrence of peat slides is not as significant in Wicklow as in the West of Ireland. This is possibly due to the fact that peat deposits are generally thinner, and deep deposits are not very common in Co. Wicklow.

The complex interaction between hydrology, underlying geology, geomorphology and geotechnical properties has been studied to try and understand the mechanisms of failure and areas of susceptibility. Further work is underway to understand the geotechnical behaviour of the peat in landsliding and properties which may cause certain locations to be susceptible.

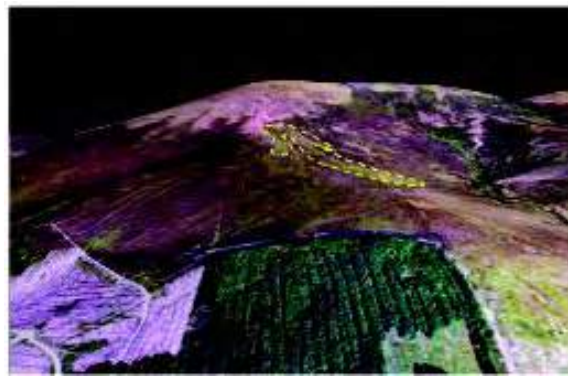


Fig. 8.5 Peat Slide in Co. Wicklow. Osi 2000 Colour aerial photographs draped over DEM and viewed obliquely using 3D visualisation software at GSI. © Government of Ireland 2004 Osi Permit No. DNE 0001001.

GIS Mapping of landslides & production of susceptibility maps

Christine Colgan (in association with GSI)

The landslides that occurred in the west of Ireland in 2003 emphasised the need for a landslides database and susceptibility mapping of the country.

For the creation of this database in Microsoft Access, an inventory of previous landslides had to be compiled. Information was collected from research articles/journals and field observations (in the case of the Pollatomish landslides). A webpage was also created to enlist landslides observed by the general public around the country (<http://www.gsi.ie/workgsi/geohazards/myform.htm>), the results from which were verified before being entered into the database.

To date, the database contains 117 separate landslides, with information gathered about these events under the headings:

1. Location details
2. Type of slide
3. Size and extent
4. Damage
5. Causes
6. Contributory factors

From this database a regional map that contains all known landslides in Ireland has been created using Geographic Information Systems (GIS) with the type of landslide subdivided into the following five categories: bog flow, bog slide, creep, flow and rock fall. This database also provides a general source of information on landslides in Ireland for interested parties.

In the case of vulnerability mapping, geology (source: GSI), soil type (source: Teagasc) slope (source: OSI) and average rainfall (Met Eireann) maps were combined. It is hoped to ascribe values to each factor based on susceptibility allowing for the creation of a slope stability/vulnerability map to be created. This map can then be tested against known locations of landslides, for example the Pollatomish landslides.

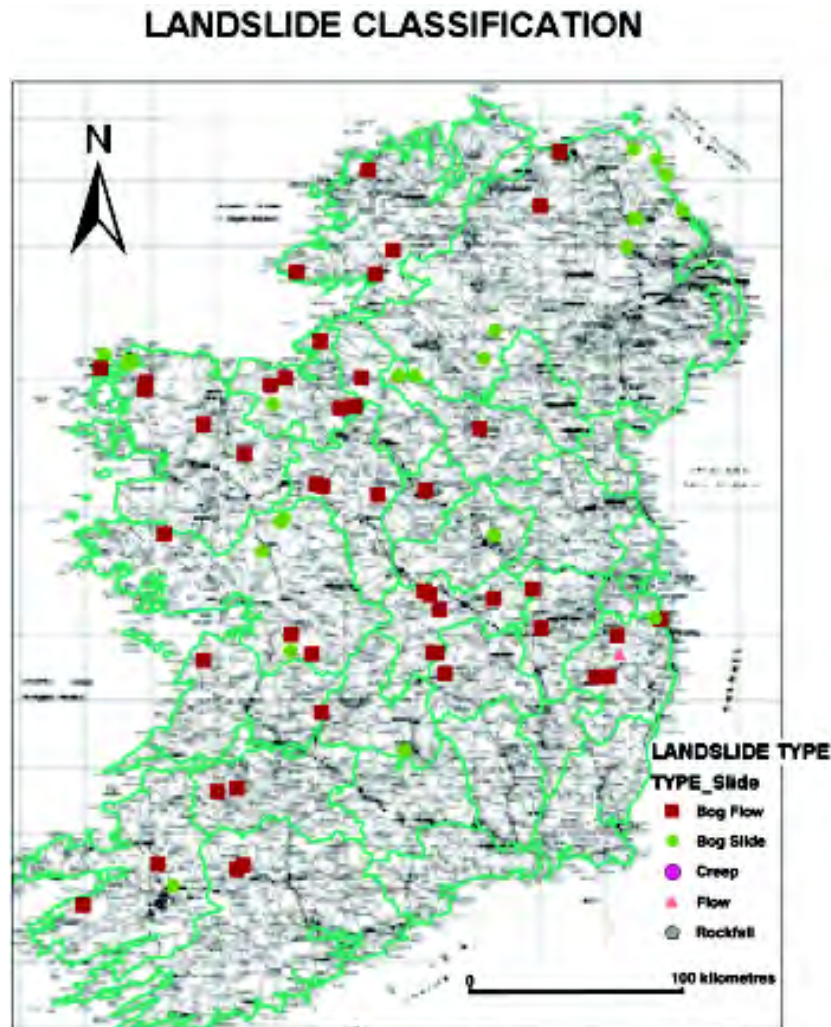


Fig. 8.6 Locations of known landslides in Ireland which have been subdivided by type of slide.

Submarine slope failure morphology offshore Ireland

Gavin Elliot

The Irish offshore region is nearly 10 times the area of the Irish mainland. However up until the last 30 years very little systematic work had been undertaken there, particularly the Atlantic margin (Fig. 8.5). Over the last 20 years researchers at the Department of Geology at UCD together with DIAS and other institutes, have been involved in attempting to unravel the mysteries of the Atlantic margin from deep crustal studies to seabed surface morphology.

The seabed morphology was poorly constrained until two extensive sidescan sonar surveys were undertaken in 1996 and 1998 respectively. These surveys imaged the numerous submarine canyons that incise the margin 100 km west of Ireland. Integration of the sidescan sonar data with the existing seismic reflection data and bathymetry data revealed that the canyons could be up to 400m deep, in excess of 40 km long and in one case enclosed in between 30° walls. The sidescan sonar also imaged (with resolution down to 5m) numerous headwall scarps of submarine landslides. Only headwall scarps can be imaged as the main body of the failure has been transported as debris flows into the deep basin and can be found on the basin floor.

The largest failure is found on the margin of the Rockall Bank (Fig. 8.5) and it has displaced $\sim 55\text{km}^3$ of material into the basin leaving a large run-out lobe and evacuation scour. This large failure is thought to consist of two main phases of movement on low gradient slopes (average gradient $2\text{-}3^\circ$). This failure has been dated at 15-16,000 years BP based on radiocarbon dating from cores.

Although this failure seems well understood much work remains to be done to answer such questions as:- the age of the other failures? rates of failure? nature of the substrate? the relationship between the slope failures and the canyons systems ?.

The Irish National Seabed Survey which commenced in 2000 is providing high resolution bathymetric data that will help us to understand these important questions that are relevant to both offshore hydrocarbon exploration and production and also submarine telecommunications cable locations.

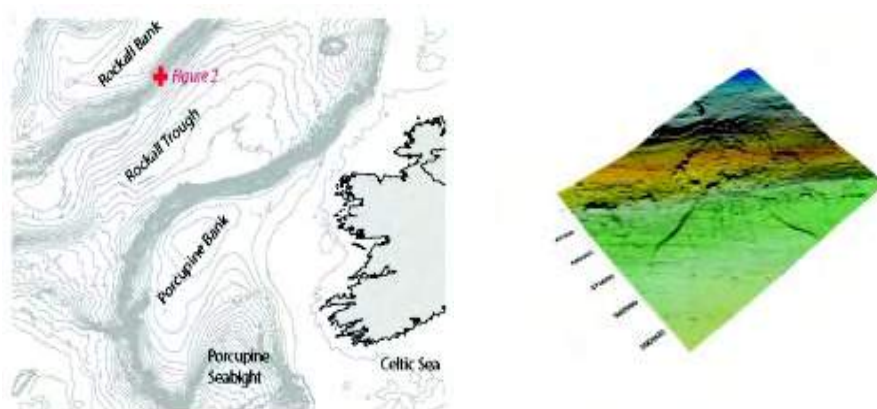


Fig. 8.7 Ireland's Offshore Area and Large-scale Failure on Rockall Bank

Shear strength of peat

Noel Boylan and Michael Long

Work on the assessment of shear strength of peat was started by Prof. E. T. Hanrahan at University College Dublin (UCD) as early as 1948, and was the first reported research on the shear strength of peat in the world (Hanrahan, 1952, 1954, Hanrahan and Walsh, 1965 and Hanrahan et al., 1967). This early work mostly concerned the problems of road construction in raised bog areas. Recent attention on the subject of peat strength has focused on the material behaviour in landslides following the two devastating slides in the west of Ireland in 2003.

There are very significant problems associated with work on peat strength due to the high water content and compressibility of the material, the influence of fibres, its inherent non-homogeneity and the very low in situ stresses normally encountered. Although most of the existing work on peat strength assumes that its behaviour follows the laws of classical soil mechanics, this is far from clear. Researchers around the world, particularly in Canada, have expressed doubt on the application of existing techniques such as in situ vane testing, cone penetration testing and laboratory triaxial testing to peat.

