INTERNATIONAL SOCIETY FOR
SOIL MECHANICS AND
GEOTECHNICAL ENGINEERING

This paper was downloaded from the Online Library of the International Society for Soil Mechanics and Geotechnical Engineering (ISSMGE). The library is available here:

https://www.issmge.org/publications/online-library

This is an open-access database that archives thousands of papers published under the Auspices of the ISSMGE and maintained by the Innovation and Development Committee of ISSMGE.

Proceedings of the XVII ECSMGE-2019
Geotechnical Engineering foundation of the future
ISBN 978-9935-9436-1-3
© The authors and IGS: All rights reserved, 2019
doi: 10.32075/17ECSMGE-2019-0033

XVII European Conference
ECSMGE 2019
Reykjavik
on Soil Mechanics
and Geotechnical Engineering

The assessment of the economic impacts of landslides on a road network

L'évaluation des impacts économiques des glissements de terrain sur un réseau routier

M. G. Winter
Transport Research Laboratory (TRL), Edinburgh, United Kingdom
University of Portsmouth, Portsmouth, United Kingdom

ABSTRACT: Landslides can have significant socio-economic impacts even when serious injuries and fatalities do not occur. Such impacts can include the severance of access to and from relatively remote communities for services and markets for goods; employment, health and educational opportunities; and social activities. The types of economic impact can be classified as: direct economic impacts, direct consequential economic impacts, and indirect consequential economic impacts. In addition, the vulnerability shadow cast by relatively small landslide events can be extensive and its geographical extent can, in many instances, be determined by the transport network rather than the relatively small footprint of the event itself. Using a number of debris flow events in Scotland this paper places values on the economic impacts of landslides. It also demonstrates the widespread impact of the events by means of the vulnerability shadow cast.

RÉSUMÉ: Les glissements de terrain peuvent avoir des impacts socioéconomiques importants même en l'absence de blessures graves et de décès. Ces impacts peuvent inclure la rupture de l'accès aux communautés et aux communautés relativement éloignées pour les services et les marchés de biens; possibilités d'emploi, de santé et d'éducation; et activités sociales. Les types d'impact économique peuvent être classés comme suit: impacts économiques directs, impacts économiques consécutifs directs et impacts économiques indirects indirects. En outre, l'ombre de vulnérabilité provoquée par des glissements de terrain relativement faibles peut être considérable et son étendue géographique peut, dans de nombreux cas, être déterminée par le réseau de transport plutôt que par l'empreinte relativement faible de l'événement lui-même. À l'aide d'un certain nombre d'événements de flux de débris en Écosse, cet article place les valeurs sur les impacts économiques des glissements de terrain. Il démontre également l'impact généralisé des événements au moyen de l'ombre de vulnérabilité.

Keywords: Landslides; Debris Flow; Roads; Economics

1 INTRODUCTION

In Scotland in August 2004 a series of debris flows was associated with monthly average rainfall substantially in excess of the norm. Critically, some of the resulting landslides affected important parts of the trunk (strategic) road network, linking not only cities but also smaller, remote communities. Notable events occurred at the A83 between Glen Kinglas and to the north of Cairndow (9 August), the A9 to the north of Dunkeld (11 August), and the A85 at Glen Ogle (18 August). While there were no major injuries, the most dramatic events occurred at the A85 Glen Ogle, where 57 people had to be airlifted to safety when they became trapped between two major debris flows.

The A83 Rest and be Thankful site, while not affected in August 2004, has been extremely active in recent years with multiple debris flow events and associated closures; events in 2007, 2008, 2009, 2011, 2012 and 2014 had an adverse effect on the travelling public. This has meant that the area has become the focus of not only concern but also of extensive landslide management and mitigation activity. This culminated in a study being commissioned to assess and make recommendations on potential landslide remediation actions (Anon. 2013a; Winter & Corby, 2012).

In the absence of serious injuries and fatalities, the real impacts of these events were economic and social. These include the cost of transport delays and diversions and the severance of access to and from relatively remote communities for services and markets for goods; employment, health and educational opportunities; and social activities.

The A83, carrying up to around 5,500 vehicles per day (all vehicles, two-way, 24-hour annual average daily traffic: AADT) was closed for just over a day, the A9 (up to around 13,800 vehicles per day) was closed for two days, initially with single lane working under convoy, and the A85 (up to around 4,400 vehicles per day) was closed for four days. The figures are for the most highly trafficked month: July or August. Minimum flows occur in January or February and are roughly half those of the maxima reflecting the importance of tourism and related seasonal industries to the economy. There was substantial disruption to local and tourist traffic, and goods vehicles.

