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Assessment of the Economic Impacts of Landslides and Other Climate-Driven Events

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Contents

Executive Summary

The economic impacts of landslide events on a road or other form of linear infrastructure can be classified as

- direct economic impacts,
- direct consequential economic impacts, and
- indirect consequential economic impacts.

The same approach can also be applied to other discrete climate-driven events such as flooding.

Direct economic impacts include the 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 relate to 'disruption to infrastructure' and relate to loss of utility. For example, the costs of closing a road and diverting traffic or implementing single-lane (shuttle) working with traffic lights. The costs of fatal/non-fatal accidents are also included.

Indirect consequential economic impacts are the effects on businesses that relate to any loss of business due to, for example, the dependence upon the transport network for incoming and/or outgoing goods, and for the transport of staff and visitors as well as any associated longer term impacts on a business.

This report presents the results of a study to determine the economic impacts of primarily landslide events, but also of flooding events. The extent of such impacts can be considerable, particularly in rural areas where the road network is sparse and offers few route alternatives; a small event can affect economic activities over a considerable area. The vulnerability shadow is used to visually demonstrate the potential widespread nature of economic impacts.

The main landslide and flood events considered are described and the principles underlying economic impacts and their extent examined, drawing upon examples from Jamaica, Nepal and China as well as the UK. An extensive literature review relates the available information on the cost of landslide events, issues surrounding vehicular vulnerability, budgetary issues, the socio-economic impacts of landslides, and potential methods for assessing indirect consequential costs.

It is not intended that the results be directly extrapolated to other, including future, landslide and flood events but to give a view of the type of impacts that have occurred in the past; these could potentially, and with care, be used to qualitatively and indirectly describe the types of impacts that future events may have. A more detailed articulation of future events would, of course, require further analysis.

The findings from the work presented herein shed substantial light on the economic impacts of landslide and flood events on the road network in Scotland but wholesale changes to the way in which generally accepted economic assessment model(s) are used are not indicated. It is however recommended that more effort be expended to capture the costs direct economic impacts immediately after events, not least as these can be very difficult to determine at a later stage. In addition, the QUADRO approach to determining direct consequential impacts may provide an additional tool for event

analysis, not least as it is specifically designed for roadworks that may involve full closure, convoy working and shuttle working.

The trial of the use of questionnaire surveys to derive indirect consequential economic impacts produced numerical data that is perhaps less robust than the ideal. Notwithstanding this, the qualitative outcomes from the derivative Word maps are insightful and extremely useful, as set-out below. As these outcomes are generic, rather than site or region specific, the future use of such questionnaire surveys is not currently indicated.

The results for the A83 Rest and be Thankful are considered to be supportive of the existing assessments, findings and conclusions in respect of the Options Appraisal published in 2013 and no specific changes to the options or their hierarchy are indicated from the results presented herein.

In conclusion it seems clear that the economic impacts of landslides that affect the Scottish strategic road network are significant. While the direct consequential costs of such events may not be as great as those of some flood events that affect more densely populated, and highly trafficked, peri-urban areas, the costs are borne by a smaller number of individuals and individual businesses.

Given the mix of different costs calculated herein it is not intended that those costs should be aggregated to arrive at a total figure for the economic impact on the economy. Rather, this work is intended to articulate the differing types of costs in the context of the different sectors that bear those costs.

Detailed conclusions for each of direct economic impacts, direct consequential economic impacts and indirect consequential economic impacts are set out below.

1 Introduction

Roads in Scotland provide vital communication links to remote communities. Severance of the access of these communities to services and markets as a result of, for example, a landslide or flooding, has significant economic and social consequences. While landslides can occur at almost any time of year, summer (July and August) and winter seasons (October/November to January) have been identified (Winter et al. 2005; 2009). The Scottish landscape has a high economic value and the most important peak in tourist activity coincides with the summer landslide season.

Rainfall-induced debris flows, a form of landslide, are a particularly common occurrence in Scotland. In August 2004 a series of such events was associated with monthly average rainfall significantly in excess of the norm. Some of the resulting landslides affected important parts of the trunk (strategic) road network, linking not only cities but also smaller, remote communities.

Whilst there was no loss of life and no major injuries associated with the rainfall induced landslide events of August 2004 the real impacts were economic and social, in particular the severance of access to and from relatively remote communities.

Even events that directly affect only a short stretch of road can cast a considerable vulnerability shadow, that is the wider area where direct and indirect economic impacts of the event are experienced (Winter & Bromhead 2012; Winter 2014a; 2014b).

This report presents the results of a study to determine the economic impacts of landslides that affect the Scottish trunk (strategic) road network. The principles are also applied to flood events.

The main landslide and flood events that are considered in this report are described in Section 2 these range from the August 2004 events that severely affected the Scottish strategic road network (Winter et al. 2005; 2006), through a major landslide event in October 2007 at the A83 Rest and be Thankful (Winter et al. 2009) and a significant flood event in 2012 at the A77, A76, A71 Bellfield Junction, to another landslide event at the A83 Rest and be Thankful in October 2014.

The principles underlying economic impacts and a categorisation of such impacts as direct, direct consequential and indirect consequential is described along with the principle of the vulnerability shadow that articulates the areal extent of the impacts (Winter & Bromhead, 2012) in Section 3. The description of the vulnerability shadow draws upon examples from Jamaica, Nepal and China, as well as the UK. An extensive literature review (Section 4) relates the available information on the cost of landslide events, issues surrounding vehicular vulnerability, budgetary issues, the socio-economic impacts of landslides, and potential methods for assessing indirect consequential costs.

Section 5 presents the results of an assessment of the direct economic impacts for five landslide events and two flooding events. The data are derived from records held by the Operating Company (variously Amey, BEAR Scotland and Scotland TranServ depending upon the area and date) and the Performance Audit Group (PAGplus).

Section 6 presents the results of an assessment of the direct consequential economic impacts for the same five landslide events and one of the flood events. The data are derived from modelling the changes to traffic movements caused by the events to obtain projected delay, carbon and accident costs and, where pertinent, the costs of accidents forming part of the events are included. The results are presented as total costs for each event and also as daily costs for each type of impact for each event.

Section 7 presents the results of questionnaire surveys to determine the indirect consequential economic impacts. Results are presented for three events – two landslides and one flood event. In addition to a conventional quantitative analyses word maps are used to qualitatively analyse the free-text reposes provided by survey respondents.

A series of six appendices contains details of the direct consequential economic impact analysis, a review of means of measuring indirect consequential economic impacts, the three survey questionnaires used to evaluate indirect consequential economic impacts and a series of detailed word maps derived from the final questionnaire survey.

2 Landslide and Flooding Events

2.1 Landslide Events

Rainfall-induced debris flows are a common occurrence in Scotland and in 2004 a series of such events was associated with monthly average rainfall substantially in excess of the norm. Some areas of Scotland received more than 300% of the 30-year average August rainfall (source: www.metoffice.gov.uk), while in Perth & Kinross figures of the order of between 250% and 300% were typical. Although the percentage of the monthly average rainfall that fell during August was lower in the west, parts of Stirling and Argyll & Bute still received between 200% and 250% of the monthly average.

Critically, some of the resulting landslides affected important parts of the trunk (strategic) road network, linking not only cities but also smaller, remote communities (Figure 1). Notable events occurred at the A83 (Figure 2) between Glen Kinglas and to the north of Cairndow (9 August), the A9 (Figure 3) to the north of Dunkeld (11 August), and the A85 (Figure 4) at Glen Ogle (18 August).

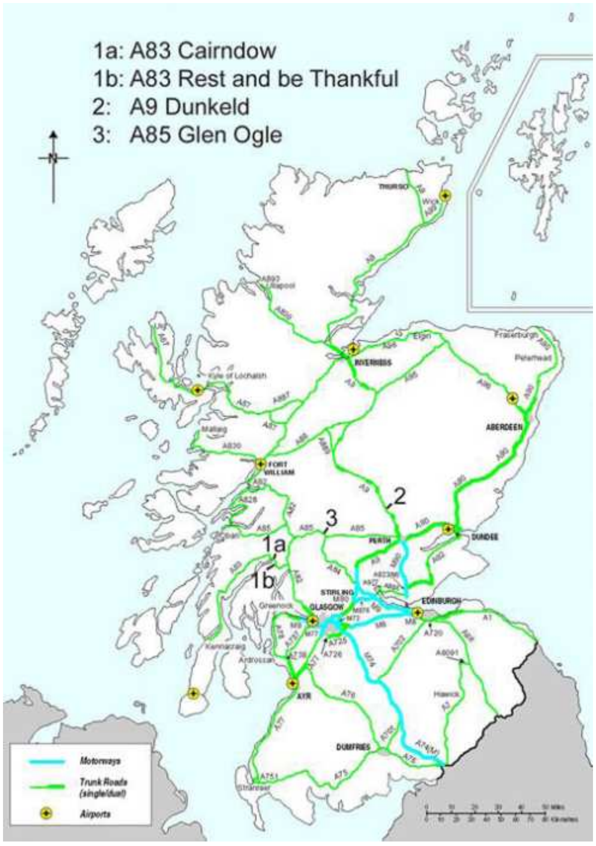

Figure 1. Map showing the trunk road network, including motorways, in Scotland. The locations of the three main debris flow event groups that affected the trunk road network in Scotland in August 2004 are shown.

While the overall rainfall levels for August were relatively high, the storm rainfall associated with these events was particularly significant. A retrospective analysis of rainfall radar data was undertaken by SEPA for Callander, some 20km distant from Glen Ogle. The analysis indicated that approximately 85mm of rain fell in the storm event and that 48mm of that rain fell in just 20 minutes, reaching a peak intensity of 147mm/hour.

The 30-year average August rainfall varies between 67mm on the east coast and 150mm in the west of Scotland (Anon., 1989).

Figure 2. Debris fan containing boulders (estimated up to nine tonnes) at the A83 Cairndow event, dated 9 August 2004.

Figure 3. Debris flow dated 11 August 2004 at the A9 north of Dunkeld. (Image 12 August 2004, courtesy of Alan McKenzie, BEAR Scotland.)

Figure 4. The A83 in Glen Ogle was blocked by two debris flows on 18 August 2004. RAF and Royal Navy helicopters are pictured airlifting some of the 57 occupants from the 20 trapped vehicles to safety. (© Perthshire Picture Agency: www.ppapix.co.uk.)

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 events of August 2004 are described in detail by Winter et al. (2006). These events are by no means unique and further debris flows have affected both the A9 and the A83, for example, since August 2004. The event pictured at the A83 in Figures 5 and 6 occurred at around 0330 hours on Sunday 28 October 2007. Figure 5 illustrates the event and the surrounding hillside; the photograph is taken from the opposite side of the valley and evidence of numerous past events can be clearly observed. Figure 6 illustrates the event in more detail and it is clear that the system of mass movement comprises two discrete but related events. First, the flow above the road commenced with a relatively small slide (or slides) into an existing drainage channel. This then triggered the movement of a large amount of marginally stable material in and around the stream channel depositing an estimated 400 tonnes of material at road level. Second, this material blocked the open drain which carries water along the upslope side of the road to a series of culverts beneath the road. While the material from above the road had limited impact upon the slopes below the road, water diverted from the drain was channelled across and over the edge of the road causing some significant undercutting of the slope below and associated deposition further down the hill as can be seen in Figure 6.

Events have been frequent at the A83 Rest and be Thankful (see Wong & Winter 2018; Winter 2018). A further event occurred at around 06:30 hours on the morning of 28 October 2014. The majority of this large event (circa 2,000 tonnes) was arrested by one of the debris flow catch fences that had been installed. However, the event exceeded the design capacity of the fence, which collapsed allowing the remainder of the debris to reach the road (Figure 7). A related event also occurred, reaching the road in Glen Kinglas.

Figure 5. View of the hillside above and below the approach to the Rest and be Thankful from the east (from NGR NN 23160 06559 on the opposite side of Glen Croe). Not only can the event dated 28 October 2007 be clearly seen but evidence of numerous past events can be seen on the surrounding hillside.

2.2 Flooding Events

In general terms, it has proven difficult to obtain information and data relating to flooding events. Indeed, for the January 2011 event that affected the A8 at Inverclyde it proved impossible to determine even the direct economic impacts (see Section 5) let alone the direct consequential and indirect consequential impacts. Similarly, for the January 2012 event that affected the A78 between Largs to Skelmerlie, information and data proved elusive even though the direct economic impacts were determined (see Section 5). In similar fashion it proved difficult to obtain a verifiable narrative of either event.

The A77, A76 and A71 Bellfield Junction (Kilmarnock) flooding event of 21 September 2012 proved to be an exception. This event is thought to have been caused by multiple blockages in the drainage system in an area of low-lying ground in the area to the south of the A76 (Figure 8) and a disused railway embankment that runs approximately parallel to the road. This area includes the River Cessnock which then joins the River Irvine to the north of the A71. This caused flooding to the A76 itself the floodwater from which travelled through the service area to block the A71 and thence to the roundabout that forms part of the grade-separated junction; the water then spilled over the roundabout onto the A77 (Figure 9) which, at that location, forms the lower part of the grade separation. The various roads were closed for approximately one day (A77), one day with a further two days of one-lane working with traffic control (A76), and three days (A71).

Flooding also occurred at the same location earlier that year on 5 July 2012. The rainfall that caused this earlier event was much more localised while that on the 21 September was widespread and certainly affected the entire catchment. The same area had previously flooded on 3 January 1932.

Figure 6. View of the debris flows above and below the A83 on the approach to the Rest and be Thankful (from NGR NN 23160 06559 on the opposite side of Glen Croe). The head scar is at approximately 370m AOD, the A83 at 240m AOD and the Old Military Road (OMR) at 180m AOD.

Several flooding events that affected the road network in East and South Ayrshire at or about the time of the September 2012 event. Some of these overlapped temporally and others did not, and the geographical spread of the events was quite considerable. In order to make the work of estimating the economic impacts (Sections 5 to 8) manageable, only the event at the A77, A76, A71 Bellfield Junction was considered in detail.

Figure 7. Debris flow event at the A83 Rest and be Thankful, 28 October 2014.

Figure 8. The 21 September 2012 flooding at the A77, A76, A71 Bellfield Junction is thought to have originated in this area of low-lying ground to the south of the A76.

Figure 9. Floodwater spilling from the roundabout that forms part of the grade-separated A77, A76, A71 Bellfield Junction onto the A77. (Purely for reasons of availability of suitable imagery this image is from the 5 July 2012 event.) (Photograph courtesy of Scotland TranServ.)

3 Economic Impacts and Their Extent

3.1 Economic Impacts

The A83 Rest and be Thankful site, in particular, has been extremely active in recent years with multiple debris flow events and associated closures in 2007, 2008, 2009, 2011, 2012 and 2014 which 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).

It was, perhaps, fortuitous that there were no major injuries to those involved in these events. However, the real impacts of such events are economic and social, in particular the severance of access to and from relatively remote communities. Winter et al. (2005; 2006; 2009) reported on the 2004 events including those at the A83 (carrying around 5,500 vehicles per day: all vehicles two-way, 24-hour annual average daily traffic, AADT) which was closed for slightly in excess of a day; the A9 (around 13,500 vehicles per day) which was closed for two days prior to reopening, initially with single lane working under convoy; and the A85 (around 4,500 vehicles per day) which 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 other seasonal industries to Scotland's economy. Substantial disruption was thus experienced by local and tourist traffic, and goods vehicles.

Debris flows typically occur in either the winter (October/November to January) or summer (July and August) season, although they can occur outside these periods (Winter et al. 2005). Due to the major contribution that tourism makes to Scotland's economy the impacts of such events can be particularly serious during the summer. Nevertheless, the impacts of any debris flow event occurring during the winter should not be underestimated and events are arguably more frequent during this period. 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 et al. 2008; Winter & Bromhead 2008; 2012).

The qualitative economic impacts of such landslide 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, 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 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 & 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 relate to 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 casualties and accidents 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. These impacts include those due to the dependence upon the transport network for incoming and/or outgoing goods, and for the transport of staff and visitors as well as any associated longer term impacts. If a given route is closed for a long period then how does that affect confidence in, and the ongoing viability and credibility of, local business. Manufacturing and agriculture (e.g. forestry in western Scotland) 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 above primarily relates to the articulation of the economic impacts that affect linear infrastructure, particularly roads, Alimohammadlou et al. (2013) attempt to describe landslide losses in a more generic sense whilst including many of the elements described in the foregoing.

A similar scheme was presented by Benson (2012) in respect of disaster losses and considered the following:

Direct losses: Relate to human life and injury and physical damage to productive and social assets.

Indirect losses: Refer to disruptions to the flow of goods and services stemming from the direct losses.

Secondary effects: Concern the impacts on socio-economic imbalances and the functioning and performance of an economy.

These bear very close correlation with the scheme described above and followed in this report. Clearly Benson's work has a broader disaster impact focus than the landslide and flood impacts on the road network considered herein.

3.2 The Extent of Economic Impacts

The vulnerability shadow (Winter & Bromhead 2012) is closely linked to economic impacts and determines their extent and overall magnitude. The vulnerability shadow is a largely qualitative means of expressing the areal extent of the impact of hazards such as landslides and floods (Winter 2014a). It is thus a measure of the area over which the effects of the risks associated with the hazard are experienced. The magnitude of the vulnerability will not be constant in the area affected and may, as a first level approximation, be expected to decrease with distance from the hazard event. The is the potential to further develop the concept of the vulnerability shadow in order that it is based on quantitative measures and to thus also take account of variability in the magnitude of the vulnerability.

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. In the case of the A83 landslide event at the Rest and be Thankful in 2007, the event itself was of the order of around 400m^3 with a footprint that closed a few tens of metres of the road (Winter 2014a).

The vulnerability shadow has been evaluated using knowledge of the local transport networks and the socio-economic activity associated with the network that has been built-up over a period of 25 years. This includes an holistic evaluation of major nodes, origins and destinations and includes both experience and knowledge gleaned from formal surveys (e.g. Winter et al. 2013). The vulnerability shadow was thus estimated (Figure 10) to be of the order of 2,800km^2 (total area approximately 3,500km^2, 20% allowed for areas of sea).

The area has a population density of approximately 13 people/km^2 (www.argyll-bute.gov.uk). Potentially, the event may have had an economic impact upon up to approximately 36,400 people in Argyll & Bute, plus any transient (e.g. tourist) population.

It is instructive to make some simple comparisons with Hong Kong SAR, which has an average population density of around 6,500 people/km^2 (www.gov.hk). This dictates a much greater transport network density. Thus, and purely for the sake of comparison, in order to have an economic impact on the same number of people the vulnerability shadow cast need only be approximately 5.6km^2 (2km by 2.8km, for example). It is not suggested that the economic impacts would be similar for events with vulnerability shadows of these diverse sizes in Argyll & Bute and Hong Kong. However, it is clear that the low density/dispersed network in Argyll & Bute dictates a large vulnerability shadow while the much more dense/less dispersed network in Hong Kong means that vulnerability shadows will be small, with the exception of events that affect critical infrastructure corridors, as more alternatives routes will exist and will be more proximal to the event (Winter 2014a).

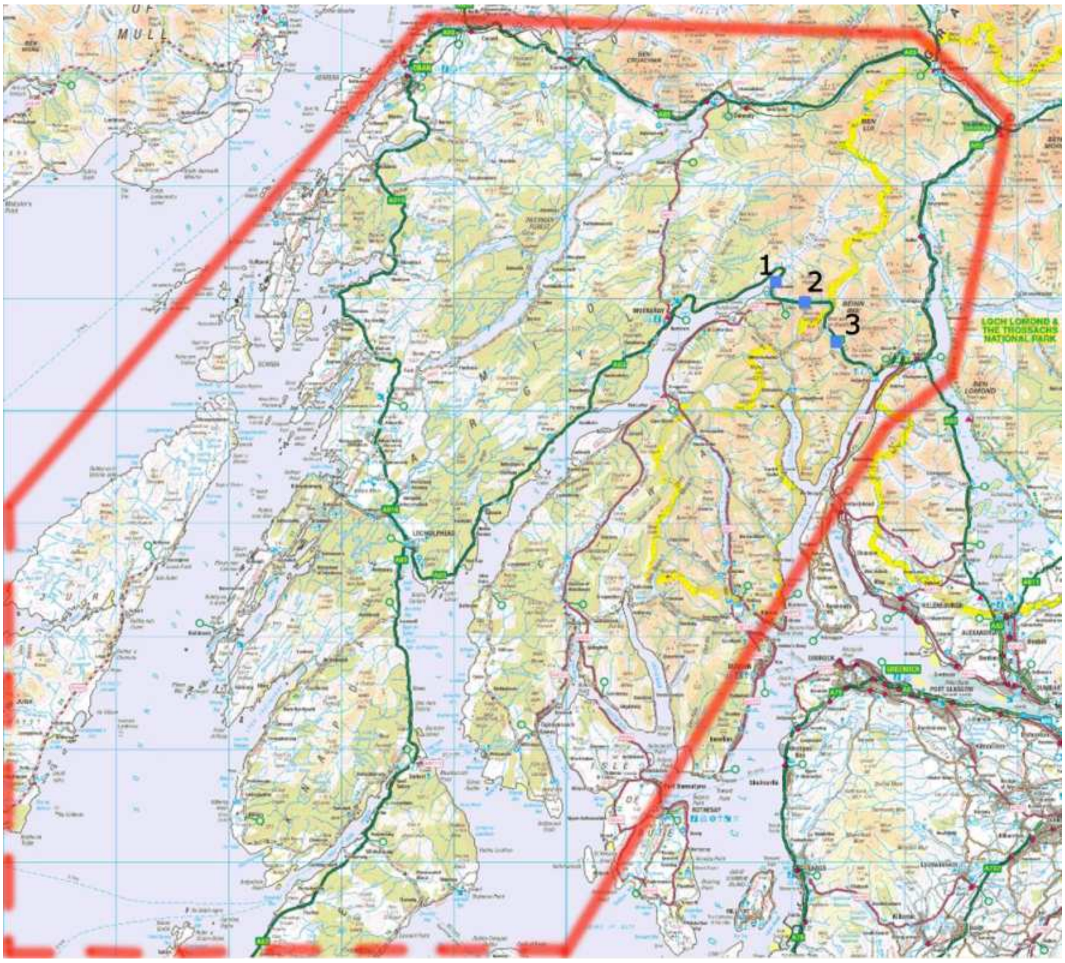

Figure 10. A relatively small debris flow events (blue square '3') closed the A83 at the Rest and be Thankful on 28 October 2007; the vulnerability shadow that was cast (bounded in red) was extensive (Winter 2014a; 2014b). The 2004 events at Cairndow ('1') and Glen Kinglas ('2') are also shown. (Image based on OS 1:250,000 mapping. © Crown Copyright. All rights reserved Scottish Government 100020540, 2018.)

A landslide on the B1 route in the Blue Mountains of Jamaica (Figure 11) effectively severed the local coffee production industry from the most direct route to the international market for this high value product. As such a single landslide event placed severe constraints on the economy of the Blue Mountains. Again, while the footprint of the actual event was relatively small, the vulnerability shadow was projected over a much greater area creating tangible economic and social losses.

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. 2007; Winter et al. 2010a; 2010b; Winter & Shearer 2013).

However, it is clear that for some events it is the hazard itself and not the transport network and, more pointedly, its density that determines the location, shape and extent (morphology) of the vulnerability shadow. However, it is important to recognise that the morphology of the vulnerability shadow related to other types of event, Glacial Lake Outburst Floods (GLOFs) for example, may be determined by the nature of the hazard itself.

Figure 11. Landslide on the B1 road at Section in Portland Parish, Jamaica. This event severed much of the local coffee production industry from the ports used to ship the product to market. (This picture is a photo-collage and some distortion is inevitable.)

An example in which the hazard itself determines the vulnerability shadow is that of the Seti River debris flow in Nepal (Figure 12). On 5 May 2012 a major event caused significant erosion and deposition in the river channel over a distance of around 40km. The event was initially thought to have resulted from a failed landslide dam. However, subsequent inspection of satellite imagery and aerial photography (Petley & Stark 2012; Petley 2014), and more detailed site inspection and investigation (Dahal & Bhandary 2013) led to a rather different conclusion; that the event was a debris flow initiated by part of a 22Mm^3 rock avalanche originating on the slopes of Annapurna IV entering the upper stream channel at high speed. An estimated 71 people lost their lives at Kharapani, some 20km north of Pokhara. The vulnerability shadow was constrained by the dimensions of the hazard flow within the stream channel, extending beyond these bounds only where infrastructure was damaged, including the footbridge at Kharapani.

Similarly, it is entirely possible that the event itself and the transport network may define the vulnerability shadow during different phases of an event. The Zhouqu debris flow disaster (Gansu Province, PR China) occurred at around midnight on 8 August 2010 and claimed the lives of around 1,750 people, dead or missing (Dijkstra et al. 2014; Winter 2019). The vulnerability shadow was initially constrained by the hazard as the debris flow swept through the gorge and the town below (Figure 13). Approximately at the base of the picture, but just out of shot, is the main road that links Zhouqu to the rest of China. As the road was also blocked by the event, the vulnerability shadow spread in both directions along the valley and was thus considerably more extensive than it might otherwise have been if the debris flow run-out had been less extensive. Thus, in this case, the morphology of the vulnerability shadow was determined by both the hazard, in the initial phase of transport and deposition, and the transport network (the road), in the latter phase as the run-out zone was reached.

Figure 12. Residents of Kharapani located on the platform in the middle distance on the Seti River, Nepal, were among fatalities from the 5 May 2012 debris flow event. The abutment of the suspended footbridge is on the platform.

Figure 13. The channel in which the 8 August 2010 Zhouqu debris flow occurred (Gansu Province, PR China) (from Winter 2019). The road and river that pass through the valley are located just below the bottom of the picture.

4 Literature Review

An investigation of the available literature has been undertaken. A noticeable outcome is that there is relatively little published research that deals with the economic impacts of landslides, this is especially so for those economic impacts that would be described as indirect consequential. Unsurprisingly, the vast majority of the literature focuses on geomorphological and geological conditions for triggering, the mechanics of failure, and the engineering of management and mitigation measures amongst other technical aspects. The importance of planning regulation in controlling developments in landslide prone areas to minimise risk also features.

While working from a broader disaster recovery perspective and at a country-scale, Benson (2012) noted that there are two alternative hypotheses regarding the macroeconomic consequences of disasters:

1) That disasters destroy existing productive and social capital and divert scarce resources from planned investments, thus a major disaster might be expected to force an economy onto a lower growth trajectory.

2) That disasters can generate construction-led booms and offer the opportunity to upgrade capital, raising productivity and competiveness, thus a major disaster could stimulate increased economic growth.

Guha-Sapir & Hoyois (2012) additionally noted that the indirect (and secondary) effects of disasters have come to the fore only recently and that systematic data and studies that report on these effects are rare. They also note that even where data is available (at a country level) that comparison is difficult as assessment methods for economic losses are not standardised and that loss of life was not included in economic loss calculations, seriously underestimating the losses. Their analysis also suggest that damage to the economy dominates the impacts of disaster in high income countries but that loss of life dominates the impact so disasters in low income countries, albeit that economic damage remains important in the latter. Similarly they report that uninsured losses are in excess of 95% in low income countries (and in excess of 90% in middle income countries). The equivalent figure is more than 60% in high income countries. This latter figure appears at first sight surprisingly high but may be accounted for by the fact that government property is often not insured but underwritten by the government itself and large tracts of agricultural and public land may not be insured against disaster.

In a related piece of work Eidsvig et al. (2014) developed a method for assessing the socioeconomic vulnerability of communities to landslide hazards. Their model included economic indicators alongside demographic and social, and preparedness, response and recovery indicators making the clear link that vulnerability is inversely proportional to wealth (i.e. vulnerability decreases with increased wealth and increases with reduced wealth).

While many papers address issues relating to the costs from flooding, and also from wind damage, the impacts of landslides do not feature significantly. Furthermore much of the available research relates to landslides that have occurred in the USA, many of which had significant impacts both in terms of loss of life and economic losses. Cost estimations, where available, tend to be from research that would now be considered as out-of-date. Nevertheless these data do provide an insight into the potential losses from landslides.

Highland (2006) assessed the feasibility of collecting accurate and reliable information on direct economic losses associated with landslides in seven States. State surveys examined the availability, distribution and inherent uncertainties of economic loss data in their area. The data collection process involved:

- Applying State geological information to:
  - Potential sources of landslide loss data.
  - Extent of standardisation of landslide loss data.
  - Availability and accessibility of landslide damage losses by source.
  - Distinctions between direct and indirect landslide losses.
- Additional investigations to estimate landslide damage loss estimation.

The study concluded that records are inadequate and that a standardised approach to landslide loss inventory would reduce the cost, and improve the usability and availability of landslide loss information. Further work by Highland (2012) deals in more detail with both direct economic impacts and also some aspects of direct consequential and indirect consequential economic impacts, although these are usually described in a qualitative manner. Interestingly Highland describes decreased economic activity in some areas and increased economic activity in other areas (e.g. as a result of the Glenwood Canyon Rockfall) and both higher than usual flight costs and an increase in the incidence of charter aeroplane use between key locations on either side of the event.

A related study (Klose et al. 2015) collected data and modelled the costs incurred due to landslides that affected the federal road network in the Lower Saxon Uplands in NW Germany. The approach used the data collected at a local level to extrapolate direct costs for the region, using the results of a susceptibility survey and an infrastructure exposure model. However, this study deals only with direct economic impacts. Hearn et al. (2008) deal with both direct and direct consequential economic impacts, but their approach to direct consequential impacts appears it be based on the assumption that all vehicles (and drivers and passengers) that would normally use the road for the period of the closure will wait for it to be reopened. While this might be appropriate for Lao, where the study was conducted, and reflects the morphology of the road network it does not account for either diversions or restrictions of traffic flow as are more normal in Europe.

The lack of a robust database of landslide events makes a quantitative national economic analysis difficult. Almost 40 landslides are reported in the media in the UK annually (38 in 2010) (Gibson et al. 2012). Anon. (2013a) noted that between 1st January 2007 and 31st October 2012, the A83 at the Rest and Be Thankful was closed five times as a result of landslides and these and other landslides have been enumerated and described (e.g. Winter et al. 2005; 2006; 2009) extensively in recent years. Despite this Dobbie et al. (2011) consider that landslides are rare in Scotland. Whatever the rarity or otherwise of such events, better data is critical to the effective management of risks, as highlighted for flood hazards and risks by the Association of British Insurers (Anon. 2010).

4.1 Cost of Landslides

The overall costs associated with landslide events include those that are both direct and indirect. Direct costs typically include property damage and clean-up costs associated with the physical impacts of landslides. Indirect costs, according to MacLeod et al. (2005)

and Schuster & Highland (2001; 2007), however, are the additional economic factors beyond the physical damage and include:

- Loss of the use of infrastructure.
- Emergency response costs.
- Engineering evaluations.
- Litigation.
- Environmental impact.
- Loss of recreational use.
- Reduced property values in areas threatened by landslides.
- Loss of tax revenue from properties devalued by landslides.
- Loss of industrial, agricultural, and forest productivity, and of tourist revenues, as a result of damage to land or facilities or interruption of transportation systems.
- Loss of human or domestic animal productivity (due to death, injury or trauma).
- Costs of measures to prevent or mitigate potential landslide activity.

This scheme differs to that proposed by Winter & Bromhead (2012) and presented in Section 2 only in that costs associated with the short- to medium-term loss of the use of the infrastructure and associated costs are included with indirect costs rather than indirect consequential costs.

Landslide losses also can be divided into the costs incurred by private and public entities (Fleming & Taylor 1980). Private costs are incurred mainly as damage to land and structures, either private property or corporate industrial facilities. A destructive landslide can result in financial ruin for property owners if, as is often the case in the USA, landslide insurance, or other means to offset damage costs, is unavailable.

Public costs are those costs borne by government agencies, be they national, regional, or local. The largest direct public costs resulting from landslides most often have been for repairing or relocating roads and associated structures such as footways and storm drains. Indirect public costs include inter alia loss of tax revenue, reduction or loss of capacity of critical infrastructure, reduction in the productivity of government-owned forests, impact on the quality of fisheries, etc. (Schuster & Highland 2001; 2007).

The evidence from the literature review shows that estimates of the costs of landslides are sparse, particularly estimates of the indirect costs. Calculations have been made on the costs of flooding however and these are also relevant to an analysis of landslides. The floods in the summer of 2007 that affected areas of England and Wales have been estimated to have caused damage costing £4 billion, comprising £3 billion in insurance claims (Pitt 2008) and about £1 billion in other costs (Chatterton et al. 2010). Of the £1 billion borne by businesses some 75% was recovered through insurance. There were 35,000 insurance claims by businesses in the UK associated with the 2007 floods. Depending upon which estimate is considered the average commercial insurance claim ranged between £24,000 and £90,000. Economic losses were estimated as being between £0.29 billion and £0.55 billion. These exclude indirect consequential economic impacts but the estimates of the costs of business disruption were calculated to be relatively low at between £160,000 and £168,000 – the main damage from the floods was to property.