Work at UCD on the basic properties of peat including scanning electron microscope studies has suggested that the conventional "effective stress" approach may not be appropriate for peat. Currently work is focusing on attempting to understand the mechanical behaviour of peat in relatively well-controlled circumstances. These include work in the field using specially constructed T-bar and spherical ball probes and in the laboratory using a large-scale direct simple shear (DSS) apparatus. Numerical models will be applied to the results in order to develop a framework for understanding peat strength. For the purposes of this work peat test bed sites have been established on blanket bogs in Co. Mayo and Co. Galway and in raised bogs at Athlone, Portumna, Tuam and Charlestown.

Steep slopes in glacial till

Michael Long

Much of Dublin is underlain by competent lodgement till known locally as Dublin Boulder Clay, (DBC) (Skipper et al. 2005). Local experience (Long et al., 2003) confirmed that steep excavations, up to 8 m or so, could stand unsupported for periods of at least three to four months. Since for many developments temporary support is only required for short periods engineers have been attempting to use this natural property of the soil for the purposes of deep excavation construction in order to avoid costly retaining walls or soil nailed support systems.

Work is ongoing at UCD in order to understand the mechanical behaviour of the DBC in these situations. Initially it was thought that the soil possessed a high effective cohesion (c') or some cementation bonding between the particles. Laboratory triaxial testing and scanning electron microscopy studies on high quality (triple tube rotary cored) soil samples have confirmed that neither of these factors is significant. Instead it has been concluded that the temporary stability of these steep slopes is controlled by near surface negative pore water pressures (suctions) induced by stress relief due to soil excavation. The effect of sand and gravel lenses within the till in reducing or eliminating the suction were found to be very significant.

These findings have been confirmed by measurements of suctions during the construction of the northern cut and cover section of the Dublin Port tunnel (Long et al., 2004) and by back analysis of the behaviour of the steep cuts using the finite element method. This latter work has been carried out by the Geotechnical Consulting Group, London (GCG) assisted by UCD (Menkiti et al. 2004).

Strength of peat at low effective stresses.

Eric Farrell and Martin Carney

Recent landslide events in peats have highlighted the difficulty in predicting the relevant shear strength parameters for such soils. The permeability of peats is such that it is questionable if undrained shear strength parameters are relevant, particularly as different values of c_u are obtained when using different size vanes in in-situ tests. The effective stress parameters determined in laboratory tests generally indicate $c' \approx 0$, however it is difficult to carry out such tests at low effective stresses as the membrane forces and other equipment effects can become significant. Furthermore, different values of the effective stress parameters are obtained with different test methods.

The objective of this testing programme is to develop an entirely new test method to determine the effective stress parameters of peat, particularly an assessment of c' . Peat is known to have high values of ϕ' but this would not be expected to be a significant contribution to strength where $\sigma'_n \approx 0$. This new approach will involve testing relatively large block samples of peat in conditions where the boundary effects are minimal. A video extensometer will also be used in the test to enable the deformation pattern of the peat to be studied using as it approaches failure. These tests will give valuable information on the strength of peat at effective stress levels comparable to those that exist in raised and blanket bogs, which are known to be susceptible to bog bursts.

Landslides. A problem for the future?

Daragh McDonagh

The main topics covered in this study were:- the economic significance of landslides, landslide types and processes, landslide triggering mechanisms, principles of hazard reduction and risk assessment and decision making under certainty and uncertainty of landslide activity.

The author reviewed landslides in Ireland in general, noting the greater occurrence in the west and south on upland blanket bogs, during autumn and winter months. The author analysed the different causes of landslide triggering with particular reference to the two most recent landslides; in Pollatomish, Co. Mayo and in Derrybrien, Co. Galway. An in-depth study of the landslide in Pollatomish was carried out, the primary cause of which was intense rainfall over a nine hour period.

The socio-economic significance of landslides is emphasised because landslide losses continue to grow as human development expands into unstable hillside areas under the pressures of increasing population. A significant proportion of world landslide losses involves transportation - highways, railways, rivers and pipelines. The nation most severely affected by landslides is Japan, which suffers estimated total (direct plus indirect)

landslide losses of \$4 billion annually. The author looked at mitigation options available in Japan, examining what ideas this country can take from their experiences, and also determined other possible methods of control that could be implemented in this country.

The author finally analysed the significance of using “landslide hazard maps” to try to predict where the next landslide is set to strike. Hazard maps would aim to take all the factors that a landslide needs into account (steep slope, blanket peat, areas of heavy rainfall etc), place this information on a map of Ireland and determine the high, medium and low risk areas in this country. Under conditions of environmental similarity, the spatial distribution of past (relict) and recent slope-failures is the key for predicting slope movements in the future.

Landslides and the Irish Planning Process

Steve Tonry

The project work for this degree was a review of the treatment of landslides in the Irish planning process with recommendations for changes. Problems highlighted were the lack of a current database and mapping along with planning guidelines. A review of literature in Ireland and a comparison with the planning perspective in USA, UK, Australia and EU was undertaken. On the Irish perspective, a review was undertaken of the role of Geology in EIS, the work of GSI and the LWG, status of a National Database, GIS and web use in this area and cost implications of change. Information was obtained from the LWG and a questionnaire was constructed for an evaluation of engineers and planners knowledge of the area. Conclusions pointed to the serious nature of the problem, the lack of policy and knowledge at present, the range of potential solutions available, and cost benefit of preventative action.

8.5 Recommendations

Further research is required into understanding Landslides in the Irish context, particularly in the following areas:

- Peat Strength and Behaviour

- Strength and Behaviour of Irish subsoils including glacial tills

- Multi-disciplinary studies of landslide phenomenon (Geomorphology, Engineering, Biology of Peat, Climate, Planning)

- Likely effects of climate change on Landslide Susceptibility

In particular, based on the results of research as outlined above, more informed research work can then be carried out into the area of **landslide susceptibility mapping** and **hazard and risk assessment** to identify areas which are subject to landslides or have the potential for landslides.

This research requires access to existing research funding or preferably a new dedicated funding stream.

In order to ensure that such research is relevant to tackling the issues raised by the work of the ILWG, it, or its successor, should have a co-ordination or advisory role in the funding of such research.

The Irish Landslides Database now constructed provides a vital resource for research on this topic, it needs to be maintained and added to in the future to continue to be of value.

The ILWG has acted to date as both a co-ordinator and stimulator of research into this topic, therefore it should continue this role in some form, after fulfilling its stated aims of constructing a national database and producing an Irish Landslide Booklet.

9. RECOMMENDATIONS FOR FUTURE WORK

9.1 Introduction

The Irish Landslides Working Group recommends that a large body of research be completed with regard to landslide assessment hazard in Ireland, both in the short, medium, and long terms. The growing pressure for development in more marginal land areas, and the potential impacts of climate change, make further surveying and research an important imperative on health and safety grounds and in the context of the sustainable development of the Irish landscape.

Landslide hazard is a major geohazard and is included as a survey and research theme in the Geoscience Initiative recently prepared by the Geological Survey of Ireland, and currently being proposed to Government for funding. In addition landslides are being examined in an all-Ireland context. There has been extensive co-operation between the Geological Survey of Ireland and the Geological Survey of Northern Ireland on this and other geoscience themes. The work will require a multi-disciplinary team bringing together various types of expertise, and therefore a multi-agency approach.

This landslides report lays the foundation of such research, in documenting the issues involved. Following from this there is an immediate need to increase public awareness about landslide risk in Ireland. In the medium to long terms, gaps in our knowledge about past landslide events should be filled, surveying work needs to be done to produce landslide susceptibility maps for Ireland, and research on the geotechnical properties of landslide materials, such as peat, is required. Subsequent to this research, landslide issues need to be fully integrated into the planning process through the publication of planning guidance.

Several key recommendations for future work on landslides in Ireland follow. Much of this work, by its very nature, will run concurrently to some extent. This is the case with the landslide susceptibility mapping and the research on the geotechnical properties of the materials in landslides. Planning guidance must await the extensive data compilation from surveying and the production of landslide susceptibility maps.

The project work has been put into a broad order of priority to reflect the relative importance of the various work programmes. Within the second priority susceptibility mapping and landslides research are regarded as being of equal importance.

For each project, the main objectives are set out and estimated costs given to reflect a three-year programme in all cases. These are followed by the list of specific tasks involved in the project.

The concluding section will outline the strategic framework to implement this work programme.

9.2 Recommendations for Future Work

1. Public Awareness/Outreach

It is important that there is much greater public awareness of landslide hazard in Ireland so that the general public know of the potential for slope instability in certain areas and the possible consequences in terms of life and property.

Main Objectives

- Increase public/private sector awareness of landslide hazard in Ireland
- Provide practical support and guidance to developers/regulators

Specific Tasks

- Widespread distribution of the Landslides Report, including press releases to national and local newspapers
- Presentation of workshops on landslide hazard in Ireland

- Publication and distribution of an information leaflet
- Organisation of a national seminar on landslide hazard

Tasks to be undertaken by the Irish Landslides Working Group under the Geological Survey of Ireland.

Cost:- €15,000

2. Landslide Susceptibility Mapping and Research on Geotechnical Properties of Landslides

Surveys of past landslide events and research into landslide materials and mechanisms underpin all future strategy on this geohazard in Ireland.