This paper describes part of a study to assess the economic impacts of selected debris flow events in Scotland, based on the scheme presented by Winter and Bromhead (2012).

2 ECONOMIC IMPACTS

Tourism makes a major contribution to Scotland's economy and the impacts of landslides can be particularly serious during the summer debris flow season of July and August. Nevertheless, the impacts of events occurring during the winter, particularly in the season of October/November to January, should not be underestimated and events are arguably more frequent during the winter. Not surprisingly, the debris flow events described created a high level of interest in the media in addition to being seen as a key issue by politicians at both the local and national level. Indeed, the effects of such small events which may, at most, affect directly a few tens of metres of road cast a considerably broader vulnerability shadow (Winter & Bromhead, 2012).

The qualitative economic impacts include:

- the loss of utility of parts of the road network
- the need to make often extensive detours in order to reach a destination
- the severance of access to and from relatively remote communities for services and markets for goods; employment, health and educational opportunities; and social activities

The economic impacts of a landslide event and its associated vulnerability shadow that closes a road, or other form of linear infrastructure were summarized by Winter and Bromhead (2012), in three categories, as follows:

- Direct economic impacts
- Direct consequential economic impacts
- Indirect consequential economic impacts

Direct economic impacts: The direct costs of clean-up and repair/replacement of lost/damaged infrastructure in the broadest sense and the costs of search and rescue.

Direct consequential economic impacts: These generally relate to 'disruption to infrastructure' and surround loss of utility. For example, the costs of closing a road (or of single-lane working with traffic lights) with a given diversion, are relatively simple to estimate using well-established models. The costs of fatal/non-fatal injuries and other incident accident costs may also be included here and may be taken (on a societal basis) directly from published figures (Anon., 2013a). These costs are for road traffic accidents, or indeed rail accidents, but there seems to be no particular reason why they should be radically different for a landslide as both are likely to include the recovery of casualties from vehicles. Indeed, for events in which large numbers of casualties may be expected to occur, data relating to railway accidents may be more appropriate

Indirect consequential economic impacts: Often landslide events affect access to remote rural areas with economies based on transport-dependent activities; the vulnerability can be extensive and determined by the transport network rather than the event itself. If a given route is closed for a long period then how, for example, is confidence in, and the ongoing viability of, local business affected? Access to markets for manufacturing and agriculture (e.g. forestry in western Scotland) is constrained and the costs increase, business profits are affected, and short- to long-term viability may be affected. There may also be impacts on tourist (and other service economy) businesses. It is important to understand how the reluctance of visitors to travel to and within 'landslide areas' is affected after a publicised event in which casualties and a period of inaccessibility (reduced or complete) may have been involved, affects the short- and long-term tourism travel patterns to an area. Such costs form a fundamental element of the overall economic impact on society of such events. They are thus important to governments as they should affect the case for assigning budgets to landslide risk reduction activities. However, these are also the most difficult costs to determine as they are generally widely dispersed both geographically and socially. Additionally, in an environment in which compensation might be anticipated, albeit often erroneously, those that have the best data, the businesses affected by such events, may be those that anticipate such compensatory events.

The vulnerability shadow cast can be extensive and its geographical extent determined by the transport network, including closures and diversion routes, rather than the relatively small event footprint (Winter & Bromhead, 2012). In the October 2007 event at the A83 Rest and be Thankful, around 400m^3 of material was deposited at road level with a footprint that closed a few tens of metres of the road (Winter, 2014); the vulnerability shadow can be estimated to be of the order of 2,800km^2 (Fig. 1) which is, for the purpose of comparison, approximately two-and-a-half times the total land area of Hong Kong SAR.

The economic impacts and the vulnerability shadow are concepts that apply equally to other discrete climate driven events that have the potential to close parts of the road network such as flood events. Like landslides such flood events are generally thought to be likely to increase in frequency as a result of climate change (Galbraith et al., 2005; Anon., 2011; Winter et al., 2010; Winter & Shearer, 2013).

The work of Schuster and Highland (Schuster, 1996; Highland, 2006; Schuster & Highland, 2007) has been especially informative and helpful in determining the approach to this work. Typically other work in this area deals primarily with direct economic impacts (Klose et al., 2015) with some consideration of direct consequential economic impacts (Highland, 2010). Indeed, Highland (2010) describes decreased economic activity in some areas and increased economic activity in other areas as a result of the changing access either side of landslide events.