In 2009, floods in Cumbria led to significant damage to business – £174 million was paid out by the insurance industry with an average £60,000 per business (Anon., 2010). According to the Environment Agency, flood defence spending can bring an 800% return on investment, through a reduction in the long-term costs of damage from flooding (Anon., 2010). This does raise the question as to whether investment made to ameliorate the impacts of landslides would have similar rates of return.

Socio-economic losses (both direct and indirect) due to landslide activity can be significant and these may be growing in some areas of the world as human development expands into unstable hill slope areas under the pressures of population growth. In addition, Petley (2010) suggests that the available evidence points to an increase in the number of rainfall-induced fatal landslides in Asia as a result of global climate change. The United States has relatively good estimates of reported economic losses with estimated total annual losses (direct and indirect) of about US$2 billion per year (at 2000 values) (Schuster & Highland 2001; 2007). The number of landslide fatalities in the United States is estimated at around 25 to 50 per annum. The economic losses in other countries are somewhat more difficult to assess but loss of life and socio-economic impacts are significant in nations from each continent; China and Italy perhaps stand out as examples of nations in which the losses are particularly high.

The California Department of Transportation conducted research in Mendocino County in north California following the Confusion Hill landslides on the US-101 route (Anon. 2003). Mendocino County is not dissimilar to northern Scotland as it is relatively peripheral in location and tourism is an important industry. In addition the detour incurred by traffic following the event was 75 miles, the same distance as that for the Glen Ogle event (see Appendix A). The Glen Ogle diversion is 75 miles (120km) from the A82/A85 to the A85/A84 junctions. The actual diversion distance is, of course, to some extent dependent upon both origin and destination and does not account for the distance that would otherwise have been travelled if the closure were not in place so the additional distance travelled is somewhat less. In this case the distance between the A82/A85 to the A85/A84 junctions on the A85 is around 16 miles (26km) so the additional distance travelled by those following the diversion is around 59 miles (94km)

The Californian study produced some headline figures for cost and delays relating to this heavily trafficked route (around 5,800 vehicles per day AADT of which 475 are trucks with five or more axles), as follows:

- It was estimated that the cost to the travelling public (all vehicles) of the diversion was around $238,000 per day ($7.1 million per month).
- A one-lane closure results in around 30 to 60 minutes delay per vehicle, and would cost an estimated $56,000 per day ($1.7 million per month) in travel delays.
- It was argued that the added cost of travel and inconvenience would discourage tourism – the leading economic and business sector – which accounts for 25% of all spending in the area.
- It was further estimated that a 25% loss of that tourism spending would result in a $13 million per month loss in business sales, which would endanger the viability of

many smaller tourist-dependent establishments. It would also have an adverse impact upon local tax revenues.

- The average cost of rectifying a catastrophic landslide at Confusion Hill was estimated to be of the order of $45 million while the cost of a proposed realignment of the highway was estimated at $71 million.
- Total benefits from avoiding the costs of a closure, including travel time and vehicle operating cost savings, were estimated to be $185.6 million.
- The benefit-cost ratio was estimated at 2.6; indicating a net benefit that could potentially, and depending on other claims for funding, justify the investment.

As part of a wider US study (Spiker & Gori 2003; Highland 2006) the Nebraska Geological Survey (Eversoll 2005) identified the following costs for defined time periods as a result of landslide events:

- 1981-1991 = $1,100,000.
- 1992-2002 = $3,598,508.

These figures are considered significant not least as Nebraska is not generally considered to have a major landslide problem, although Eversoll does suggest that around 10 to 15 landslides occur and are studied each year (1882 to 2005).

In Hamilton County, Ohio the costs of landslide damage averaged about $5,170,000 per annum between 1973 and 1978 (Rockaway, 2002; Rockaway et al. 2005). Fleming & Taylor (1980) believed that these estimates were lower than the actual costs incurred because many records were incomplete or unavailable and that the indirect costs (e.g. legal fees, architectural fees, etc.), which were excluded from the study, could have exceeded the direct costs.

In Oregon, economic losses due to landslides for a typical year were estimated to be over $10 million but in years with heavy storms, such as 1996, could exceed $100 million (Wang et al. 2002).

In Pennsylvania the total public and private costs of landslides in Allegheny County averaged at least $4 million per annum from 1970 to 1976 while the State Department of Transportation spent an of average $10 million a year on landslide repairs (Delano 2002).

Losses for the Heather Drive landslide in Layton, Utah were determined from a variety of sources including City records, County tax records and newspaper articles; the costs were found to vary between around $0.5 million and £1.1 million (Ashland, 2003).

Nationwide in the US landslide losses were estimated to range between $1.2 and $2.4 billion annually according to the Utah Geological Survey (Ashland, 2003; Schuster, 1996), despite losses often being poorly documented. These figures compare to the total costs of the damage caused by the Nisqually earthquake event which were estimated at $2 billion (Highland, 2003).

Example costs of landslides in the US have been estimated by MacLeod et al. (2005), see Table 1. In some cases in Table 1 the indirect costs appear to be significantly in excess of the direct costs.

In his unpublished keynote address to the IAEG Congress in Turin, Burns (Personal Communication, 2014) suggested that in the USA around 25 to 50 deaths result from landslides each year and that the financial losses associated with all (not just fatal) events are on average around $3.5bn. Of particular interest are the losses from the Oso landslide that occurred on 22 March 2014. With 43 deaths, Burns reported this as the most significant fatal landslide in the history of the USA. Losses were reported to have reached a total of $160M, with $7M being the value attributed to buildings damaged and destroyed, $3M to building contents and vehicle losses and the remaining $150M to the emergency response and clean-up operations. No attempt seems to have been made, as yet, to place a value on the disruption to traffic and the broader economy in the area, or to estimate the cost to society of the fatalities.

Table 1. Examples of direct and indirect costs of landslides in the USA (from MacLeod et al. 2005).

Date	Location	Direct costs	Indirect costs	Source of indirect cost
1968-69	Bay area (nine counties)	$44 to $60 million	$39 million	Reduced market value
1983	Thistle, Utah	$300 to $480 million	$150 million (lost by one rail company)	Road closure and reduced production, increased unemployment/ lower incomes
1983	Closure of US Highway 50 in California and Nevada	$5.7 million	$111 million (for the loss of access for two months)	Loss of tourism revenue
1997	Closure of US Highway 50 in California	$5.3 million	Over $59 million	Detour costs and lack of access for four weeks

According to Fleming & Taylor (1980), where studies of the costs of landslides have been conducted it is apparent that:

- Costs to both the public and private sectors due to landslide damage are much larger than anticipated.
- Taxpayers and public officials are generally unaware of the magnitude of the cost, owing perhaps to a lack of any centralisation of data.
- Incomplete records and unavailability of records result in lower reported costs than actually were incurred.

The slow-moving Ashcroft Thompson River landslides affect the Canadian Pacific Railroad in southern British Columbia. More than 20 landslides have occurred in the area ranging in size from 10,000m^3 to 5Mm^3. This has led to a significant amount of work being undertaken to understand the slides and to establish an appropriate management and mitigation system (Bunce 2008; Bunce & Chadwick 2012; Bunce & Quinn 2012; Lacasse 2013). Mitigation options proved either costly and/or had a negative environmental impact, especially on the river fishery. Management has thus been introduced through a monitoring system to provide early warning of significant movements. Individual landslides were costing the railway relatively little in terms of maintenance and reduced operating efficiency (Lacasse 2013), but detailed economic assessments revealed (Bunce & Quinn 2012) that a 20 year return period slide would, for example, cost the railway around CA$12M but society CA$800M. This information was used to justify expenditure on both research, and management and mitigation activities.

Osuchowski & Roberts (2011) present data for landslides costs in the Wollongong area of Australia. They present data for several different areas and in relation to particular event sets, as follows:

In general, they set out costs for direct costs between

- Woonoona Heights: AU$1.7M.
- Harry Graham Drive: AU$4.12M.
- Costs resulting from the August 2008 storms: AU$4.8M.
- Morrison Avenue: AU$8M.
- Mt Ousley Road: AU$40M (excluding AU$100k per annum monitoring costs).
- Lawrence Hargrave Drive: AU$80M (excluding AU$200k per annum monitoring costs and around AU$1.1M in legal costs).

It seems clear that the wide variation in these costs occurs for a number of interrelated reasons including, but not exclusively, the severity of the incident(s), the difficulty of remediation, the complexity of the solution(s) proposed, the importance and density of infrastructure, the presence or otherwise of buildings, the ability of the local authority to pay for the works, and the availability of central government funds. The latter two factors might be equated to the willingness to pay (Winter & Bromhead 2012). The expenditure on road repairs at Harry Graham Drive was equated to an equivalent cost to ratepayers of AU$7,400 per metre of road and it was also noted that many sites remained unaddressed due to the prohibitive cost of repairs.

Although Osuchowski & Roberts (2011) present data for 'indirect' costs these are typically for investigative works and relocation of new infrastructure and would be viewed as direct costs in the framework considered here. Indirect costs associated with increased travel time and distance, increased transport costs, loss of trade and tourism, and decreased property values are described as 'unknown'. It was concluded that existing cost and loss models were not suited to effectively capture that nature of short term and long term landslide impacts, even though it was clear that the impacts and costs of, for example, a home being destroyed by a landslide were no less than similar losses caused by other types of geo-disasters such as tropical cyclones or floods.

4.2 Vehicular Vulnerability

Whilst vehicles travelling on a network are at risk from either impacting or being impacted by landslides, it is important to recognise the potential effects from secondary events. The vulnerability of road vehicles is, of course, greatly increased when an obstruction, such as a landslide, causes the traffic to stop and the headway between vehicles decreases (i.e. the vehicles are not only stationary but also closer together). The vulnerability to secondary events, such as those reported for both the A85 at Glen Ogle and the A9 to the north of Dunkeld (Winter et al. 2006) is then much greater and the importance of rapid and effective evacuation is highlighted (Winter & Bromhead 2012).

In discussing the risk to standing traffic from rock fall Fell & Hartford (1997) clearly indicate that the risk depends upon, amongst other factors, the length of time that the vehicles are stationary. This is well-illustrated by Bunce et al. (1997) who demonstrate that in the particular case that they present the risk to a moving vehicle from a falling rock is approximately one order of magnitude less than that to which a vehicle remaining stationary for 30 minutes at the same location is exposed.

Work on the rail network at Maple Ridge in British Columbia (Bunce 2008) calculated the annual probability of a freight or passenger train crew fatality as a result of a landslide hitting a moving train as 1.2×10^{-5}, whilst that for a moving train hitting a landslide was two orders of magnitude greater at 3.6×10^{-3}. Interestingly, it was concluded that in British Columbia the risk of a fatality from a landslide hitting a stationary train was minimal, primarily because trains were only rarely stationary in areas of landslide hazard.

4.3 Budgetary Issues

Budgets for landslide risk mitigation will often be set in direct competition with those for the mitigation of other risks. Finlay & Fell (1997), for example, point out that the contemporaneous fatality rate in Australia, per million of the population, due to all landslides was around two orders of magnitude less than that for involvement in a road traffic accident while driving a car. Road administrations whose infrastructure is affected by landslides, for example, must balance the risks associated with both road traffic accidents and those from landslides and other hazards. It might be assumed that those risks associated with landslides might be deemed to be of relatively low importance. However, this does not take account of the fact that while the risk to life and limb from landslides may be, in relative terms, quite low, the risk to the operation of the network, and the associated socio-economic activities, from such events is of much greater magnitude (Winter & Bromhead 2012).

In addition, Winter & Bromhead (2012) note that it does seem that the risks associated with road traffic accidents are tacitly accepted. This may well be due to the fact that road traffic accidents are common and generally involve a relatively small number of casualties, compared to say an event such as a rail or air accident, even though the overall annual casualty rate is much higher. It seems unlikely, based upon the lead authors' experience that landslide risks are similarly accepted, either tacitly or otherwise; the relative infrequency of the events, compared to road traffic accidents, seems to be a likely contributor. In addition, in many parts of the world these infrequent events often involve higher numbers of fatalities (where fatalities occur). This in turn raises the profile of their coverage in the media and the amount of public and political interest generated to a much higher level, more akin to that of a rail or air accident.

4.4 Socio-economic Impacts of Landslides

According to Glenk et al. (2010) the socio-economic impacts of landslides and soil erosion affect six broad soil functions as identified in Table 2, in which a range of direct and indirect costs are highlighted. While many such costs are not incurred as a result of landslides they do have a wide catchment area as highlighted for landslides in terms of the vulnerability shadow in Section 3. Studies demonstrate that little actual data exists to enable robust quantitative assessments to be made on many of the impacts of landslides (e.g. Dobbie et al. 2011; Anon. 2013a). For example, data is not available concerning the impact of landslides upon recreational activities. Furthermore no estimates of the health impacts are available. The cost classification (private, social, mitigation, defensive and non-use value) used by Dobbie et al. (2011) is not one that would be applied in a standard cost-benefit analysis, however. Nevertheless this study provides an idea of some of the indirect consequential costs that might be considered.

Table 2. The socio-economic impacts of landslides and soil erosion (from Dobbie et al. 2011).

Soil Function	Cost Type	On site/ Off site	Description	Impact Status[1]	Data Status[2]
Providing the basis for food and biomass production	Private cost	On	Loss of agricultural productivity	Low to medium	Y
		On	Costs of sediment removal from ditches	Medium	Y
	Mitigation cost	On	Costs of erosion prevention	Low	Y
Controlling and regulating environmental interactions	Social cost	Off	Impacts on health	Low	N
		Off	Costs associated with erosion-related water treatment	Medium	Y
	Private cost/ social cost	Off	Damage from floods, landslides or mudslides	Medium	Y
	Defensive cost	Off	Expenditure to reduce off-site impacts of erosion	Low	N
Storing carbon and maintaining the balance of gases in the air	Social cost	Off	Loss of carbon-rich topsoils, increased wetness leading to greater losses of greenhouse gases. Loss of carbon through peat slides.	High	Y
Providing valued habitats and sustaining biodiversity	Non-use value cost	Off	Adverse impacts on natural ecosystems	Variable	Y
Protection of cultural and archaeological heritage	Non-use value cost	Off	Soil erosion may expose buried archaeological remains	Variable	Y
Providing a platform for buildings and roads	Social cost	Off	Costs of sediment removal	Medium-to-high	Y
	Social cost	Off	Damage to infrastructure by landslides	Low	Y
	Social cost	Off	Impact on recreational activities	Variable	N

[1] Impact status is based on a 20 to 25 year timescale assessment of the severity of biophysical change, geographical extent and contribution of single economic impact.
[2] Y = economic estimates are available in Görlach et al. (2004), Harris et al. (2006) and Anon. (2009a; 2009b); N = no data available.

Various estimates of costs have been reported by Dobbie et al. (2011) from other research:

- Soil erosion: £0.10 to £38.19 per hectare per year.
- Retaining buffer strips: £15.50 per hectare per year.
- Loss of organic matter and subsequent losses of CO_2 from arable land: £36.00 per hectare per year.
- Erosion damage in Scotland: £1.3 million (2008 data)
- Cost of drinking water treatment: £19.8 million.

Results from an international survey of how companies in the transport, logistics and infrastructure sectors dealt with the repercussions of extreme weather events disclosed that business people did not have a good grasp of linkages between the probability of such events and the risks of business damage. Very few had catalogued the problems encountered and could not therefore appraise the risk and the tolerance of a company of that risk; nor could they take decisions on which risk prevention strategy to pursue. Even when companies recognised the need for proactive actions to mitigate against weather events, the resources allocated were meagre.

Keeping reserves, for example standby staff, buffer stocks or equipment was considered unwise; many vital business operations were outsourced due to the need for lean production. The research by Ludvigsen & Klaeboe (2011) suggested that as a result the negative consequence of factors such as delayed responses and longer delivery times for critical components had not been factored into decisions.

A survey undertaken in Great Britain by the Freight Transport Association (FTA) of 5,000 members covering the impact of snowfalls in January and December 2011, reported by Ludvigsen & Klaeboe (2011), led to the development of strategies to ensure that critical commodities such as medicines, heating oil and LPG (Liquid Petroleum Gas) could be delivered in an emergency. One feature of those strategies is the monitoring of the most exposed part of the road network and critical junctions to identify 'hot spots' prone to causing traffic disruptions and flow stoppages.

An associated international survey of freight and logistics companies (again reported by Ludvigsen & Klaeboe 2011) on the impacts of extreme weather events highlighted that almost none of the participants had registered monetary values of the additional expenses which bad weather had imposed upon them. Furthermore they expected more assistance from the authorities in dealing with the consequences of weather impacts.

4.5 Methods for Assessing Indirect Consequential Costs

A detailed review of the potential methods of estimating the indirect consequential economic impacts of landslide event is presented in Appendix B. Each approach has been assessed against key criteria that are relevant to the investigation of the indirect consequential economic impacts of landslides in Scotland and tabulated. These key criteria are:

- Suitability for the study of the economics of landslides (and similar events).
- Ability to gather data locally.

- Ability to reduce data to a common metric.
- Avoidance of bias.

In order 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 a survey of businesses has been trialled in Section 6.

5 Direct Economic Impacts

Direct economic impacts (Section 3) 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'.

It was intended that the Direct Economic Impacts of four events would be determined. However, as the project has progressed the following events were identified:

Site 1: A83 Glen Kinglas to Cairndow, 18 August 2004.

Site 2: A9 North of Dunkeld, 11 August 2004.

Site 3: A85 Glen Ogle, 09 August 2004.

Site 4: A83 Rest and be Thankful, 28 October 2007.

Site 5: A77, A76, A71 Bellfield Junction, 21 September 2012.

Site 6: A83 Rest and be Thankful, 28 October 2014.

Site 7: A78 Largs to Skelmerlie coastal flooding, January 2012.

Site 8: A8 Inverclyde flooding, January 2011.

As noted in Section 2, direct economic impacts ought to 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 were readily available from Scotland TranServ who were the OC for the north-west at the time of enquiry. This earlier event was chosen over more recent events (2008 to 2013) due to the extended duration of the associated closures and the well-documented and significant subsequent remedial actions.

Data from less recent events such as the landslide events of 2004 (Winter et al. 2005; 2006; 2009) proved more difficult to obtain (Table 3); as Highland (2006) points out past data are generally labour intensive to retrieve. These events occurred during the tenure of the previous OC and of the former Performance Audit Group (PAG). Cost data relating to the events is contained in a legacy system and this can be accessed only by interrogation using the job number assigned to a particular activity (i.e. it cannot be interrogated using a route, location or description). 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).

In addition, it has proven impossible to locate any data related to the January 2011, A8 Inverclyde flooding events despite discussions with the OC, at the time Amey, and PAGplus. This most likely indicates that clean-up works were undertaken as part of normal operations and that the effects were somewhat less than had previously been anticipated. The A77, A76, A71 Bellfield Junction flooding was identified as an alternative.

The available data for each event is given in Table 3 at prices for the year of the event and at 2012 prices in Table 4 to allow a direct comparison with other event data presented in this report.

Table 3. Direct economic impacts (at event year prices).

Event	Emergency response (£)	Remedial works (£)	Total (£)
Site 1: Landslides A83 Glen Kinglas to Cairndow, 09 August 2004	300,000[1]		300,000
Site 2: Landslides A9 N of Dunkeld, 11 August 2004	700,000[1]		700,000
Site 3: Landslides A85 Glen Ogle, 18 August 2004	500,000[1]		500,000
Site 4: Landslide A83 Rest and be Thankful, 28 October 2007	270,081.47[2]	1,155,716.77[3]	1,425,798.24
Site 5: Flooding A77, A76, A71 Bellfield Jn, 21 September 2012	16,755.71	8,332.77	25,088.48
Site 6: Landslide A83 Rest and be Thankful, 28 October 2014	262,801.20	0[4]	262,801.20
Site 7: Flooding A78 Largs to Skelmerlie, January 2012	4,854.04	22,179.52	27,033.56
Site 8: Flooding A8 Inverclyde, January 2011	No data available (see text)		

[1] The gross figure of £1.5M for the three 2004 sites is taken from contemporaneous reports to Scottish Ministers. The division of costs between the events was estimated in cooperation with the Civil Servant responsible for that reporting at the time of the events, the recollections of the first author and those of a member of the senior management team of the Operating Company responsible for the A85, A9 and A83 in 2004 (BEAR Scotland).

[2] Clear-up and clear-up management, geotechnical and design input, management and advice, helicopter surveys and associated assessment activities, and traffic management.

[3] Comprises: debris barrier (including design, tender, award, construction and supervision) £358,213.96 (at event year prices); works prior to culvert replacement (including ongoing traffic management and carriageway protection, culvert design, geotechnical design and certification, ground investigation and diversion fibre optic telecommunications cable) £152,551.94; and culvert replacement (construction) £644,950.87. These works were undertaken in direct response to the October 2007 event and may thus be attributed to this event.

[4] While an extensive programme of remedial works has been undertaken at the wider A83 Rest and be Thankful site, some of which is focussed on the location of the 28 October 2014 event, this was installed prior to the event and thus cannot be attributed to this event. In broad terms the remedial measures, including both management and mitigation measures (Winter, 2014), worked as anticipated and would not have been expected to prevent a debris flow of this size from reaching the road.

The notes to Tables 3 and 4 state that the costs for remedial works for the A83 Rest and be Thankful landslide in October 2007 include those attributable to the construction of fences that eventually became the first phase of a much wider mitigation programme. These costs are approximately £358k at event year prices or £425k at 2012 prices. It is arguable whether or not these costs should be included here or should be considered part of a wider more strategic programme of expenditure so the costs attributable to the October 2007 A83 Rest and be Thankful event are between £1,275k and £1,700k at 2012 prices.

Data from the five landslide events and two flooding events yield direct economic impacts from approximately £25k to £1,700k (£1,275k if the costs of the fences are excluded); the two flooding events yield the lowest direct economic impacts at less than £30k, while those for the landslide events range from around £250k to £1,700k (£1,275k if the costs if the fences are excluded). Cleary these costs are significantly higher for landslide events than for flood events; this most likely reflects the fact that more active measures are needed to remove landslide debris than are needed to remove flood waters. The lower costs for flooding events are supported by Milne et al. (2016) who include direct economic impact costs of around £30k (at 2012 prices) for an additional coastal flood at the A76 between Skelmorlie and Largs in January 2014.

Prices are presented for a constant year throughout this report in order to allow a valid comparison of events. 2012 was selected as this 'base' to minimise the time period over which costs were discounted and as it was the year for which the most recent road accident costs were available at the time of the initial analysis (see Section 6.1).

Table 4. Direct economic impacts (at 2012 prices[1]).

Event	Emergency response (£)	Remedial works (£)	Total (£)
Site 1: Landslides A83 Glen Kinglas to Cairndow, 09 August 2004	395,043[2]		395,043
Site 2: Landslides A9 N of Dunkeld, 11 August 2004	921,766[2]		921,766
Site 3: Landslides A85 Glen Ogle, 18 August 2004	658,405[2]		658,405
Site 4: Landslide A83 Rest and be Thankful, 28 October 2007	320,772[3]	1,372,629[4]	1,693,401
Site 5: Flooding A77, A76, A71 Bellfield Jn, 21 September 2012	16,756	8,333	25,088
Site 6: Landslide A83 Rest and be Thankful, 28 October 2014	245,328	0[5]	245,328
Site 7: Flooding A78 Largs to Skelmerlie, January 2012	4,854	22,180	27,034
Site 8: Flooding A8 Inverclyde, January 2011	No data available (see text)		

[1] Throughout this report the Discount Factor, D_F is calculated from = $1 / (1+D_R)^N$ where D_R is the discount rate and N is the number of years. D_R is taken as 3.5% in line with the HM Treasury Green Book recommendation for periods of zero to 30 years.
[2] Estimated from an aggregate figure of £1.5M reported to Senior Civil Servants and Ministers.
[3] Clear-up and clear-up management, geotechnical and design input, management and advice, helicopter surveys and associated assessment activities, and traffic management.
[4] Comprises: debris barrier (including design, tender, award, construction and supervision) £425,446 (at 2012 prices); works prior to culvert replacement (including ongoing traffic management and carriageway protection, culvert design, geotechnical design and certification, ground investigation and diversion fibre optic telecommunications cable) £181,184; and culvert replacement (construction) £765,999. These works were undertaken in direct response to the October 2007 event and may thus be attributed to this event.
[5] While an extensive programme of remedial works has been undertaken at the wider A83 Rest and be Thankful site, some of which is focussed on the location of the 28 October 2014 event, this was installed prior to the event and thus cannot be attributed to this event. In broad terms the remedial measures, including both management and mitigation measures (Winter, 2014), worked as anticipated and would not have been expected to prevent a debris flow of this size from reaching the road.

6 Direct Consequential Economic Impacts

Direct consequential economic impacts are those that relate to 'disruption to infrastructure' and in large part relate to 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 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 involving large numbers of casualties, data relating to railway accidents may be more appropriate.

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.

To assess the extent of this impact, QUADRO (QUeues And Delays at ROadworks) was used to model six case studies, as follows:

Site 1: Landslide at A83 Glen Kinglas to Cairndow, 18 August 2004.

Site 2: Landslide at A9 North of Dunkeld, 11 August 2004.

Site 3: Landslide at A85 Glen Ogle, 09 August 2004.

Site 4: Landslide at A83 Rest and be Thankful, 28 October 2007.

Site 5: Flood at A77, A76, A71 Bellfield Junction, 21 September 2012.

Site 6: Landslide at A83 Rest and be Thankful, 28 October 2014.

Further details of the analyses are given in Appendix A. Peak month traffic figures, usually August, were used throughout to avoid any potential undercounting of the impacts.

6.1 Accident Costs

An essential part of the make-up of direct consequential economic impacts is the cost of casualties, or accidents. Transport Scotland and the Department for Transport (Anon. 2002 to 2014; Anon. 2013b) present annual costs of road accidents by casualty severity and road type in Scotland and Great Britain respectively. These are reproduced for Scotland in 2012, as an example, in Table 5.

The numbers reported relate to the total value to society of the benefits of prevention of road accidents. The costs of individual casualties are also presented and are lower than the values in Table 5 for two reasons (Anon. 2013b):

1) An injury accident is classified according to the most severe casualty but will on average involve more than one casualty (e.g. a 2012 fatal accident in Great Britain involved an average of 1.07 fatalities, 0.296 serious casualties and 0.43 slight casualties).

2) There are some costs which are part of the valuation of an injury accident but which are not specific to casualties:

    - The costs of damage to vehicles and property.
    - Police costs and administrative costs of accident insurance.

Table 5. Example costs per reported road accident by road type in Scotland for 2012 (at 2012 prices) (from Anon. 2002 to 2014).

Costs (£ 2012)	Road Type				All Roads
Accident Type	**Built-up roads** (speed limit 40mph or less)	**Non Built-up roads** (speed limit >40mph)	**Motorways** (including A(M) roads)	**Trunk Roads Only**	
Fatal	1,814,995	2,053,313	1,786,437	2,186,740	1,951,042
Serious	210,127	243,899	237,673	252,848	224,578
Slight	21,141	24,462	29,240	25,597	22,512
Average for all severities	69,749	130,542	74,878	116,191	90,034
Damage only	1,877	2,788	2,681	2,520	2,061
Average for all accidents	5,506	17,305	11,076	13,743	7,914

Both casualty and accident costs include the following elements of cost (Anon. 2013b):

- Loss of output due to injury. This is calculated as the present value of the expected loss of earnings, plus employers' non-wage payments.
- Ambulance costs and the costs of hospital treatment.
- The human costs of casualties. These are based on the willingness to pay to avoid pain, grief and suffering to the casualty, relatives and friends, as well as intrinsic loss of enjoyment of life in the case of fatalities.

It is important to note that the accident costs presented for Scotland are generally higher than those for Great Britain as a whole. This is generally recognised to be *inter alia* due to the more rural and remote nature of the network in Scotland which increases some costs.

In this context it seems that the most effective data for use in determining this element of the direct consequential economic impacts of landslides and floods is the cost of accidents (as opposed to the cost of casualties) for the road type that was effected by the landslide. This also enables costs of vehicle 'damage only' incidents to be accounted for when there are no casualties, as has been the case for the events studied to date.

In most cases the road type will be adequately described as 'non built-up' as almost all of the roads under consideration have a speed limit in excess of 40mph, however, they are also, in the main, trunk roads. The only exception is the A71 which forms part of Site

5. Here the A71 is a primary route and to the west is dual-carriageway. The data for 'trunk roads only' thus seems to be the most appropriate data set for use.

Costs for different severities and for damage only are given for trunk road accidents in Scotland in Appendix A.1 for the years 2001 to 2013.

The actual accident costs for Sites 1 to 6 (above) do not involve casualties so in this instance the figures for Damage Only accidents are most appropriate. Based on contemporaneous images and discussions with those involved in work immediately following the events, the number of vehicles involved in each of the incidents is as follows (Table 6):

Site 1: One car, albeit unconfirmed (one vehicle in total).

Site 2: Two cars, one car with caravan, one van and one truck (five vehicles in total).

Site 3: One car (4WD) and two vans (including an Operating Company vehicle) (three vehicles in total).

Site 4: One car that appears to have driven partially over the run-out at road level (one vehicle in total).

Site 5: None that are known of.

Site 6: None that are known of.

Although the costs used are per accident, the nature of the events is such that each vehicle damaged is a separate incident, or accident. That is, there is no contact between vehicles and often if the vehicles are at opposite sides of the event the route taken by those offering assistance will be entirely different and the response completely separate.

The data in Appendix A.1 has been used as a look up table to populate the incident accident cost columns per vehicle in Tables 7 to 9 and total costs in Tables 10 to 12. Tables 7, 8, 10 and 11 give accident costs at prices for the year of the event. Tables 9 and 12 give accident costs at 2012 prices allowing a direct comparison with other event data presented in this report.

6.2 The QUADRO Model

The purpose of QUADRO is to provide a method for assessing the costs imposed on road users while roadworks are being carried out, considering:

- Delays to road users: the change in users' journey times, priced using the value of road users' time (e.g. the cost to their employer's business of the time spent travelling during the working day) based on the type of vehicle, its occupants and the purpose of the trip.
- 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: Anon, 2012a and WebTAG: Anon, 2012b).
- Accident costs: the change in the occurrence of accidents, in terms of the additional delay caused and the direct costs of the accidents (e.g. property damage, police time and insurance administration). Clearly these are not the same as the accident costs referred to in Section 6.1.

The program contains a model for allocating traffic to the diversion route if, during a partial closure, the site becomes overloaded, representing both the road users that queue through the site and those that take an alternative route. The details of QUADRO, including all assumptions made in its calculations, are provided in the manual (DMRB 14). The initial analysis was conducted using an earlier version of QUADRO that returned results at 2002 prices (Winter et al. 2014b). The results presented here exclusively use QUADRO Version R12 (released in early 2014), which returns results at 2010 prices.

6.2.1 Diversion Routes

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 Transport Scotland's map application[1] where available; for Site 2, local road traffic flows (A923, A924 and A93) were provided by Perth and Kinross Council and for Site 5 by Ayrshire Roads Alliance.

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 analysis for Site 5 was particularly complex and to avoid double-counting it was assumed that the traffic travelling to each destination was split as a proportion of the total flow at the origin. The proportions were calculated based on the traffic flows at the destinations. The recalculated traffic flows are shown in Appendix A.

In addition the assumption was made for Site 5 that there is no interaction between the diversion routes. This will mean that the total user delay cost calculated is, if anything, an underestimation. Some roads are part of multiple diversion routes so by assuming there is no interaction the traffic modelled on each route is lower than it would have been in reality. Nonetheless, this approach should give a good approximation of user delay cost.

The analysis for Site 6 made provision for the three types of traffic management used during the aftermath of the event: closure, convoy on the Old Military Road (OMR) and shuttle working (single lane with traffic lights) working. QUADRO limits the closure length for convoy and shuttle working to 500m. Therefore, in order to provide a reasonable estimate of the delay, carbon and accident costs for convoy working on the OMR the costs were modelled for convoy lengths of 100m, 200m, 300m, 400m and 500m and the results extrapolated to 4,000m (the length of the convoy at the OMR). The results of the extrapolation are presented in Appendix A.2.

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[1] http://www.transportscotland.gov.uk/road/technology/traffic-count/map-application

Table 6. Site and incident parameters.