Landslide Susceptibility Mapping

Main objectives

- Expansion and enhancement of the National Landslides Database
- Production of landslide susceptibility maps on a phased regional basis
- Assessment of the feasibility of landslide hazard and risk mapping in Ireland
- Assessment of the impact of climatic change on slope instability in Ireland

Specific Tasks

- Field survey of past landslide events
- Acquisition of reference data on past events from all available sources
- Use of remote sensing techniques and manipulation of thematic and digital datasets in a GIS framework
- Coastal landslide survey in relation to coastal erosion
- Development of a landslides classification scheme for Ireland
- Development of a robust landslides susceptibility mapping methodology for Ireland
- Assessment of available data sources to enable detailed costings to be made of landslide impacts
- Development of a risk assessment methodology for Ireland based on international best practice
- Pilot project on risk assessment
- Review of climate datasets in relation to the occurrence of past landslide events and assessment of projected future climate change on slope stability

Tasks to be undertaken by the Geological Survey of Ireland in consultation with external agencies.

Two consultants for a three-year period €240,000

GIS/IT Database

Access to DEM

Fieldwork

Overheads €250,000

Cost:- €490,000

Research on Geotechnical Properties of Landslides

These research projects on the geotechnical properties of landslide materials will be undertaken in University College Dublin and Trinity College Dublin under the supervision of geotechnical engineers, who are members of the Irish Landslides Working Group. The research is costed over a three-year period in each case.

Priority 1 Peat slides and peat strength

Detailed analysis of the landslides database; field studies at selected sites; work on peat strength; development of two Irish peat research sites, one on blanket bog and the other on raised bog; detailed geotechnical and hydrogeological characterisation of the two sites. This has high relevance to the understanding of slope failure on peat.

Funding of 2 PhD students – field work and instrumentation costs

Cost:- €200,000

Priority 2 Stable slopes in glacial till

Review of case histories of steep natural slopes and cuts in glacial tills; selection of a field study site; detailed investigation of the site; rotary coring for sample retrieval; installation of considerable instrumentation on site.

The results of this research will have wide application given the extensive distribution of glacial till deposits in Ireland

Funding of 1 PhD student – field work and instrumentation costs

Cost:- €150,000

Priority 3 Stable slopes in marine tills

Geotechnical study of the marine-derived clays of southeast Ireland encountered in road infrastructure development and coastal erosion problems.

Funding of 1 PhD student – travel costs

Cost:- €80,000

Total Cost of Geotechnical Research — €430,000

3. Landslides and Public Policy

The most important benefit of all the proposed projects listed above would be the full integration of landslide hazard into public policy and guidelines on the planning process. Such integration can only be implemented when appropriate and readily accessible datasets on landslide susceptibility mapping and landslide risk assessment are available.

Main Objectives

- Increase an awareness of landslide hazard in Ireland
- Full integration of landslide hazard into public policy and guidelines on the planning process.

Specific Tasks

- Assessment of the type and format of landslide data needed to prepare guidance on landslide hazard
- Inter-agency consideration of a clear methodology for the implementation of a landslide hazard strategy within the planning process
- Widespread consultation with all interested parties on the preparation of national guidance
- Preparation of national guidance on landslide hazard

Tasks to be undertaken by the Departments of Environment, Heritage, and Local Government, and Communications, Marine and Natural Resources in consultation with a wide range of stakeholders.

Cost:- €50,000

Cost Resumé

Total Cost :- €985,000 over a three-year period

9.3 Strategic framework for future work on landslides

- Future work on landslide hazard must be done within a well-funded strategic framework.
- The work already done by the Irish Landslides Working Group and reported in this publication should form the basis or starting point for the future work.
- The landslides hazard work should be continued within a multi-disciplinary framework led by the Geological Survey of Ireland.
- This multi-disciplinary approach would involve geologists, geomorphologists, geotechnical engineers, climatologists, planners, and those with GIS expertise.
- The collaborators would include university researchers, local authorities, government departments and agencies such as Teagasc, and consulting geologists and engineers.
- The funding necessary for the proposed work programme should be sought.

TEXT REFERENCES

- Acreman, M., 1991. The flood of July 25th 1983 on the Hermitage Water, Roxburghshire. Scottish Geog. Mag., 107, 170-178.
- Aleotti, P. and Chowdhury, R. 1999. Landslide Hazard Assessment: summary review and new perspectives. Bull. Eng. Geol. & Environment, 58, 21-44.
- Alexander, R., Coxon, P. and Thorn, R.H. 1985. Bog flows in south-east Sligo and south-west Leitrim. In Thorn, R.H. (ed.), Sligo and West Leitrim, 58-76 Field Guide No. 8. Irish Association for Quaternary Studies (IQUA)
- Alexander, R., Coxon, P. and Thorn, R.H. 1986. A bog flow at Straduff townland, County Sligo. Proc. R. Ir. Acad., 86B, 107-119.
- Anon. 1990. IAEG Commission on Landslides. Suggested nomenclature for landslides. Bull. Int. Ass. Eng. Geol., 4, 13-16.
- Bazley, R.A.B. 2004. The Quaternary. In: Mitchell, W.I. (ed.) The Geology of Northern Ireland – Our Natural Foundation Geological Survey of Northern Ireland, Belfast, 211-216.
- Boylan, N. 2005 Personal Communication
- Brunsden, D. 1993. Mass movement: the research frontier and beyond: a geomorphological approach. Geomorphology, 7, 85-128.
- Carney, J.N. 1974. A photo interpretation of mass movement features along the Antrim coast of Northern Ireland. British Geological Survey Technical Report WN/EG/74/13.
- Cole, G.A., 1897. The bog-slide of Knocknageeha, in the County of Kerry. Nature, 55 (1420), 254-256.
- Colhoun, E.A., Common, R. and Cruickshank M.M. 1965. Recent bog flows and debris slides in the north of Ireland. Scient. Proc. Roy. Dub. Soc. A, 2, 163-174
- Conway, B.W. 1977. A regional study of coastal landslips in West Dorset. Report of the Engineering Geology Unit of the Institute of Geological Science No. 77/10.
- Creighton, J.R. and Verbruggen, K. 2003. Geological report on the Pollatomish landslide area, Co. Mayo. Geological Survey of Ireland (GSI) Report.
- Cruden D.M., 1980. The anatomy of landslides. Canadian Geotechnical Jour., 17, 295-300.
- Department of the Environment. 1990. Planning Policy Guidance: Development on Unstable Land. PPG 14. London, HMSO.
- Department of the Environment. 1994. Landsliding in Britain. London, HMSO.
- Dykes, A.P. and Kirk, K.J. 2001. Initiation of a multiple peat slide on Cuilcagh Mountain, Northern Ireland. Earth Surface Processes and Landforms, 26, 395-408
- Dykes, A.P. and Kirk, K.J. (in press) Slope instability and mass movements in peat deposits. In: Martini, I. P., Cortizas, A. M., and Chesworth, W (Eds.), Peatlands. 'Development In Earth Surface Processes' series, Elsevier, Amsterdam.
- Farrell, E.R. and Hebib, S. 1998. The determination of the geotechnical parameters of organic soils. Proc. Int. Symp. on Problematic Soils, IS-TOHOKU 98, Sendai, Japan, 33-36.
- Farrell, E.R. and Wall, 1990. The soils of Dublin. Trans. Instn. Engrs. Ireland, 115, 78-97.
- Fealy, R., Loftus, M. and Meehan, R. 2004. EPA Soil and Subsoil Mapping Project – Summary Methodology Description for Subsoils, Land Cover, Habitat and Soils Mapping/Modelling. Spatial Analysis Group, Teagasc, Kinsealy
- Forster A. 1998. The assessment of slope stability for land use planning. A case study on the North East Antrim Coast. British Geological Survey. Technical Report WN/98/8
- Haefli, R. 1948. The stability of slopes acted on by parallel seepages. Proc. 2nd ICFSMFE, 1: 134-148.
- Hanrahan, E.T. 1952. The mechanical properties of peat with special reference to road construction. Bulletin, Institution of Civil Engineers of Ireland, Vol. 78, No. 5, pp. 179-215.
- Hanrahan, E.T. 1954. An investigation of some physical properties of peat. Geotechnique, Vol. 4, no. 3, 108-123.
- Hanrahan, E.T. 1977. Irish Glacial Till: Origin and characteristics. An Foras Forbartha, RC 164. Dublin