Ongoing work is targeted at broadening the data set available for direct and direct consequential economic impact and further refining the methodology and gathering data for the indirect consequential economic impacts.

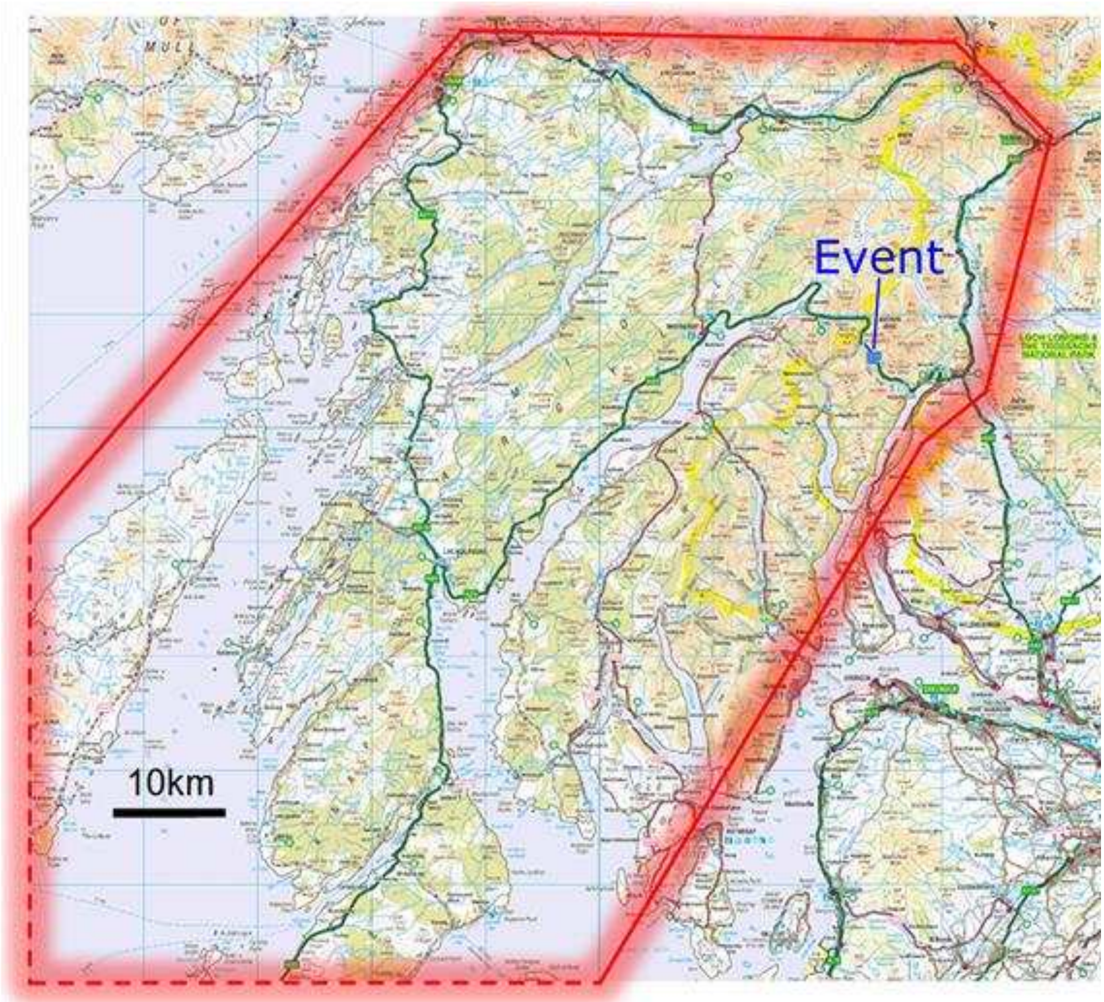

Figure 1. A relatively small debris flow event closed the A83 at the Rest and be Thankful in October 2007; the vulnerability shadow that was cast (bounded in red) was extensive (Winter, 2014)

Table 1. Direct economic impacts (at 2012 prices)

Event	Emergency (E) response	Remedial (R) works	Total
August 2004: A83 Glen Kinglas to Cairndow	£395,043 (E and R combined)		£395,043
August 2004: A9 N of Dunkeld	£921,766 (E and R combined)		£921,766
August 2004: A85 Glen Ogle	£658,405 (E and R combined)		£658,405
October 2007: A83 Rest and be Thankful	£320,772	£1,372,629	£1,693,401

3 DIRECT ECONOMIC IMPACTS

Direct economic impacts should be the most straightforward to determine. Indeed this has generally proved to be the case with relatively recent events that occurred within the currency of existing Operating Company (OC) contracts. Thus, data relating to the 2007 A83 Rest and be Thankful event was readily available from Scotland TranServ who were the OC for the north-west at the time of enquiry.

