Procedia Engineering
Volume 143, 2016, Pages 1425–1434

Advances in Transportation Geotechnics 3 . The 3rd
International Conference on Transportation Geotechnics
(ICTG 2016)

The Economic Impact of Landslides and Floods on the Road Network

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Abstract

Even in the absence of serious injuries and fatalities, landslide and flood events can have significant socio-economic impacts. These 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 economic impacts can be classified as: direct economic impacts, direct consequential economic impacts, and indirect consequential economic impacts. In addition, the vulnerability shadow cast can be extensive and its geographical extent can be determined by the transport network rather than the relatively small footprint of the event itself. Using a number of debris flow events and a flood event in Scotland this paper places values on the economic impacts of landslides and floods. It also demonstrates the widespread impact of the events by means of the vulnerability shadow that is cast..

Keywords: Landslides, debris flow, roads, economics, management; mitigation

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

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Selection and peer-review under responsibility of the Scientific Programme Committee of ICTG 2016

doi:10.1016/j.proeng.2016.06.168

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 to those involved, the real impacts of these events were economic and social. Such impacts include the cost of delays and diversion on transport networks 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 5,000 vehicles per day (all vehicles two-way, 24 hour annual average daily traffic, AADT) was closed for slightly in excess of a day, the A9 (carrying 13,500 vehicles per day) was closed for two days prior to reopening, initially with single lane working under convoy, and the A85 (carrying 5,600 vehicles per day) was closed for four days. The traffic flow figures are for the most highly trafficked month of the year (July or August). Minimum flows occur in either January or February and are roughly half those of the maxima reflecting the importance of tourism and related seasonal industries to Scotland's economy. Substantial disruption was thus experienced by 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 set-out by Winter and Bromhead (2012). In principle the impacts of floods can be assessed using the same set of principles and metrics, albeit that experience suggests that the damage is less and thus the associated closures are generally of lesser duration.

2 Economic Impacts

Due to the major contribution that tourism makes to Scotland's economy the impacts of such events can be particularly serious during the summer months, during which period debris flows usually occur in July and August. Nevertheless, the impacts of any debris flow event occurring during the winter months, between October/November and January when debris flow usually occurs, 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 of such landslide (and flood) events 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 that closes a road, and its associated vulnerability shadow, were summarized by Winter & 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. These should be relatively easy to obtain or estimate for any given event.

Direct consequential economic impacts: These generally relate to 'disruption to infrastructure' and are really about loss of utility. For example, the costs of closing a road (or implementing single-lane working with traffic lights) for a given period 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. While these are set out for the costs of road traffic accidents, or indeed rail accidents, there seems to be no particular reason why they should be radically different to those related to 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 that are based upon transport-dependent activities, and thus the vulnerability can be extensive and is determined by the transport network rather than the event itself. If a given route is closed for a long period then how, for example, does that affect confidence in, and the ongoing viability of, local business? Manufacturing and agriculture (e.g. forestry in western Scotland and coffee production in Jamaica) are a concern as access to markets is constrained, the costs of access are increased and business profits are affected and short-term to long-term viability may be adversely affected. Perhaps of even more concern are the 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 an event that has received publicity and/or caused casualties and how a period of inaccessibility (reduced or complete) affects the short- and long-term travel patterns to an area for tourist services. 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 the assignation of budgets to landslide risk mitigation and remediation 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, are also those that anticipate such compensatory events.

The vulnerability shadow cast can be extensive and its geographical extent can be determined by the transport network, including closures and diversionary routes, rather than the relatively small footprint of the event itself (Winter & Bromhead, 2012). In the particular case of the event at the A83 Rest and be Thankful in October 2007 of the order of 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 (Figure 1) which is, for the purpose of comparison, approximately two-and-a-half times the total land area of Hong Kong SAR.

The economic impact 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; Winer & Shearer, 2013).

The work of Schuster (1996), Highland (2006) and 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, 2012). Indeed, Highland 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.