- Hanrahan, E.T and Walsh, J.A. 1965. Investigation of the behaviour of peat under varying conditions of stress and strain. Proc. 6th ICSMFE, Montreal, Vol. 1, 226-230.
- Hanrahan, E.T., Dunne, J.M. and Sodha, V.G. 1967. Shear strength of peat. Proc. Geot. Conf. Oslo, Vol. I, 193-198.
- Hutchinson, J.N., Prior, D.B. and Stephens, N. 1974. Potentially dangerous surges in an Antrim mudslide. Quart. Jour. Eng. Geol., Vol.7, 363-376.
- Jennings, P. and Muldoon, P. 2003. Performance of 150 year-old railway slopes in glacial till: case study from southwest Ireland. Proc. XIII European Conference on Soil Mechanics and Geotechnical Engineering, Prague, 631-636
- Landva, A.O. 1980. Vane testing in peat.. Can. Geot.Jour., 17, 1, 1-19.
- Lee, E.M. and Jones, D.K.C. 2004. Landslide Risk Assessment. Thomas Telford, London.
- Latimer, J. 1897. Some notes on the recent bog-slip in the Co. Kerry. Transactions of the Institute of Civil Engineers of Ireland, 26, 94-97.
- Long, C. B., MacDermot, C.V., Morris, J.H., Sleeman, A.G., Tietzch-Tyler, D., Aldwell, C.R., Daly, D., Flegg, A.M., McArdle, P.M. and Warren, W.P. 1992. Geology of North Mayo. GSI 1:100,000 bedrock Series. Sheet 6 Map and Report
- Long, M. and Jennings, P. 2006. Analysis of the peat slide at Pollatomish, Co. Mayo, Ireland. Journal "Landslides" April 2006, Springer Press.
- Long, M., Menkiti, C.O., Kovacevic, N., Milligan, G.W.E., Coulet, D. and Potts, D.M. (2003). An observational approach to the design of steep sided excavations in Dublin glacial till. Proc. Underground Construction 2003, UC2003, London, Sept., Published by Hemming-Group Ltd., pp 443-454.
- Long, M., Menkiti, C.O. and Follet, B. 2004. Some experience in measuring pore water suctions in Dublin glacial till. Geotechnical News / Geotechnical Instrumentation News (GIN), Vol. 22, No. 3, Sept. 2004, 21-27.
- Long, M. and O'Riordan, N.J. 2000. A slide in Irish glacial lake clay. Proc. 8th Int. Sym. On Landslides. Landslides and Research, Theory and Practice, Cardiff, Wales June 26-30, Vol. 2, 943-948. Thomas Telford.
- Loughman, G. 1979. The residual shear strength of Irish glacial till. Unpublished MSc Thesis, Trinity College, University of Dublin.
- Lydon, I. and Long, M. 2001. Analysis of slope stability of an earth dam due to rapid drawdown effects. Proc. XVth Int. Conf. Soil Mech. And Geotech. Eng., Istanbul, Turkey, August 2001, Vol.3, 2139-2142.
- McGeever, J. 1987. The strength parameters of an organic silt. Unpublished MSc Thesis, Trinity College, University of Dublin.
- Menkiti, C.O., Long, M., Kovacevic, N., Edmonds, H.E., Milligan, G.W.E. and Potts, D.M. 2004. Trial excavation for cut and cover tunnel construction in glacial till - a case study from Dublin. Proc. Skempton Memorial Conference, Advances in Geotechnical Engineering, Eds. Jardine et al., March, Thomas Telford, ISBN 07277 3264 – 1, Vol. 2, 1090-1104.
- Morton, D.M., Alvarez, R.M. and Campbell, R.H. Preliminary Soil-Slip Susceptibility Maps, South western California. USGS, Dept. of Earth Sciences, University of California.
- O'Lionsigh, T. 2004 Landslide Scar Detection and Monitoring in Sligo and Leitrim. Unpublished Report – Geography Department, Trinity College Dublin.
- Pigott, P.T., Hanrahan, E.T. and Somers, N. 1992. Major canal construction in peat. Proc. Instn. Civ. Engrs. Water Marit. And energy, 96, Sep., 141-152.
- Preston, R and Mills, P. 2002. Generation of a Hydrologically corrected Digital Elevation Model for the Republic of Ireland. Report to accompany EPA Teagasc DEM
- Prior, D.B. and Graham, J. 1974. Landslides in the Magho district of Fermanagh, Northern Ireland. Eng. Geol., 341-359
- Prior, D.B., Stephens, N. and Archer, D.R. 1968. Composite mudflows on the Antrim coast of North-east Ireland. Geografiska Annal. Ser. A (2) 65-78.
- Prior, D.B., Stephens, N. and Douglas, G.R. 1971. Some examples of mudflow and rockfall activity in north-east Ireland. Inst. Brit. Geog. Spec. Pub. No. 3, 129-139
- Santacana, N., Baeza, B., Corominas, J., De Paz, A. and Marturia, J. 2003. A GIS-based Multivariate Statistical Analysis for Shallow Landslide Susceptibility Mapping in La Pobla de Lillet (Eastern Pyrennes, Spain). Natural Hazards, 30, 281-295.
- Schuster, R.L. and Highland, L.M. 2001 USGS Open File Report 01-0276
- Shannon Regional Fisheries Board. 2003. Press statement on Preliminary Report Derrybrien Landslide. http://www.shannon-fishery-board.ie/press-2003.htm
- Skempton, A.W. and De Lory, F.A. 1957. Stability of natural slopes in London Clay. Proc. 4th ICSMFE, Rotterdam, 2, 72-78.

- Skipper, J., Follett, B., Menkiti, C., Long, M, Clarke – Hughes, J. 2005. The engineering geology and characterisation of Dublin Boulder Clay.
Quart. Jour. Eng. Geol. and Hydrogeol. 38, 171-187.
- Sollas, W.J., Praeger, R.L., Dixon, A.F. and Delap, A., 1897. Report of the committee appointed by the Royal Dublin Society to investigate the recent bog-flow in Kerry.
Scientific Proceedings of the Royal Dublin Society, VIII: 475-510.
- Spiker, E.C. and Gori, P.L. 2000. National landslide Hazards Mitigation Strategy.
Open File Report 00-450. USGS
- Stephens, N. 1964. The Land in Northern Ireland from the Air.
H.M.S.O. Belfast
- Sweeney, J. (Ed.) 1997. Global Change and the Irish Environment.
Royal Irish Academy, Dublin. pp. 170.
- Sweeney, J., Brereton, T., Byrne, C., Charlton, C., Emblow, C., Fealy, R., Holden, N., Jones, M., Donnelly, A., Moore, S., Purser, P., Byrne, K., Farrell, E., Mayes, E., Minchin, D., Wilson, J. & Wilson, J. 2003. Climate Change: Scenarios and Impacts for Ireland.
Environmental Protection Agency 2000-LS-5.2.1-M1 Final Report
- Synge, F.M. 1968. The Glaciation of West Mayo.
Irish Geography Vol V, No.5, 372-386.
- Synge, F.M. 1969. The Wurm Limit in the West of Ireland.
In Quaternary Geology and Climate Publication 1701 National Academy of Sciences, Washington D.C.
- Tangestani, M.H. 2003. Landslide susceptibility mapping using the fuzzy gamma operation in a GIS. Jahan Catchment Area, Iran.
Map India Conference 2003.
- Tobin Consulting Engineers, 2003. Report on the landslides at Dooncarton, Glengad, Barnacuille and Pollathomais, County Mayo.
Report ref. MFG/MMcD/2003/1a ,dated 10 November2003 (see www.mayococo.ie)
- Tomlinson, R.W. 1981. The erosion of peat in the uplands of Northern Ireland.
Ir. Geog. 14, 51-64
- Tomlinson, R.W. 1981. A preliminary note on the bog-burst at Carrowmaculla, Co. Fermanagh, November, 1979.
Ir. Nat. Jour. 20 (B), 313-316.
- Tomlinson, R.W. and Gardiner, T. 1982. Seven bog-slides in the Slieve-an-Orra hills, Co. Antrim.
Jour. of Earth Science, Roy. Dub. Soc. 5, 1-9
- Varnes, J. 1978. Slope movement types and processes.
In: Schuster R.L. and Krizek, R.J. (eds.) Landslide Analysis and Control.
Special Report 176 Transportation Research Board, National Academy of Science, Washington, USA. 11-33.
- Warburton, J., Holden, J. and Mills, A. 2004. Hydrological controls of surficial mass movements in peat.
Earth Science Reviews, 67, 139-156.
- Waters, C.N., Northmore, K., Prince, G., Bunton, S., Butcher, A., Highley, D.E., Lawrence, D.J.D. and Snee, C.P.M. 1996. A Geological Background for Planning and Development in the City of Bradford Metropolitan District.
British Geological Survey Technical Report, WA/96/1.
- Whalley, W.B. and Favis-Mortlock, D. 2002. Other natural processes.
In: Implications of Climate Change for Northern Ireland: informing Strategy Development
Scottish and Northern Ireland Forum for Environmental Research (SNIFFER), 52-53.
- Wilson, P., Griffiths, D. and Carter, C. 1996. Characteristics, impacts and causes of the Carntopher bog-flow, Sperrin Mountains, Northern Ireland.
Scot. Geog. Mag. 112, 1, 39-46
- Wilson, P. and Hegarty, C. 1993. Morphology and causes of recent peat slides on Skerry Hill, Co. Antrim, Northern Ireland.
Earth Surface Processes and Landforms, 18, 593-601

APPENDIX 1

Irish Landslides Working Group Members

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Dr. Kenneth Gavin – Geotechnical Society of Ireland (GSI), Engineers Ireland (EI)

APPENDIX 2

Glossary of Terms

Blanket Bog

An extensive accumulation of peat occurring over undulating terrain in both upland and lowland areas where there is a high annual rainfall in excess of 1200mm

Boulder Clay

A glacial deposit, consisting of striated, subangular stones embedded in firm to very stiff hard clay or rock flour

Cohesion

Shear strength of a rock or soil not related to interparticle friction

Colluvium

A loose, heterogeneous mass of soil/rock fragments deposited by rainwash, sheetwash, or slow continuous downslope creep

Corrie

A deep steep-walled, half-bowl like depression, situated high on the side of a mountain and commonly at the head of a glaciated valley, caused by the erosive activity of a mountain glacier

Debris

Coarse-grained soils dominated by material of gravel-size or greater. > 2mm in diameter

Diamict

Poorly sorted unlithified material exhibiting a wide range of grain sizes

Drift

All rock material (clay, silt, sand, gravel, boulders) transported directly by a glacier and deposited by or from the ice

Earth

Fine-grained soils dominated by material of clay to sand-size, in a dry condition. < 2mm in diameter

Fall

A very rapid downward movement of rock or earth that travels mostly through air by free fall, bounding or rolling.