Data from less recent events such as the landslide events of 2004 (Winter et al., 2005; 2006; 2009) proved more difficult to obtain largely as both the operators and auditors had changed since the events occurred, as Highland (2006) points out past data are generally labour intensive to retrieve.

This has limited the resolution and reliability of the data that can be obtained for these events. What data has been obtained has been derived from high level reporting documents to Scottish Ministers and Senior Civil Servants and covers all three of the event groups from August 2004 (A83, A9 and A85). This data has been interpreted and broken down to the best of the ability of the original authors and editors of the Scottish Road Network Landslide Study reports (Winter et al., 2005; 2009). The available data is given in Table 1, adjusted to 2012 prices.

Direct economic impacts include:

- The direct costs of clean-up and the costs of search and rescue
- The repair/replacement of lost/damaged infrastructure in the broadest sense

These might otherwise be described as 'emergency response' and 'remedial works', respectively and should be relatively easy to obtain or estimate for any given event.

4 DIRECT CONSEQUENTIAL ECONOMIC IMPACTS

Direct consequential economic impacts relate to disruption to infrastructure or loss of utility and to accidents that result directly from the event.

In the cases presented here accidents have been non-injury (damage only) and the numbers associated with each event have been estimated from contemporaneous photographs.

For example, if a road is closed, either fully or partially, some or all of the users of that route will have to take an alternative, diversionary route, which may be significantly longer than the primary route. Even if no diversion is necessary, reduction in the road capacity (e.g. through a lane closure or the imposition of a speed limit) may mean that queues form, particularly at peak times, slowing the traffic flow. These effects can significantly increase road users' journey times.

The QUADRO (QUeues And Delays at Roadworks) model provides a method for assessing the costs imposed on road users while roadworks are being carried out, considering:

- Delays to road users: the change in road users' journey times, priced using the value of their time (e.g. cost to their employer's business of the time spent travelling during the working day) based on the type of vehicle, its occupants and trip purpose
- Fuel carbon emissions: change in carbon emissions due to vehicle fuel consumption, based on average figures for fuel burnt and costed using estimated abatement costs (see STAG and WebTAG: Anon., 2012a; 2012b)
- Accident costs: the change in accident, the additional delay caused and the direct costs (e.g. property damage, police time and insurance administration)

The program contains a model for allocating traffic to the diversion route if the site becomes overloaded, representing both the road users that queue through the site and those that take an alternate route in the case of a partial closure. The details of QUADRO, including all assumptions made in its calculations, are provided in the manual (Anon., 2006).

In order to carry out modelling of a road closure in QUADRO, a diversionary route needs to be defined. The QDIV (QUADRO Diversion) tool was used to model the standard diversionary routes used by the road operator.

QDIV requires each diversionary route to be defined in terms of a set of links (each defined as rural, urban, suburban or small town) that can be combined in series and parallel to build up a network. For each event, a simplified diversionary network schematic was developed and Google Maps was used to measure the length of each link. Traffic data, represented as annual average daily traffic (AADT), were sourced using data from the relevant Road Administrations.

Where information was not available (e.g. lane and verge widths), the default values suggested in the QUADRO manual were adopted. Classified (i.e. split into different vehicle types) traffic counts, and therefore the proportion of heavy vehicles, were only available for some links; either the proportion from the closest link or a nominal 10% HGVs was assumed. The site data is given in Table 2.

It was assumed that all roads affected were rural all-purpose single carriageway with a speed limit of 96km/h (60mph), reduced to 48km/h (30mph) where part of the road remained open following the landslide, and that the affected length at the site was 100m.

QUADRO calculates the costs of user delays, carbon emissions from vehicles and accidents associated with the road works, reporting the costs on the basis of an average day over a whole week. The results of the QUADRO analyses are shown in Table 3, with the totals for each site summarised in Table 4.