	Number of Vehicles Damaged	Traffic flow (AADT) (vehicles per day)[1]	HGVs (%)	Junction length (km)	Closure type(s)	Closure duration
Site 1: A83 Glen Kinglas to Cairndow, 09 August 2004	1	5,554	9	20	Full closure	2 days
Site 2: A9 North of Dunkeld, 11 August 2004	5	13,864	18	18	Full closure then shuttle working with convoy	2 days (full) 6 days convoy
Site 3: A85 Glen Ogle, 18 August 2004	3	4,403	10	26	Full closure	4 days
Site 4: A83 Rest and be Thankful, 28 October 2007	1	5,748	10	20	Full closure then shuttle working[2]	15 days (full) 27 days (single lane)[3]
Site 5: A77, A76, A71 Bellfield Junction, 21 September 2012	0	The analysis for Site 5 is particularly complex and details are given in Appendix A			A77: Full closure A76: Full closure then shuttle working A71: Full closure	A77: 25 hours A76: 19 hours (full), 2 days (single lane) A71: 67 hours
Site 6: A83 Rest and be Thankful, 28 October 2014	0	5,460	9.5	20 / 4[4]	Full closure (daytime) Full closure (night time) Convoy (daytime)[5] Convoy (night time)[5] Shuttle (daytime) Shuttle (night time) Shuttle (24 hours)	10 hours 28 hours 42 hours 56 hours 40 hours 42 hours 682 hours

[1] Peak month (usually August) taken from the Transport Scotland traffic map application at the time the analysis was undertaken (http://www.transportscotland.gov.uk/map-application).
[2] Single-lane working with traffic light control.
[3] 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.
[4] 20km for full closure, 4km for convoy working on the old Military Road (OMR).
[5] Using the OMR, the temporary diversion used when the A83 Rest and be Thankful road is closed.

6.2.2 *Analyses*

The six sites were represented as shown in Table 6.

It was assumed that all of the roads affected, with the exception of the A77 and the westerly A71, 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 or flood, and that the length of the affected site in each case was 100m.

6.2.3 *Results*

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 daily QUADRO analyses are shown in Tables 7 to 9 and total closure costs in Tables 10 to 12. Tables 7 and 10 give the output directly from QUADRO at 2010 prices, Tables 8 and 11 give the data at prices relating to the year of the event, and Tables 9 and 12 give data at 2012 prices allowing direct comparison of the economic impacts of different events.

Table 7. Incident accident costs per vehicle and QUADRO closure instance (and daily) costs.

Site (Event Year)	Incident Accident Cost (£ per Vehicle)[1]	Closure	Cost (£ per closure instance) (QUADRO)[2]		
			Delays	Carbon	Accidents
1 (2004)	1,989	Full closure (24 hours)	78,481	5,956	-4,070
2 (2004)	1,989	Full closure (24 hours)	252,874	17,371	-10,506
		Single lane closure with convoy (24 hours)	126,340	8,685	-5,253
3 (2004)	1,989	Full closure (24 hours)	66,913	6,188	-4,195
4 (2007)	2,445	Full closure (24 hours)	82,186	6,152	-4,212
		Shuttle working (24 hours)	430	6	741
5 (2012)	2,520	Full closure (24 hours)	1,445,657	69,007	-36,004
		Shuttle working (24 hours)	88,089	626	7,061
6 (2014)	2,573	Full closure (daytime, 10 hours)[3]	39,324	2,943	-1,978
		Full closure (night time, 14 hours)[3]	30,708	2,344	-1,653
		Full closure (24 hours)[3]	77,880	5,846	-4,001
		Convoy (daytime)	7,210	109	1,462
		Convoy (night time)	4,611	70	1,029
		Convoy (24 hours)	11,821	179	2,491
		Shuttle (daytime)	246	4	413
		Shuttle (night time)	157	2	291
		Shuttle (24 hours)	403	6	704

[1] At prices for the year of the event (from Appendix A.1), for Site 6 the most recently available data (for 2013) is used.
[2] At 2010 prices (the standard output from QUADRO).
[3] Note that the Full closure (daytime, 10 hours) and Full closure (night time, 14 hours) do not add up to the Full closure (24 hours) delay, carbon and accident costs. This is because the Full closure (daytime, 10 hours) cover the period 05:00 to 15:00 and the Full closure (night time, 14 hours) cover the period 17:00 to 07:00. This excludes 15:00 to 17:00 when traffic levels and therefore costs are high and double counts the period 05:00 to 07:00 when traffic levels and costs are low. This is because of the way in which the closures occurred and to allow the calculation of a total cost of the event. The Full closure (24 hours) costs are calculated for a midnight to midnight closure. This does not apply to the convoy or shuttle costs.

Table 8. Incident accident costs per vehicle and QUADRO daily closure costs (at prices for the year of the event).

Site (Event Year)	Incident Accident Cost (£ per Vehicle)[1]	Closure	Cost (£ per day) (QUADRO)		
			Delays	Carbon	Accidents
1 (2004)	1,989	Full closure (24 hours)	63,844	4,845	-3,311
2 (2004)	1,989	Full closure (24 hours)	205,713	14,131	-8,547
		Single lane closure with convoy (24 hours)	102,778	7,065	-4,273
3 (2004)	1,989	Full closure (24 hours)	54,434	5,034	-3,413
4 (2007)	2,445	Full closure (24 hours)	74,127	5,549	-3,799
		Shuttle working (24 hours)	388	5	668
5 (2012)	2,520	Full closure (24 hours)	1,548,624	73,922	-38,568
		Shuttle working (24 hours)	94,363	671	7,564
6 (2014)	2,573	Full closure (daytime, 10 hours)[2]	42,125	3,377	-2,270
		Full closure (night time, 14 hours)[2]	35,238	2,690	-1,897
		Full closure (24 hours)[2]	89,369	6,708	-4,591
		Convoy (daytime)	8,274	125	1,678
		Convoy (night time)	5,291	80	1,181
		Convoy (24 hours)	13,565	205	2,858
		Shuttle (daytime)	282	5	474
		Shuttle (night time)	180	2	334
		Shuttle (24 hours)	462	7	808

[1] For Site 6 the most recently available data (for 2013) is used.

[2] Note that the Full closure (daytime, 10 hours) and Full closure (night time, 14 hours) do not add up to the Full closure (24 hours) delay, carbon and accident costs. This is because the Full closure (daytime, 10 hours) cover the period 05:00 to 15:00 and the Full closure (night time, 14 hours) cover the period 17:00 to 07:00. This excludes 15:00 to 17:00 when traffic levels and therefore costs are high and double counts the period 05:00 to 07:00 when traffic levels and costs are low. This is because of the way in which the closures occurred and to allow the calculation of a total cost of the event. The Full closure (24 hours) costs are calculated for a midnight to midnight closure. This does not apply to the convoy or shuttle costs.

6.2.4 *Summary and Discussion*

Data from the five landslide events and one of the flood events examined for direct economic impacts in Section 5, yield direct consequential economic impacts from around £175k to £3,200k. Those impacts for landslide events cover a wide range from £175k to £1,400k with the impacts of the flood event being around £3,200k. The costs, while including the costs of accidents associated with the events, are largely related to the amount of traffic affected, the duration for which it is affected, and the nature of the delays incurred (e.g. diversion, diversion length, convoy or traffic light working); the figure for the flood event corresponds with an environment in which traffic is substantially greater than for the landslide events.

There is no apparent relation between the direct and direct consequential economic impacts of landslide and/or flood events.

Careful consideration of the relative traffic levels, and closure type and duration (Tables 10 to 12), reveals patterns that are broadly consistent with those that might be inferred intuitively, as follows:

- The relative costs of similar closures depend on the traffic levels, with costs being higher where traffic is higher (Site 2 compared to Site 1).
- Where traffic levels are high and/or multiple roads and routes are affected then costs can be significant even when closure durations are relatively short (compare Site 4 to Site 5).
- Doubling the duration incurs higher costs, but may be reduced if the traffic levels are lower (Site 1 compared to Site 3).
- A much longer duration increases the costs significantly (Site 4).

Table 9. Incident accident costs per vehicle and QUADRO daily closure costs (at 2012 prices).

Site (Event Year)	Incident Accident Cost (£ per Vehicle)[1]	Closure	Cost (£ per day) (QUADRO)		
			Delays	Carbon	Accidents
1 (2004)	2,520	Full closure (24 hours)	84,071	6,380	-4,360
2 (2004)	2,520	Full closure (24 hours) Single lane closure with convoy (24 hours)	270,885 135,339	18,608 9,304	-11,254 -5,627
3 (2004)	2,520	Full closure (24 hours)	71,679	6,629	-4,494
4 (2007)	2,520	Full closure (24 hours) Shuttle working (24 hours)	88,040 461	6,590 6	-4,512 794
5 (2012)	2,520	Full closure (24 hours) Shuttle working (24 hours)	1,548,624 94,363	73,922 671	-38,568 7,564
6 (2014)	2,520	Full closure (daytime, 10 hours)[2] Full closure (night time, 14 hours)[2] Full closure (24 hours)[2]	42,125 32,895 83,427	3,153 2,511 6,262	-2,119 -1,771 -4,286
		Convoy (daytime) Convoy (night time) Convoy (24 hours)	7,724 4,939 12,663	117 75 192	1,566 1,102 2,668
		Shuttle (daytime) Shuttle (night time) Shuttle (24 hours)	264 168 432	4 2 6	442 312 754

[1] At prices for 2012 from Table 5 (i.e. not discounted from event year prices in Tables 7 and 8).

[2] Note that the Full closure (daytime, 10 hours) and Full closure (night time, 14 hours) do not add up to the Full closure (24 hours) delay, carbon and accident costs. This is because the Full closure (daytime, 10 hours) cover the period 05:00 to 15:00 and the Full closure (night time, 14 hours) cover the period 17:00 to 07:00. This excludes 15:00 to 17:00 when traffic levels and therefore costs are high and double counts the period 05:00 to 07:00 when traffic levels and costs are low. This is because of the way in which the closures occurred and to allow the calculation of a total cost of the event. The Full closure (24 hours) costs are calculated for a midnight to midnight closure. This does not apply to the convoy or shuttle costs.

The incident accident costs are generally relatively low, reflecting the rarity of known vehicle interactions with the events. The modelled carbon costs are around 5% to 9% of the delay costs.

Of particular interest are the negative accident costs (i.e. cost reductions) and these are primarily related to full closure and diversion; the sole exception being convoy working on the A9 (Site 2) in 2004. These suggest a decrease in accident occurrence and/or accident severity as a result of the diversions. This seems most likely to be as a result of reduced traffic speeds due to the increased level of traffic on the diversionary route. However, the diversionary routes may be narrower than the routes that traffic is diverted from, indicating a likely increase in accident costs. When convoy or traffic light working has been in place (i.e. single-lane working instead of or following complete closure) these costs become positive as, for example, at the A83 landslide in 2007. Overall it is considered that the accident costs indicated are sufficiently small compared to the delay costs as to suggest a neutral effect on accident occurrence and/or severity.

Table 10. Total incident accident costs and QUADRO total closure costs.

Cost (£)	Site (Event Year)					
	1 (2004)	2 (2004)	3 (2004)	4 (2007)	5 (2012)	6 (2012)
Incident accident cost[1]	1,989	9,945	5,967	2,445	0	0
Delay cost (QUADRO)[2]	156,963	1,137,445	267,654	1,244,388	2,875,719	162,390
Carbon cost (QUADRO)[2]	11,913	78,169	24,751	92,445	141,585	8,555
Accident cost (QUADRO)[2]	-8,141	-47,277	-16,779	-43,172	-66,568	27,507
TOTAL COSTS	162,724	1,183,282	281,593	1,296,106	2,950,736	198,452

[1] At prices for the year of the event from Appendix A.1.
[2] At 2010 prices (the standard output from QUADRO).

Table 11. Total incident accident costs and QUADRO total closure costs (at prices for the year of the event).

Cost (£)	Site (Event Year)					
	1 (2004)	2 (2004)	3 (2004)	4 (2007)	5 (2012)	6 (2012)
Incident accident cost	1,989	9,945	5,967	2,445	0	0
Delay cost (QUADRO)	127,690	925,312	217,737	1,222,367	3,080,542	186,346
Carbon cost (QUADRO)	9,691	63,591	20,135	83,380	151,669	9,817
Accident cost (QUADRO)	-6,623	-34,392	-13,650	-38,939	-71,309	31,565
TOTAL COSTS	132,747	964,455	230,189	1,169,253	3,160,902	227,728

Table 12. Total incident accident costs and QUADRO total closure costs (at 2012 prices).

Cost (£)	Site (Event Year)					
	1 (2004)	2 (2004)	3 (2004)	4 (2007)	5 (2012)	6 (2012)
Incident accident cost[1]	2,520	12,600	7,560	2,520	0	0
Delay cost (QUADRO)	168,143	1,218,460	286,718	1,333,020	3,080,542	173,956
Carbon cost (QUADRO)	12,762	83,737	26,514	99,029	151,669	9,164
Accident cost (QUADRO)	-8,721	-45,288	-17,974	-46,247	-71,309	29,466
TOTAL COSTS	174,703	1,269,508	302,817	1,388,322	3,160,902	212,587

[1] At prices for 2012 from Table 5 (i.e. not discounted from event year prices in Tables 10 and 11).

The landslide events were located in rural areas and their impacts were upon those areas and relatively 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, even though the effects of the flood persisted for a much shorter time (the daily delay costs due to closure for the flooding event were almost 20 times greater than those for the landslide event). Notwithstanding this the impacts of the landslide event(s) in areas in which alternative routes are limited should not be underestimated; those impacts were borne by a much smaller number of people over an extended period and the impacts on individuals and individual businesses seem likely to have been considerably greater.

The analysis of the events at, and near to, the A83 Rest and be Thankful (Sites, 1, 4 and 6) demonstrates that the costs of a full closure of the A83 are significant ranging from £83k to £88k per day for delay costs and from £85k to £90k per day for total (delay, carbon and accident) costs (at 2012 prices, Table 9). These figures are greater than the £52k (updated to £68k in 2015/16) per day reported in the A83 Route Study (Anon, 2013a). However, given the totally different methodologies used the two sets of figures are considered to be of the same order and are not considered to be contradictory. Under convoy working on the Old Military Road (Site 6), used as a temporary diversion, these costs reduce to just under £13k per day for delays and around £15.5k per day in total. The use of shuttle working (traffic light on a single lane closure) brings the equivalent costs down to less than £0.5k per day for delays and around £1.2k for total costs. These figures clearly demonstrate the economic benefits of the use of the Old Military Road as a temporary diversion while also demonstrating that the costs remain significant and that there is a benefit to reverting to shuttle working and, of course, fully re-opening the road as soon as possible.

Indirect consequential economic impacts are considered in Section 7.

7 Indirect Consequential Economic Impacts

The concept of the vulnerability shadow (Winter & Bromhead 2012; Winter 2014a; 2014b) was introduced in Section 3.2. Essentially, this delineates the area in which the main economic impacts, primarily those that are indirect and consequential, of a hazard event are experienced. This may be controlled by the hazard itself, as in the case of Glacial Lake Outburst Floods (GLOFs), by the nature of the transport network, or by a combination of the two factors. In this section the vulnerability shadows cast by the events for which the economic impacts have been assessed in the preceding sections are described. The events are described in Section 2.

The vulnerability shadow cast by the 28 October 2007 debris flow at the A83 Rest and be Thankful is described in Section 3.2 and illustrated in Figure 10. The location of the A83 8 August 2004 debris flows at Glen Kinglas and Cairndow is subtly different as illustrated in Figure 20.

While the October 2007 debris flow event occurred to the east of the B828 (serving Lochgoilhead), the August 2004 events were located to the west of the B828 in Glen Kinglas and further to the west, beyond the A815 (serving inter alia Dunoon) to the west of Cairndow. Notwithstanding this, the variations in the diversions for the two sets of events were subtle and it is broadly considered that the extent of the vulnerability shadow will be ostensibly the same for both (Figure 20).

The location of the A9 debris flow events to the north of Dunkeld (11 August 2004) is illustrated in Figure 14. The vulnerability shadow cast for that event is extremely large, being estimated to be of the order of 8,000km^2, this reflects the importance of the A9 as the primary north-south route in Scotland, leading to the most northerly city of Inverness and numerous smaller communities along the way and beyond.

Figure 14. Three main debris flow events (blue rectangle) closed the A9 N of Dunkeld on 11 August 2004; the vulnerability shadow that was cast (bounded in red) was extensive and reflects the importance of the A9, particularly to the communities to the north. (Image based on OS 1:1,000,000 mapping. © Crown Copyright. All rights reserved Scottish Government 100020540, 2017.)

7.1 A85 Glen Ogle Landslide Events: 18 August 2004

The vulnerability shadow cast for the 18 August 2004 debris flow events at the A83 Glen Ogle (Figure 15) is, by comparison, relatively small measuring only around 800 km^2. This reflects the relatively central position of the area in Scotland and the existence of alternate routes through and around the area.

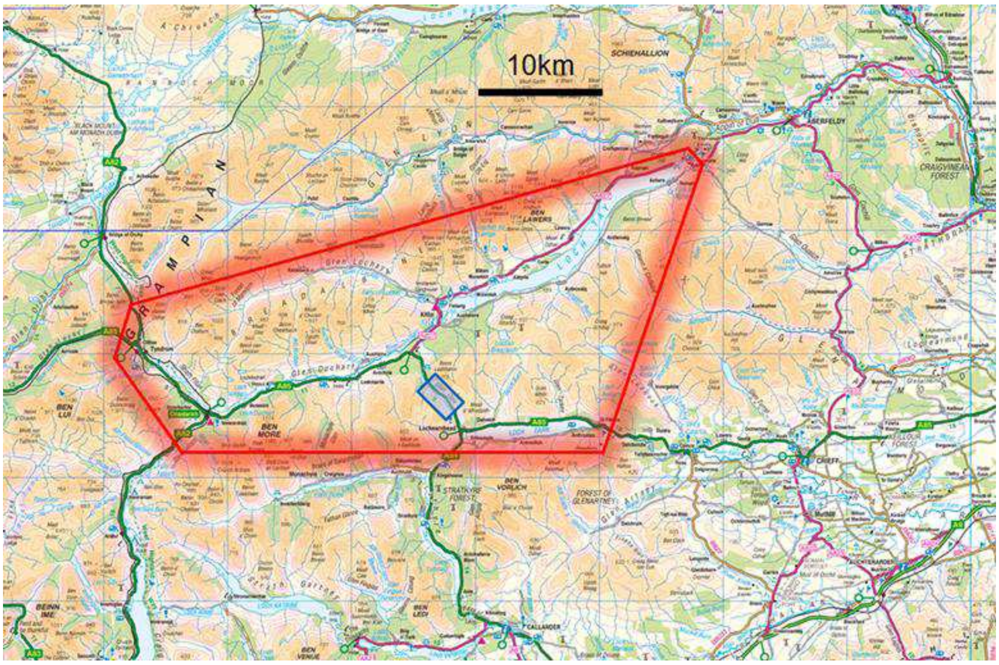

Figure 15. Two debris flow events (blue rectangle) closed the A83 in Glen Ogle on 18 August 2004; the vulnerability shadow that was cast (bounded in red) was limited by the reasonably good range of alternative routes in the area. (Image based on OS 1:250,000 mapping. © Crown Copyright. All rights reserved Scottish Government 100020540, 2018.)

7.1.1 Questionnaire Survey

A survey of businesses in the vicinity of the August 2004 landslides that affected the A85 Glen Ogle road was undertaken. The aim was to ascertain a better understanding of the impacts upon businesses and organisations in the surrounding area (see Section 8) to the landslide and, insofar as it is possible, to gather data on the impact of the event and estimated costs. These impacts vary by type of organisation, size and sector in which they operate. The information collected from the survey may be used to inform landslide management and mitigation activities in the area. The development of the survey was informed by the work presented in Section 3.6 and Appendix B that summarises potential approaches to determining the indirect consequential economic impacts of landslides and other climate-related events.

The August 2004 events at A85 Glen Ogle have been extensively reported (Winter et al. 2005; 2006; 2009; Milne et al. 2009) and followed those at the A83 and A9 earlier in the month. A short but exceptionally intense rainstorm, following a very wet antecedent period, occurred in west Stirlingshire and triggered two debris flows that blocked the road in Glen Ogle north of Lochearnhead. The southerly slip occurred first and, as advice was being offered to motorists by Trunk Road Operating Company staff, a second landslide occurred to the north of the first. While there were no major injuries to those affected, 20 vehicles were trapped between the two debris flows and 57 people had to be airlifted to safety (Figure 4). However, the real impacts of the events were economic and social, in particular the effects of the severance of access to relatively remote communities. The A85, carrying up to 5,600 vehicles per day (all vehicles two-way, 24 hour AADF – Annual Average Daily Flow), was closed for four days.

The survey questionnaire is presented in Appendix C.

The Glen Ogle event was chosen as a pilot for the survey in the first year of the study in order to understand the impacts that landslides have upon businesses and organisations in the surrounding area.

7.1.2 *Results of the Questionnaire Survey*

7.1.2.1 *The survey*

A questionnaire (see Appendix C) of businesses and other organisations in the Glen Ogle area was undertaken early in 2013 in order to better understand the impacts that the 2004 landslides had upon businesses and organisations in the surrounding area. At the time of the survey the events were not in the local press and hence it was considered that it was less likely that interviewees would be influenced by outside commentary. Furthermore it was initially considered that the event was sufficiently recent that interviewees may be likely to be able to recall most of the impacts, albeit that there had been a nine-year gap between the events and the survey.

The survey covered 24 businesses in the area: seven along the A84 road; six on the A85; nine on the A827; and two others. These businesses were primarily in the service sector (e.g. notably hotels, restaurants, inns, shops, etc.), although the survey also included one garage. That so few businesses could be contacted reflects the rural environment and relatively low population in the area.

The businesses were selected in order to ensure representation of both the routes and communities affected by the events and also to ensure broad coverage of business type. It is pertinent to note that future surveys are likely to include larger numbers of businesses.

Contact was attempted on at least two occasions with each of the 24 businesses; not all of the businesses provided responses. Responses were received from five businesses. This was largely due to the high number of businesses whose current owners were not managing the business at the time of the landslide event in 2004. Notwithstanding this the response rate was 20.8%.

7.1.2.2 *Key results*

Eleven respondents either did not own their business in 2004 or stated that they did not know anything about the event to be useful to the survey. Two other respondents stated that they were not aware of any ill effects as a result of the event while contact could not be made with another six businesses.

Of those who did respond the following are the key results:

- Two respondents were sole traders in the retail sector.

- The other respondents were a garage, a bed & breakfast establishment and a caravan and camping park.
- Four of the businesses employed fewer than five staff (one did not respond to this question).
- The turnover of three of the businesses was in the range £100,000 to £250,000 (one did not respond to this question). The bed & breakfast establishment was only open during the summer and did not answer the question related to turnover.
- In terms of their dependence on transport for in-coming and outgoing movements two respondents said they had a very high dependency for visitors and in-coming staff, while one had high dependency for all activities (staff, visitors, in-coming and out-going goods). Given the service nature of the businesses that responded this is not unexpected.
- For one business (the bed & breakfast establishment) many visitors arrive on bicycles. Thus the impact of the landslide on such visitors might not be as critical as for motorised vehicles.
- The respondents reported that their businesses were located between half a mile and six miles of the landslide site.
- No respondent said that they had been significantly affected by the 2004 Glen Ogle landslide – most seemed to adapt to the situation.
- The Glen Ogle landslide did not result in any of the respondents having to take different routes to/from their business for work or for in-coming and out-going deliveries (one did not respond to this question). This suggests that other routes were available when required or they were not dependent on certain routes at the time of the road closures.
- Of those who responded, two estimated the cost of the landslide to have been less than £1,000, while one respondent did not know the cost. One retailer noted a small drop in turnover (about £100) the day after the landslide occurred but for the rest of the week there was no effect on income. The economic impact does not therefore to appear to have been as serious as might have been expected.
- Four respondents stated that they had not been affected by other landslides in the last 20 years, although one retailer possibly had been affected by landslides on the A9. Landslides in this area were not perceived to have been a common occurrence.
- Three of the respondents had not been refused insurance as a result of landslide experience nor had they been expected to pay a higher insurance premium as a result of landslide risk (two did not respond to this question).

Specific comments made by respondents included:

- Relative low dependency on transport for in-coming and outgoing movements for one retailer was because "*some people use the A9 and some use Glen Ogle. Most deliveries come from Loch Lomond/Glasgow*".
- "*More people rented bikes to go and visit the landslide site. The landslide itself had little impact, it was the associated bad weather that was the problem - the main street was flooded*" according to one retailer.

- The garage respondent stated that as a result of the Glen Ogle landslide "*the road was shut for 3 days but it was over the weekend, so it was not long enough to have an impact*" on their business.
- Another retailer stated that the landslide "*blocked roads for a short while*", but this did not affect the shop very much because it "*gets its deliveries from the south and the blockage was to the north".*
- The bed & breakfast establishment seems to have benefitted from the Glen Ogle landslide. They were able to "*put up people in the guest house who had been trapped in the glen (and who had been airlifted out) free of charge. The same happened in different places around Killin*," which apparently "*improved the image of the town."*

According to the caravan and camping park there was no impact of the landslide itself but "*the heavy rainfall that caused the landslide, also caused localised flooding, including in the caravan park so visitors/people staying went home early. Business went back to normal the next day*".

The words used in the responses to the survey are also useful in assessing the views of respondents and in Figure 16 these are set out in the form of a Wordle Word Map.

Figure 16. Word map of responses from survey respondents: A85 Glen Ogle, 18 August 2004.

While the results of such a simple analysis must be treated with caution there is a predominance of words that do not indicate that the impact of the events was overly significant in economic or disruption terms. In addition words such as impact must also be treated carefully interpreted as a response may have used either 'impact' or 'no impact', with the same result of 'impact' being recorded in either case. In order to minimise the potential for misinterpretation the specification for the Wordle Word Map was standardised throughout this report[2].

[2] Wordle Word Map Specification: http://www.wordle.net/. Language: remove numbers, make all words lower case, remove common English words; Font: Expressway Free;

7.1.2.3 Implications of the survey

Various implications may be deduced from the survey:

- The survey results suggest that, such a survey can only elicit useful information if undertaken relatively soon after a landslide event.
- There appears to be a high turnover of business ownership which might, of course, be a reflection of the adverse impact of the Glen Ogle landslide.
- The low population and business density in areas that are at risk from landslides means that sample sizes are likely to be low.
- As a result of such a low response the results should be seen as indicative rather than being statistically significant.
- It is possible that small businesses might be expected to be significantly affected by a landslide but this survey did not demonstrate this.
- A landslide does not adversely impact all businesses – some may be able to take advantage of the changes in consumer demand that results while for other businesses the timing of a landslide and any resulting road closures may not be as unfavourable as they could be.
- Insurance data may not provide a useful source of information.
- Gathering data on the wider consequential, economic impacts of landslides from a survey should not be the only method of information although it can be used to supplement and complement evidence from other sources.

7.2 A77, A76, A71 Bellfield Junction Flooding: 21 September 2012

The vulnerability shadow cast by the 21 September 2012 flooding event at the A77, A76, A71 Bellfield Junction (Figure 17) was smaller still at around 500km^2. The road network in this area is much denser, and the population density is much higher, than that in the other areas studied and this leads to reasonable alternative routes, albeit with significant associated disruption to traffic.

7.2.1 *Questionnaire Survey*

The survey questionnaire is presented in Appendix D.

7.2.2 *Results of the Questionnaire Survey*

7.2.2.1 The survey

The businesses were selected in order to ensure representation of both the routes and communities affected by the events (see Section 8) and also to ensure broad coverage of business type. The survey questionnaire was sent by mail to 62 businesses. Further

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Layout: maximum words = 80, rounder edges, horizontal; Colour: kindled, lots of variation. Road names, place names and costs were removed prior to analysis.

contact was attempted, where possible, either by email or by phone. Not all of the businesses provided responses.

Two questionnaires were undeliverable by mail and no other contact details were available. Responses were received from seven of the remaining 60 businesses, giving a response rate of 11.7%.

Figure 17. Flooding at the A77, A76, A71 Bellfield Junction (blue rectangle) closed all three roads on 21 September 2012; the area of the vulnerability shadow that was cast (bounded in red) was limited by the availability of diversionary routes. (Image based on OS 1:250,000 mapping. © Crown Copyright. All rights reserved Scottish Government 100020540, 2018.)

7.2.2.2 Key results

Of those who did respond the key results are as follows:

- Three respondents were in the Hotel/Bed and Breakfast sector.
- Three respondents were in the leisure/visitor attraction sector.
- One respondent operated in the Oil and Gas sector.
- Two of the businesses employed fewer than five staff, three employed between five and 20 staff, and two employed between 21 and 50 staff.
- The turnover of two of the businesses was less than £50,000 per annum. A further two businesses reported turnover in the range of £50,000 to £100,000 and three businesses did not respond to this question.
- In terms of their dependence on transport for in-coming and out-going movements, five respondents said they had a high or very high dependency on visitors and in-coming goods, while four had high or very high dependency on staff.

- The respondents reported that their businesses were located between less than one mile and seven miles of the flooding site. Two respondents did not answer this question.
- Three respondents said that they had been significantly affected by the 2012 Bellfield Junction flooding, one did not know and three said that they had not been affected.
- Three respondents reported that they, their staff or customers had to take different routes to/from their business for work or for in-coming and out-going deliveries. One did not respond to this question, one answered no and two did not know.
- Of those who responded, two estimated the cost of the flooding to have been less than £1,000, while two respondents did not know the cost and one said that they could not assess the impact.
- One respondent stated that they had been affected by other flooding events in the last 20 years.
- Five of the respondents had not been refused insurance as a result of flooding experience nor had they been expected to pay a higher insurance premium as a result of flooding risk (two did not respond to this question).
- Five of the respondents stated that they would not be prepared to pay an increase in business rates to pay for new or additional flood protection and one respondent stated that they would be prepared to pay an increase of 2.5% in business rates.

The responses to the question on priorities for transport investment (Figure 18) show a clear preference for investing in road improvements over investment in rail services or flood risk removal. It should perhaps be considered that this preference, to a degree, also reflects a desire to reduce congestion.

Specific comments made by respondents included:

- One respondent stated that night "staff travelling to work were stuck for hours in traffic when the flooding occurred".
- One respondent said that their business was affected by flooding but not specifically the flooding at the Bellfield Junction.
- One respondent stated that "Staff took different route to get to work – came off the A76 through Hurlford/Crookedholm instead of going through Bellfield".

The Wordle Word Map for this event (Figure 19), like that for the A85 (Figure 16), also features a predominance of words that do not indicate that the impact of the events was overly significant in economic or disruption terms.

The results of this survey are specific to the Bellfield Junction flooding event. While the detours resulting from the events were significant there is more than one access route to the area and not all routes were affected. The results should not, therefore, be seen as in any way indicative of the likely outcomes from surveys conducted in other areas where access might be significantly more restricted.

7.2.2.3 *Implications of the survey*

Various implications may be deduced from the survey:

- The survey results suggest that, such a survey can only elicit useful information if undertaken relatively soon after a flooding event.
- As a result of such a low response the results should be seen as indicative rather than being statistically significant.
- It is possible that small businesses might be expected to be significantly affected by a flooding event but this survey did not demonstrate this.
- Notwithstanding the above the duration of the event was relatively short and much of the resulting disruption occurred during the night.
- Insurance data may not provide a useful source of information.
- Gathering data of the wider consequential, economic impacts of flooding from a survey should not be the only method of information although it can be used to supplement and complement evidence from other sources.

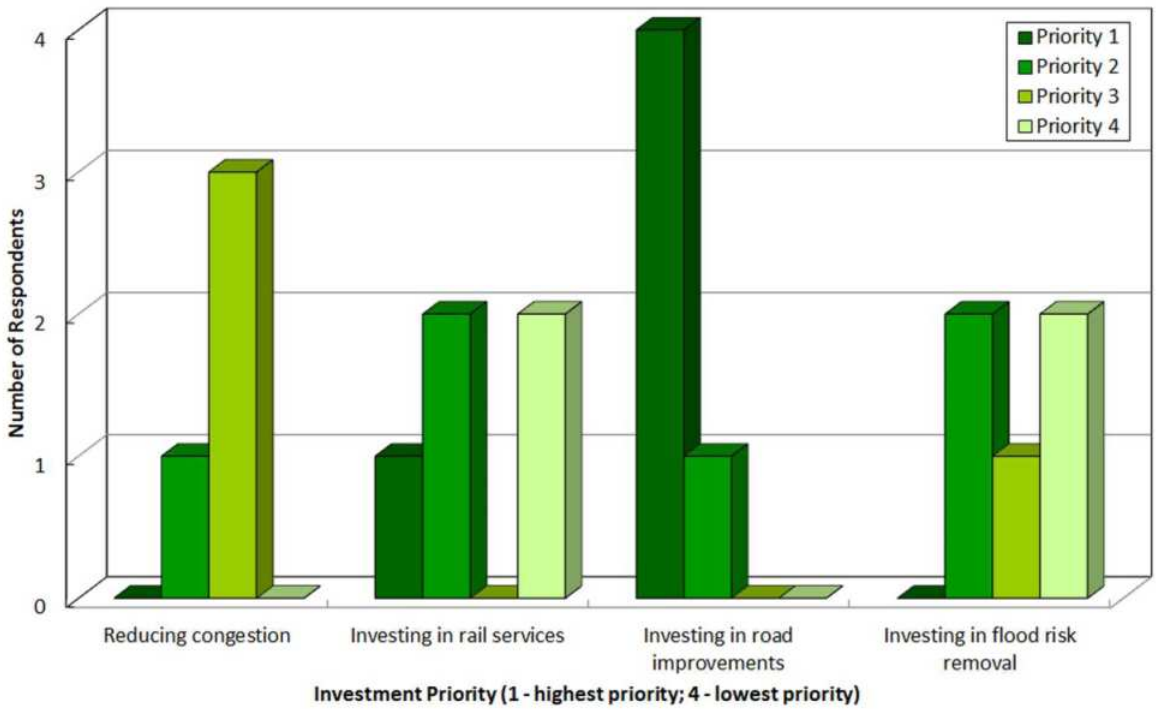

Figure 18. Transport investment preferences expressed by businesses that responded to the questionnaire: A77, A76, A71 Bellfield Junction Flooding, 21 September 2012.