Flow

A mass movement of material that exhibits a continuity of motion and a plastic or semi-fluid behaviour

Hard Pan

A relatively hard, impervious, and often clayey layer of soil lying at or just below the surface, produced as a result of the cementation of particles by precipitation of insoluble materials such as silica, iron oxide, or calcium carbonate

Head

A thick, poorly stratified mass of locally derived angular rubble mixed with sand and clay, formed by solifluction in periglacial conditions

Ice Age

A time of extensive glacial activity and expansion of icesheets, specifically the latest glacial epoch, the Pleistocene Epoch

Image spatial resolution

Area that is represented by each individual pixel in an image; the smaller the area, the more accurate and thus detailed the image. An image with 2m resolution indicates that each pixel covers an area of 2 metres at real scale.

Lacustrine

Pertaining to, produced by, or formed in a lake

Landslide

The downslope transport, under gravitational influence, of soil and rock material en masse

Landslide Hazard

The probability of occurrence within a specified period of time and within a given area, of a potentially damaging landslide event (Varnes, 1984)

Landslide Risk

The probability of a landslide event occurring and the cost of the adverse consequences of that landslide event

$Risk = Hazard \times Vulnerability$

Landslide Susceptibility

The likelihood of occurrence of a landslide event

Landslide Vulnerability

The degree of loss resulting from the occurrence of a landslide of a given magnitude (Varnes, 1984)

Landslip

A synonym for "landslide" – the term "Landslip" no longer in much usage

Mass Movement

Movement of a portion of the land surface, usually downslope – a general descriptive term

Moraine

A mound, ridge, or other distinct accumulation of unsorted, unstratified glacial drift deposited by (former) icesheets and glaciers

Mud

Fine-grained soils dominated by material of clay to sand-size, in a wet condition. < 2mm in diameter

Orogeny

The process of the formation of mountains and more specifically the process by which structures in fold-belt mountains were formed – folding, thrusting, faulting

Periglacial

An environment in which frost action is an important factor, or phenomena induced by a periglacial climate beyond the periphery of the icesheet

Permafrost

Any soil or subsoil occurring in arctic, sub-arctic, or alpine regions which has been frozen continuously for a long time

Quaternary

The upper system of the Cenozoic Era beginning 2.3 million years ago and which forms the current period of geological time. It is made up of the Pleistocene (Ice Age) and the Holocene (Postglacial) Epochs

Raised Bog

An accumulation of peat with its greatest thickness being at the centre giving it a convex-upward surface. They are found in the midlands of Ireland and are principally composed of moss peat

Raster image

An image composed of a rectangular grid of pixels. Each pixel contains a defined value about its colour, size, and location in the image.

Regolith

The layer of fragmented and unconsolidated rock material overlying the bedrock

Scree

Rock fragments, usually coarse and angular, derived from and lying at the base of cliffs or very steep slopes

Shear Strength

The internal resistance of a body to shear stress, typically including a frictional part and a part independent of friction called cohesion

Slickensides

A lineated fault or slip surface, having groove lineations which may indicate the direction of slippage on the surface

Slide

A mass movement of earth material under shear stress along one or several surfaces. The movement may be rotational or planar (translational)

Solifluction

The slow viscous downslope flow of waterlogged soil, usually in areas underlain by frozen ground ie. in periglacial areas

Spread

The dominant movement in a spreading landslide is lateral extension due to shearing or tensional fractures

Talus

See "Scree"

Till

Largely unsorted and unstratified material deposited directly underneath a glacier and consisting of a heterogeneous mixture of clay, silt, sand, gravel, and boulders

Topple

A mass movement that consists of the forward rotation of units of rock about a pivot point under the force of gravity

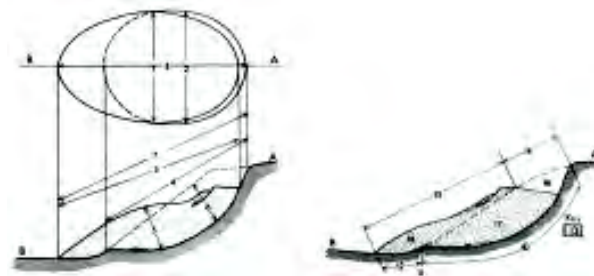
Tsunami

A gravitational seawave produced by any large-scale, short duration disturbance of the sea-floor due to an earthquake, sea floor subsidence or a volcanic eruption

APPENDIX 3

Nomenclature for Landslides (Anon, 1990)

Bull. Int. Ass. Eng. Geol., 41, 13 - 16



Landslide Features

Crown (1)

The practically undisplaced material still in place and adjacent to the highest parts of the main scarp.

Main scarp (2)

A steep surface on the undisturbed ground at the upper edge of the landslide, caused by movement of the slide material away from the undisturbed ground.

Top (3)

The highest point of contact between the displaced material (13) and the main scarp (2).

Head (4)

The upper parts of the landslide along the contact between the displaced material and the main scarp (2).

Minor scarp (5)

A steep surface on the displaced material of the landslide, produced by differential movements within the sliding mass.

Main body (6)

The part of the displaced material of the landslide that overlies the surface of rupture between the main scarp (2) and the toe of the surface of rupture (11).

Foot (7)

The portion of the landslide that has moved beyond the toe of the surface of rupture (11) and overlies the original ground surface.

Tip (8)

The point of the toe (9) farthest from the top (3) of the landslide.

Toe (9)

The lower, usually curved margin of the displaced material of a landslide, it is the most distant from the main scarp (2).

Surface of rupture (10)

The projection of the main scarp (2) surface under the displaced material of a landslide.

Toe of surface of rupture (11)

The intersection (sometimes buried) between the lower part of the surface of rupture (10) of a landslide and the original ground surface.

Surface of separation (12)

The part of the original ground surface overlain by the foot (7) of the landslide.

Displaced material (13)

Material displaced from its original position on the slope by movement in the landslide.

Zone of depletion (14)

The area of the landslide within which the displaced material (13) lies below the original ground surface.

Zone of accumulation (15)

The area of the landslide within which the displaced material lies above the original ground surface.

Depletion (16)

The volume bounded by the main scarp (2), the depleted mass (17) and the original ground surface (Cruden, 1980).

Depleted mass (17)

Part of the displaced mass which overlies the rupture surface (10) but underlies the original ground surface.

Accumulation (18)

The volume of the displaced mass (13) which lies above the original ground surface (Cruden, 1980).

Flank (19)

The side of the landslide. Compass directions are preferable in describing the side but if left and right are used, they refer to the slide viewed from the crown.

Landslide Dimensions

L_r The length of the rupture surface

The distance from the toe of the surface of rupture to the crown.

L_d Length of the displaced mass

The distance from the tip to the top.

L Total length

The distance from the tip of the landslide to its crown.

W_r Width of the rupture surface

The maximum width between the flanks of the landslide, perpendicular to the length, L_d

W_d Width of the displaced mass

The maximum breadth of the displaced mass perpendicular to the length, L_d

D_r The depth of the rupture surface:

The maximum depth of the rupture surface below the original ground surface measured perpendicular to the original ground surface.

D_d Depth of the displaced mass

The maximum depth of the displaced mass, measured perpendicular to the surface of the displaced material.

APPENDIX 4

LANDSLIDE WEATHER
*LANDSLIDE_ID
*LANDSLIDE_NAME
ANTECEDENT_RAINFALL
TIME PERIOD
INTENSITY RATING
WEATHER STATION
DISTANCE
COMMENT

LANDSLIDE_REFERENCE
*LANDSLIDE_ID
*LANDSLIDE_NAME
*SOURCE
AUTHOR
CO-AUTHOR(S)
DATE
VOLUME NUMBER
PAGE NUMBER
COMMENT

KEY
TABLE NAME
AUTOMATIC FIELDS
LOOK-UP LIST
TEXT-BOX
* COMPULSORY FIELDS

LANDSLIDE TERRAIN
*LANDSLIDE_ID
*TERRAIN_TYPE
SLOPE TYPE
ELEVATION_TOP OF SLOPE
SLOPE_ANGLE
SLOPE_ASPECT
SLOPE_VEGETATION
BEDROCK_TYPE
SLOPE DRAINAGE
QUATERNARY_TYPE
QUATERNARY_TYPE2
AQUIFER TYPE
SPRINGS
GROUNDWATER LEVEL

LANDSLIDE_EVENT
*LANDSLIDE_ID
*LANDSLIDE_NAME
LANDSLIDE_DATE
LANDSLIDE_TIME
COMMENT
*INPUT BY
*INPUT DATE

LANDSLIDE LOCATION
*LANDSLIDE_ID (Auto)
*LANDSLIDE_NAME
LANDSLIDE_ADDRESS_1
LANDSLIDE_ADDRESS_2
*LANDSLIDE_COUNTY
EASTING
NORTHING
ACCURACY
*1:50,000 MAP
1:10,560 MAP
INLAND
COASTAL

LANDSLIDE DIMENSIONS
*LANDSLIDE_ID
*LANDSLIDE_NAME
ELEVATION_CROWN
ELEVATION_TIP
TOTAL_SLIDE.LENGTH
RUPTURE_MAX.LENGTH
RUPTURE_MAX.WIDTH
RUPTURE_DISP.MASS.MAX
RUPTURE_SURFACE.DEPTH.MAX
COMMENT

LANDSLIDE_MECHANISM
*LANDSLIDE_ID
*LANDSLIDE_NAME
*TYPE
STYLE
MATERIAL
FAILURE_CAUSE1
FALILURE_CAUSE2
FAILURE_CAUSE3
PRIOR_INDICATIONS
CONTRIBUTORY_FACTORS
UNSPECIFIED