The relative traffic levels, and closure type and duration (Table 2), reveals patterns that are broadly consistent with those that might be inferred intuitively, as follows:

- The costs of similar closures depend on traffic levels and with costs being higher where traffic is higher (A9 cf. A83 2004)
- Doubling the duration incurs higher costs, but may be reduced if the traffic levels are lower (A83 2004 cf. A85)
- A much longer duration increases the costs significantly (A83 2007)

Of particular interest are the negative costs (i.e. cost reductions) for traffic accidents during post-event diversions and/or restricted traffic flow accident cost that suggest a decrease in accident numbers and/or accident severity; this seems most likely to be as a result of reduced traffic speeds

5 INDIRECT CONSEQUENTIAL ECONOMIC IMPACTS

There is a wide range of possible approaches to estimating the indirect consequential economic impacts of landslides and bespoke methods designed to address a particular set of circumstances (MacLeod et al., 2005; Anon., 2013b) as described by Winter et al. (2018).

Surveys of businesses in the areas of events have provided useful qualitative information (Winter et al., 2018). For events of lesser impact descriptors that relate to the hazard are used: 'landslide', 'flooding' and other words that describe the event itself are also to the fore.

In contrast responses to events of greater impact and or repetition such as at the A83 tend to relate to the effects, risks, or impacts, that derive from the event: with the most frequently used word being 'road', with words such as 'closed', 'staff', 'visitors', 'due', 'access', 'tourism', 'minor' and 'island' also coming to the fore. These latter responses seemingly describe the consequences of the hazard, or the economic risks associated with the hazard, rather than the hazard itself, implying a greater economic impact or, at least, a greater awareness of the economic impact.

6 SUMMARY AND CONCLUSIONS

This paper presents the initial results of a study to develop methods of obtaining data on the economic impacts of landslides and the first attempts to obtain such data. The economic impacts of landslides are considered in three categories: direct economic impacts, direct consequential economic impacts, and indirect consequential economic impacts. This approach is also applicable to other events that reflect relatively discrete closures due to climate driven events such as flooding.

Table 2. Site parameters for the direct consequential economic impacts analysis

Event	No. Veh. damaged	Traffic flow (AADT) (vehicles/ day)[1]	HGVs (%)	Junction Length (km)	Closure type(s)	Closure duration
August 2004: A83 Glen Kinglas to Cairndow	1	5,554	9	20	Full closure	2 days
August 2004: A9 N of Dunkeld	5	13,864	18	18	Full closure then shuttle working with convoy	2 days full 6 days convoy
August 2004: A85 Glen Ogle	3	4,403	10	26	Full closure	4 days
October 2007: A83 Rest and be Thankful	1	5,748	10	20	Full closure then shuttle working[2]	15 days 27 days shuttle[3]

[1] Peak monthly figure, usually for August. [2] Single lane working with traffic light control.
[3] This figure represents the duration of the closure due to the instability and the immediate engineering works required to allow the reopening of the road. It is acknowledged that the road was subsequently subject to single lane working with traffic light control for a significantly longer period due to engineering works necessitated by the combination of this and subsequent events in the immediate vicinity.

Table 3. Incident accident costs (per vehicle) and QUADRO daily closure costs (at 2012 prices)

Cost (£)	August 2004: A83 Glen Kinglas to Cairndow	August 2004: A9 N of Dunkeld (Full closure / shuttle working)	August 2004: A85 Glen Ogle	October 2007: A83 Rest and be Thankful (Full closure / shuttle working)
Accident incident cost	2,520	2,520	2,520	2,520
Delay cost	84,071	270,885 / 135,339	71,679	88,040 / 461
Carbon cost	6,380	18,608 / 9,304	6,629	6,590 / 6
Accident cost	-4,360	-11,254 / -5,627	-4,494	-4,512 / 794

Table 4. Total incident accident costs and QUADRO total closure costs (at 2012 prices)

Cost (£)	August 2004: A83 Glen Kinglas to Cairndow	August 2004: A9 N of Dunkeld (Full closure / shuttle working)	August 2004: A85 Glen Ogle	October 2007: A83 Rest and be Thankful (Full closure / shuttle working)
Accident incident cost	2,520	12,600	7,560	2,520
Delay cost	168,143	1,218,460	286,718	1,333,020
Carbon cost	12,762	83,737	26,514	99,029
Accident cost	-8,721	-45,288	-17,974	-46,247
Total	174,703	1,269,508	302,817	1,388,322

The work presented includes data for four Scottish landslide events from 2004 and 2007. Direct costs range between approximately £400k and £1,700k, and direct consequential costs between £160k and £1,400k. The latter are largely dependent upon traffic levels and the duration of the disruption. Work on indirect consequential impacts has provided valuable qualitative insights.