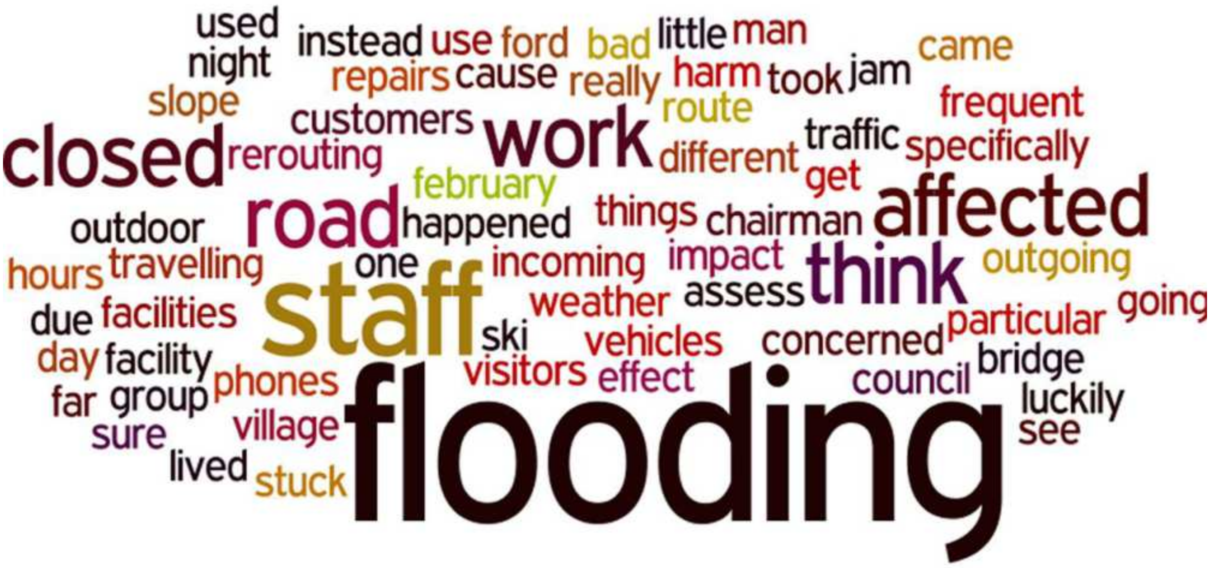

Figure 19. Word map of responses from survey respondents: A77, A76, A71 Bellfield Junction Flooding: 21 September 2012.

- The greatest economic impact reported was 'less than £1,000' and indirect consequential economic impacts do not, therefore, appear to have been as significant as might have been anticipated.

7.3 A83 Rest and be Thankful, 28 October 2014

The event occurred at around 06:30 hours on the morning of 28 October 2014. The majority of this large event (circa 2,000 tonnes) was arrested by one of the debris flow catch fences that had been installed as mitigation measures. However, the event exceeded the design capacity of the fence, which collapsed allowing the remainder of the debris to reach the road. A related event also occurred, reaching the road in Glen Kinglas.

The vulnerability shadow for events at or near this location has been previously described as set out in Figure 10. The area delineated was shown by dashed lines in the south and the west partly in order to make the map easier to read. In Figure 20 the vulnerability shadow cast is set-out in full and divided into Areas 1 to 7 to reflect the differing areas within the vulnerability shadow.

7.3.1 Questionnaire Survey

The survey questionnaire is presented in Appendix E.

7.3.2 Results of the Questionnaire Survey

7.3.2.1 The survey

The survey questionnaire was sent by mail to 465 businesses located in Areas 1 to 7, in July 2015. The businesses were selected in order to ensure representation of both the routes and communities likely to have been affected by the event and also to ensure broad coverage of business type. In addition the questionnaire was forwarded to an unknown number of businesses by recipients outside these areas; these are categorised as 'Other'. Not all of the businesses provided responses. A summary of the numbers of questionnaires mailed, delivered and completed is shown in Table 13 and the percentages of those successfully delivered are shown by area in Figure 21.

The number of questionnaires sent out broadly reflects the number of businesses and thus the population in each of the Areas.

In the questionnaire, Questions 1 to 4 dealt with general contact information and are, of course, not reported on here.

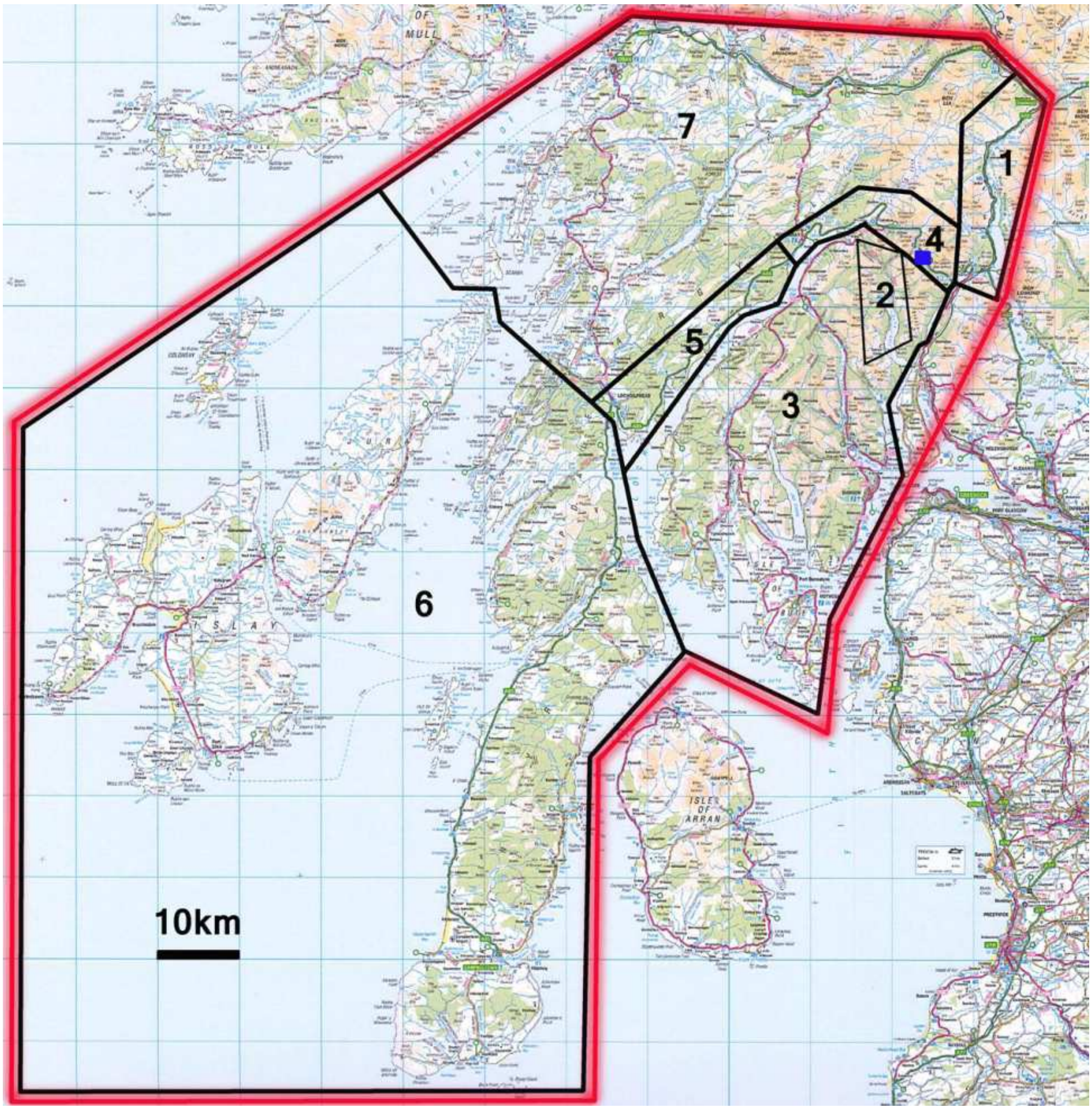

Figure 20. A relatively small debris flow event (blue rectangle) closed the A83 at Rest and be Thankful in October 2014; the vulnerability shadow that was cast (bounded in red) was extensive (Winter 2014a; 2014b). The definition of the vulnerability shadow in this image is refined and extended; previously the areas to the south and west have been indicated by dashed lines at the edge of the image (e.g. Figure 10). The different areas defined within the A83 vulnerability shadow. (Image based on OS 1:250,000 mapping. © Crown Copyright. All rights reserved Scottish Government 100020540, 2018.)

Table 13. Summary of mailed and completed questionnaires.

Area	No. of questionnaires mailed (A)	No. of questionnaires undeliverable (B)	No. of questionnaires delivered (A-B)	No. of delivered questionnaires completed and returned
Area 1	42	3	39	7
Area 2	14	0	14	1
Area 3	56	4	52	6
Area 4	40	0	40	7
Area 5	72	3	69	15
Area 6	173	11	62	30
Area 7	68	2	66	9
Other[1]	0	0	0	2
Total	465	23	442	77

[1] Two completed questionnaires were returned from outside the survey areas, these were forwarded by original recipients.

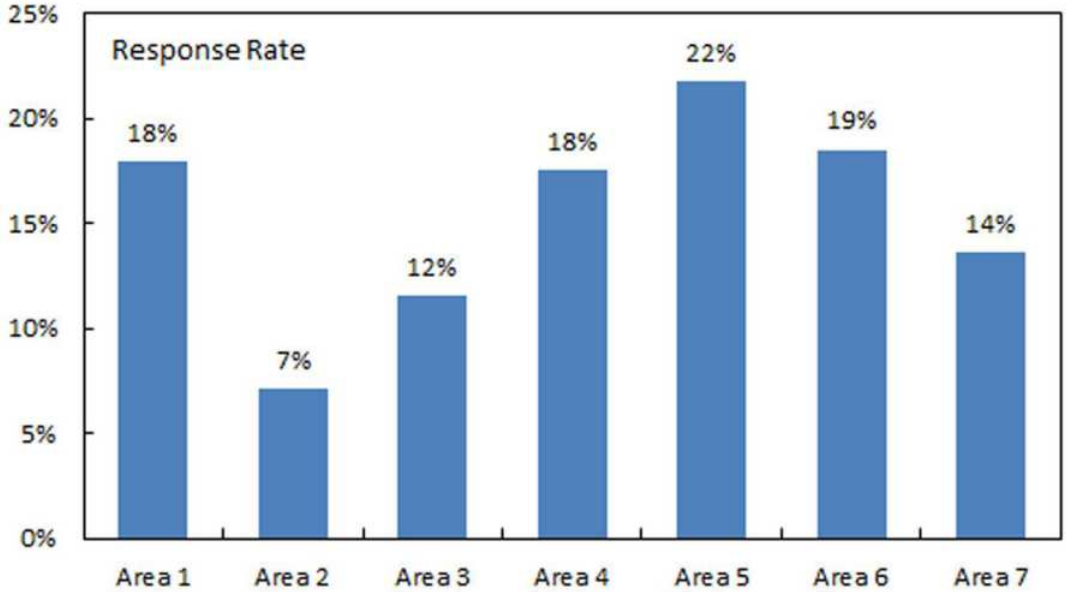

Figure 21. Percentage of successfully delivered questionnaires that were returned completed for each area. (The overall response rate was 17%.)

7.3.2.2 Key results

Respondents were asked to identify the main business sector in which they operate (Question 5). Table 14 summarises the sectors of the 77 businesses that completed questionnaires by area. Figure 18 shows the percentage of respondents in each business sector. The largest business sector of respondents in the survey area is Hotels/Bed and Breakfast (29%), followed by Retail-sole trader (17%), and Leisure activities (16%).

Table 14. The number of businesses that responded to the questionnaire by area and business sector.

Area	1	2	3	4	5	6	7	Other	Total
Agriculture/dairy	0	0	0	0	0	1	0	0	1
Banking/Insurance/financial services	0	0	1	0	1	1	0	0	3
Car/vehicle sales, garages and repairs	0	0	0	0	0	1	0	0	1
Construction and building	0	0	0	0	3	1	0	0	4
Fisheries	0	0	0	0	0	1	0	0	1
Food processing	0	0	0	0	0	0	1	0	1
Haulage and distribution	0	0	0	1	1	2	0	0	4
Hospitals/healthcare and medical services	0	0	0	0	0	2	0	0	2
Hotels/Bed and Breakfast	5	0	1	1	1	9	5	0	22
Leisure activities e.g. outward bound centres, visitor attractions	0	1	2	2	2	0	2	2	12
Restaurants, cafes and public houses	2	0	0	0	1	1	0	0	4
Retail-multiple store	0	0	0	0	0	1	0	0	1
Retail-sole trader	0	0	3	1	3	6	0	0	13
Transport e.g. bus and taxi	0	0	0	1	0	1	0	0	2
Other	0	0	0	0	3	2	0	0	5
								Total	76

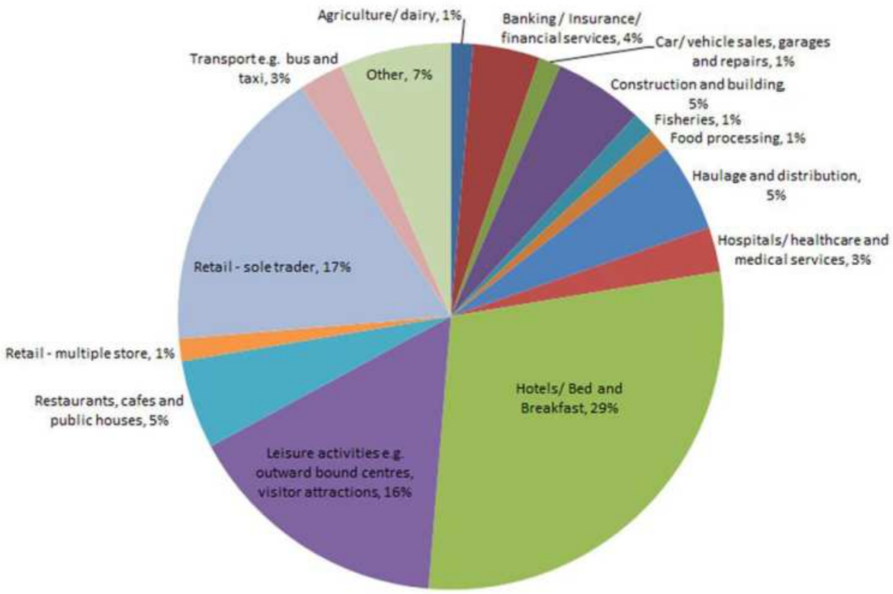

Figure 22. Percentage of respondents in each business sector. (The percentages do not quite sum to 100% due to rounding.)

Respondents were asked about the number of people employed by the business or organisation (Question 6). Table 15 summarises the responses to this question by area. Figure 23 shows the percentage of businesses reporting workforce size in each category. Of the businesses that responded to this question, 46% reported the number of people employed by their business to be less than five, with more than 70% reporting less than 20 employees.

Table 15. Reported workforce size.

Area	No. of employees					Null response
	<5	5-20	21-50	51-99	≥100	
1	4	0	2	1	0	0
2	0	0	1	1	0	0
3	1	3	1	1	0	0
4	4	3	0	0	0	0
5	8	4	1	0	2	0
6	15	7	3	1	1	1
7	3	3	2	0	0	1
Other	0	1	0	0	1	0
Total	35	21	10	4	4	2

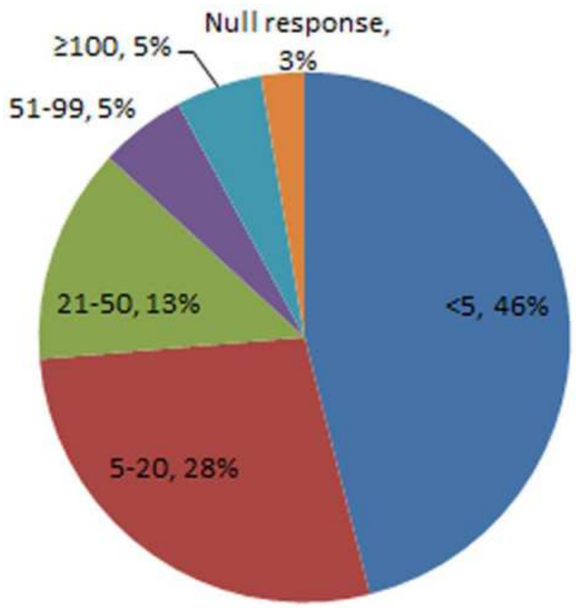

Figure 23. Reported workforce size as a percentage of responses.

Survey respondents were asked to report the annual turnover of the business (Question 7). The responses to this question are summarised by area in Table 16. Some respondents, 9%, did not answer this question. Figure 24 shows the percentage of businesses reporting annual turnover in each value category, ranging from less than £50,000 per annum to more than £1 million per annum.

Six businesses (9%) did not respond to this question, 30 businesses (44%) reported a turnover of less than £250k per annum, a further seven (10%) reported turnover of between £250k and £500K, while 12 (18%) reported turnover of £500k to £1 million, and 12 businesses (18%) reported a figure of greater than £1 million.

Table 16. Reported annual business turnover.

Area	Turnover per annum						Null response	Total
	<£50k	£50k - <£100k	£100k - <£250k	£250k - <£500k	£500k - <£1M	≥<£1		
1	1	4	0	0	1	1	1	8
2	0	0	0	0	1	0	0	1
3	0	0	1	2	1	1	1	6
4	0	2	0	1	3	1	0	7
5	2	0	5	0	1	4	3	15
6	6	2	7	4	5	5	1	30
7	0	0	0	0	0	0	0	0
Other	0	0	0	0	0	0	0	0
Total	9	8	13	7	12	12	6	67

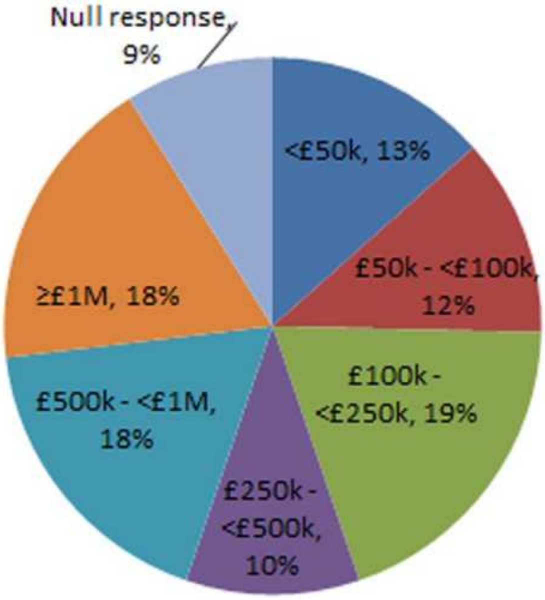

Figure 24. Reported annual turnover as a percentage of responses. (The percentages do not quite sum to 100% due to rounding.)

The businesses surveyed were asked to rate the dependence of their business on road transport (Question 8) for the following: staff (e.g. commuting), visitors, incoming goods and out-going goods. There were five possible ratings for each variable; not dependant, low dependency, medium dependency, high dependency and very high dependency. The responses to this question are shown in Table 17.

Table 17. Dependence of businesses on road transport.

	Staff (e.g. commuting)								Visitors							
Area	Null response	**Dependency**					Weighted Score	Normalised Weighted Score	Null response	**Dependency**					Weighted Score	Normalised Weighted Score
		None	Low	Medium	High	Very High				None	Low	Medium	High	Very High		
1	0	3	1	0	1	2	12	1.7	0	0	0	0	2	5	26	3.7
2	0	0	0	0	0	1	4	4.0	0	0	0	0	0	1	4	4.0
3	1	4	1	0	0	0	1	0.2	0	1	0	1	1	3	17	2.8
4	0	2	1	0	2	2	15	2.1	0	0	1	0	0	6	25	3.6
5	1	3	5	1	5	0	22	1.6	1	1	0	1	4	8	46	3.3
6	3	13	6	2	3	2	27	1.0	4	1	3	4	5	13	78	3.0
7	1	3	3	0	0	2	11	1.4	1	0	0	0	0	8	32	4.0
Other	0	1	1	0	0	0	1	0.5	0	0	0	1	0	1	6	3.0
Total	6	29	18	3	11	9	93	1.3	6	3	4	7	12	45	234	3.3

	Incoming Goods								Out-going Goods							
Area	Null response	**Dependency**					Weighted Score	Normalised Weighted Score	Null response	**Dependency**					Weighted Score	Normalised Weighted Score
		None	Low	Medium	High	Very High				None	Low	Medium	High	Very High		
1	0	0	0	2	0	5	24	3.4	0	3	1	0	0	3	13	1.9
2	0	0	0	0	0	1	4	4.0	1	0	0	0	0	0	0	0.0
3	0	1	0	1	1	3	17	2.8	0	2	1	1	0	2	11	1.8
4	0	0	0	1	0	6	26	3.7	1	1	0	2	0	3	16	2.7
5	0	0	0	0	3	12	57	3.8	0	1	1	3	1	9	46	3.1
6	2	0	1	1	8	18	99	3.5	1	7	4	1	2	14	68	2.4
7	1	1	1	0	1	5	24	3.0	1	4	0	0	1	3	15	1.9
Other	0	1	1	1	0	0	2	1.0	0	2	0	0	0	0	0	0.0
Total	3	3	3	6	13	50	253	3.4	4	20	7	7	4	34	169	2.3

A weighted score was calculated by multiplying the number of responses in each type of dependency by the assigned weighting values (weightings were assigned as follows: No dependency, 0; Low dependency, 1; Medium dependency, 2; High dependency, 3; Very high dependency, 4). This allows comparisons of the reported dependency on each factor within an area (but not between areas as the numbers of responses varies), for example, Area 1 has a weighted score of 12 for 'staff (e.g. commuting)', 26 for 'visitors', 24 for 'incoming goods' and 13 for 'out-going goods'. These data are illustrated in Figure 25.

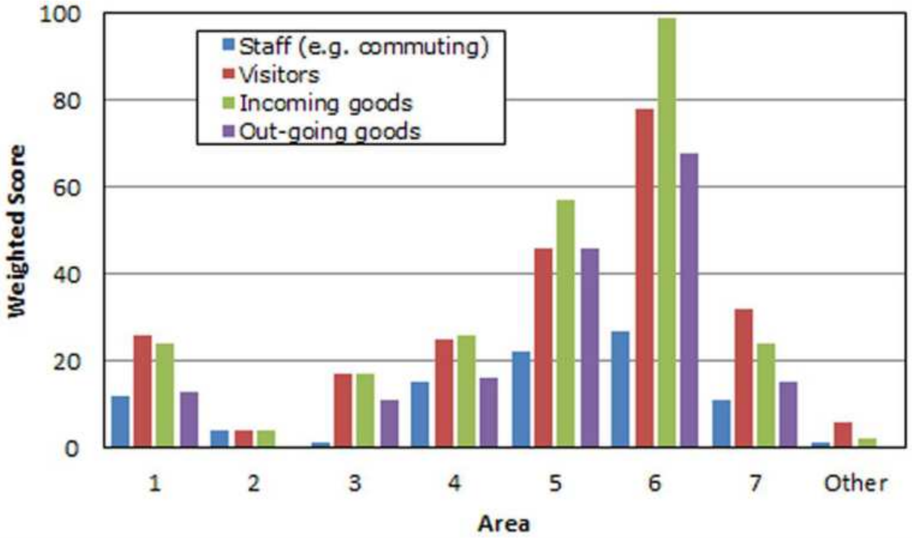

Figure 25. Weighted scores for dependency on road transport by area.

It is clear that in each area, based purely on the number of responses, that the greatest dependencies on road transport are for visitors and incoming goods, with the exception of Area 2 in which the single respondent indicated that staff dependency on road transport was equally important. These data are normalised by the number of respondents from each area (Figure 26) to allow a comparison between areas and this emphasises both the consistency of result between the seven areas (and Other) but also better highlights that the dependency for out-coming goods is also significant.

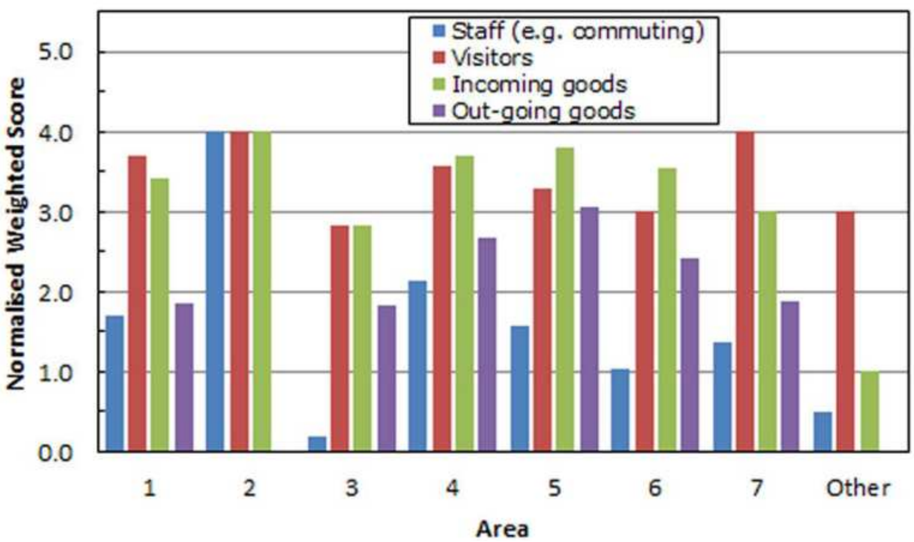

Figure 26. Normalised weighted scores for dependency on road transport by area.

Combining the normalised data for all areas in Figure 27 gives a very clear picture of a high dependency on road transport of visitors and incoming goods and a lower but still highly significant dependence upon out-going goods. The level of dependence of staff is much lower but still significant.

This seems likely to be a reflection on the business mix of the respondents to the survey. A total of 76 responses were received: 22 from 'Hotel/bed and breakfast' businesses, 12 from businesses providing 'Leisure activities', 13 from 'Retail - sole traders' and 4 from 'Restaurants, cafes and public houses'. These are all business sectors that have a relatively high dependence on visitors and incoming goods. Of the 76 survey responses 74% (56) reported employee numbers of less than 20 (46% less than five) and this seems likely to be reflected in the lower dependence on road transport for staff commuting.

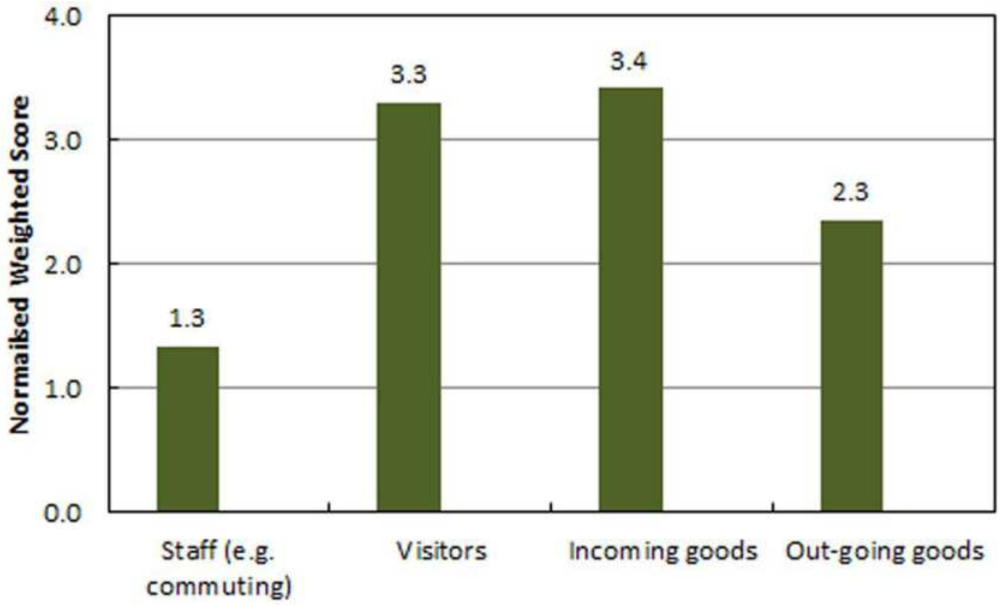

Figure 27. Normalised weighted score for dependency on road transport, all Areas.

The businesses surveyed were asked (Question 9a to 9d and 9i) whether their business was affected by the landslide on 28 October 2014, how far the business location is from the landslide site, whether this landslide caused them or others associated with the business to use different routes and whether the business had been affected by landslides in the past. The responses to these questions are summarised by Area in Table 18 and Figure 28. The results suggest that most (71%) of the businesses that responded were affected by the 2014 landslide; this rises to 80% if inconclusive the null responses and 'do not know' responses are excluded. The respective figures for business affected by other landslides are 66% and 86%, reflecting a greater degree of uncertainty in the responses. The individual results for each area are also interesting. All of the businesses (100%), that knew and responded, in Areas 2, 3, 4 and 'Other' reported that they were affected by the landslide; Area 5 reported that 93% of responding businesses were affected; Area 6, 77%; Area 1, 50%; and Area 7, 43%.

Table 18. Effect of landslide(s) on businesses.

Area	Yes	No	Do not know/null response	Ave. miles to site	Different route used			Affected by other landslides		
					Yes	No	Do not know/null response	Yes	No	Do not know/null response
1	3	3	1	25	2	4	1	1	2	4
2	1	0	0	7	1	0	0	1	0	0
3	6	0	0	2	6	0	0	4	1	1
4	7	0	0	12	4	2	1	7	0	0
5	14	1	0	42	13	1	1	13	0	2
6	20	6	4	75	20	2	8	20	2	8
7	3	4	2	53	4	3	2	4	3	2
Other	1	0	1	30	1	0	1	1	0	1
Total	55	14	8		51	12	14	51	8	18

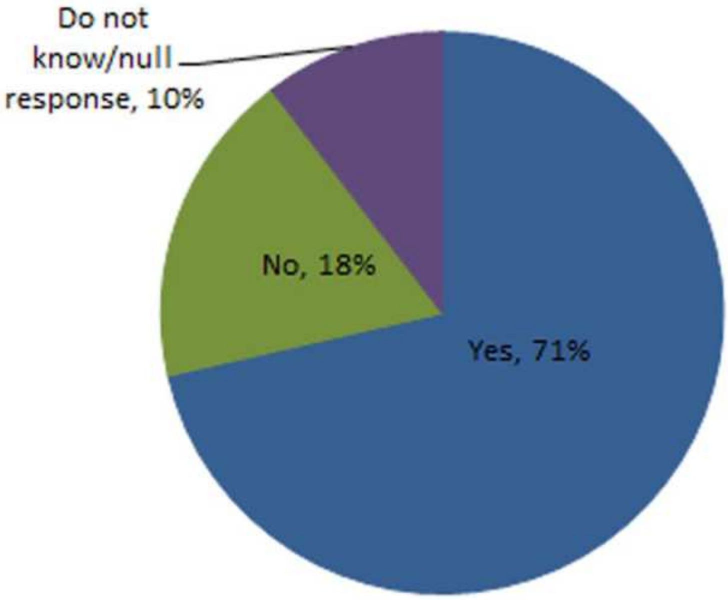

Figure 28. Percentage of businesses affected by the landslide. (The percentages do not quite sum to 100% due to rounding.)

Respondents were asked to estimate the cost to their business of the landslide in terms of lost revenue and higher costs, both actual and anticipated (Question 9e). Table 19 shows the number of respondents in each area estimating such costs in each category. Figure 29 shows the total number of respondents estimating their losses in each of the value ranges. Of the respondents, 62% either did not respond to this question, did not know the cost, or reported a cost of less than £1,000. Only three (4%) respondents reported costs in excess of £10,000. The number of responses indicating costs associated with the landslide is highest for Areas 3, 4, 5 and 6 (70% to 85%) while for Areas 1 and 5 the equivalent figure is around 60%; there were no responses indicating costs in Areas 2 but only one questionnaire was returned from this area.

Multiplying the number of respondents in each cost range by the central point of that range, and taking the <£1k and ≥£100k ranges as £0.5k and £150k respectively, gives estimated total costs for the 54 businesses that gave a figures of around £270k or an average of around £5k per business. This average figure is strongly influenced by the highest reported loss (£50k to £100k); if this is excluded the average cost per business reduces to around £3.7k.

Table 19. Estimated financial impact of landslide on businesses.