LANDSLIDE IMPACTS
*LANDSLIDE_ID
*LANDSLIDE_NAME
BUILDINGS DAMAGE
LOSS OF LIFE
LOSS OF ANIMALS
WATERCOURSE POLLUTION
INFRASTRUCTURE DAMAGE
LAND LOSS
MEASURES_REMEDIATIONS
COSTS_REMEDIATION
COSTS_OTHER
COMMENT

LAND_USE
TYPE

Landslide Events in Ireland

LANDSLIDE ID	LANDSLIDE NAME	COUNTY	EASTING	NORTHING	MATERIAL	MECHANISM TYPE	TERRAIN TYPE
1	Clogher1488	TYRONE	250706	351955	PEAT	FLOW	RAISED BOG
2	Kapanilane1697	LIMERICK	121710	137516	PEAT	FLOW	RAISED BOG
3	Slieve1873	GALWAY	155650	262750	PEAT	COMPLEX	RAISED BOG
4	Moor1883	ROSCOMMON	169500	282500	PEAT	FLOW	RAISED BOG
5	Newtownforbes1883	LONGFORD	210800	279500	PEAT		RAISED BOG
6	LoughatorickNorth1890	GALWAY	165500	199500	PEAT	FLOW	BLANKET BOG
7	Brishey1895	DERRY	273500	410800	PEAT	FLOW	BLANKET BOG
8	Gorteenameale1988	LAOIS	226303	202450	PEAT	FLOW	BLANKET BOG
9	Geevagh1984	SLIGO	186240	318905	PEAT	FLOW	BLANKET BOG
10	Meenacharvy1945	DONEGAL	159550	384750	PEAT	FLOW	BLANKET BOG
11	Cuilcagh1998	FERMANAGH	213290	330747	PEAT	SLIDE UNSPECIFIED	BLANKET BOG
12	Gorteenameale1776	LAOIS	226500	202500	PEAT	BURST	BLANKET BOG
13	Knocklayd1788	ANTRIM	311500	436400	PEAT		BLANKET BOG
14	JoycesCountry1821	GALWAY	97362	257446	PEAT		BLANKET BOG
15	Ballywindelland1824	DERRY	289800	428000	PEAT	FLOW	RAISED BOG
16	Geevagh1831	SLIGO	185885	319217	PEAT	FLOW	BLANKET BOG
17	Kanturk1840	CORK	133813	103601	PEAT		RAISED BOG
18	Randalstown1835	ANTRIM	309800	394000	PEAT	FLOW	RAISED BOG
19	Belmullet1867	MAYO	77500	328500	PEAT		BLANKET BOG
20	Carrowmore1931	MAYO	89367	324444	PEAT	FLOW	BLANKET BOG
21	LoughBray1938	WICKLOW	314300	214850	PEAT	SLIDE UNSPECIFIED	BLANKET BOG
22	Derrylea1954	KILDARE	258500	215000	PEAT		RAISED BOG
23	Glendun1963	ANTRIM	317250	431500	PEAT	FLOW	BLANKET BOG
24	Barnesmore1963	DONEGAL	204800	387000	PEAT	FLOW	BLANKET BOG
25	SlieveRushen1965	CAVAN	222450	332300	PEAT	FLOW	BLANKET BOG
26	Glendossaun1973	OFFALY	223901	202059	PEAT		BLANKET BOG
27	Clogher1712	TYRONE	250706	351955	PEAT		RAISED BOG
28	Slieve-an-Orra1980_1	ANTRIM	314900	427700	PEAT	SLIDE UNSPECIFIED	BLANKET BOG

LANDSLIDE ID	LANDSLIDE NAME	COUNTY	EASTING	NORTHING	MATERIAL	MECHANISM TYPE	TERRAIN TYPE
29	Corbehagh1934	CLARE	150800	191800	PEAT	FLOW	BLANKET BOG
30	Edenderry1916	OFFALY	263400	231350	DEBRIS	UNSPECIFIED	CANAL BANK
31	Pollagh1954	OFFALY	215250	222700			
32	Daingean1975	OFFALY	249400	229500	PEAT	FLOW	
33	Kilmaleady1821	OFFALY	226700	235400	PEAT	FLOW	RAISED BOG
34	Tully1870	ROSCOMMON	171000	284500	PEAT	FLOW	RAISED BOG
35	Minnis North1966	ANTRIM	333650	413700	MUD	FLOW	CLIFF
36	Tullywood2003	WESTMEATH	211000	241500			
37	Owenaher Valley	SLIGO	143797	317971			
38	Culmullagh	MAYO	115898	308211			
39	Edenderry	OFFALY	263400	231350	PEAT	FLOW	EMBANKMENT
40	Pollatomish2003	MAYO	81000	337600	PEAT	SLIDE TRANSLATIONAL	BLANKET BOG
41	Drumnagreagh1974	ANTRIM	334000	413000	MUD	SLIDE TRANSLATIONAL	ESCARPMENT
42	Slieve-an-Orra1980_2	ANTRIM	314000	428000	PEAT		BLANKET BOG
43	Carrownteeaaun2001	MAYO	130275	290628	PEAT	FLOW	BLANKET BOG
44	Mullaghcleevaun1937	WICKLOW	302570	205035	PEAT	FLOW	HIGH HILL
45	Carrowmaculla1979	FERMANAGH	243500	335200	PEAT	BURST	BLANKET BOG
46	Derrybrien2003	GALWAY	159300	204680	PEAT	SLIDE TRANSLATIONAL	VALLEY
47	Derrymullen1839	OFFALY	276200	226300			
48	Castlegarde1708	LIMERICK	179750	150550	PEAT		RAISED BOG
49	Knocknageeha1896	KERRY	113350	98650	PEAT	FLOW	BLANKET BOG
50	Kilmore1909	GALWAY	142299	249507			
51	Ballaghline1900	CLARE	115049	198375			
52	Addergoole More1745	GALWAY	151850	261850	PEAT		RAISED BOG
53	Dundrum1788	TIPPERARY	200850	145750	PEAT	BURST	BLANKET BOG
54	Rhine1809	LONGFORD	218115	277599	PEAT	BURST	
55	Owenmore1819	MAYO	87480	322709	DEBRIS	FLOW	VALLEY
56	Tullynascreen1985	LEITRIM	188725	329656	PEAT	FLOW	BLANKET BOG
57	Slieve-An-Orra1980_3	ANTRIM	313600	428400	PEAT		BLANKET BOG
58	Geevagh1945	SLIGO	185978	319082	PEAT	FLOW	BLANKET BOG
59	Bray2003	WICKLOW	328500	217170		FALL	CLIFF
60	Tralee1997	KERRY	94000	104000			

LANDSLIDE ID	LANDSLIDE NAME	COUNTY	EASTING	NORTHING	MATERIAL	MECHANISM TYPE	TERRAIN TYPE
61	Bray 1840 ?	WICKLOW	328500	217170			
62	Cuicagh1992	FERMANAGH	205563	331051	PEAT	BURST	BLANKET BOG
63	FortHenry1948	LIMERICK	170054	174591	EARTH	SLIDE UNSPECIFIED	EMBANKMENT
64	Ballybrew1947	WICKLOW	318999	219550	TILL	SLIDE ROTATIONAL	VALLEY
65	Killiney2000	DUBLIN	326189	225253	MUD	SLIDE UNSPECIFIED	
66	Slievenakilla1986	LEITRIM	205438	321590	PEAT	BURST	BLANKET BOG
67	Greystones2002	WICKLOW	328589	214591			
68	RockyValley2003	WICKLOW	323280	214600			
69	Ballyhoolahan1900	CORK	131000	101400	PEAT		RAISED BOG
70	Dargle1998	WICKLOW	325000	218000			
71	DonegalTown1999	DONEGAL	195000	378000			
72	Mullinavat1999	KILKENNY	256670	121316	DEBRIS	SLIDE UNSPECIFIED	
73	Forestalstown	KILKENNY	268888	124592	ROCK	FALL	LEDGE
74	Ballyhahill1997	LIMERICK	119508	146133	DEBRIS	SLIDE UNSPECIFIED	EMBANKMENT
75	Doon1988	LIMERICK	184987	154490	MUD	SLIDE UNSPECIFIED	EMBANKMENT
76	Bilboa Bridge1995	LIMERICK	179764	151553	DEBRIS	SLIDE UNSPECIFIED	
77	Ticknock2001	DUBLIN	317340	225810			
78	Cullahill Mountain	LAOIS	235480	172290			
79	Maidenhead/Arless	LAOIS	264860	184130			
80	Chapel Hill	LAOIS	239000	208000			
81	Lisheen1900	OFFALY	209066	205991	PEAT	UNSPECIFIED	BLANKET BOG
82	Gortacreenteen2004	KERRY	101591	67019	DEBRIS	SLIDE UNSPECIFIED	EMBANKMENT
83	Mell	LOUTH	307069	277127		SLIDE UNSPECIFIED	EMBANKMENT
84	Sallypark1989	WATERFORD	260032	113142	DEBRIS	BURST	EMBANKMENT
85	Kilbride Camp1999	WICKLOW	308649	219127			
86	Glendasan1986	WICKLOW	311538	197556			
87	Slieve-an-Orra1980_4	ANTRIM	313100	428400	PEAT	SLIDE UNSPECIFIED	BLANKET BOG
88	The Cut	LAOIS	229000	204000			
89	Cullenagh Mountain	LAOIS	248000	189000			
90	SlieveFelim1946	LIMERICK	0	0	PEAT		
91	Fuhiry1997	CORK	113730	72070	PEAT	SLIDE UNSPECIFIED	MOUNTAIN VALLEY
92	Kilkinnikin West1983	CORK	57577	40977	DEBRIS	FALL	CLIFF