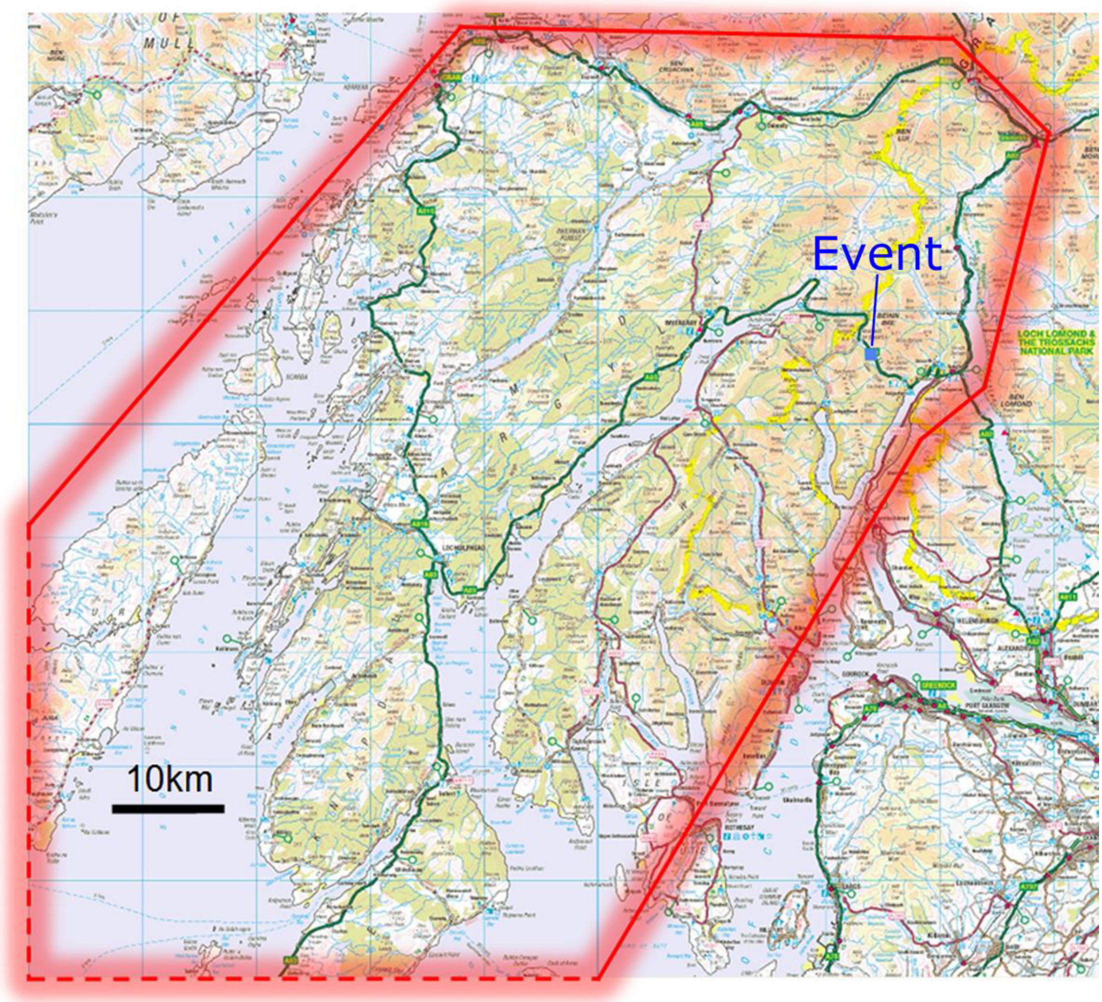

Figure 1: A relatively small debris flow event closed the A83 at the Rest and be Thankful in October 2007; the vulnerability shadow that was cast (bounded in red) was extensive [4]

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 as was data for the 2012 flooding event.

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 [10] 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

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

These might otherwise be described as 'emergency response' and 'remedial works', respectively.

Event	Emergency response	Remedial works	Total
August 2004: A83 Glen Kinglas to Cairndow	£395,043		£395,043
August 2004: A9 N of Dunkeld	£921,766		£921,766
August 2004: A85 Glen Ogle	£658,405		£658,405
October 2007: A83 Rest and be Thankful	£320,772	£1,372,629	£1,693,401
September 2012: A77, A76, A71 Bellfield Junction	£16,756	£8,333	£25,088

Table 1: Direct economic impacts (at 2012 prices)

4 Direct Consequential Economic Impacts

Direct consequential economic impacts are those that relate to 'disruption to infrastructure' and are really about loss of utility or the cost imposed on road users. For example, the costs of closing a road (or implementing single-lane working with traffic lights) for a given period with a given diversion, are relatively simple to estimate using well-established models. The costs of fatal/non-fatal injuries and incident damage only accidents are also be included here and may be taken (on a societal basis) directly from published figures (Anon., 2013b). While these are set out for the costs of road traffic accidents, or indeed rail accidents, there seems to be no particular reason why they should be radically different to those related to 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. In all of the cases presented here the accidents have been non-injury accidents (damage only) and the numbers associated with each event have been estimated from event contemporaneous photographs taken by the first author and others.