Area	<£1k	£1k-£5k	£5k-£10k	£10k-£50k	£50k-£100k	≥£100k	Do not know	Null Response
1	2	2	0	0	0	0	2	1
2	0	0	0	0	0	0	0	1
3	2	2	1	0	0	0	1	0
4	2	2	1	1	0	0	1	0
5	3	1	4	0	1	0	5	1
6	10	7	4	1	0	0	5	3
7	5	2	0	0	0	0	1	1
Other	1	0	0	0	0	0	1	0
Total	25	16	10	2	1	0	16	7

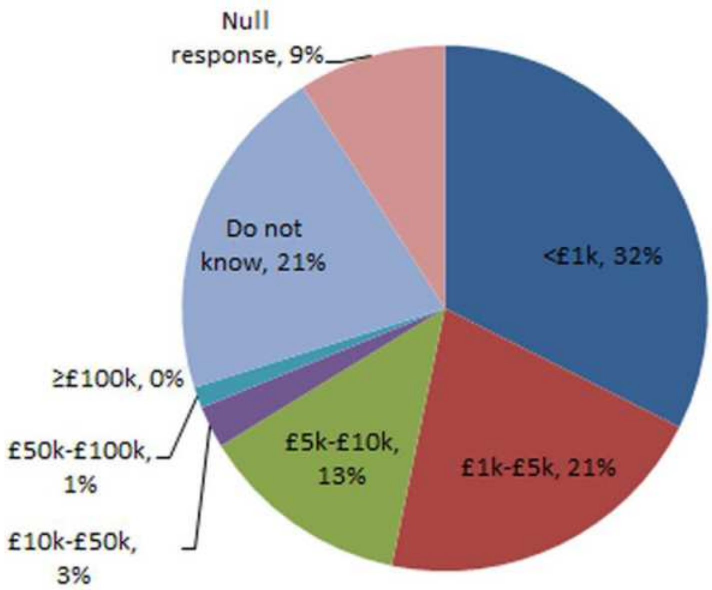

Figure 29. Percentage of businesses reporting costs in each range.

There were also 16 respondents that stated that they did not know the cost to their business of the landslide event and seven that gave a null response (i.e. did not respond). If the costs to these businesses are assumed to be close to zero then the average cost per business reduces to around £3.5k and to around £2.6k if the highest reported loss (£50k to £100k) is excluded. These costs represent lost revenue (or turnover) and/or higher costs and not lost profit.

These figures may well be an overestimate, for a number of reasons, including that:

- Those businesses most affected are most likely to respond to this question while those less affected may not respond at all.
- The number of landslide events in recent years at this location may have led respondents to give figures that are closer to the total costs incurred as a result of all events, rather than the costs of the single event for which details were requested.

- The figures may include an element of the Direct Consequential costs that are covered in Section 6 and include delay costs.

It should also be noted that the majority (83%) of questionnaires were not returned. This may indicate that the impacts on those businesses were either unknown, potentially because they were insignificant or zero. If it is further assumed that the 365 businesses that did not respond to the questionnaire also had costs at or close to zero as a result of the landslide then the cost per business is around £0.5k. It should, however, be noted that the assumption of zero costs for non-responding businesses is only one possible scenario. Equally it may be that the costs were not zero but that they were difficult to identify and calculate and/or the businesses took the view that as the event was in the past there was little to be gained in identifying these costs.

Table 20. Transport investment priorities expressed by businesses.

	Priority (1 – highest; 4 – lowest)	**1**	**2**	**3**	**4**
Area 1	Reducing congestion	0	1	1	0
	Investing in rail services	1	0	1	0
	Investing in road improvements	3	1	0	0
	Investing in landslide management and mitigation	1	0	0	2
Area 2	Reducing congestion	0	0	0	0
	Investing in rail services	1	0	0	0
	Investing in road improvements	0	0	0	0
	Investing in landslide management and mitigation	0	0	0	0
Area 3	Reducing congestion	0	1	3	0
	Investing in rail services	1	0	0	3
	Investing in road improvements	2	3	0	1
	Investing in landslide management and mitigation	3	2	1	0
Area 4	Reducing congestion	0	2	1	3
	Investing in rail services	0	0	4	2
	Investing in road improvements	5	1	0	0
	Investing in landslide management and mitigation	1	3	1	1
Area 5	Reducing congestion	0	0	9	3
	Investing in rail services	0	0	3	9
	Investing in road improvements	5	8	0	0
	Investing in landslide management and mitigation	9	5	0	0
Area 6	Reducing congestion	0	0	8	6
	Investing in rail services	0	1	6	8
	Investing in road improvements	12	13	0	0
	Investing in landslide management and mitigation	13	10	1	0
Area 7	Reducing congestion	1	2	2	1
	Investing in rail services	1	2	1	2
	Investing in road improvements	4	2	0	0
	Investing in landslide management and mitigation	0	0	3	3
Other	Reducing congestion	0	0	0	0
	Investing in rail services	0	0	0	0
	Investing in road improvements	1	0	0	0
	Investing in landslide management and mitigation	1	1	0	0
Total all areas	Reducing congestion	1	6	24	13
	Investing in rail services	4	3	15	24
	Investing in road improvements	32	28	0	1
	Investing in landslide management and mitigation	28	21	6	6

It is also important to note that 5% of the questionnaires sent were returned as being undeliverable. This may indicate that those businesses have ceased trading but there is no suggestion that the impacts of landslide events contributed to this.

Respondents were asked to rank in order of priority four options for transport investment: reducing congestion; investing in rail services; investing in road improvements; investing in landslide management and mitigation. Table 20 summarises the investment priorities reported within each area.

Figure 30 shows the preferences expressed by respondents in all areas for each investment option and priority. It is clear that 'Investing in road improvements' or 'Investing in landslide management and mitigation' was the first priority of most respondents with only a small number expressing a preference for 'Investing in rail services' or 'Reducing congestion' as the first priority for investment. This is on contrast to the responses for the Bellfield Junction flooding survey (Figure 18) in which the predominant preference was for 'Investing in road improvements', followed by 'Investing in rail services', with no respondents preferring either 'Reducing congestion' or 'Investing in flood risk removal'.

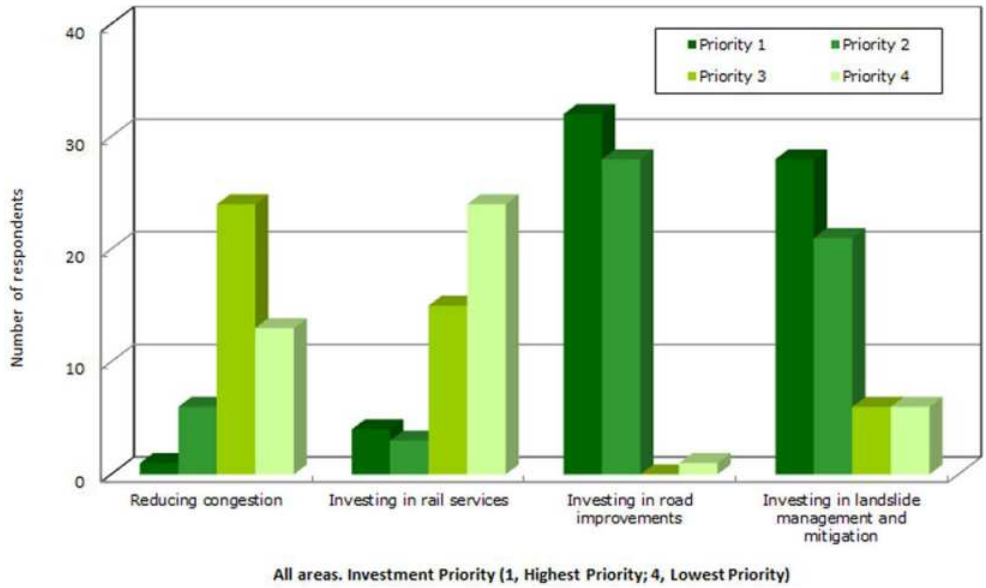

Figure 30. Transport investment preferences expressed by businesses that responded to the questionnaire: A83 Rest and be Thankful, 28 October 2014.

The Wordle Word Map for this event (Figure 31), in contrast to those for the A85 and A77 events (Figures 16 and 19), features a predominance of words that indicate that the impact of the event was significant in economic or disruption terms (e.g. loss, time, closed, etc.).

Word maps for the individual areas denoted in Figure 20, along with other responses, are presented in Appendix F. What is perhaps most noticeable is that landslide(s) does not feature as the most commonly used word as it does for the A85 survey returns and as does flooding for the A77 returns. Road is the most common word and while landslide(s)is still commonly used, other words such as 'loss', 'business', 'deliveries', 'visitors', 'time' and so on come to the fore perhaps suggesting a greater familiarity with the event and a focus on the consequences. This is reinforced by the word maps for the individual areas (Appendix F) in which the most commonly used words are 'closed', 'staff', 'visitors', 'road', 'due', 'access', 'tourism', 'minor' and 'island'.

Figure 31. Word map of responses from survey respondents: A83 Rest and be Thankful, 28 October 2014

7.3.2.3 Implications of the survey

This survey was significantly more extensive both in terms of the area covered and the number of questionnaires sent out than were previous surveys of the A85 Glen Ogle landslide event and the A77 Bellfield Junction Flooding events. This reflects both the areal extent of the vulnerability shadow cast by events at the A83 Rest and be Thankful and also the frequency of such events that effect both the network and the communities that it serves. The extent of the survey also relates to the maturity of the work conducted as a trial was completed examining the A85 Glen Ogle landslide event (Section 7.1) and the first full survey was completed for the A77 Bellfield Junction flooding event (Section 7.2).

The surveyed included large numbers of tourist sector businesses, retail businesses and also other industries that rely on transport in order to operate successfully. These businesses predominantly (74%) employ less than 20 people although 13% employ between 21 and 50 people. Approximately 44% of the businesses reported a turnover of less than £250k while 46% reported a turnover of £250k or more (9% did not answer this question).

The businesses surveyed are particularly dependent upon road transport for incoming goods and visitors, with a slightly lower dependence on road transport for out-going goods and a lower dependence upon road transport for staff (e.g. commuting). The data indicate that the area is highly dependent upon road transport for the successful operation of its economy. A significant proportion (71%) of businesses that responded were affected by the 2014 landslide event and 66% (two-thirds) had been affected by previous landslides. The financial impact of the landslide event on businesses in the area is clearly significant and an average figure of around £7.5k per business has been calculated. However, this is likely to be an overestimate as those businesses most affected are most likely to respond to this question while those less affected may not respond at all. The average figure is also strongly influenced by the two highest losses reported which account for just over half of the average figure.

Priorities for investment were clearly articulated by the survey respondents with investment in road improvements being the highest preference followed by investment in landslide management and mitigation.

7.4 Summary

Questionnaires surveys to evaluate indirect consequential economic impacts were undertaken for three events. For the A85 Glen Ogle landslide, the survey for which was run as a trial, and the A77, A76, A71 Bellfield Junction Flooding event, the indirect consequential impacts were relatively small. In both cases the vulnerability shadow cast by the event is also relatively small, largely as there are viable alternative means of access. In addition, the durations of these impacts were relatively short; the main impacts being confined to a period of approximately two days.

The results of the survey for the A83 Rest and be Thankful event present a contrast. The survey itself was significantly larger to reflect the extensive vulnerability shadow cast by the event and the large number of businesses located therein; the response rate to this survey was approximately 17%. The responses indicate that most of the businesses that responded were in the tourist, retail and transport sectors, the majority employed fewer than 20 people but turnover was roughly equally split between those reporting turnover <£250k and those reporting turnover of £250k or more. The results indicate that the businesses are particularly dependent upon road transport, especially for incoming good and visitors but also to a slightly lesser degree for out-going goods. Dependence on road transport for staff (e.g. commuting) was relatively low. Unsurprisingly investment in road improvements was the highest investment priority, closely followed by investment in landslide management and mitigation.

The financial impact of the landslide event on businesses in the area was also evaluated and the figures at first seem to suggest an average cost of around £5k per business. However, this is strongly influenced by the highest loss reported; excluding this gives an average figure of £3.7k. However, a large proportion of respondents reported that they did not that they did not know the cost of the event or provided a null response. If the costs to these businesses are assumed, not unreasonably, to be close to zero then the average cost per business reduces to around £3.5k and to around £2.6k if the highest reported loss is excluded. These costs represent lost revenue (or turnover) and/or higher costs and not lost profit; they are also likely to be an overestimate of the real costs. If it is thus assumed that the 365 businesses that did not respond to the questionnaire also had costs at or close to zero as a result of the landslide then the average cost per business is around £0.5k.

The Word maps provide an interesting, but exclusively qualitative, perspective on the free-text responses offered by the survey respondents. For the A85 and A77 responses, the most frequently used words are 'landslide' and 'flooding' respectively, words that describe the event itself. In contrast the most frequently used word in the A83 responses was 'road', with words such as 'closed', 'staff', 'visitors', 'due', 'access', 'tourism', 'minor' and 'island' also coming to the fore in the responses attributable to the individual areas. These responses seemingly describe the consequences of the hazard, or the economic risks associated with the hazard, rather than the hazard itself, implying a significantly greater economic impact or, at least, a greater awareness of the economic impact.

8 Summary and Conclusions

This report presents the results of a study of the economic impacts of landslide and other climate-driven events that affect the trunk (strategic) road network in Scotland. 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 & Bromhead (2012), in three categories, as follows:

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

This approach can be equally applied to other events that reflect relatively discrete closures due to climate-driven events such as flooding. The areal extent of the economic impacts can be significant and independent on the size of the event – typically being governed by the density of the road network and the number and quality of alternative routes – this extent is described using the concept of the vulnerability shadow (Winter & Bromhead, 2012).

The work presented herein includes extensive background material including descriptions of the main events considered, a literature review of past work on the economic impacts of landslide events and of potential means of estimating indirect consequential economic impacts.

The literature review demonstrates that the costs of landslides, both direct and indirect, can be significant. This is supported by the estimates of direct and direct consequential economic impacts. However, the literature review also demonstrates that there appears to be a lack of reliable data on the indirect consequential costs of landslides.

It is not intended that the results be directly extrapolated to other, including future, landslide and flood events but to give a view of the type of impacts that have occurred in the past; these could potentially, and with care, be used to qualitatively and indirectly describe the types of impacts that future events may have. A more detailed articulation of future events would, of course, require further analysis.

The findings from the work presented herein shed substantial light on the economic impacts of landslide and flood events on the road network in Scotland but wholesale changes to the way in which generally accepted economic assessment model(s) are used are not indicated. It is however recommended that more effort be expended to capture the costs direct economic impacts immediately after events, not least as these can be very difficult to determine at a later stage. In addition, the QUADRO approach to determining direct consequential impacts may provide an additional tool for event analysis, not least as it is specifically designed for roadworks that may involve full closure, convoy working and shuttle working.

The trial of the use of questionnaire surveys to derive indirect consequential economic impacts produced numerical data that is perhaps less robust than the ideal. Notwithstanding this, the qualitative outcomes from the derivative Word maps are insightful and extremely useful, as set-out below. As these outcomes are generic, rather than site or region specific, the future use of such questionnaire surveys is not currently indicated.

The results for the A83 Rest and be Thankful are considered to be supportive of the existing assessments, findings and conclusions in respect of the Options Appraisal published in 2013 and no specific changes to the options or their hierarchy are indicated from the results presented herein.

In conclusion it seems clear that the economic impacts of landslides that affect the Scottish strategic road network are significant. While the direct consequential costs of such events may not be as great as those of some flood events that affect more densely populated, and highly trafficked, peri-urban areas, the costs are borne by a smaller number of individuals and individual businesses.

Given the mix of different costs calculated herein it is not intended that those costs should be aggregated to arrive at a total figure for the economic impact on the economy. Rather, this work is intended to articulate the differing types of costs in the context of the different sectors that bear those costs.

Detailed conclusions for each of direct economic impacts, direct consequential economic impacts and indirect consequential economic impacts are set out below.

8.1 Direct Economic Impacts

Data from five landslide events and two flooding events yield direct economic impacts from approximately £25k to £1,700k (or around £1,275k if the costs attributed to fences are excluded); the two flooding events yield the lowest direct economic impacts at less than £30k. Cleary these costs are significantly higher for landslide events than for flood events; this most likely reflects the fact that more active measures are needed to remove landslide debris than are needed to remove what are, in the cases studied, relatively localised flood waters that in part drain naturally. The lower costs for flooding events are supported by work on An additional flooding event at the A76 between Skelmorlie and Largs in January 2014, to which are attributed direct economic impact costs of around £30k (at 2012 prices) (Milne et al. 2016).

8.2 Direct Consequential Economic Impacts

Data from the same five landslide events and one of the flood events for which direct economic impacts were determined, yield direct consequential economic impacts from around £175k to £3,200k. Those impacts for landslide events cover a wide range from £175k to £1,400k with the impacts of the flood event being around £3,200k. The costs, while including the costs of accidents associated with the events, are largely related to the amount of traffic affected, the duration for which it is affected, and the nature of the delays incurred (e.g. diversion, diversion length, convoy or traffic light working); the figure for the flood event corresponds with an environment in which traffic is substantially greater than for the landslide events.

There is no apparent relation between the direct and direct consequential economic impacts of landslide and/or flood events.

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

- The relative costs of similar closures depend on the traffic levels, with costs being higher where traffic is higher.
- Where traffic levels are high and/or multiple roads and routes are affected then costs can be significant even when closure durations are relatively short.
- Doubling the duration incurs higher costs, but may be reduced if the traffic levels are lower.
- A much longer duration increases the costs significantly.

The costs of accidents from known incidents related to the event are included along with the modelled costs of delay, carbon and accidents resulting from the diversions or other changes to the movement of traffic as a result of the landslide or flood event. The incident accident costs are generally relatively low, reflecting the rarity of known vehicle interactions with the events. The modelled carbon costs are around 5% to 9% of the delay costs while modelled accident costs are generally negative; the latter are considered to be sufficiently small compared to the delay costs as to suggest a neutral effect on accident occurrence and/or severity.

The landslide events were located in rural areas and their impacts were upon those areas and relatively small towns and villages. The flooding event was located in a much more developed part of Scotland and 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, even though the effects of the flood persisted for a much shorter time (the daily delay costs due to closure for the flooding event were almost 20 times greater than those for the landslide event). Notwithstanding this the impacts of the landslide event(s) in areas in which alternative routes are limited should not be underestimated; those impacts were borne by a much smaller number of people over an extended period and the impacts on individuals and individual businesses seem likely to have been considerably greater.

The analysis of the events at, and near to, the A83 Rest and be Thankful demonstrates that the costs of a full closure of the A83 are significant ranging from £83k to £88k per day for delay costs and from £85k to £90k per day for total (delay, carbon and accident) costs (at 2012 prices, Table 9). These figures are greater than the £52k (updated to £68k in 2015/16) per day reported in the A83 Route Study. However, given the totally different methodologies used the two sets of figures are considered to be of the same order and are not considered to be contradictory. Under convoy working on the Old Military Road (Site 6), used as a temporary diversion, these costs reduce to just under £13k per day for delays and around £15.5k per day in total. The use of shuttle working (traffic light on a single lane closure) brings the equivalent costs down to less than £0.5k per day for delays and around £1.2k for total costs. These figures clearly demonstrate the economic benefits of the use of the Old Military Road as a temporary diversion while also demonstrating that the costs remain significant and that there is a benefit to reverting to shuttle working and, of course, fully re-opening the road as soon as possible.

8.3 Indirect Consequential Economic Impacts

In order to evaluate indirect consequential economic impacts questionnaire surveys were undertaken for three events. For the A85 Glen Ogle landslide, the survey for which was run as a trial, and the A77, A76, A71 Bellfield Junction Flooding event, the indirect consequential impacts were relatively small. In both cases the vulnerability shadow cast by the event is also relatively small, largely as there are viable alternative means of access. In addition, the durations of these impacts were relatively short; the main impacts being confined to a period of approximately two days. It should be noted that the gap between the event and the trial survey at A85 Glen Ogle was nine years.

The results of the survey for the A83 Rest and be Thankful event present a contrast. The survey itself was significantly larger to reflect the extensive vulnerability shadow cast by the event and the large number of businesses located therein; the response rate to this survey was approximately 17%. The responses received indicated that most of the businesses that responded were in the tourist, retail and transport sectors, the majority employed fewer than 20 people but turnover was roughly equally split between those reporting turnover <£250k and those reporting turnover of £250k or more. The results indicate that the businesses are particularly dependent upon road transport, especially for incoming good and visitors but also to a slightly lesser degree for out-going goods. Dependence on road transport for staff (e.g. commuting) was relatively low. Unsurprisingly investment in road improvements was the highest priority, closely followed by investment in landslide management and mitigation.

The financial impact of the landslide event on businesses in the area was also evaluated and an average figure of between £2.6k and £5k per business has been estimated – the range reflecting the diversity of the different assumptions that can be made regarding the extreme values, both high and low, reported by questionnaire respondents. However, these costs, which represent lost revenue (or turnover) and/or higher costs and not lost profit, are also likely to be an overestimate of the real costs. Thus, if it is further assumed, at one end of the range of possible assumptions, that the businesses that did not respond to the questionnaire had costs at or close to zero as a result of the landslide then the average cost per business is around £0.5k. It should, however, be noted that the assumption of zero costs for non-responding businesses is only one possible scenario. Equally it may be that the costs were not zero but that they were difficult to identify and calculate and/or the businesses took the view that as the event was in the past there was little to be gained in identifying these costs.

The Word maps provide an interesting, but exclusively qualitative, perspective on the free-text responses offered by the survey respondents; this aids the understanding and articulation of nature of the responses received. For the A85 and A77 responses, the most frequently used words are 'landslide' and 'flooding' respectively, and other words that describe the event itself are also to the fore. In contrast the most frequently used word in the A83 responses was '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. In essence, responses to events of lesser impact tend to relate to the hazard, or event, itself while responses to events of greater impact tend to relate to the effects, risks, or impacts, that derive from the event.

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Appendix A **Details of Direct Consequential Economic Impact Analysis**

A.1 Value of Accident Prevention

Table 21. Cost per accident (in £ Year) by severity for reported road accidents on Trunk Roads Only roads by year in Scotland (from Anon. 2002 to 2014).

	Accidents Costs on Trunk Roads Only (£ Year)												
Accident Type	**2001 (£ 2001)**	**2002 (£ 2002)**	**2003 (£ 2003)**	**2004 (£ 2004)**	**2005 (£ 2005)**	**2006 (£ 2006)**	**2007 (£ 2007)**	**2008 (£ 2008)**	**2009 (£ 2009)**	**2010* (£ 2009)**	**2011* (£ 2010)**	**2012 (£ 2012)**	**2013 (£ 2013)**
Fatal	1,535,928	1,635,828	1,657,314	1,647,231	1,652,835	1,796,626	1,979,098	2,114,935	1,838,976	2,006,133	1,923,020	2,186,740	2,071,915
Serious	180,075	189,063	186,680	203,179	213,428	217,111	231,557	246,496	227,541	224,019	225,743	252,848	264,589
Slight	17,789	18,527	19,779	20,096	21,284	21,657	24,232	24,069	23,520	22,872	23,854	25,597	25,764
Average for all severities	108,033	121,043	119,856	116,114	118,676	133,080	141,058	124,367	121,879	122,490	117,949	116,191	148,214
Damage only	1,721	1,808	1,880	1,989	2,076	2,167	2,445	2,496	2,377	2,362	2,458	2,520	2.573
Average for all accidents	11,965	13,364	13,107	12,917	13,458	14,977	15,931	14,318	14,209	14,152	13,629	13,743	16,877

* Note that the data for 2010 and 2011 are presented at 2009 and 2010 prices, respectively, in the source documents.

A.2 Details of QUADRO Analyses

Note that all QUADRO results where costs are involved are given at 2010 prices in line with the standard output from the software.

Each diagram shows a geometric representation of the diversionary network. The closure is highlighted with a ⦸ and the grey circles are Transport Scotland and local authority count stations. The counts used are those temporally closest to the events. All distances are marked in km, measured using Google Maps. Where available, the flows used are the seven-day averages for the nearest available August.

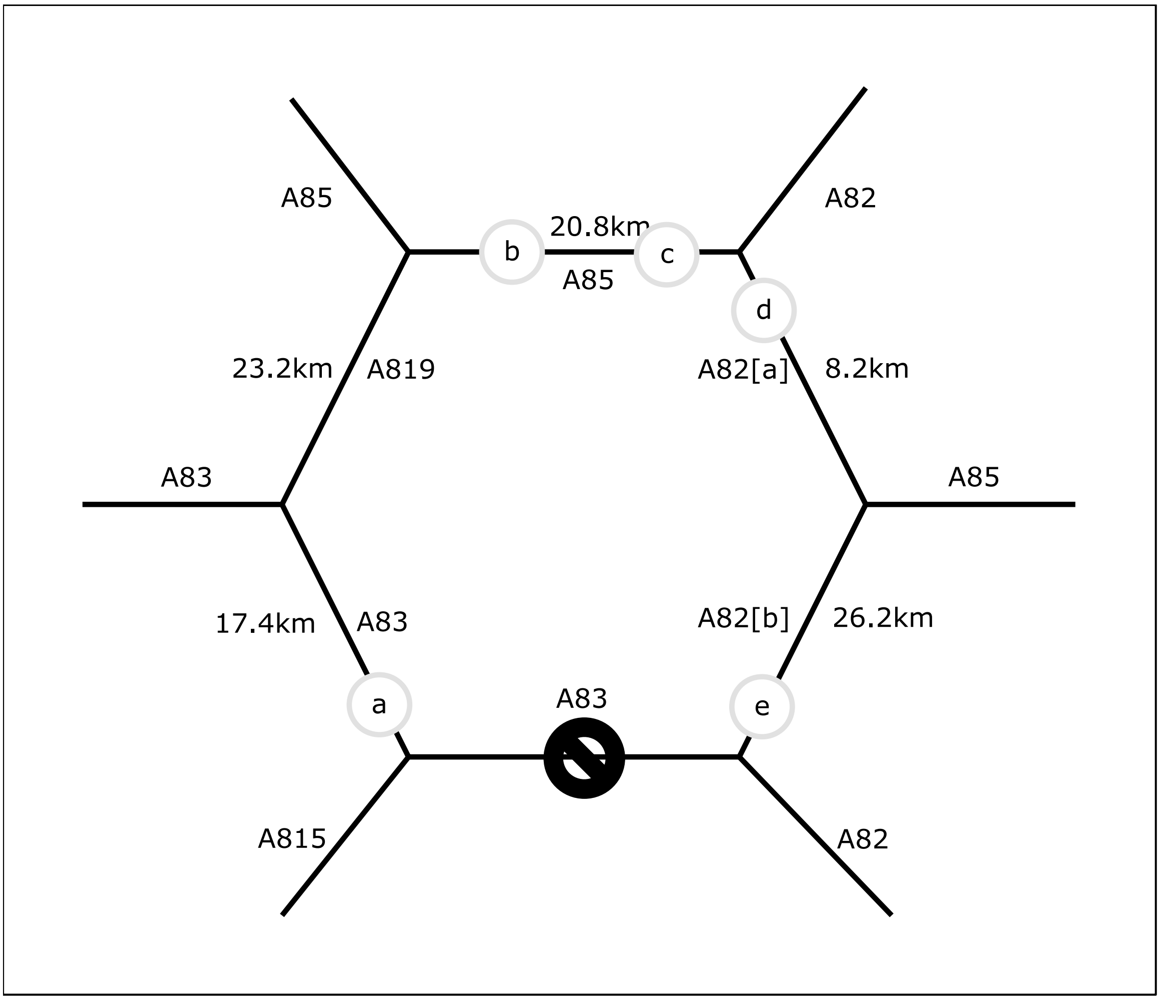

Figure 32. Site 1: A83 Glen Kinglas to Cairndow, August 2004.
Traffic count stations: a) ATC08063 [2,275, Aug. '04]; b) JTC10069 [1,725, Aug. '05]; c) ATC08056 [1,750, Aug. '05]; d) 108370 [4,109 (6%), Aug. '07]; and e) ATCCS001 [2,987, Aug. '04].

Table 22. Input summary for Site 1: A83 Glen Kinglas to Cairndow, August 2004.

Item	1 A83	2 A819	3 A85	4 A82[a]	5 A82[b]
16-hour flow	2,275	1,500[1]	1,750	4,109	2,987
Class	1[2]	1	1	1	1
Accident type	8[3]	8	8	8	8
Design standard	0[4]	0	0	0	0
Length (km)	17.4	23.2	20.8	8.2	26.2
Width (m)	7.3[5]	7.3	7.3	7.3	7.3
Hilliness (m/km)	30[6]	30	30	30	30
%HGVs	6	6	6	6[7]	6
Bendiness (°/km)	75[8]	75	75	75	75
Hardstrip width (m)	0[9]	0	0	0	0
Verge width (m)	1[10]	1	1	1	1
Side roads (#/km)	0[11]	0	0	0	0
Sight distance (m)	0[12]	0	0	0	0
Speed limit (km/h)	96[13]	96	96	96	96

[1] Estimated.
[2] 'Rural single carriageway'.
[3] 'Older single 2-lane A road'.
[4] Not to TD 9/93 (DMRB 6.1.1).
[5] Assumed 3.65m per lane, standard for Class 1 per QUADRO manual.
[6] Suggested value for 'hilly' in QUADRO manual.
[7] Calculated from traffic data for link 4, assumed same for all links.
[8] Suggested value for Class 1 'average' in QUADRO manual.
[9] Suggested value from QUADRO manual.
[10] Suggested value from QUADRO manual.
[11] Assumed none significant.
[12] Sets automatic use of empirical relationship.
[13] Assumed national single-carriageway speed limit applies.

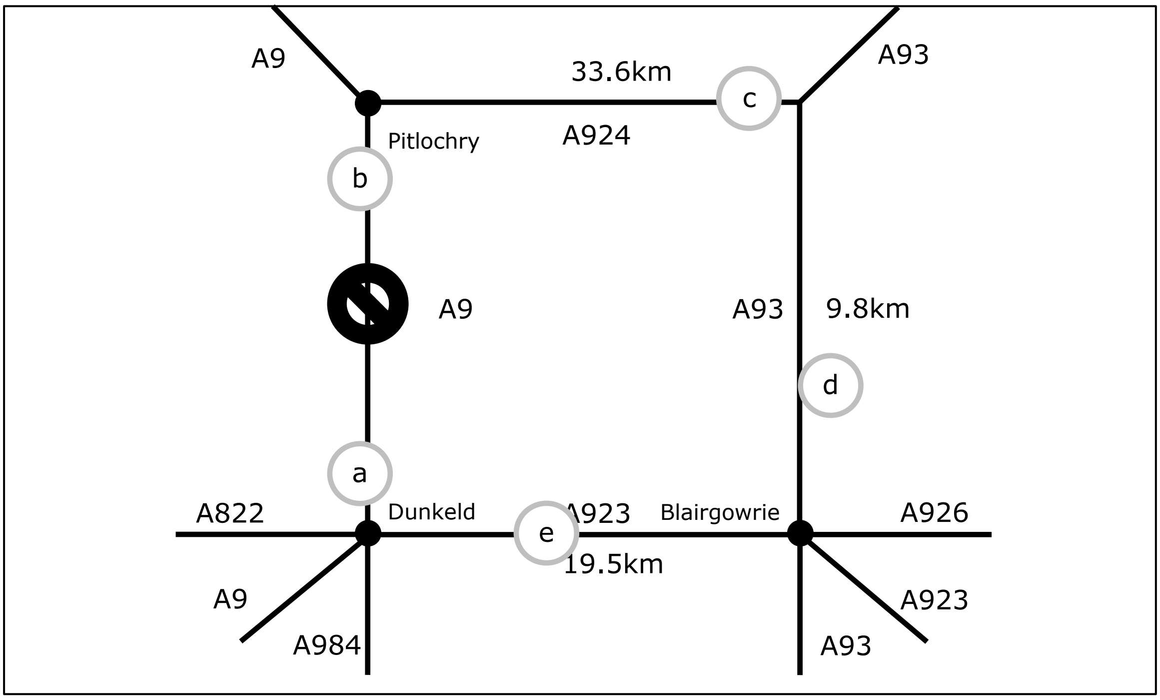

Figure 33. Site 2: A9 North of Dunkeld, August 2004.

Traffic count stations: a) ATC03022 [L1 8,844, L2 9,105, Aug. '05]; b) JTC00306 [NB 7,892 (14%), SB 8,037 (14%), Aug. '04]; Perth and Kinross data: c) A924 at Kirkmichael [SB 414, Sept. '04]; d) A93 at Craighall [SB 1,105, July '09]; and e) A923 Blairgowrie-Dunkeld [SB 3,460, Mar. '07].

Table 23. Input summary for Site 2: A9 North of Dunkeld, August 2004.