7 ACKNOWLEDGEMENTS

Transport Scotland's funding of this work is gratefully acknowledged.

8 REFERENCES

Anon. 2006. Design Manual for Roads and Bridges (DMRB): Volume 14: Economic Assessment of Road Maintenance – QUADRO4 User Manual, June.

Anon. 2011. Scottish road network climate change study: UKCP09 update. Report by Jacobs for Transport Scotland.

Anon. 2012a. *Scottish Transport Appraisal Guidance*. Transport Scotland, Edinburgh.

Anon. 2012b. *TAG UNIT 3.3.5: The Greenhouse Gases Sub-Objective, August*. Department for Transport, London,.

Anon. 2013a. *Reported road casualties Scotland 2012*. Transport Scotland, Edinburgh.

Anon. 2013b. A83 Trunk Road Route Study: Part A – A83 Rest and be Thankful. Final Report. Report prepared by Jacobs for Transport Scotland, 212p.

Galbraith, R.M., Price, D.J., Shackman, L. 2005. (Eds.). *Scottish road network climate change study*, 100p,. Scottish Executive, Edinburgh.

Highland, L.M. 2006. Estimating landslide losses – preliminary results of a seven-state pilot project. *US Geological Survey Open File Report 2006-1032*. USGS, Reston, VA.

Highland, L.M. 2012. Landslides in Colorado, USA: impacts and loss estimation for the year 2010. *US Geological Survey Open File Report 2012-1204*. USGS, Reston, VA.

Klose, M., Damn, B., Terhorst, B. 2015. Landslide cost modelling for transportation infrastructures: a methodological approach. *Landslides* **12**, 321-334.

MacLeod, A., Hofmeister, R.J., Wang, Y., Burns, S. 2005. Landslide indirect losses: methods and case studies from Oregon. *Open File Report O-05-X*. State of Oregon, Department of Geology and Mineral Industries, Portland, OR.

Schuster, R.L. 1996. Socioeconomic significance of landslides. *Landslides – Investigation and Mitigation* (Eds: Turner. A.K., Schuster, R.L.), Transportation Research Board Special Report 247: 36-75. National Research Council, Washington, DC.

Schuster, R.L., Highland, L.M. 2007. The Third Hans Cloos Lecture. Urban landslides: socioeconomic impacts and overview of mitigative strategies. *Bulletin of Engineering Geology & the Environment* **66**, 1-27.

Winter, M.G., Corby, A. 2012. A83 Rest and be Thankful: ecological and related landslide mitigation options. *Published Project Report PPR 636*. TRL, Wokingham.

Winter, M.G., Bromhead, E.N. 2012. Landslide risk: some issues that determine societal acceptance. *Natural Hazards* **62**(2), 169-187.

Winter, M.G., A strategic approach to landslide risk reduction. *International Journal of Landslide and Environment*, **2**(1), 14-23.

Winter, M.G., Dent, J., Macgregor, F., Dempsey, P., Motion, A., Shackman, L. 2010. Debris flow, rainfall and climate change in Scotland. *Quarterly Journal of Engineering Geology & Hydrogeology* **43**(4), 429-446.

Winter, M.G., Shearer, B. 2013. Climate change and land-slide hazard and risk - a Scottish perspective. *Published Project Report PPR 650*. TRL, Wokingham.

Winter, M.G., Macgregor, F., Shackman, L. (Eds.). 2005. *Scottish Road Network Landslides Study*, 119p. The Scottish Executive, Edinburgh.

Winter, M.G., Heald, A., Parsons, J., Shackman, L., Macgregor, F. 2006. Scottish debris flow events of August 2004. *Quarterly Journal of Engineering Geology and Hydrogeology* **39**(1), 73-78.

Winter, M.G., Macgregor, F., Shackman, L. (Eds.). 2009. *Scottish road network landslides study: implementation*, 278p. Transport Scotland, Edinburgh.

Winter, M. G., Shearer, B., Palmer, D., Peeling, D., Peeling, J., Harmer, C., Sharpe, J. 2018. Assessment of the economic impacts of landslides and other climate-driven events. *Published Project Report PPR 878*. TRL, Wokingham.