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: the change in carbon emissions due to vehicle fuel consumption, based on average figures per litre of fuel burnt and costed using estimated abatement costs (see STAG and WebTAG) (Anon., 2012a; b);
- Accident costs: the change in the occurrence of accidents, in terms of 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., 2015).

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, sub-urban 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 form 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 (see Table 2).

It was assumed that all of the roads affected were rural all-purpose single carriageways 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 length of the affected site in each case was 100m.

QUADRO calculates the costs of user delays and diversions, 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 (see Table 3), totals for each site are summarised in Table 4. Implicit are assumptions regarding the costs of time (vehicle occupancy, journey purpose, and the value of time for both occupants and vehicles), vehicle operating costs (and associated carbon costs), and the value of accidents that occur within the section(s) of road under consideration (Anon. 2015) and the values are based on national statistics.

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

- The costs of similar closures depend on traffic levels; costs being in proportion to traffic (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. These reduced accident costs suggest a decrease in accident numbers and/or accident severity and seem most likely to be as a result of reduced traffic speeds leading to an increased opportunity to avoid accidents and lower severity when they do occur.

The landslide events were located in rural areas and their impacts are upon those areas and small towns and villages. The flooding event was located in a much more developed part of Scotland and on the edge of a town (Kilmarnock, population almost 45,000). This peri-urban location places a different complexion on the direct consequential economic impacts which were more than twice those of the A83 2007 event for a much shorter duration. Notwithstanding this the impacts of the A83 event(s) should not be underestimated: those impacts were borne by a much smaller number of people over an extended period; the impacts on individuals and individual businesses seem likely to have been considerably greater. This part of the analysis also does not take account of the longer term indirect consequential economic impacts (see Section 5).

Event	Number vehicles damaged	Traffic (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 full 27 days shuttle[3]
September 2012: A77, A76, A71 Bellfield Junction	0	6,400 to 13,800	6	0.3 to 4.9	A77: Full closure A76: Full closure then shuttle working A71 Full closure	25 hours 19 hours full 2 days shuttle 67 hours

[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 2: Site parameters for the direct consequential economic impacts analysis

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)	September 2012: A77, A76, A71 Bellfield Junction (Full closure/shuttle working)
Accident incident cost	2,520	2,520	2,520	2,520	2,520
Delay cost	84,071	270,885 / 135,339	71,679	88,040 / 461	1,548,624 / 94,363
Carbon cost	6,380	18,608 / 9,304	6,629	6,590 / 6	73,922 / 671
Accident cost	-4,360	-11,254 / -5,627	-4,494	-4,512 / 794	-38,568 / 7,564

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)	September 2012: A77, A76, A71 Bellfield Junction (Full closure/shuttle working)
Accident incident cost	2,520	12,600	7,560	2,520	0
Delay cost	168,143	1,218,460	286,718	1,333,020	3,080,542
Carbon cost	12,762	83,737	26,514	99,029	151,669
Accident cost	-8,721	-45,288	-17,974	-46,247	-71,309
Total	174,703	1,269,508	302,817	1,388,322	3,160,902

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

5 Indirect Consequential Economic Impacts

There is a wide range of possible approaches to estimating the indirect consequential economic impacts of landslides. These include:

- Cost-benefit analysis;
- Cost-effectiveness analysis;
- Willingness to pay;
- Multi-criteria analysis;
- Methods based upon Transport Appraisal.

In addition there are bespoke methods designed to address a particular set of circumstances (McLeod et al., 2005; Anon., 2013).

A survey of businesses has been undertaken in the area of the 2004 A85 event. This is part of a first phase of work to ascertain the availability and reliability of data that would be required in order to identify, and to develop, a measurement methodology of the indirect consequential economic impacts of landslides in Scotland.

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 associated 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 events that reflect relatively discrete closures including climate-driven flooding.

The work presented herein includes data for four Scottish landslide events that occurred in 2004 and 2007. Direct costs range between approximately £400k and £1,700k while direct consequential costs range between around £180k and £1,400k. The latter are largely dependent upon the amount of traffic that uses the road and the duration of the disruption. For a flood event in a more developed peri-urban part of Scotland the direct costs were small but the direct consequential costs (c. £3,200k) much greater than for any of the landslide sites considered. It is also worth noting that flood event was of a relatively short duration compared to the high cost landslide event. Work is ongoing to define the indirect consequential costs of both landslide and flood events.

Acknowledgement

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

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