Item	**1 A924**	**2 A93**	**3 A923**
16-hour flow	414	1,105	3,460
Class	1	1	1
Accident type	8	8	8
Design standard	0	0	0
Length (km)	33.6	9.8	19.5
Width (m)	7.3	7.3	7.3
Hilliness (m/km)	30	30	30
%HGVs	11[1]	11	6
Bendiness (°/km)	75	75	75
Hardstrip width (m)	0	0	0
Verge width (m)	1	1	1
Side roads (#/km)	0	0	0
Sight distance (m)	0	0	0
Speed limit (km/h)	96	96	96

[1] Approximated based on Event 3, Link 3.

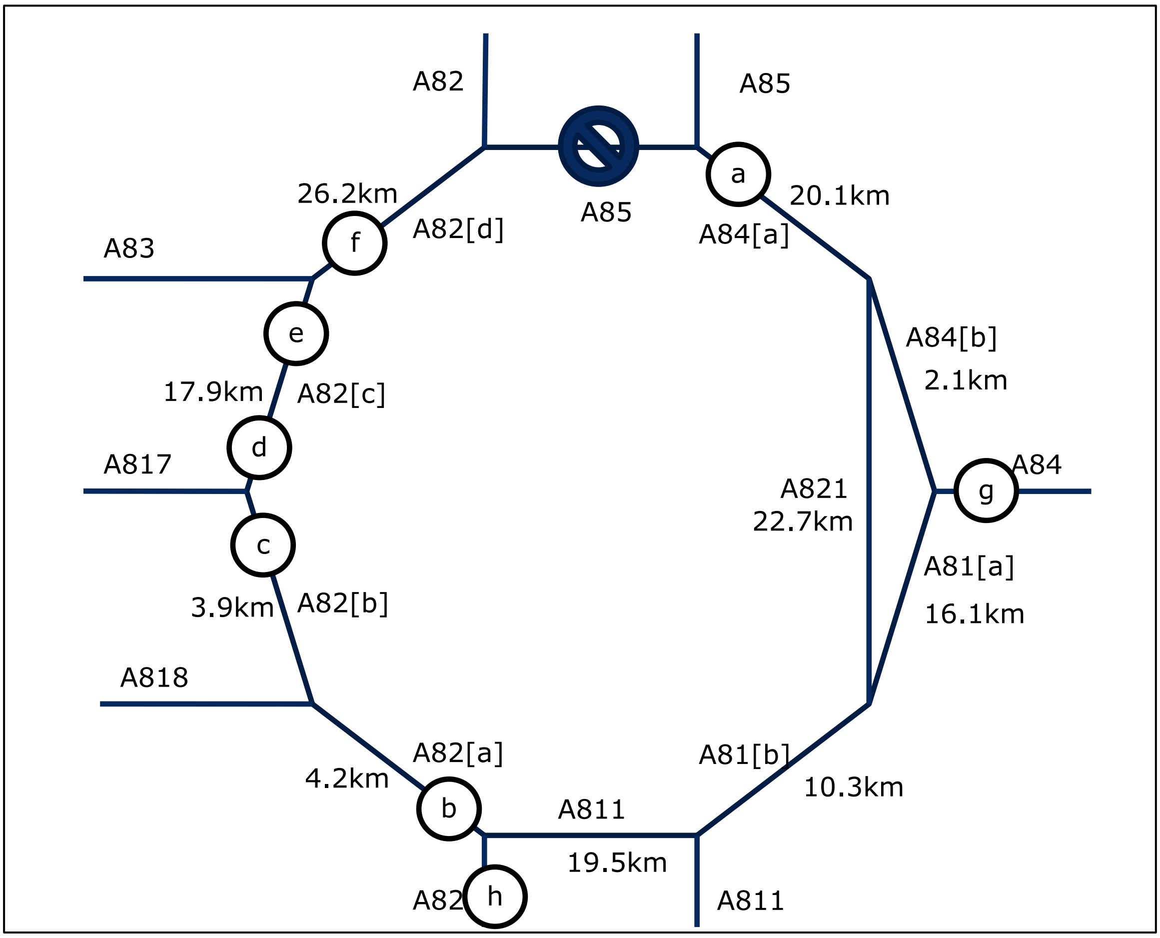

Figure 34. Site 3: A85 Glen Ogle, August 2004.

Traffic count stations: a) ATC06003 [SB 2,348, NB 2,086, Aug. '04]; b) ATC08086 [SB 11,646 NB 11,811, Aug. '04]; c) 108260 [7,382 (5%), Aug. '08]; d) ATC08084 [6,267, Aug. '06] – not used; e) ATC08119 [5,604, Aug. '04]; f) ATCCS001 [2,987, Aug. '04]; g) ATC06006 [SB 4,466, NB 4,347, Aug. '05]; and h) JTC00016 [SB 12,412, NB 7,902, Aug. '04].

Table 24. Input summary for Site 3: A85 Glen Ogle, August 2004.

Item	**1 A84[b]**	**2 A81[a]**	**3 A821**	**4 A84[a]**	**5 A81[b]**	**6 A811**	**7 A82[a]**	**8 A82[b]**	**9 A82[c]**	**10 A82[d]**
16-hour flow	2,148[1]	2,250[1]	200[1]	2,348	2,450[1]	0[2]	11,646	7,382	5,604	2,987
Class	1	1	1	1	1	1	1	1	1	1
Accident type	8	8	8	8	8	8	8	8	8	8
Design standard	0	0	0	0	0	0	0	0	0	0
Length (km)	2.1	16.1	22.7	20.1	10.3	19.5	4.2	3.9	17.9	26.2
Width (m)	7.3	7.3	7.3	7.3	7.3	7.3	7.3	7.3	7.3	7.3
Hilliness (m/km)	30	30	30	30	30	30	30	30	30	30
%HGVs	5	5	5	5	5	5	5	5[3]	5	5
Bendiness (°/km)	75	75	75	75	75	75	75	75	75	75
Hardstrip width (m)	0	0	0	0	0	0	0	0	0	0
Verge width (m)	1	1	1	1	1	1	1	1	1	1
Side roads (#/km)	0	0	0	0	0	0	0	0	0	0
Sight distance (m)	0	0	0	0	0	0	0	0	0	0
Speed limit (km/h)	96	96	96	96	96	96	96	96	96	96

Note: numerical order of route sections is not strictly in clockwise direction, due to input requirements of QDIV.
[1] Estimated from traffic count stations a and g.
[2] Assumed negligible based on traffic count stations b and h.
[3] Calculated from traffic data for link 8, assumed same for all links.

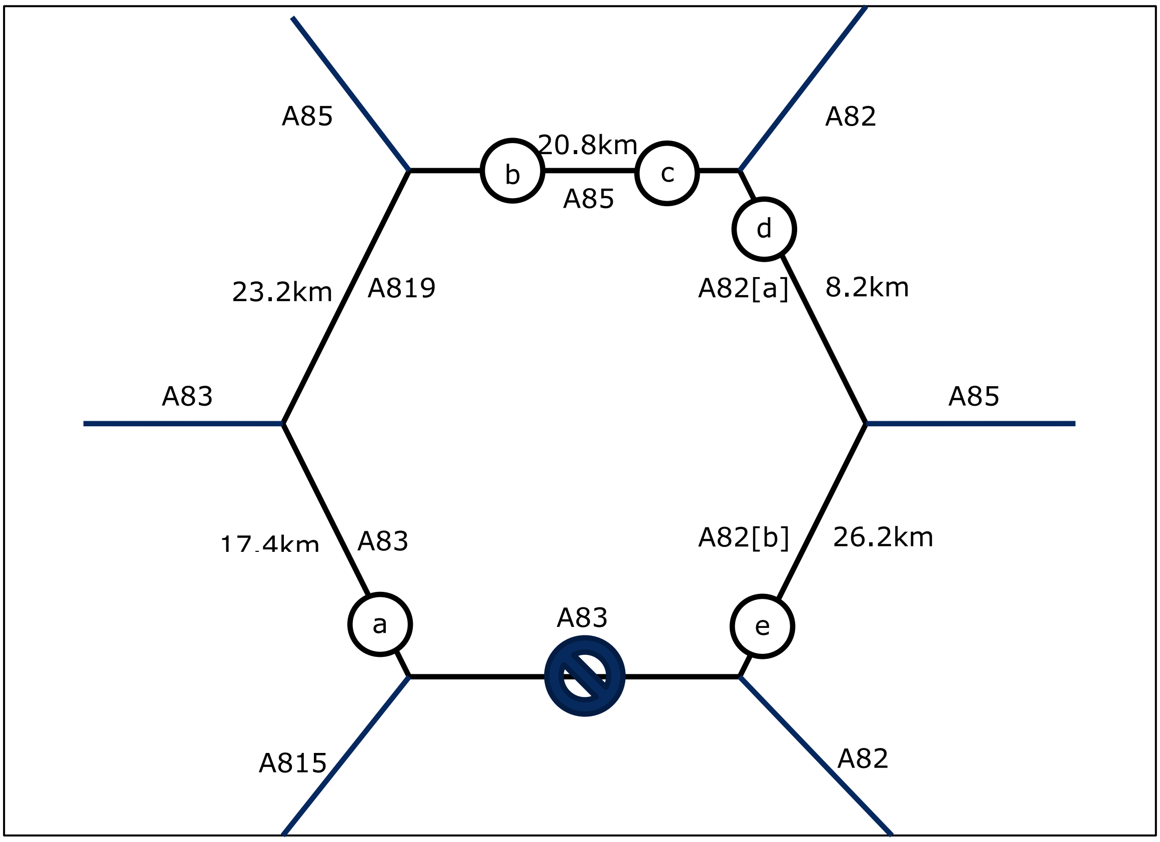

Figure 35. Site 4: A83 Rest and be Thankful, October 2007.

Traffic count stations: a) ATC08063 [1,666, Oct. '07]; b) JTC10069 [1,211 (14%), Oct. '07]; c) ATC08056 [1,318, Oct. '07]; d) 108370 [2,835 (8%), Oct. '07]; e) ATCCS001 [1,806, Oct. '07]

Table 25. Input summary for Site 4: A83 Rest and be Thankful, October 2007.

Item	**1 A83**	**2 A819**	**3 A85**	**4 A82[a]**	**5 A82[b]**
16-hour flow	1,666	1,500	1,318	2,835	1,806
Class	1	1	1	1	1
Accident type	8	8	8	8	8
Design standard	0	0	0	0	0
Length (km)	17.4	23.2	20.8	8.2	26.2
Width (m)	7.3	7.3	7.3	7.3	7.3
Hilliness (m/km)	30	30	30	30	30
%HGVs	14	14	14[1]	8[2]	8
Bendiness (°/km)	75	75	75	75	75
Hardstrip width (m)	0	0	0	0	0
Verge width (m)	1	1	1	1	1
Side roads (#/km)	0	0	0	0	0
Sight distance (m)	0	0	0	0	0
Speed limit (km/h)	96	96	96	96	96

[1] Calculated from traffic data for link 3, assumed same for links 1 and 2.
[2] Calculated from traffic data for link 4, assumed same for link 5.

The Bellfield Junction was closed due to flooding in September 2012 and the closures that were put in place were as follows:

- A77 total closure from 21 September 2012 23:00 to 22 September 2012 24:00 (total 25 hours)
- A76 total closure from 21 September 2012 23:00 to 22 September 2012 18:00 (total 19 hours)
- A76 one lane closed traffic light controlled from 22 September 2012 18:00 to 24 September 2012 18:00 (total 2 days)
- A71 total closure from 21 September 2012 at 23:00 to 24 September 2012 at 18:00 (total 67 hours).

The analysis for Site 5 was particularly complex and to avoid double-counting it was assumed that the traffic travelling to each destination was split as a proportion of the total flow at the origin. The proportions were calculated based on the traffic flows at the destinations. The recalculated traffic flows are shown in Table 25. Where information was not available 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. These links showed HGV percentage around 3% so this was assumed for all links.

Table 26. Recalculated traffic levels for Site 5: A77, A76, A71 Bellfield Junction, September 2012.

		Apportioned Traffic by destination				
Origin	Total Traffic	A77 South	A77 North	A71 West	A71 East	A76 South
A77 South	36,505	-	18,740	6,356	6,670	3,764
A77 North	46,811	16,837	-	8,150	8,554	4,826
A71 West	20,463	7,360	10,505	-	3,739	2,110
A71 East	21,320	7,668	10,945	3,712	-	2,198
A76 South	12,898	4,639	6,621	2,246	2,357	-

A total of 15 diversion routes was identified as set out in Table 19. It was assumed that all routes are Rural, and that the length of the flood-affected site in each case was 100m. QUADRO calculates the costs of user delays for an average day over a whole week.

Figures 35 to 42 and Tables 27 to 34 illustrate the individual diversions and give basic information on input data.

The results of the QUADRO analyses are shown in Tables 28 and 29.

Table 27. Diversion Route Parameters for Site 5: A77, A76, A71 Bellfield Junction, September 2012.

Route	Parameter					
	Origin/ Direction	Destination / Direction	Road Type	Recalculated Traffic flow (AADT)	Junction length (km)	Speed Limit (kph)
Diversion Route 1	A77NB	A77NB	Dual 2 lane	18470	12.1	112
Diversion Route 2	A77NB	A71EB	Dual 2 lane	6356	21.3	112
Diversion Route 3	A77SB	A77SB	Dual 2 lane	16837	13	112
Diversion Route 4	A77 SB	A71WB	Dual 2 lane	8854	10.6	112
Diversion Route 5	A77 SB	A71EB	Dual 2 lane	8150	19.3	112
Diversion Route 6	A77 SB	A76SB	Dual 2 lane	4826	17	112
Diversion Route 7	A71WB	A71WB	Single 2 lane	3739	5.3	96
Diversion Route 8	A71WB	A77NB	Single 2 lane	7360	19.5	96
Diversion Route 9	A71WB	A77SB	Single 2 lane	7360	21	96
Diversion Route 10	A71EB	A71EB	Dual 2 lane	3712	5.4	112
Diversion Route 11	A71EB	A77NB	Dual 2 lane	10945	13.6	112
Diversion Route 12	A71EB	A77SB	Dual 2 lane	7668	7.9	112
Diversion Route 13	A71EB	A76SB	Dual 2 lane	2198	9.5	112
Diversion Route 14	A76NB	A77NB	Single 2 lane	4639	32.3	96
Diversion Route 15	A76NB	A71WB	Single 2 lane	2357	7.4	96

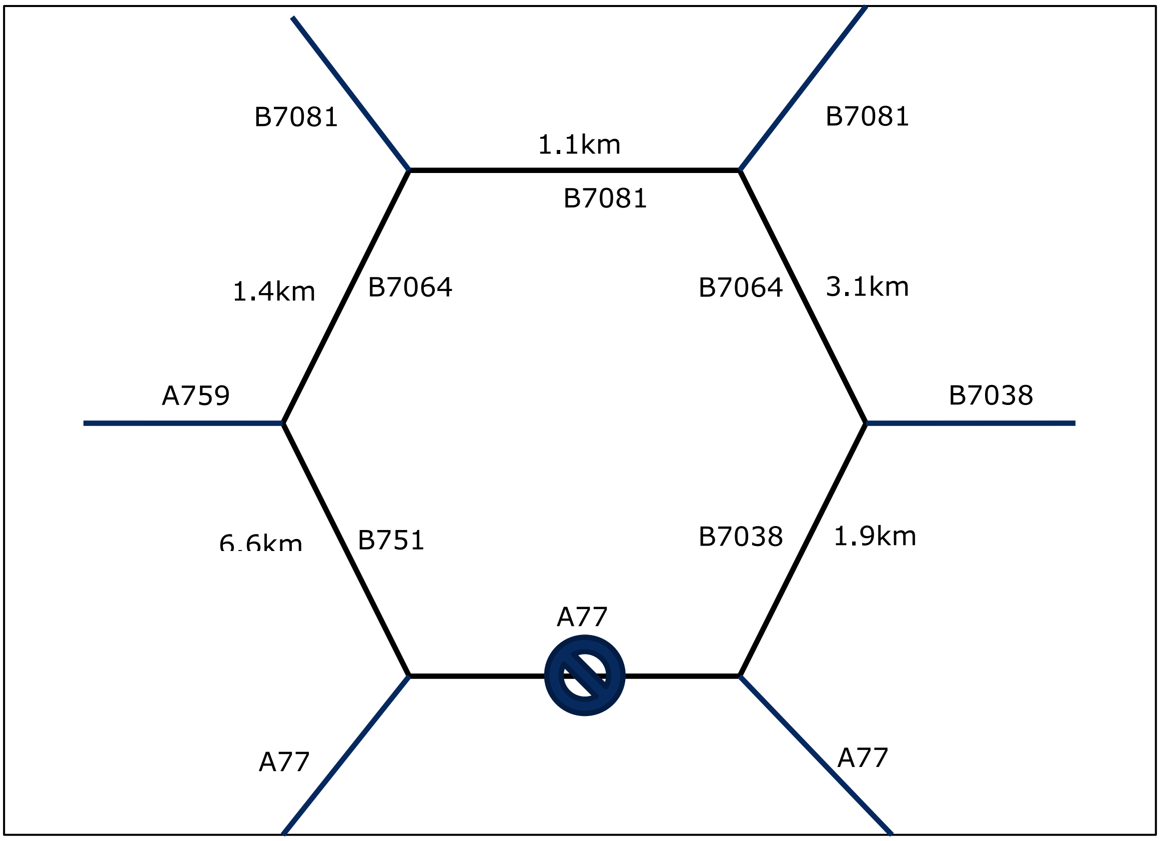

Figure 36. Site 5: A77, A76, A71 Bellfield Junction, September 2012. Diversion routes 1 and 3 (reversed).

Table 28. Input summary for Site 5: A77, A76, A71 Bellfield Junction, September 2012. Diversion routes 1 and 3 (reversed).

Item	B751	B7064	B7081	B7064	B7038
16-hour flow	7917	13783	13783	14102	14102
Class	1	1	1	1	1
Accident type	9	9	9	9	9
Design standard	0	0	0	0	0
Length (km)	6.6	1.4	1.1	3.1	1.9
Width (m)	7.3	7.3	7.3	7.3	7.3
Hilliness (m/km)	30	30	30	30	30
%HGVs	6	6	6	6	6
Bendiness (°/km)	75	75	75	75	75
Hardstrip width (m)	0	0	0	0	0
Verge width (m)	1	1	1	1	1
Side roads (#/km)	0	0	0	0	0
Sight distance (m)	0	0	0	0	0
Speed limit (km/h)	96	96	96	48	48

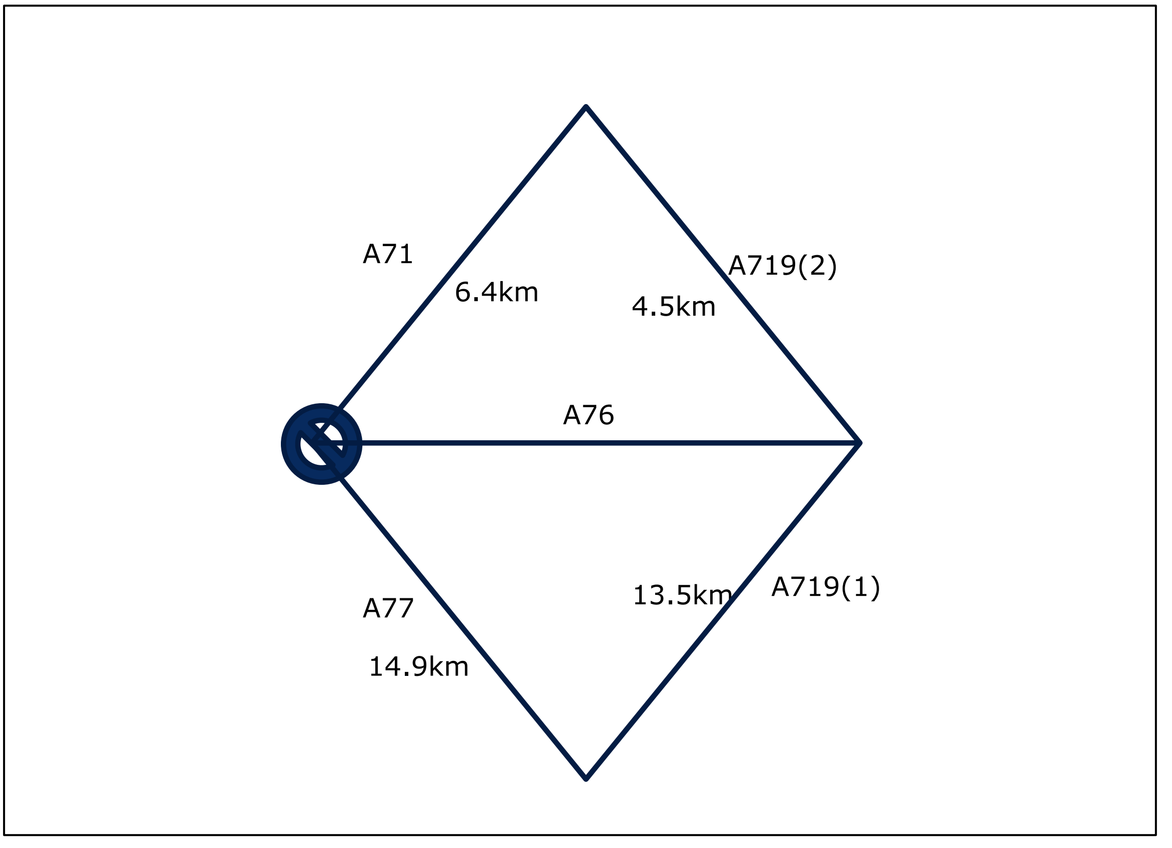

Figure 37. Site 5: A77, A76, A71 Bellfield Junction, September 2012. Diversion routes 2 and 9.

Table 29. Input summary for Site 5: A77, A76, A71 Bellfield Junction, September 2012. Diversion routes 2 and 9.

Item	A719(1)	A719(2)
16-hour flow	13719	2439
Class	1	1
Accident type	8	8
Design standard	0	0
Length (km)	13.5	4.5
Width (m)	7.3	7.3
Hilliness (m/km)	30	30
%HGVs	6	6
Bendiness (°/km)	75	75
Hardstrip width (m)	0	0
Verge width (m)	1	1
Side roads (#/km)	0	0
Sight distance (m)	0	0
Speed limit (km/h)	96	96

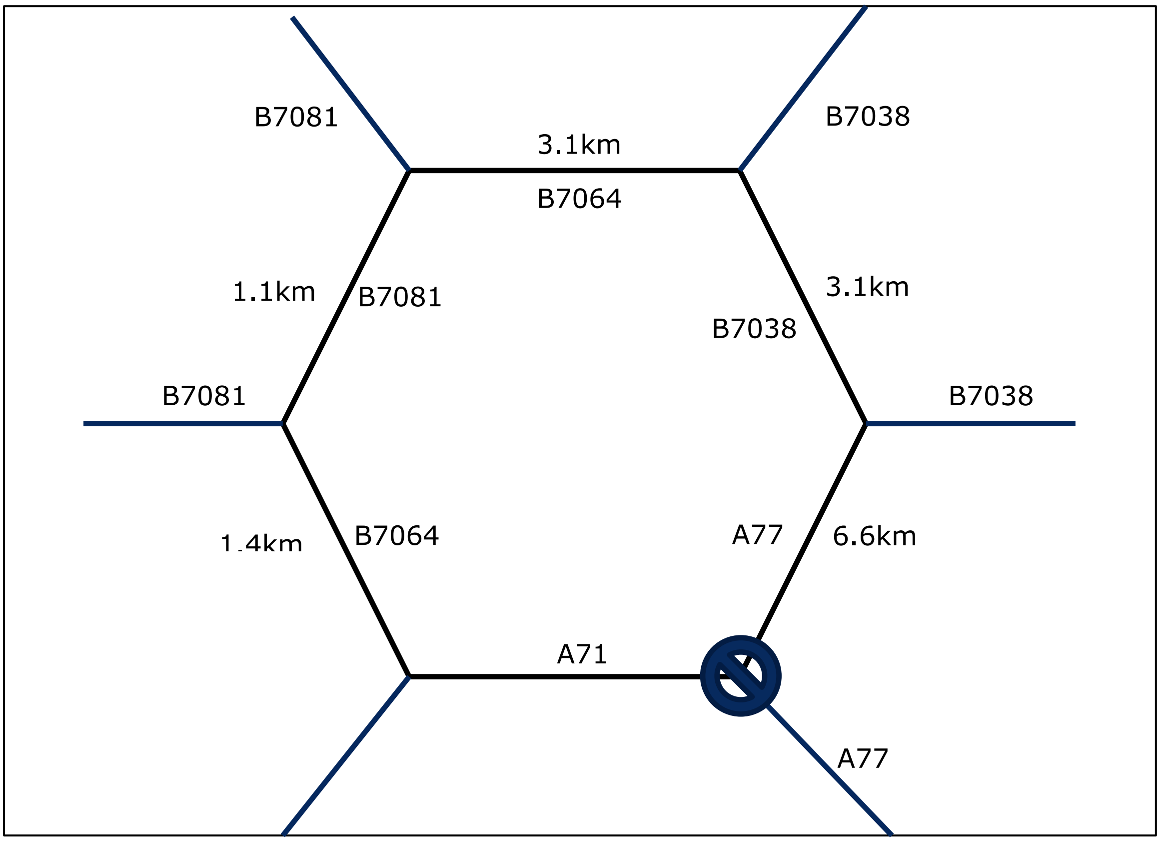

Figure 38. Site 5: A77, A76, A71 Bellfield Junction, September 2012. Diversion routes 4 and 11.

Table 30. Input summary for Site 5: A77, A76, A71 Bellfield Junction, September 2012. Diversion routes 4 and 11.

Item	**B7038**	**B7064**	**B7081**	**B7064**
16-hour flow	14102	14102	13783	13783
Class	1	1	1	1
Accident type	9	9	9	9
Design standard	0	0	0	0
Length (km)	1.9	3.1	1.1	1.4
Width (m)	7.3	7.3	7.3	7.3
Hilliness (m/km)	30	30	30	30
%HGVs	6	6	6	6
Bendiness (°/km)	75	75	75	75
Hardstrip width (m)	0	0	0	0
Verge width (m)	1	1	1	1
Side roads (#/km)	0	0	0	0
Sight distance (m)	0	0	0	0
Speed limit (km/h)	48	48	96	96

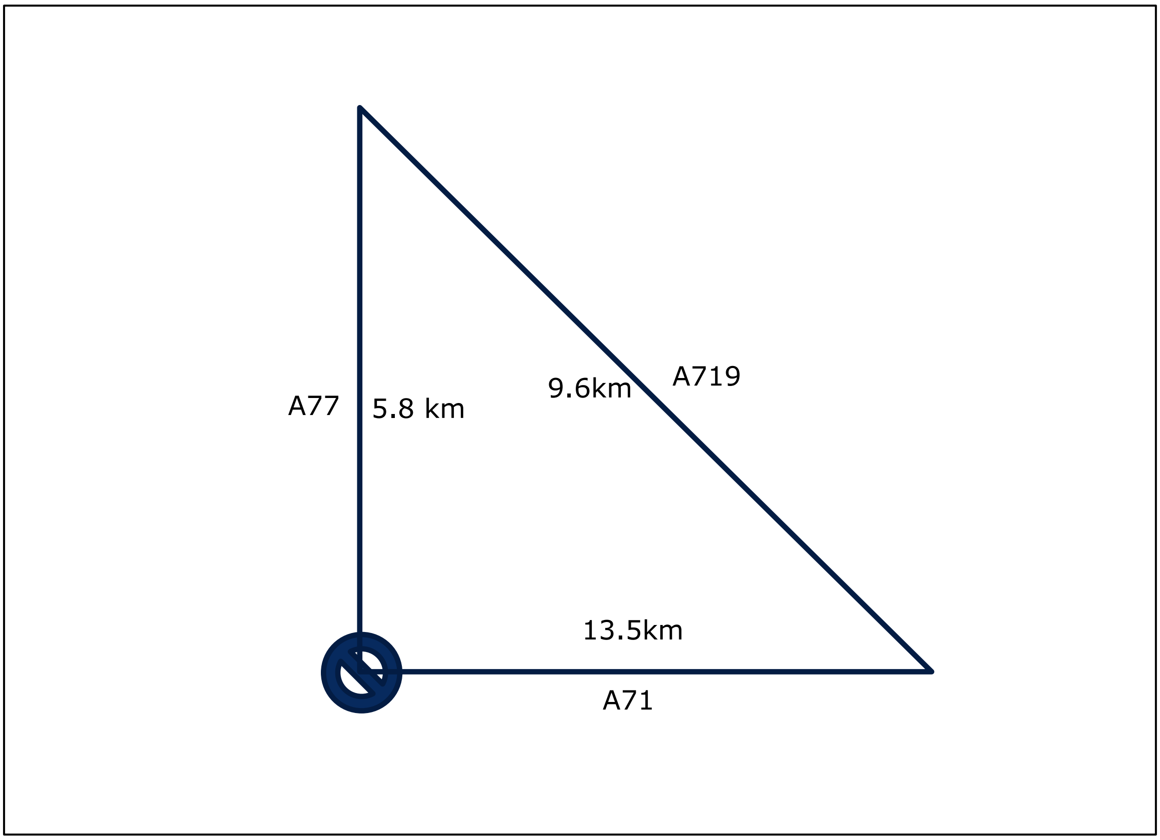

Figure 39. Site 5: A77, A76, A71 Bellfield Junction, September 2012. Diversion routes 5 and 8.

Table 31. Input summary for Site 5: A77, A76, A71 Bellfield Junction, September 2012. Diversion routes 5 and 8.

Item	A719
16-hour flow	13719
Class	1
Accident type	8
Design standard	0
Length (km)	9.6
Width (m)	7.3
Hilliness (m/km)	30
%HGVs	6
Bendiness (°/km)	75
Hardstrip width (m)	0
Verge width (m)	1
Side roads (#/km)	0
Sight distance (m)	0
Speed limit (km/h)	96

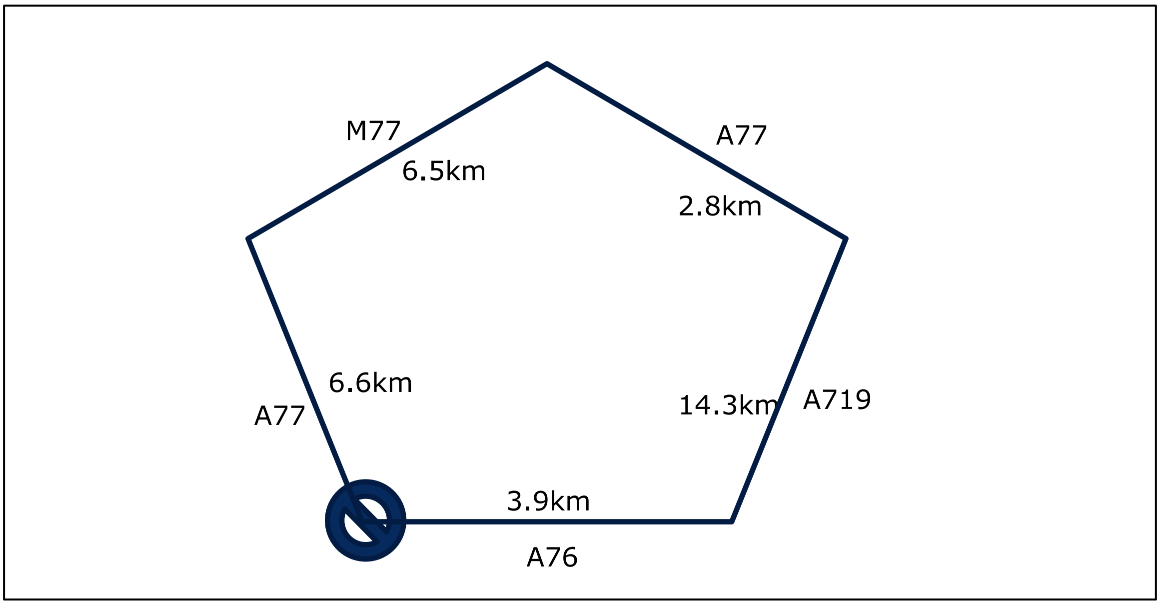

Figure 40. Site 5: A77, A76, A71 Bellfield Junction, September 2012. Diversion routes 6 and 14.

Table 32. Input summary for Site 5: A77, A76, A71 Bellfield Junction, September 2012. Diversion routes 6 and 14.