LANDSLIDE ID	LANDSLIDE NAME	COUNTY	EASTING	NORTHING	MATERIAL	MECHANISM TYPE	TERRAIN TYPE
93	Goulacullin2001	CORK	114329	55075	EARTH	FALL	
94	Dromderrig2001	CORK	163815	49444	ROCK	TOPPLE	ESTUARY
95	Derryulk2005	CLARE	148361	184847	EARTH	SLIDE UNSPECIFIED	EMBANKMENT
96	Crossboy2004	SLIGO	176982	329645	DEBRIS	SLIDE UNSPECIFIED	
97	Ballypatrick	TIPPERARY	230900	128700	DEBRIS	FLOW	HIGH HILL
98	Toor	TIPPERARY	231100	130000	UNSPECIFIED FLOW		HIGH HILL
99	Cummer More1995	TIPPERARY	192388	158011	UNSPECIFIED	SLIDE UNSPECIFIED	
100	Glengarra2004	TIPPERARY	193665	123000	UNSPECIFIED	SLIDE UNSPECIFIED	MOUNTAIN
101	Carnhill1978	MAYO	81583	335797	PEAT	FLOW	HIGH HILL
102	Derreens2005	MAYO	80865	329288	PEAT	FLOW	
103	Glencullin Upper1900	MAYO	92159	326667	UNSPECIFIED		
104	Conaghra	MAYO	103051	339543	UNSPECIFIED		
105	Lackabane1999	KERRY	93221	92410	TILL	SLIDE ROTATIONAL	HILL
106	Diswellstown1990	DUBLIN	308048	236112	SAND & GRAVEL	SLIDE TRANSLATIONAL	VALLEY
107	Lackabane2002	KERRY	92908	92285	TILL	SLIDE TRANSLATIONAL	HILL
108	Glencullen Mountain1976	DUBLIN	317570	218713	TILL	SLIDE ROTATIONAL	
109	Hillhead Road2005	DOWN	308807	323624	ROCK	TOPPLE	ROAD
110	Sheehan	MAYO	90945	319809	PEAT	SLIDE TRANSLATIONAL	BOG
111	Downhill2002	DERRY	275141	435897	ROCK	FALL	CLIFF
112	Trostan	ANTRIM	319368	423265	ROCK	FALL	CLIFF
113	Ballinastoe1986	WICKLOW	316670	208029	DEBRIS	FLOW	VALLEY
114	Ballinastoe(2)1986	WICKLOW	316739	207402	DEBRIS	FLOW	VALLEY
115	Cloghoge (1)1986	WICKLOW	315413	205458	UNSPECIFIED	COMPLEX	MOUNTAIN VALLEY
116	Cloghoge (2)1986	WICKLOW	315326	204967	UNSPECIFIED	COMPLEX	MOUNTAIN VALLEY
117	Sheskin1988	MAYO	94241	327272	PEAT	FLOW	BLANKET BOG

APPENDIX 6

Landslides Bibliography for Ireland

- Alexander, R.,** Coxon, P. and Thorn, R.H. 1985. Bog flows in south-east Sligo and south-west Leitrim.
In Thorn, R.H. (ed.), Sligo and West Leitrim, 58-76 Field Guide No. 8, Irish Association for Quaternary Studies (IQUA)
- Alexander, R., Coxon, P. and Thorn, R. T. 1986. A bog flow at Straduff townland, County Sligo.
Proc. R. Ir. Acad., B86 (4), 107-119
- Anon. (n.d.: probably about 1902). Bog-slips in Ireland.
In Antiquities of the Queens County and County Kildare, 53-54
- Bishopp, D.W.** and Mitchell, G.F. 1946. On a recent bog-flow in Meenacharvy Townland, Co. Donegal.
Scient. Proc. Roy. Dub. Soc. 24, 151-156
- Bourke, Mary. 1990. The geomorphic effects of the August 1986 storm on a glaciated upland catchment in the Wicklow Mountains.
Unpublished MA Thesis. National University of Ireland
- Bourke, Mary and Thorp, Martin. 2005. Rainfall-triggered slope failures in eastern Ireland.
Irish Geog., 38,1,1-22.
- Bowler, M. and Bradshaw, R. 1985. Recent accumulation and erosion of blanket peat in the Wicklow Mountains.
New Phytol., 101, 543-550
- Bradshaw, R. and McGee, E. 1988. The extent and time-course of blanket peat erosion in Ireland.
New Phytol., 108, 219-224
- Cole, G.A.J.,** 1897. The bog-slide of Knocknageesha, in the County of Kerry.
Nature, 55, (1420) 254-256
- Colhoun, E.A., 1966. The debris flow at Glendalough, Co. Wicklow and the bog-flow at Slieve Rushen, Co. Cavan, January 1966.
Ir. Nat. Jour., 15, 199-206
- Colhoun, E.A., Common, R. and Cruickshank M.M. 1965. Recent bog flows and debris slides in the north of Ireland
Scient. Proc. Roy. Dub. Soc. A, 2, 163-174
- Collins, J.F. and Cummins, T. 1996. Agroclimatic Atlas of Ireland.
Dublin, AGMET.
- Coveney, S. and O'Donovan G. 2001. The potential of LANDSAT Thematic Mapper satellite imagery as a tool for assessing degradation of blanket bog and wet heath.
Tearmann: Irish Journal of Agri-environmental research, 1, (1): 65-77
- Cruickshank, M.M. and Tomlinson, R.W. 1990. Peatland in Northern Ireland: inventory and prospect.
Irish. Geog. 23, 1, 17-30
- Dauncey, P.C.,** O'Riordan, N.J. and Higgins, J. 1987. Controlled failure and back analysis of a trial embankment at Athlone.
Proc. Eur. Conf. Soil Mechanics and Foundation Engineering, Dublin, 21-24
- Delap, A.D., Farrington, A., Preager, R.L. and Smyth, L.B. 1932. Report on the Recent Bog Flow at Glencullin, Co. Mayo.
Scient. Proc. Roy. Dub. Soc. 20, (17), 181-192
- Delap, A.D. and Mitchell, G.F. 1939. On a recent bog-flow in Powerscourt Mountain Townland, Co. Wicklow
Scient. Proc. Roy. Dub. Soc. 22, 195-198
- Douglas, G.R. 1980. Magnitude and frequency study of rockfall in Co. Antrim, N. Ireland.
Earth Surface Processes, 5, 123-129
- Duchas 1998. A Manual for the production of grazing impact assessments in upland and peatland habitats.
Duchas and the Dept. of Agriculture, Food and Forestry.
- Dykes, A.P. and Kirk, K.J. 2000. Morphology and interpretation for a recent multiple peat slide event on Cuilcagh Mountain, Northern Ireland.
In Bromhead, E., Dixon, R. and Ibsen, M-L (Eds.) Landslides in Research, Theory and Practice (Volume 1). Thomas Telford, London, 495-500
- Dykes, A.P. and Kirk, K.J. 2001. Initiation of a multiple peat slide on Cuilcagh Mountain, Northern Ireland.
Earth Surface Processes and Landforms, 26, 395-408
- Feehan, J.** and O'Donovan, G. 1996. The Bogs of Ireland
University College Dublin, Dublin . pp 518
- Forster A. 1998. The assessment of slope stability for land use planning. A case study on the North East Antrim Coast.
British Geological Survey, Technical Report WN/98/8
- Gavin, K.** and Jennings, P (in Prep) Stability of man-made glacial till slopes in southwest Ireland.
- Griffith, R. 1821. Report relative to the Moving Bog of Kilmaleady, in the King's County, made by order of the Royal Dublin Society.
Jour. R. Dubl. Soc., 1 (1856 1857), 141-144