Item	**A77**	**A719**
16-hour flow	5408	13719
Class	1	1
Accident type	8	8
Design standard	0	0
Length (km)	2.8	14.3
Width (m)	7.3	7.3
Hilliness (m/km)	30	30
%HGVs	6	6
Bendiness (°/km)	75	75
Hardstrip width (m)	0	0
Verge width (m)	1	1
Side roads (#/km)	0	0
Sight distance (m)	0	0
Speed limit (km/h)	96	96

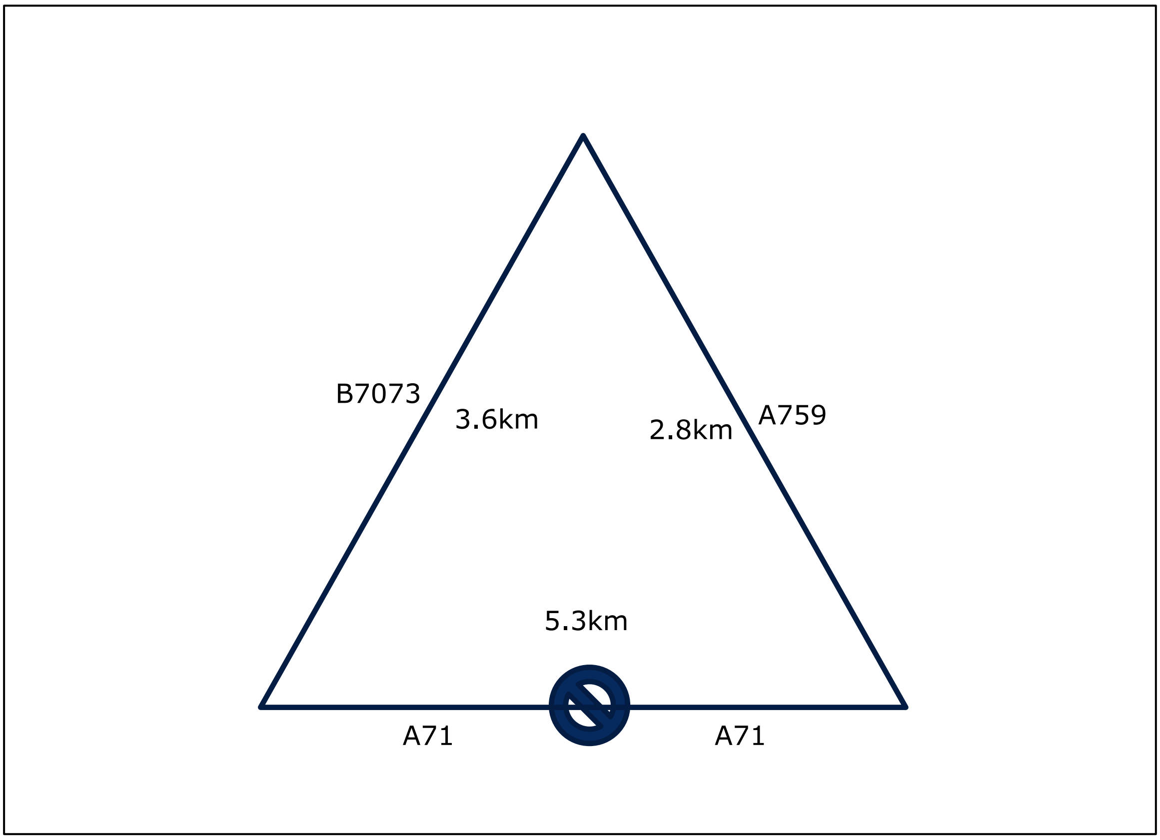

Figure 41. Site 5: A77, A76, A71 Bellfield Junction, September 2012. Diversion routes 7 and 10.

Table 33. Input summary for Site 5: A77, A76, A71 Bellfield Junction, September 2012. Diversion routes 7 and 10.

Item	**B7073**	**A759**
16-hour flow	10349	6410
Class	1	1
Accident type	9	8
Design standard	0	0
Length (km)	3.6	2.8
Width (m)	7.3	7.3
Hilliness (m/km)	30	30
%HGVs	6	6
Bendiness (°/km)	75	75
Hardstrip width (m)	0	0
Verge width (m)	1	1
Side roads (#/km)	0	0
Sight distance (m)	0	0
Speed limit (km/h)	48	96

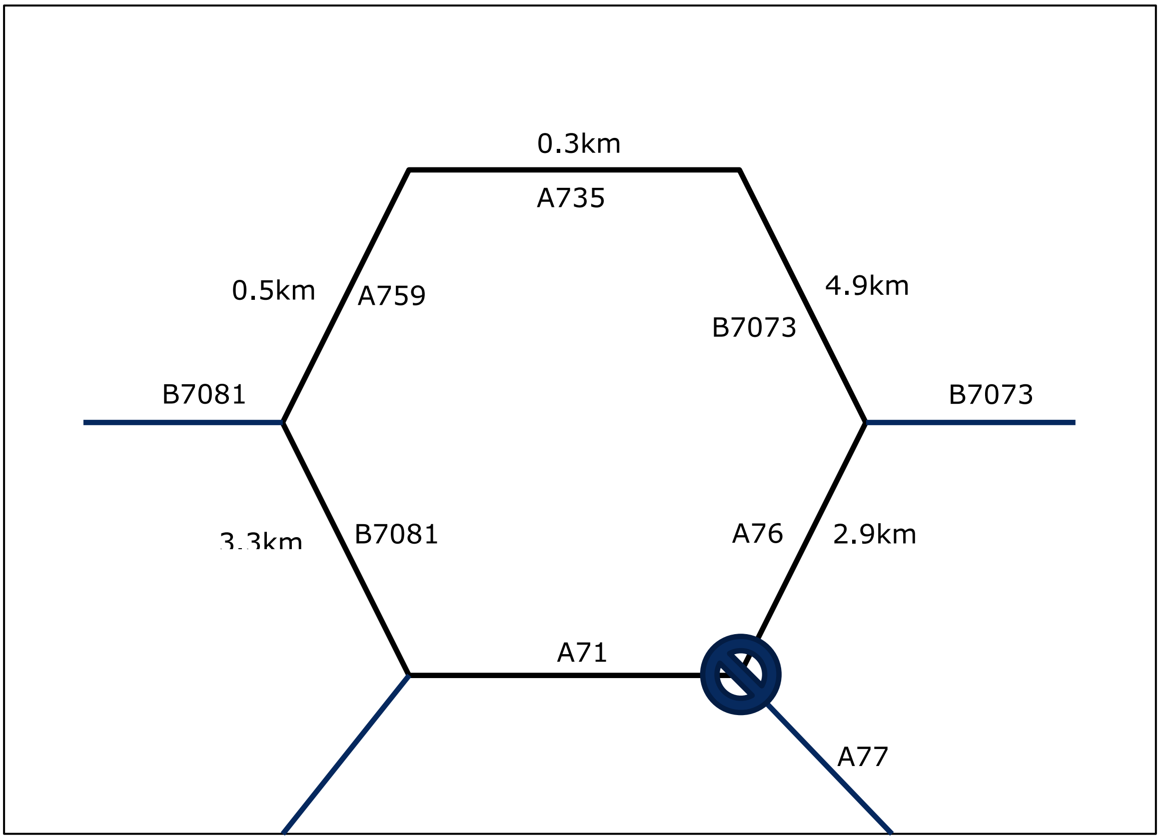

Figure 42. Site 5: A77, A76, A71 Bellfield Junction, September 2012. Diversion routes 13 and 15.

Table 34. Input summary for Site 5: A77, A76, A71 Bellfield Junction, September 2012. Diversion routes 13 and 15.

Item	**B7081**	**A759**	**A735**	**B7073**
16-hour flow	13783	6410	6410	10349
Class	1	1	1	1
Accident type	9	8	8	9
Design standard	0	0	0	0
Length (km)	3.3	0.4	0.3	4.9
Width (m)	7.3	7.3	7.3	7.3
Hilliness (m/km)	30	30	30	30
%HGVs	6	6	6	6
Bendiness (°/km)	75	75	75	75
Hardstrip width (m)	0	0	0	0
Verge width (m)	1	1	1	1
Side roads (#/km)	0	0	0	0
Sight distance (m)	0	0	0	0
Speed limit (km/h)	96	96	96	48

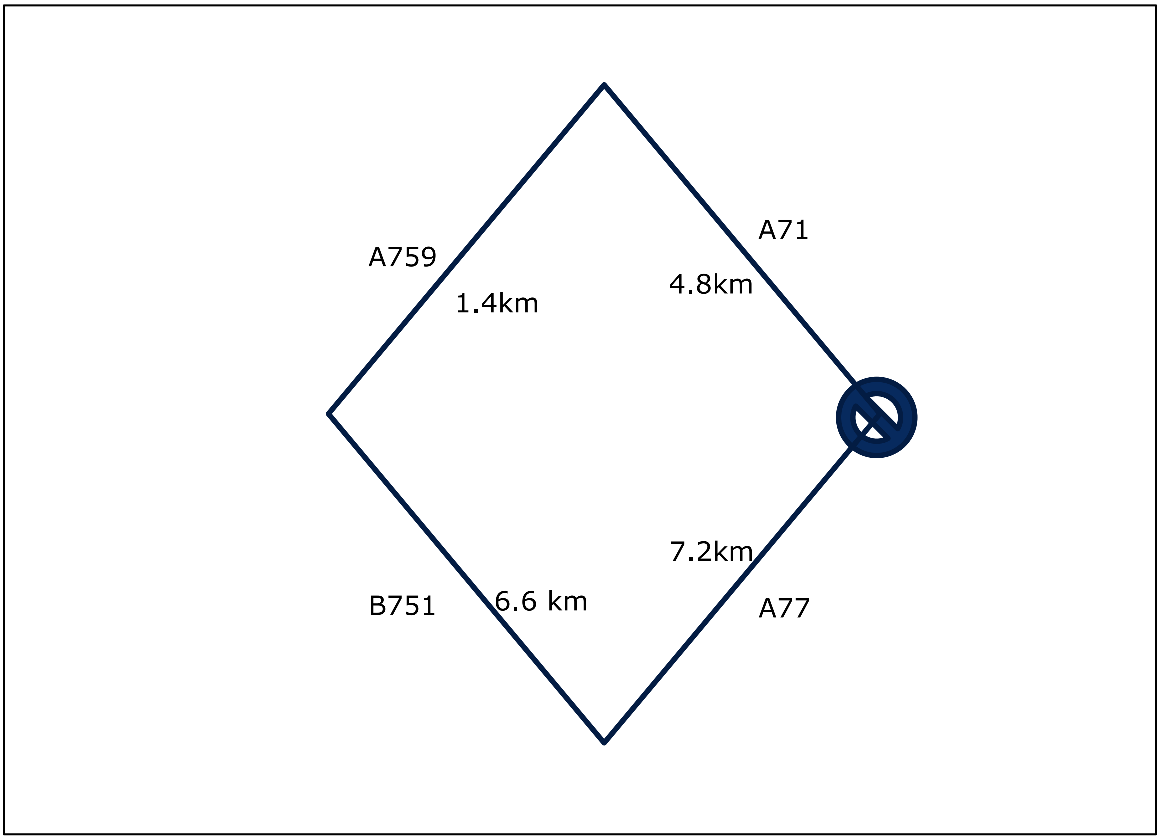

Figure 43. Site 5: A77, A76, A71 Bellfield Junction, September 2012. Diversion route 12.

Table 35. Input summary for Site 5: A77, A76, A71 Bellfield Junction, September 2012. Diversion route 12.

Item	A759	B751
16-hour flow	13783	7917
Class	1	1
Accident type	9	9
Design standard	0	0
Length (km)	1.4	6.6
Width (m)	7.3	7.3
Hilliness (m/km)	30	30
%HGVs	6	6
Bendiness (°/km)	75	75
Hardstrip width (m)	0	0
Verge width (m)	1	1
Side roads (#/km)	0	0
Sight distance (m)	0	0
Speed limit (km/h)	96	96

Table 36. QUADRO results for Site 5: A77, A76, A71 Bellfield Junction, September 2012: basic user and shuttle working data.

Diversion Route	Total Closure Daily User Time Delay Cost (£)	Total Closure Daily Carbon Cost (£)	Total Closure Daily Accident Cost (£)	Shuttle Working Daily User Time Delay Cost (£)	Shuttle Working Daily Carbon Cost (£)	Shuttle Working Daily Accident Cost (£)	Number of Hours of Total Closure	Number of Hours of Shuttle Working	Total Closure User Cost (£)	Shuttle Working Total User Cost (£)
1: A77NB - A77NB	£327,582	£12,805	-£3,471	£53,383	£339	£314	25	0	£350,954	£0
2: A77NB - A71EB	£81,092	£3,906	-£2,090	£577	£4	£113	67	0	£231,451	£0
3: A77SB - A77SB	£136,024	£4,744	-£3,427	£19,780	£114	£291	25	0	£143,063	£0
4: A77SB - A71WB	£84,074	£2,708	-£1,525	£901	£7	£157	67	0	£238,008	£0
5: A77SB - A71EB	£107,426	£5,151	-£2,425	£802	£6	£145	67	0	£307,507	£0
6: A77SB - A76SB	£62,992	£3,153	-£1,285	£412	£3	£86	19	48	£51,348	£1,001
7: A71WB - A71WB	£41,272	£2,282	-£685	£259	£4	£482	67	0	£119,677	£0
8: A71WB - A77NB	£105,447	£7,875	-£5,394	£588	£9	£949	67	0	£301,300	£0
9: A71WB - A77SB	£103,814	£7,773	-£5,663	£588	£9	£949	67	0	£295,704	£0
10: A71EB - A71EB	£67,393	£2,807	-£291	£303	£2	£66	67	0	£195,163	£0
11: A71EB - A77NB	£97,480	£3,028	-£2,399	£1,241	£9	£195	67	0	£273,886	£0
12: A71EB - A77SB	£110,744	£5,635	-£961	£738	£5	£136	67	0	£322,210	£0
13: A71EB - A76SB	£41,154	£1,568	-£344	£170	£1	£39	19	48	£33,550	£420
14: A76NB - A77NB	£53,810	£4,197	-£5,439	£5,701	£77	£1,652	19	48	£41,617	£14,862
15: A76NB - A71WB	£25,351	£1,375	-£605	£2,644	£38	£1,485	19	48	£20,680	£8,335
	£1,445,657	£69,007	-£36,004	£88,089	£626	£7,061			£2,926,118	£24,617

Table 37. QUADRO results for Site 5: A77, A76, A71 Bellfield Junction, September 2012: total daily and total costs.

Diversion Route	Total Daily User Time Delay Cost (£)	Total Daily Carbon Cost (£)	Total Daily Accident Cost (£)	Total User Time Delay Cost (£)	Total Carbon Costs (£)	Total Accident Costs (£)	Total User Cost (£)
1: A77NB - A77NB	£327,582	£12,805	-£3,471	£341,230.80	£13,338.84	-£3,615.18	£350,954
2: A77NB - A71EB	£81,092	£3,906	-£2,090	£226,380.64	£10,905.05	-£5,834.98	£231,451
3: A77SB - A77SB	£136,024	£4,744	-£3,427	£141,691.67	£4,941.67	-£3,570.24	£143,063
4: A77SB - A71WB	£84,074	£2,708	-£1,525	£234,705.39	£7,560.23	-£4,257.69	£238,008
5: A77SB - A71EB	£107,426	£5,151	-£2,425	£299,896.79	£14,379.08	-£6,768.99	£307,507
6: A77SB - A76SB	£63,404	£3,156	-£1,199	£50,692.32	£2,501.95	-£845.35	£52,349
7: A71WB - A71WB	£41,272	£2,282	-£685	£115,218.46	£6,370.58	-£1,912.29	£119,677
8: A71WB - A77NB	£105,447	£7,875	-£5,394	£294,373.67	£21,983.98	-£15,057.45	£301,300
9: A71WB - A77SB	£103,814	£7,773	-£5,663	£289,815.28	£21,698.83	-£15,810.40	£295,704
10: A71EB - A71EB	£67,393	£2,807	-£291	£188,139.19	£7,835.41	-£811.18	£195,163
11: A71EB - A77NB	£97,480	£3,028	-£2,399	£272,132.07	£8,452.77	-£6,698.40	£273,886
12: A71EB - A77SB	£110,744	£5,635	-£961	£309,161.53	£15,730.24	-£2,681.60	£322,210
13: A71EB - A76SB	£41,324	£1,570	-£305	£32,920.02	£1,243.96	-£194.16	£33,970
14: A76NB - A77NB	£59,512	£4,275	-£3,787	£54,002.49	£3,477.54	-£1,001.64	£56,478
15: A76NB - A71WB	£27,996	£1,413	£880	£25,358.63	£1,164.71	£2,491.10	£29,014
	£1,454,584	£69,127	-£32,741	£2,875,719	£141,585	-£66,568	£2,950,735

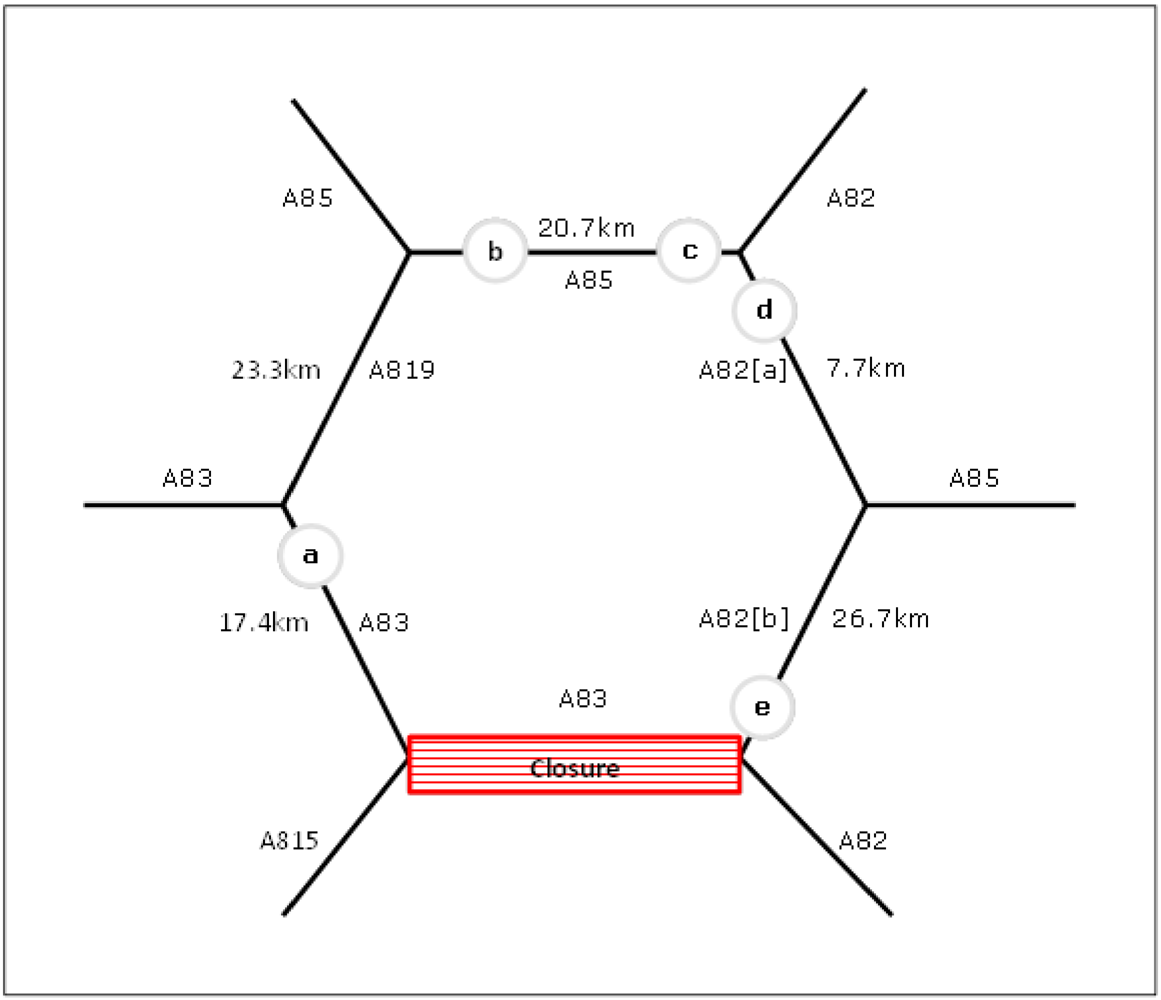

Figure 44. Site 6: A83 Rest and be Thankful, October 2014.

Traffic count stations: a) ATC08063 [2,347, 2009-10]; b) JTC10069 [12,332, 2009-10; c) ATC08056 [2,314, 2009-10]; d) 108370 [5,429, 2009-10; and e) ATCCS001 [3,647, 2009-10].

Table 38. Input summary for Site 6: A83 Rest and be Thankful, October 2014.

Item	1) A83	2) A819	3) A85	4) A82[a]	5) A82[b]
AADF	2,347	1,500[1]	2,323	5,429	3,647
Class	1[2]	1	1	1	1
Accident type	8[3]	8	8	8	8
Design standard	0[4]	0	0	0	0
Length (km)	17.4	23.3	20.7	7.7	26.7
Width (m)	7.3[5]	7.3	7.3	7.3	7.3
Hilliness (m/km)	30[6]	30	30	30	30
% HGVs	9.49[7]	9.49	9.49	9.49	9.49
Bendiness (°/km)	75[8]	75	75	75	75
Hardstrip width (m)	0[9]	0	0	0	0
Verge width (m)	1[10]	1	1	1	1
Side roads (#/km)	0[11]	0	0	0	0
Sight distance (m)	0[12]	0	0	0	0
Speed limit (km/h)	96[13]	96	96	96	96

1 Estimated as no traffic count data available.
2 "Rural single carriageway".
3 "Older single 2-lane A road".
4 Not to TD 9/93.
5 Assumed 3.65m per lane, standard for Class 1 per QUADRO manual.
6 Suggested value for "hilly" in QUADRO manual.
7 Value obtained by taking average % of HGVs from 7 day average data in 2010 from traffic count station, JTC08338 located on closed section of A83.
8 Suggested value for Class 1 "average" in QUADRO manual.
9 Suggested value from QUADRO manual.
10 Suggested value from QUADRO manual.
11 Assumed none significant.
12 Sets automatic use of empirical relationship.
13 Assumed national single-carriageway speed limit applies (96km/h = 60mph).

Table 39. Timings of closures between the 28th of October and 5th December 2014

Date	Start time	End time	Total (Hours)	Type of closure
28 October 2014	05:00	15:00	10	Full closure (day)
28 October 2014	15:00	17:00	2	Convoy (day)
28 October 2014	17:00	07:00	14	Full closure (night)
29 October 2014	07:00	17:00	10	Convoy (day)
29 October 2014	17:00	07:00	14	Full closure (night)
30 October 2014	07:00	17:00	10	Convoy (day)
30 October 2014	17:00	07:00	14	Convoy (night)
01 November 2014	07:00	17:00	10	Convoy (day)
01 November 2014	17:00	07:00	14	Convoy (night)
02 November 2014	07:00	17:00	10	Shuttle (day)
02 November 2014	17:00	07:00	14	Convoy (night)
03 November 2014	07:00	17:00	10	Shuttle (day)
03 November 2014	17:00	07:00	14	Shuttle (night)
04 November 2014	07:00	17:00	10	Shuttle (day)
04 November 2014	17:00	07:00	14	Shuttle (night)
05 November 2014	07:00	17:00	10	Shuttle (day)
05 November 2015	17:00	10:00	14	Shuttle (night)
06 November 2014	10:00	17:00	10	Convoy (day)
06 November 2014	17:00	07:00	14	Convoy (night)
07 November – 05 December 2014	07:00	17:00	682	Shuttle (24hr)

Table 40. Total hours for each type of closure

Type of closure	Total (hours)
Full closure (day)	10
Full closure (night)	28
Convoy (day)	42
Convoy (night)	56
Shuttle (day)	40
Shuttle (night)	42
Shuttle (24hr)	682

The analysis for the 28 October 2014 A83 Rest and be Thankful event included: full closure, convoy on the Old Military Road (OMR) and shuttle working (single lane with traffic lights). QUADRO limits the closure length for convoy and shuttle working to 500m. Therefore, in order to provide a reasonable estimate of the costs of convoy working these were modelled for convoy lengths of 100m, 200m, 300m, 400m and 500m and the results extrapolated to 4,000m, the length of the OMR convoy (Figures 45 to 47). For delay costs (Figure 45) and carbon costs (Figure 46) a power law was used to provide a best fit, while for accident costs (Figure 47) a linear fit was used; in all cases an excellent fit was obtained ($R^2 \geq 0.9992$) giving confidence in the extrapolation provided that the basic assumption that costs increase with closure length holds.

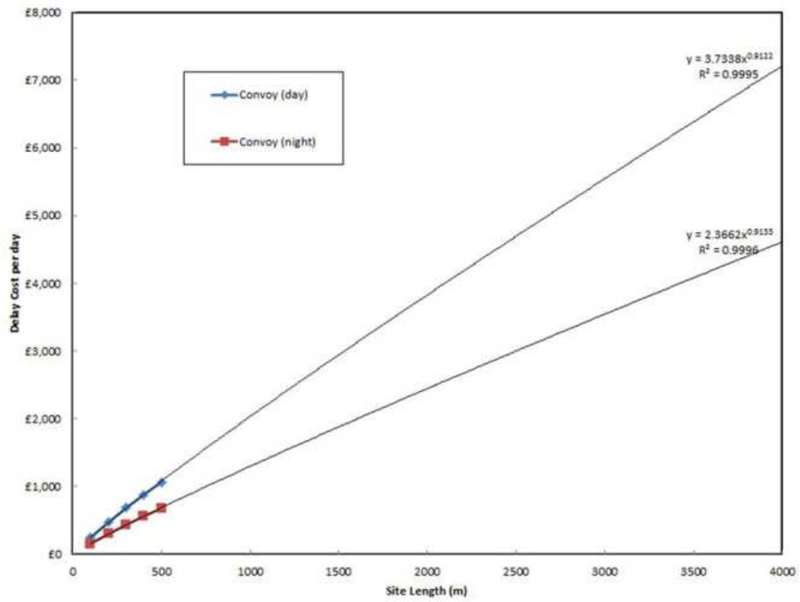

Figure 45. Extrapolation of delay costs for convoy working on the Old Military Road when the A83 is closed at the Rest and be Thankful, 28 October 2014 event.

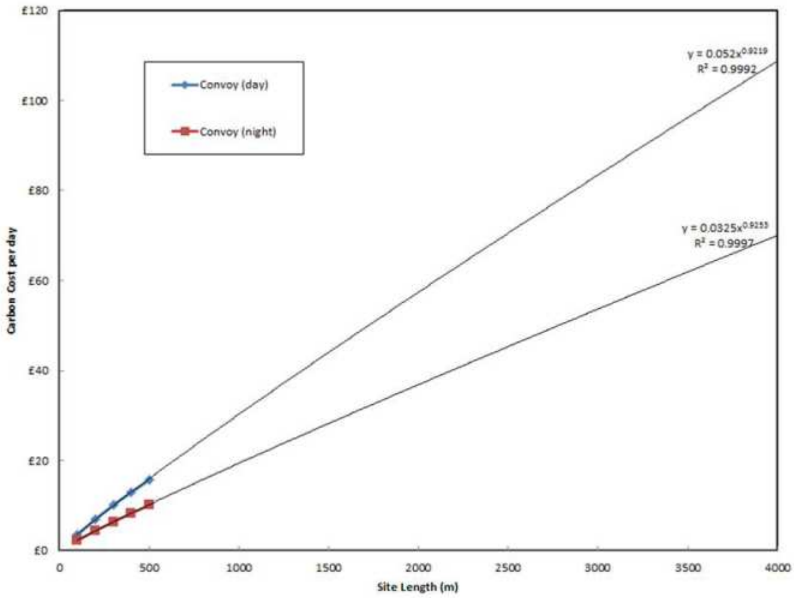

Figure 46. Extrapolation of carbon costs for convoy working on the Old Military Road when the A83 is closed at the Rest and be Thankful, 28 October 2014 event.

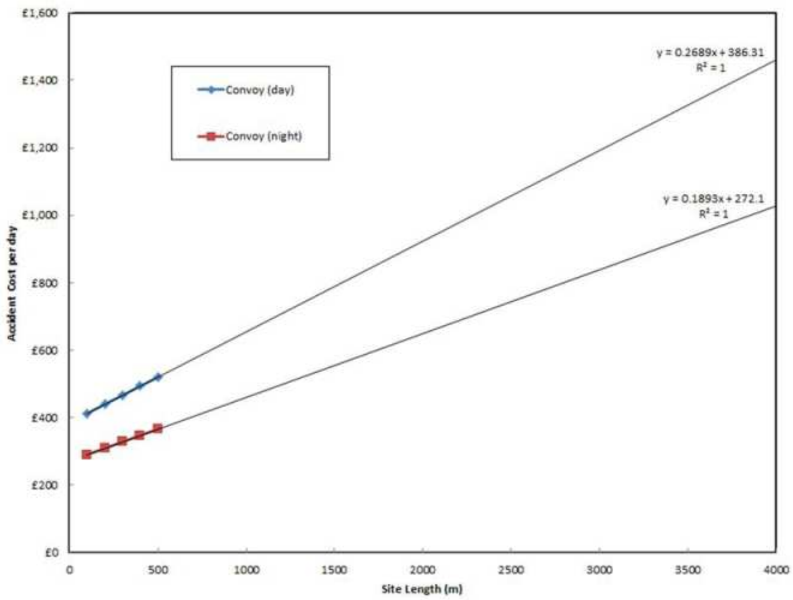

Figure 47. Extrapolation of accident costs for convoy working on the Old Military Road when the A83 is closed at the Rest and be Thankful, 28 October 2014 event.

Appendix B Indirect Consequential Economic Impacts

B.1 Introduction

Transport appraisal is undertaken to assist investment decisions. To be effective, transport appraisal must deal consistently with competing proposals, be even-handed across modes and take account of a wide range of effects (including indirect consequential impacts if possible).

Indirect consequential economic impacts have an important characteristic – they are not traded entities that can easily be monetised[1]. Monetisation enables the value of impacts to be calculated and compared against other impacts using a common metric.

Monetisation is the process of converting or establishing something into legal tender.

In order to estimate the monetary value of non-traded goods and services, economics has developed a range of approaches that are considered here for application to the assessment of the indirect consequential economic impacts of landslides in Scotland. These are briefly described below with a view to assessing which might be most appropriate for the project.

Each approach can be assessed against key criteria that are relevant to the investigation of the indirect consequential economic impacts of landslides in Scotland. These key criteria are that they:

- Are suitable for the study of the economic impacts of landslides (and similar events).
- Have the ability to gather data locally.
- Have the ability to reduce data to a common metric.
- Avoid bias.

A common problem is the inability to gather robust data for a useful estimation to be made. For example, while indirect costs of landslides may be significant they may also be difficult to estimate, as described by MacLeod et al. (2005), because:

- Indirect costs can accumulate over time and so are not tracked.
- Multiple public agencies may be involved in data collection.
- Private information is not collected due to perceived or real privacy concerns.
- It may be difficult to gather information if law suits are involved.
- In times of emergency or shock associated with a landslide event, indirect costs may not be recorded or later remembered.
- Landslide costs may be combined with other costs, such as those resulting from flooding.
- The costs of clearing landslides from transport infrastructure may be merged with general maintenance costs.

[1] Monetisation is the process of converting or establishing something into legal tender.

- Landslides that occur on private roads are rarely reported in loss data.
- Insurance is rarely offered for landslides so loss data is not tracked (this is more of an issue in the USA, where MacLeod et al. (2005) conducted their work, as landslide risks are not covered under general property insurance policies).

Different approaches are considered in the following sections.

B.2 Cost-Benefit Analysis (CBA)

Cost–Benefit Analysis (CBA) is a systematic process for calculating and comparing benefits and costs of a project or investment. It has two purposes:

1. To determine if an investment or decision is sound (i.e. the justification for/ feasibility of the decision).
2. To provide a basis for comparing projects. This involves comparing the total expected cost of each option against the total expected benefits, to see whether the benefits outweigh the costs, and by how much.

In CBA, the benefits and costs of a proposed investment are expressed in monetary terms based on market prices, and are adjusted for the time value of money, so that all the project's benefits and costs (which tend to occur at different points in time) are expressed on a common basis in terms of their net present value (NPV).

The benefit-cost ratio (BCR) summarises the overall value for money of a project or proposal. It is the ratio of the benefits of a project relative to the costs, both expressed in monetary terms. All benefits and costs are expressed in discounted present values and, should the BCR exceed unity, then the proposal is considered viable and potentially a good investment; the higher the BCR the better the investment is likely to be. However, it can be misleading when comparing proposals; a high BCR may be a consequence of low costs but also of relatively low benefits, while a large investment may generate very high benefits, but at a very high cost as well. It is therefore essential to compare like with like in investment decisions. So in addition to considering the BCR, the total net benefits as well as the overall costs should also be considered in the decision making process.

Whereas it may be relatively easy to identify and measure the direct costs of a landslide, indirect consequential economic impacts are much more difficult to quantify and monetise.

CBA has evolved into the NATA approach (the New Approach to Transport Appraisal). It provides the basis for the appraisal of multi-modal studies and major road schemes as well as public transport schemes. NATA has three criteria at its core: economic, social and environmental factors. The approach requires decision-makers to take a more balanced approach to ensure that all three factors are given equal consideration, rather than only considering those factors that can be easily monetised.

B.3 Cost-Effectiveness Analysis

Cost-effectiveness analysis (CEA) is similar to CBA. It is an analysis that compares the relative costs, and outcomes (effects), of two or more courses of action. Cost-effectiveness analysis is often used in situations where it may be inappropriate to monetize an effect, e.g. health benefits. Typically the CEA is expressed in terms of a ratio where the numerator is a gain, for example improvements in health from a measure (e.g. years of life or Quality Adjusted Life Years (QALY), premature births averted, sight-years gained) and the denominator is the cost associated with the gain: i.e. the benefits gained for the costs incurred. Thus a ratio of outcomes to costs can be calculated.

B.4 Willingness To Pay

Measuring the value of non-traded or non-monetised goods and services can be assisted by calculating the willingness to pay (WTP) of consumers.

The willingness to pay is the maximum amount a person would be willing to pay, sacrifice or exchange in order to receive a good or service, or to avoid something undesired, such as pollution. A transaction is beneficial when the willingness to pay exceeds the market price (if one can be identified or a surrogate found). For example, landslide risk is driven not only by the willingness to accept risk, but also by the willingness to pay to mitigate that risk. This willingness to accept risk is related to the willingness (and ability) to pay to reduce that risk and the willingness to alter the environment in the pursuit of lower risk (Winter and Bromhead, 2012).

Several methods have been developed to measure consumer willingness to pay. These methods can be differentiated by whether they measure consumers' hypothetical, or actual, willingness to pay or whether they measure consumer willingness to pay directly or indirectly. These include hedonic pricing, choice modelling, stated preference and revealed preference techniques. Clearly the willingness to pay will be constrained by an individual's wealth and other financial commitments. One common indicator of willingness to pay is insurance premiums.

B.4.1 Insurance

Insurance is one means of limiting the economic consequences of events, such as landslides or flooding (Dlugolecki, 2004). In addition to offering protection for events triggered by landslides, insurance involves estimating not only the financial risks of such events but also the willingness to pay for protection or remedial measures by those most likely to be affected. The financial risks associated with a landslide are then transferred to others who find it easier to bear that risk and also to identify more precisely the responsibilities for mitigation and adaptation. According to Dlugolecki (2004) weather risks are increasing by 2 to 4% per annum on household property accounts; the impact on businesses and other employers is likely to be much more significant. Increased rainfall and storms could cause more upland landslides in Scotland. This would increase insurance premiums. Keaton et al. (2007) give an overview of the issues related to the insurance of landslide risks in the USA.

Over the period 1998 to 2003, claims for storm and flood damage apparently doubled in the UK, compared to the previous five years, 1993 to 1998 (Dlugolecki, 2004). Insurance costs could well rise in real terms in the future – historic claims and climate data will not provide reliable guides to estimating the financial impacts of extreme weather events. Such events are relatively rare but cause greater disruption. Losses could rise by 18% as a result of a 2^{o}C temperature increase; a 6^{o}C rise could lead to a 30 to 35% increase in losses in Scotland according to the Anon. (2009). This would impose a significant cost on business. Adaptation to avoid the impacts of extreme weather events would impose an additional cost on business.

If it could be gathered, insurance data could provide the basis for calculating the willingness to pay by those affected by landslides in Scotland to undertake remedial measures to minimise the indirect inconsequential impacts. This approach would, of course, work only for insured assets such a buildings as infrastructure, in particular that owned by Governments is not generally insured but underwritten by central funds.

B.4.2 Hedonic pricing

In economics, hedonic pricing is a revealed preference[2] method of estimating demand or the value of items that cannot be easily measured. It divides an item into its constituent characteristics, and obtains estimates of the contributory value of each characteristic. This requires that the good being valued can be reduced to its constituent parts and that the market values of those constituent parts can be ascertained.

Hedonic models are commonly used in land and property appraisal, land economics and Consumer Price Index (CPI) calculations.

Certain environmental attributes can influence the market price of a good or service; hedonic pricing is used to assess their economic values. It is applied to reveal the effect of environmental attributes in changes in the local land and property pricing, for example. It is frequently used for estimating costs related to:

- The overall quality of the environment in terms of air pollution, water pollution and noise.
- Environmental amenities which include aesthetics and closeness to recreational sites such as parks, beaches, etc.

Hedonic pricing is based on the fact that prices are affected by the individual characteristics of the good. For example, the price of a house will depend on the location, the access by road and rail, the proximity to employment opportunities, the floor space, the number of rooms and state of repair and other relevant factors. The method helps to estimate the value of a commodity based on people's willingness to pay as and when its characteristics change. It uses surrogate markets[3] to estimate the value of an amenity, such as a 'forever open road' which offers the benefits of incident-free travel, for example.

A hedonic pricing method could form the basis for estimating the value of keeping transport infrastructure open to business and other establishments in areas prone to landslides.

B.4.3 Choice modelling

Choice modelling techniques may be used to estimate the willingness to pay through a choice experiment. Choice modelling attempts to model the decision process of an

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[2] Revealed preference is a method for comparing the influence of policies on consumer behaviour, assuming that the preferences of consumers can be revealed by their purchasing habits.

[3] A surrogate market is a concept that is used when one cannot directly estimate the market price for certain goods. A similar good sold may be chosen as a proxy.

individual, or segment, in a particular context. It may be used to estimate non-market environmental benefits, and costs, such as the impacts of landslides.

Well-specified choice models are sometimes able to predict, with some accuracy, how individuals would react in a particular situation. Unlike a poll or a survey, predictions are able to be made over large numbers of scenarios within a particular context.

Choice modelling is regarded by some as the most suitable method for estimating consumers' willingness to pay for quality improvements in multiple dimensions (Anon., 2001). Choice modelling has the advantage of forcing respondents to consider trade-offs between attributes within an explicit frame of reference that includes an array of attributes and alternatives. A choice experiment requires that individuals be forced to make a trade-off between two or more options, sometimes also allowing 'None' or 'Neither' as a valid response. This datum provides the key missing information necessary to separate and independently measure the utility of performance and price. As a result it enables implicit prices to be estimated for attributes and welfare impacts to be estimated for multiple scenarios. This presentation of alternatives requires that respondents compare alternatives.

Simply asking individuals to rate or choose their preferred item from a scalar list will generally yield no more information than the fact that human beings want all the benefits and none of the costs; there is a need for context-specific information.

Choice modelling could be undertaken through a seminar approach involving representatives of local businesses. It could form the basis for estimating the value of different options for keeping transport infrastructure open to business and other establishments in areas prone to landslides.

B.4.4 Stated preference

A major advance in choice modelling has been the use of Stated Preference. With Revealed Preference, the complexities and interrelationships of decision-making in the real world will affect decisions. Stated Preference, however, focusses on individuals' preferences in a particular context.

A problem with all Stated Preference methods, however, is that individuals do not have to back up their choices with real commitments (and expenditure) when they answer a survey, and to some extent they could behave inconsistently in a real-world situation.

Nevertheless it could form the basis for estimating the value of different options for keeping transport infrastructure open to business and other establishments in areas prone to landslides.

B.5 Multi-criteria Analysis

Multi-criteria analysis (MCA) explicitly considers multiple criteria in decision-making, recognising that there are usually multiple conflicting criteria that need to be evaluated in making decisions. While cost, or price, is usually one of the main criteria in taking investment decisions some measure of quality is typically another criterion considered but this is often in conflict with cost. For complex problems it is important to structure the problem and explicitly evaluate multiple criteria especially where there are many stakeholders who may be affected by the consequences. Structuring complex problems and considering multiple criteria explicitly is considered to lead to more informed and better decisions.

Both the NATA, and STAG (Anon., 2012a) approaches involve MCA principles. Clearly any estimate of the impact of the indirect consequential impacts of landslides would need to consider a wide range of factors.

B.6 STAG (Scottish Transport Appraisal Guidance)

Transport investment in Scotland is usually assessed using STAG – the Scottish Transport Appraisal Guidance (Anon., 2012a). This is intended to provide transport practitioners working on Scottish-based transport projects with access to the latest information and guidance that they will need when developing and assessing transport schemes and strategies. It is similar to the NATA approach.

STAG is one process comprising four phases:

- Pre-Appraisal.
- Part 1 Appraisal.
- Part 2 Appraisal.
- Post Appraisal.

It is recommended that STAG is applied proportionally, but comprehensively, with the level of detail determined by the scale of the transport challenges under consideration. STAG is based on the principle of being objective-led, rather than solution-led; this allows the appraisal of options against Planning Objectives, STAG Criteria and to establish policy directives. The STAG process also requires plans for robust monitoring and evaluation as part of an investment proposal.

An appraisal using STAG is required when Scottish Government funding, support or approval is sought for justified proposals to change the transport system. Its use is encouraged in other circumstances when there is a need for changes to the transport system and may be applied to issues including:

- Assessing measures to improve the reliability of the transport network.
- Assessing issues in relation to the safety of the transport network.
- Considering public transport and road network coverage.
- Access to services.
- Land-use development.

These issues are particularly important for managing landslides.

But STAG is not recommended for use when considering issues related to maintenance or renewal which will not significantly change an existing asset or materially impact upon the operation of this asset. However, it must be adopted when there is likely to be:

- The creation of a new asset.
- A significant enhancement to an existing asset.
- Any change to an existing asset which will materially impact upon the operation of this asset.

STAG focusses on the infrastructure costs of transport investments (i.e. the direct economic impacts) as well as the direct consequential (or wider) economic impacts. Thus a STAG appraisal would not require any estimation of the indirect consequential economic impacts.

Depending upon the type of approach being considered as a means of addressing the impacts of landslides (e.g. the construction of a new road or only remedial works; see also Winter 2014b) a STAG appraisal may or may not be required.

B.7 The Oregon Method

A study by MacLeod et al. (2005) in Oregon set out a methodology to assist in the calculation of indirect costs. It reviewed three sets of indirect loss methodologies applicable to landslides:

- Unit cost estimation – separates the cause and effect impacts into its components to estimate costs on the basis of readily available information.
- Probability-based estimation – involving estimating the likely impact of landslides based on other experience.
- Survey data collection – using interviews with property owners, businesses, construction contractors, hauliers, etc., to identify the costs of mitigation efforts and other costs. Personal account surveys using inventories, interviews, and other records of economic impact are used to gather data.

These three methods provide options for selecting loss estimation techniques. According to MacLeod et al. (2005), everyone involved in assessing indirect costs can attest to the difficulty of obtaining data and achieving a complete and accurate estimate, yet indirect loss estimation is vital for a more complete picture of overall landslide losses. Indirect costs often exceed (and sometimes greatly exceed) direct costs.

When data is incomplete and/or resources are inadequate, according to MacLeod et al. (2005) some may question whether it is worthwhile to attempt estimating indirect losses. In establishing the indirect component of landslide cost, there is always a trade-off between the practicalities of loss assessment and the adequacy of the details provided. However, representative loss estimation provides a basis for more informed decision making, for example implementing mitigation actions to better protect water systems from landslide impacts.

The Oregon method could form the basis for estimating the value of different options for keeping transport infrastructure open to business and other establishments in areas prone to landslides.

B.8 The Jacobs Approach

A study of landslides on the A83 at the Rest and be Thankful has been undertaken by Jacobs (Anon., 2013a), outlining another approach. From information gathered during consultations for the project, the Jacobs team quantified the additional costs to the transport and tourism sectors in the A83 study area resulting from the closure of the A83 at Rest and be Thankful and the use of the diversion route.

In 2007 traffic flows of 5,000 vehicles per day had been recorded on the stretch of the A83 road that was closed by debris. The road was closed for 42 days in total (but see Section 5 for details) and then opened with single lane traffic light control. The disruption to local residents was considerable because of the lengthy diversion around the blockage (see Appendix A) the effects of which are detailed by Anon. (2013). The 2007 landslide is shown in Figures 2 and 3. The A83 route has been subsequently closed by landslides in 2009, 2011 and again in 2012. The December 2011 landslide followed a period of very heavy rain in the area.

A detailed economic assessment was undertaken by Jacobs on three options for alternative routes. The economic appraisal was conducted using welfare economics[4] techniques, based on STAG. The approach to the calculations involved (Anon., 2013):

- Calculating the additional costs incurred per day from the closure of the road, by sector.
- Grossing up the daily costs to reflect the central scenario which assumed that the average length of closure is 5½ days.
- Converting costs into 2010 prices.
- Assuming that there is one closure per year.
- Assuming that the additional costs would result in reduced income to the study area calculate the number of jobs that could be supported by the reduced income using Gross Value Added (GVA)[5] per employee.
- Testing the sensitivity of the results to the assumptions regarding the length of closure through two sensitivity tests – low and high:
    - Low – the average duration of road closures since 2009 which was 2.5 days.
    - High – the number of days the road has been closed over the last 12 months due to landslides which was 13 days.

The additional costs to the A83 economy of one landslide at the Rest and Be Thankful were estimated to be £286,300 (in 2010 prices) under the central scenario (Anon., 2013). These were considered to be ‘minimum’ additional costs, as many of the potential impacts identified had not been capable of quantification, particularly the long term effects as a result of changing perceptions of the area.

Assuming that these additional costs are a direct loss of income to the local area, the number of jobs which could be supported by this ’lost‘ income was calculated using GVA per employee. Under the central scenario, the lost income would support almost 12 jobs in the A83 study area and a further 10 jobs would be supported under the high scenario.

The sensitivity analysis showed that the additional costs to the A83 economy from one landslide at the Rest and Be Thankful were therefore in the range £130,200 to £676,800 (Anon., 2013). Assuming these costs represented a direct loss of income to the local

[4] Welfare economics is a branch of economics that analyses social welfare benefits resulting from the allocation of resources.

[5] Gross value added (GVA) is a measure of the value of goods and services produced in an area, industry or sector of an economy.

area, the number of jobs which could be supported by this 'lost' income was in the range 5 to 28.

Using the GVA as in the Jacobs approach could form the basis for estimating the value of different options for keeping transport infrastructure open to business and other establishments in areas prone to landslides.

B.9 Bias

Whatever approach is undertaken it will inevitably involve some form of sampling[6] of the population affected by a landslide and making a statistical inference[7]. It is essential that any method for measuring the indirect consequential economic impacts of landslides is unbiased. A statistic[8] is biased if it is calculated in such a way that it is systematically different from the population parameter of interest.

Statistical bias can be of various types that could be relevant to this study, including:

- *Selection bias* where individuals or groups are more likely to take part in a research project than others, resulting in biased samples.
- *Spectrum bias* arises from evaluating diagnostic tests on biased samples, leading to an overestimate of the sensitivity and specificity of the test.
- *Omitted-variable bias* appears in estimates of parameters in a regression analysis when the assumed specification is incorrect, in that it omits an independent variable that should be in the model.
- *Funding bias* may lead to selection of outcomes, test samples, or test procedures that favour a study's financial sponsor.
- *Reporting bias* involves a skew in the availability of data, such that observations of a certain kind may be more likely to be reported and consequently used in research.
- *Analytical bias* arises due to the way that the results are evaluated.
- *Exclusion bias* arises due to the systematic inclusion of certain individuals from the study.

B.10 Conclusions

Each approach has been assessed against key criteria that are relevant to the investigation of the indirect consequential economic impacts of landslides in Scotland (see Table 41). These are:

- Suitable for the study of the economics of landslides (and similar events).
- Ability to gather data locally.
- Ability to reduce data to a common metric.

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[6] A sample is a subset of a population. A population is the collection of items under investigation. Statistical inference involves making assertions about a population(s) from a sample(s).

[7] Statistical inference is the process of drawing conclusions from data that is subject to random variation.

[8] A statistic is a measure of an attribute of a sample (e.g. its arithmetic mean). It is an estimate of the population parameter.

- Avoidance of bias.

In order 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 a survey of businesses has been undertaken.

In terms of the key criteria that are relevant to the investigation of the indirect consequential economic impacts of landslides in Scotland perhaps the best approach could be a combination of the most important elements of these approaches, using the Jacobs approach for the Rest and be Thankful to provide a reference point and comparison. This could be combined with a choice experiment or another stated preference or willingness to pay approach while aiming to ensure the avoidance of bias.

Table 41. Comparison of different approaches to economic assessment.

Assessment method	Data availability	Common metric	Bias	Suitability
Cost Benefit Analysis	Would need data collection	Yes - monetary	Possibly omitted-variable bias if non-monetised benefits are excluded from the analysis	Cost Benefit Analysis is a standard approach to transport investment decisions now adapted to include non-monetised impacts in NATA. It does not require any estimation of indirect consequential economic impacts but could be adapted to include these.
Cost Effectiveness Analysis	Would need data collection depending on numerator applied	Not necessarily	Possibly spectrum bias if a wide range of numerators included which would need weighting	Cost Effectiveness Analysis is best for a single identified outcome. Probably not appropriate for measuring indirect impacts.
Willingness to pay	Would need data collection – business survey	Yes - monetary	Possibly selection bias if respondents focus on specific elements	Assessing the willingness to pay by those most likely to be affected by landslides would provide a market-based indicator. It would need to be adapted to include an estimation of the indirect consequential economic impacts.
Insurance data	Insurance data might be difficult to gather	Yes - monetary	Only if certain businesses are uninsured	Insurance data could be used as a proxy of willingness to pay. It could provide a surrogate estimation of the indirect consequential economic impacts.
Hedonic pricing	Would need data collection – business survey	Yes - monetary	Possibly spectrum bias if only a selection of attributes included	Hedonic pricing requires an assessment of the contribution of different factors to the overall value. It could also provide a surrogate estimation of the indirect consequential economic impacts if relevant criteria are identified.
Stated preference	Would need data collection – business survey or a workshop	Yes – scale ranking	Possibly spectrum bias if only a selection of attributes included	Stated preference is assessed in non-real world conditions and actual responses may differ. It would need to be adapted to include an estimation of the indirect consequential economic impacts.

Table 41 (Continued). Comparison of different approaches to economic assessment.

Assessment method	**Data availability**	**Common metric**	**Bias**	**Suitability**
Choice modelling	Would need data collection – a workshop	Yes – scale ranking	Possibly spectrum bias if only a selection of attributes included	Choice modelling is assessed in non-real world conditions and actual responses may differ. It would require appropriate criteria to be identified for an estimation of the indirect consequential economic impacts.
Revealed preference	Would need data collection – business survey	Yes - monetary	Possibly analytical bias depending on other factors that may have influenced the decision	Revealed preference decisions may be influenced by other effects. It could be linked to insurance data and would require appropriate criteria to be identified for an estimation of the indirect consequential economic impacts.
Multi-criteria Analysis	Would need data collection	Not necessarily	Possibly analytical bias depending on other factors that may have influenced the decision	Cost Benefit Analysis has been adapted to include non-monetised impacts involving MCA such as NATA. It could be adapted to include an estimation of indirect consequential economic impacts.
STAG	Would need data collection	Yes - monetary	Possibly omitted-variable bias if non-monetised benefits are excluded from the analysis	The standard approach to transport investment decisions in Scotland. It does not require any estimation of indirect consequential economic impacts but could be adapted to include these.
The Oregon Method	Would need data collection – business survey	Yes - monetary	Possibly analytical bias depending on probabilities given to events	It does not require any estimation of indirect consequential economic impacts but could be adapted to include these.
Jacobs approach	Would need data collection – business survey	Yes - monetary	Possibly omitted-variable bias if non-monetised benefits are excluded from the analysis	The Jacobs approach covers some of the indirect impacts of landslides and might be adapted to include an estimation of indirect consequential economic impacts.

Appendix C **Trial Survey Questionnaire: A85 Glen Ogle 2004**

The aim of this survey is to understand the impacts of the August 2004 landslides upon businesses and organisations in the area surrounding the A85 Glen Ogle. These impacts will vary by type of organisation, size and sector in which they operate. The information collected will be used to inform landslide management and mitigation activities in the area.

Q1: Name of respondent: ………………………………………………………………………………………………….

Q2: Position in organisation: ………………………………………………………………………………………………

Q3: Name of business or organisation: ……………………………………………………………………………….

Q4: Contact details (phone or email for use if there are any queries about responses. This data will be used for research purposes only, to allow us to map your organisation in relation to landslips):

Q4a: Phone number: ……

Q4b: email: ………

Q4c: Address of business or organisation: ………………………………………………………………………

……

Q5: Business or organisation sector: (please tick main sector in which you operate)

Sector	
Agriculture/ dairy	
Banking/ insurance/ financial services	
Car/ vehicle sales, garages and repairs	
Construction and building	
Energy (including wind farms)	
Fisheries	
Forestry	
Food processing	
Haulage and distribution	
Hospitals/ Healthcare and medical services	
Hotels/ Bed & Breakfast	
IT services	
Leisure activities e.g. outward bound centres, visitor attractions	
Oil and gas	
Paper, packaging and printing	
Professional services e.g. legal, accountancy	
Restaurants, cafes and public houses	
Retail – multiple store	
Retail – sole trader	
Transport e.g. bus and taxis	
Other (please state)	

Q6: Number of employees in the business or organisation (please tick one only)

- ☐ <5
- ☐ 5-20
- ☐ 21-50
- ☐ 51-99
- ☐ ≥100

Q7: Turnover per annum (please tick one only)

- ☐ < £50k
- ☐ £50K to < £100K
- ☐ £100K to < £250K
- ☐ £250K to < £500K
- ☐ £500K to <£1 million
- ☐ ≥ £1 million

Q8: Dependence of business/ organisation on transport for in-coming and outgoing movements (please tick one option for each row)

	Not dependent	**Low dependency**	**Medium dependency**	**High dependency**	**Very high dependency**
Staff					
Visitors					
In-coming goods					
Out-going goods					

Q9: Landslide experience

Q9a: Was your business/ or organisation affected by the 2004 Glen Ogle landslides?

- ☐ Yes (if yes, please answer question 9b)
- ☐ No
- ☐ Don't know

Q9b: How close is your business or organisation to the landslides site? (Miles approx.)

………

Q9c: Please briefly describe the impact of these landslides upon your business or organisation? ……
………
………
………

………
……………………………………………………………………………

Q9d: Did the landslides result in you taking different routes to/from your business or organisation for work or for in-coming and out-going deliveries?

- ☐ Yes
- ☐ No
- ☐ Don't know

If yes, please describe what alternative routes you used during the landslides? (Please give road number or describe route.)

………
………

Q9e: What do you estimate was the cost to your business of the landslides? (£ thousand)

- ☐ < £1,000
- ☐ £1,000 to < £5,000
- ☐ £5K to < £10K
- ☐ £10K to < £50K
- ☐ £50K to <£100k
- ☐ ≥ £100k
- ☐ Don't know

Q9f: Can you provide a breakdown of this figure?

………
………
………
………
………

Q9g: Has your business/ organisation been affected by any other landslides in the last 20 years, besides the one discussed above?

- ☐ Yes (if yes, please answer question 9h)
- ☐ No
- ☐ Don't know

Q9h: In which month and year did the landslide referred to in Question 9g occur?

……………………………………………………………………

Q10: Insurance premiums

Q10a: Has your organisation been refused insurance as a result of landslide experience?

Yes	No

Q10b: Do you think that you pay a higher insurance premium due to the risk of landslides?

Yes	No

Q10c: If so, how much extra do you believe that you are paying? (Please tick one.)

- ☐ <5% more
- ☐ 5-20% more
- ☐ 21-50% more
- ☐ 51-99% more
- ☐ >100% more

TRL thanks you for your assistance by completing this questionnaire.

Appendix D Survey Questionnaire: A77, A76, A71 Bellfield Junction 2012

The aim of this survey is to understand the impacts of extreme weather events (e.g. flooding and landslides) upon businesses and organisations in the local area. In this instance the impact being reviewed is from flooding which occurred in the Bellfield area near Kilmarnock surrounding the A77, A76 and A71 road junction on 21 September 2012. These impacts will vary by type of organisation, size and sector in which they operate. The information collected may be used to inform flood management and mitigation activities for the road network in the area.

Q1: Name of respondent: ……………………………………………………………………………………………

Q2: Position in organisation: ………………………………………………………………………………………

Q3: Name of business or organisation: ……………………………………………………………………

Q4: Contact details (phone or email for use if there are any queries about responses. This data will be used for research purposes only, to allow us to map your organisation in relation to flooding):

Q4a: Phone number: ………………………………………………………………………………………………………

Q4b: e-mail: ………

Q4c: Address of business or organisation:

……

……

Q5: Business or organisation sector: (please tick main sector in which you operate)

Sector	
Agriculture/ dairy	
Banking/ insurance/ financial services	
Car/ vehicle sales, garages and repairs	
Construction and building	
Energy (including wind farms)	
Fisheries	
Forestry	
Food processing	
Haulage and distribution	
Hospitals/ Healthcare and medical services	
Hotels/ Bed & Breakfast	
IT services	
Leisure activities e.g. outward bound centres, visitor attractions	
Oil and gas	
Paper, packaging and printing	
Professional services e.g. legal, accountancy	
Restaurants, cafes and public houses	
Retail – multiple store	
Retail – sole trader	
Transport e.g. bus and taxis	
Other (please state)	

Q6: Number of employees in the business or organisation (please tick one only)

☐ **<5** ☐ **5-20** ☐ **21-50** ☐ **51-99** ☐ **⩾100**

Q7: Turnover per annum (please tick one only)

☐ **< £50k** ☐ **£50k to < £100k** ☐ **£100k to < £250k**

☐ **£250k to < £500k** ☐ **£500k to <£1 million** ☐ **⩾ £1 million**

Q8: Dependence of business/ organisation on road transport for in-coming and outgoing movements (please tick one option for each row)

	Not dependent	**Low dependency**	**Medium dependency**	**High dependency**	**Very high dependency**
Staff (e.g. commuting)					
Visitors					
In-coming goods					
Out-going goods					

Q9: Flooding experience

Q9a: Was your business/ or organisation affected by flooding in 2012?

□ **Yes** (if yes, please answer questions 9b and 9c)

□ **No** □ **Don't know**

Q9b: How close was your business or organisation to the flooding site? (Miles approx.)

……

Q9c: Please briefly describe the impact of the flooding on the operations of your business or organisation?

……

……

Q9d: Did the flooding result in you (or your staff/ customers) taking different routes to/from your business or organisation for work (including commuting) or for in-coming and out-going deliveries?

□ **Yes** □ **No** □ **Don't know**

If yes, please describe what alternative routes you used during the flooding? (Please give road number or describe route if possible.)

……
……

Q9e: What do you estimate was the cost to your business of the flooding in terms of lost revenue and higher costs (both actual and anticipated? (£ thousand)

☐ < £1,000 ☐ £1,000 to < £5,000 ☐ £5k to < £10k ☐ £10k to < £50k

☐ £50k to <£100k ☐ ⩾ £100k ☐ Don't know

Q9f: Can you provide a breakdown of this figure?

……
……

Q9g: Has your business/ organisation been affected by any other flooding events in the last 20 years, besides the one discussed above?

☐ Yes (if yes, please answer question 9h)

☐ No ☐ Don't know

Q9h: In which month and year did the flooding referred to in Question 9g occur?

………………………………………………………………

Q10: Insurance premiums

Q10a: Has your organisation been refused insurance as a result of flood damage?

Yes	No

Q10b: Do you think that you pay a higher insurance premium due to the risk of flooding?

Yes	No

Q10c: If so, how much extra do you believe that you are paying? (Please tick one.)

☐ <5% more ☐ 5-20% more ☐ 21-50% more ☐ 51-99% more ☐ >100% more

Q11: Please rank the most important transport issue (Please rank the most important as 1 and the second most important as 2 etc)

☐ **Reducing congestion**

☐ **Investing in rail services**

☐ **Investing in road improvements**

☐ **Investing in the removal of flood risks**

Q12: The prevention of flooding is expensive. What increase in your business (non-domestic) rates would you be prepared to pay for new or additional flood protection?

☐ **1%** ☐ **2.5%** ☐ **5%** ☐ **10%** ☐ **more than 10%** ☐ **no increase**

TRL thanks you for your assistance by completing this questionnaire.

Appendix E **Survey Questionnaire: A83 Rest and be Thankful 2014**

The aim of this survey is to understand the impacts of extreme weather events (e.g. flooding and landslides) upon businesses and organisations in the local area. In this instance the impact being reviewed is from the landslide that occurred at the **A83 Rest and be Thankful on 28 October 2014**. These impacts will vary by type of organisation, size and sector in which they operate. The information collected may be used to inform management and mitigation activities for the road network in the area.

We are conscious that there have been other events at that location and ask that you add any comments on events other than the 28 October 2014 event in your response to Questions Q9i and Q9j.

Q1: Name of respondent: ……………………………………………………………………………………………

Q2: Position in organisation: …………………………………………………………………………………

Q3: Name of business or organisation: ……………………………………………………………………

Q4: Contact details (phone or email for use if there are any queries about responses. This data will be used for research purposes only, to allow us to map your organisation in relation to the landslide):

Q4a: Phone number: ……………………………………………………………………………………………………

Q4b: e-mail: ……

Q4c: Address of business or organisation:

……

……

Q5: Business or organisation sector: (please tick main the sector in which you operate)

Sector	
Agriculture/ dairy	
Banking/ insurance/ financial services	
Car/ vehicle sales, garages and repairs	
Construction and building	
Energy (including wind farms)	
Fisheries	
Forestry	
Food processing	
Haulage and distribution	
Hospitals/ Healthcare and medical services	
Hotels/ Bed & Breakfast	
IT services	
Leisure activities e.g. outward bound centres, visitor attractions	
Oil and gas	
Paper, packaging and printing	
Professional services e.g. legal, accountancy	
Restaurants, cafes and public houses	
Retail – multiple store	
Retail – sole trader	
Transport e.g. bus and taxis	

Other (please state)	

Q6: Number of employees in the business or organisation (please tick one only)

☐<5 ☐ 5-20 ☐ 21-50 ☐ 51-99 ☐ ⩾100

Q7: Turnover per annum (please tick one only)

☐ < £50k ☐ £50k to < £100k ☐ £100k to < £250k

☐ £250k to < £500k ☐ £500k to <£1 million ☐ ⩾ £1 million

Q8: Dependence of business/ organisation on road transport for in-coming and outgoing movements (please tick one option for each row)

	Not dependent	Low dependency	Medium dependency	High dependency	Very high dependency
Staff (e.g. commuting)					
Visitors					
In-coming goods					
Out-going goods					

Q9: Landslide experience

Q9a: Was your business/ or organisation affected by the landslide on 28 October 2014?

☐ **Yes** (if yes, please answer questions 9b and 9c)

☐ **No** ☐ **Don't know**

Q9b: How close was your business or organisation to the landslide site? (Miles approx.)

……

Q9c: Please briefly describe the impacts of the landslide, both positive and negative, on the operations of your business or organisation?

……
……

Q9d: Did the landslide result in you (or your staff/ customers) taking different routes to/from your business or organisation for work (including commuting) or for in-coming and out-going deliveries?

☐ Yes ☐ No ☐ Don’t know

If yes, please describe what alternative routes you used during the period following the landslide? (Please give road number or describe route if possible.)

………
………

Q9e: What do you estimate was the cost to your business of the landslide in terms of lost revenue and higher costs (both actual and anticipated?)

☐ < £1,000 **☐ £1,000 to £5,000** **☐ £5k to £10k** **☐ £10k to £50k**

☐ £50k to £100k **☐ ⩾ £100k** **☐ Don’t know**

Q9f: Can you provide a breakdown of this figure?

………
.………

Q9g: Do you think that there have been other effects (financial or otherwise) on your business from this incident?

………
.………

Q9h: Can you quantify these effects and /or provide a breakdown?

………
.………

Q9i: Has your business/ organisation been affected by any other landslide events in the last 20 years, besides the one discussed above?

☐ Yes (if yes, please answer question 9h)

☐ No **☐ Don’t know**

Q9j: In which month and year did the landslide referred to in Question 9i occur?

Please include any comments that you may have on any other landslide events here.

………
………
………
………
………
………
………
………
………
………
………

....
....
....

Q10: Please rank the most important transport issue (Please rank the most important as 1 and the second most important as 2 etc)

☐ **Reducing congestion**

☐ **Investing in rail services**

☐ **Investing in road improvements**

☐ **Investing in the management and mitigation of landslide risks**

Thank you for your assistance.

Appendix F **Word Maps: A83 Rest and Be Thankful (2014)**

Figure 48. Word map of responses from survey respondents: A83 Rest and be Thankful, 28 October 2014; Area 1.

Figure 49. Word map of responses from survey respondents: A83 Rest and be Thankful, 28 October 2014; Area 2.

Figure 50. Word map of responses from survey respondents: A83 Rest and be Thankful, 28 October 2014; Area 3.

Figure 51. Word map of responses from survey respondents: A83 Rest and be Thankful, 28 October 2014; Area 4.

Figure 52. Word map of responses from survey respondents: A83 Rest and be Thankful, 28 October 2014; Area 5.

Figure 53. Word map of responses from survey respondents: A83 Rest and be Thankful, 28 October 2014; Area 6.

Figure 54. Word map of responses from survey respondents: A83 Rest and be Thankful, 28 October 2014; Area 7.

Figure 55. Word map of responses from survey respondents: A83 Rest and be Thankful, 28 October 2014; Other.