- Hammond, R.** 1979. The Peatlands of Ireland.
An Foras Taluntais, Dublin
- Hanrahan, E.T. 1954. An investigation of some physical properties of peat.
Geotechnique, 4, 108-123.
- Hanrahan, E.T. 1977. Irish Glacial Till: Origin and Characteristics.
An Foras Forbartha, RC 164. Dublin. pp 81
- Harty, V.D. 1953. Slide in Fort Henry Embankment River Shannon, Ireland.
Proc. 3rd Int. Conf. Soil Mechanics and Foundation Engineering, Vol. II, 8, 255-258
- Hendrick, E. 1990. A bog flow at Bellacorrick Forest, Co. Mayo.
Irish Forestry, 47, 32-44
- Hutchinson, J.N., Prior, D.B. and Stephens, N. 1974. Potentially dangerous surges in an Antrim mudslide.
Quart. Jour. Eng. Geol., Vol.7, 363-376.
- Jennings, P.** and Muldoon, P. 2003. Performance of 150 Year-Old Railway Slopes in Glacial Till.
Eur. Conf. Soil Mechanics and Foundation Engineering, Prague, 631-636.
- Kinahan, G.H.,** 1897. Peat Bogs and Debacles.
Trans. Inst. of Civil Eng. of Ireland, 26, 98-123
- Large, A.R.G.** 1991. The Slievenakilla bog-burst: investigations into peat loss and recovery on an upland blanket bog.
Ir. Nat. Jour., 23, 354-359
- Latimer, J. 1897. Some notes on the recent bog slips in the Co. of Kerry.
Trans. Inst. of Eng. of Irel., 26, 94-97
- Logue, J.J. 1975. Extreme rainfalls in Ireland.
Dublin: Meteorological Service, Technical Note No. 40
- Long, M. and Jennings, P. 2006. Analysis of the peat slide at Pollatomish, Co. Mayo, Ireland.
Journal "Landslides", April, 2006. Springer Press
- Long, M., Menkiti, C.O., Kovacevic, N., Milligan, G.W.E., Coulet, D. and Potts, D. M. 2003. An observational approach to the design of steep sided excavations in Dublin glacial till.
Proc. Of the Underground Construction Conference. Brintex, London, 443-454
- Long, M. and Murphy, B. 2003. Difficulties with ground anchorages in hard rock in Dublin, Ireland.
Geotechnical and Geological Engineering, 21, 87-111.
- Long, M.M. and O'Riordan, N.J. 2000. A Slide in Irish glacial lake clay.
Proc. 8th Int. Symposium on Landslides, Landslides in Research, Theory and Practice. Cardiff, Wales, June 26-30, Vol. 2, 943-948
- Lydon, I.M. and Long, M.M. 2001. Analysis of slope stability of an earth dam due to rapid drawdown effects.
Proc. XVth Int. Conf. Soil Mechanics and Geotech. Eng., Istanbul, Turkey, August 2001, Vol. 3, 2139-2142
- McGreal, W.S.** and Larmour, R. 1979. Blanket peat erosion: theoretical considerations and observations from selected conservation sites in Slieveanorra Forest National Nature Reserve, Co. Antrim.
Ir. Geog. 12, 57-67
- McKenna, J., Carter, R.W.G. and Bartlett, D. 1992. Coast erosion in north-east Ireland:- Part II cliffs and shore platforms.
Ir. Geog., 25, 111-128.
- Menkiti, C.O., Long, M., Kovacevic, N., Edmonds, H.E., Milligan, G.W.E. and Potts, D.M. 2004. Trial excavation for cut and cover tunnel construction on glacial till – a case study from Dublin.
Proc. Of the Skempton Memorial Conference, Advances in Geotechnical Engineering, Imperial College, Thomas Telford, London, 1090-1104.
- Mitchell, G.F. 1935. On a Recent Bog-Flow in County Clare.
Scient. Proc. Roy. Dub. Soc. 21, 247-252
- Mitchell, G.F. 1938. On a recent bog-flow in the County Wicklow.
Scient. Proc. Roy. Dub. Soc. 22, 49-54
- Ousley, R.** 1788. An account of the moving bog and the formation of a lake, in the county of Galway, Ireland.
Trans. R. Ir. Acad., B2, 3-6
- Preager, R.L.** 1897. Bog-bursts, with special reference to the recent disaster in Co. Kerry.
Ir. Naturalist, 6, 141-162
- Preager, R.L. 1897. A bog-burst seven years later.
Ir. Naturalist, 6, 201-203
- Preager, R.L. 1906. The Ballycumber bog-slide.
Ir. Naturalist, 15, 177-178
- Preager, R.L., Sollas, W. J., Dixon, A.F. and Delap, A. 1897. Report of the committee appointed by the Royal Dublin Society to investigate the recent bog-flow in Kerry.
Sci. Proc. Roy. Dubl. Soc., 8, part 5, 475-508
- Prior, D.B. 1975. A mudslide on the Antrim coast, 24th November 1974.
Ir. Geog. 8, 55-62

- Prior, D.B. and Graham, J. 1974. Landslides in the Magho district of Fermanagh, Northern Ireland.
Eng. Geol., **341-359**
- Prior, D.B. and Stephens, N. 1971. A method of monitoring mudflows
Eng. Geol., **5**, 239-246
- Prior, D.B. and Stephens, N. 1972. Some movement patterns of temperate mudflows. Examples from Northeast Ireland.
Bull. Geol. Soc. Am. **83**, 2533-3544
- Prior, D.B., Stephens, N. and Archer, D.R. 1968. Composite mudflows on the Antrim coast of North-east Ireland.
Geografiska Annal. Ser. A (2) **65-78**
- Prior, D.B., Stephens, N. and Douglas, G.R. 1970. Some examples of modern debris flows in north-east Ireland.
Zeit. fur Geom. **14**, 275-288
- Prior, D.B., Stephens, N. and Douglas, G.R. 1971. Some examples of mudflow and rockfall activity in north-east Ireland.
Inst. Brit. Geog. Spec. Pub. No. 3, 129-139
- Smith**, B. and Ferris, C-L. 1997. Giant's Causeway: management of erosion hazard.
Geog. Review, **11**, 30-378.
- Statham, S.T. 1975. Slope instabilities and recent slope development in Glencullen, Co. Wicklow.
Ir. Geog. **8**, 42-54
- Tomlinson**, R.W. 1979. Water levels in peatlands and some implications for runoff and erosional processes.
In Pitty A, Ed. Geographical approaches to fluvial processes. Geo Books, Norwich, 149-162
- Tomlinson, R.W. 1981. A preliminary note on the bog-burst at Carrowmaculla, Co. Fermanagh, November, 1979.
Ir.Nat. Jour. **20 (B)**, 313-316.
- Tomlinson, R.W. 1981. The erosion of peat in the uplands of Northern Ireland.
Ir. Geog. **14**, 51-64
- Tomlinson, R.W. and Gardiner, T. 1982. Seven bog-slides in the Slieve-an-Orra hills, Co. Antrim.
Jour. of Earth Science, Roy. Dub. Soc. **5**, 1-9
- White**, Young, Green. 2001. Level 2 feasibility report: Limerick Division Earthworks. February 2001. Contract CE641 Project 13 Cuttings and Embankments. Iarnod Eireann Infrastructure Department
- Wilson, P. and Cunningham, A. 2003. Examples of recent rockfalls from basalt cliffs in Northern Ireland.
Ir. Geog. **36**, 170-177.
- Wilson, P., Griffiths, D. and Carter, C. 1996. Characteristics, impacts and causes of the Carntopher bog-flow, Sperrin Mountains, Northern Ireland.
Scot. Geog. Mag. **112**, **1**, 39-46
- Wilson, P. and Hegarty, C. 1993. Morphology and causes of recent peat slides on Skerry Hill, Co. Antrim, Northern Ireland.
Earth Surface Processes and Landforms, **18**, 593-601

APPENDIX 7

Useful Web Links

www.gsi.ie Geological Survey of Ireland

<http://www.bgs.ac.uk/products/geosure/landslides.html> British Geological Survey

www.bgs.ac.uk/gsni Geological Survey of Northern Ireland

<http://landslides.usgs.gov> United States Geological Survey

http://www.virtualguidebooks.com/Wyoming/JacksonTetons/GrosVentre/GrosVentreSlide_FS.html Image of Gros Ventre Slide, USA

<http://www.art.man.ac.uk/Geog/fieldwork/landslides.htm> Dark Peak Field Centre, Peak District England

<http://www.mines.edu/academic/geology/landslidevail2007/> First North American Landslide Conference, Vail Colorado, June 3 – 8, 2007 USA

<http://www.fema.gov/hazards/landslides/> Federal Emergency Management Agency (FEMA) United States

<http://www.kingston.ac.uk/~ku00323/landslid/slides.htm> Kingston University Landslides Slide Show. UK

<http://www.planning.org/landslides/docs/main.html> American Planning Association

<http://ilrg.gndci.cnr.it/> International Landslides Research Group

http://landslides.usgs.gov/html_files/nlic/nlicpub.html USGS Landslides Publication List

<http://www.gcric.org/geo/slope.html> US Global Change Research Information office

http://gsc.nrcan.gc.ca/landslides/clp/index_e.php Natural Resources Canada

<http://icl.dpri.kyoto-u.ac.jp/> International Consortium on Landslides

<http://www.unesco.org/science/earthsciences/> UNESCO Earth Sciences

<http://www.scotland.gov.uk/Publications/2005/07/08131738/17395> Scottish Road Network Landslides Study

<http://atlas.gc.ca/site/english/maps/environment/naturalhazards/majorlandslides> The Atlas of Canada

<http://www.geonet.org.nz/aboutlandslides.html> New Zealand

<http://www.ecy.wa.gov/programs/sea/landslides/maps/maps.html> Puget Sound Washington State USA

<http://www.earthsci.org/geopro/massmov/massmov.html> Earth Science Australia

http://www.sgu.se/sgu/en/geologi_samhalle/skred_e.htm Geological Survey of Sweden

http://www.icivilengineer.com/Geotechnical_Engineering/Slope_Engineering/Landslides/ iCivil Engineer

<http://www.jurassiccoast.com/index.jsp?articleid=26375> Dorset and Devon UK

<http://www.eohandbook.com/igosp/Geohazards.htm>

Integrated Global Observing Strategy (IGOS) – Geohazards. Information on the Geohazards theme developed by IGOS.

<http://www.em.gov.bc.ca/Mining/Geolsurv/Surficial/landslid/default.htm>

British Columbia –Ministry of Energy & Mines - Info on Landslides in British Columbia and landslides in general.

<http://nedies.jrc.it/index.asp?ID=93>

Natural and Environmental Disaster Information Exchange System (NEDIES) – Report on Landslide Disasters in Europe and Lessons Learnt

<http://www.gesource.ac.uk/hazards/Mass.html>

GESource Natural Hazard Site. Links to resources covering landslides, mudslides and similar topics.

<http://www.geohazards.no/>

The International Centre for Geohazards (ICG) – Norway. The ICG carries out research on the assessment, prevention and mitigation of geohazards, including risk of landslide in soil and rock due to rainfall, flooding, earthquakes and human intervention.

http://www.consrv.ca.gov/cgs/rghm/landslides/ls_index.htm - California Geological Survey