# 1 INTRODUCTION

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In August 2004 Scotland experienced rainfall substantially in excess of the norm. Some areas of Scotland received more than 300% of the 30-year average August rainfall[1], 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[2].

The rainfall was both intense and long lasting and as a result a large number of landslides, in the form of debris flows, were experienced in the hills of Scotland. A small number of these intersected the trunk (strategic) road network, notably the A83 between Glen Kinglas and to the north of Cairndow (9 August), the A9 to the north of Dunkeld (11 August), and the A85 at Glen Ogle (18 August).

The most dramatic events occurred at Glen Ogle, where 57 people had to be airlifted to safety when they became trapped between two major debris flows (see cover picture). It was, perhaps, fortuitous that there were no major injuries to those involved. However, the real impacts of the August events were economic and social, in particular the severance of access to and from relatively remote communities.

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 need to acknowledge such natural processes and act accordingly was recognised by Transport Scotland and an initial landslides study (designated at the outset as Study 1, Part 1) was commissioned alongside a second study on climate change. This latter study was designed to identify the potential impacts and consequent necessary actions in the light of anticipated climate change and is not considered further in this report, although it is important to note that action has been taken to ensure that the two studies are complementary (Galbraith *et al*., 2005a; 2005b).

The landslides study comprises two parts (Part 1 and Part 2). The initial study (Winter *et al*., 2005a; 2005b) collated and presented the background information and developed the plan for the second part. The second part of the landslides study presents the proposed means of debris flow management on the trunk road network and is documented in this report.

The overall purpose of the landslides study is to ensure that Transport Scotland has systematically assessed and ranked the hazards posed by debris flows and has in place a management and mitigation strategy for the Scottish trunk road network. The purpose of the ranking system is to allow the future effects of debris flow events to be appropriately managed and mitigated as budgets permit, thus ensuring that the exposure of road users to the consequences of future debris flows is minimised.

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[1] The 30-year average August rainfall in Scotland varies between 67mm on the east coast and 150mm in the west of Scotland (Anon, 1989).
[2] Source: http://www.metoffice.com/climate/uk/2004/august/maps.html.

It is important to recognise that it is not possible to prevent landslide events from occurring and some may occur in such close proximity as to affect the operation of the trunk road network.

The work undertaken and set out in this report is therefore targeted at developing the evidence base for allocating resources to reduce the exposure of road users to landslide hazards and/or to reduce the physical hazard. Notwithstanding this, the latter actions involve higher cost solutions and are likely to be applied only in rare cases.

Since the events of August 2004 a number of other events have affected the trunk road network. Examples include incidents on the A9 to the north of Inverness in 2006 and on the A83 at the Rest and be Thankful in 2007. Such events should not be seen as isolated occurrences and planning to take account of further such episodes in the future should be regarded as sound management practice.

The sections contained in this report are briefly described in the following paragraphs.

The different types of landslides that can occur are described in Section 2, including the debris flow-type landslides with which this report is mainly concerned. The events of August 2004, that led to the work reported here being commissioned, are described in some detail and some other events that have occurred since that date are briefly described. The main times of year during which such events occur in Scotland are also indicated.

The response to the 2004 events is detailed in Section 3 and the initial work that was undertaken in the immediate aftermath is described in the context of the two Transport Scotland reports produced (Winter *et al*., 2005a; 2005b). This section goes on to describe the background and intentions behind the work presented in later sections of this report. The key dissemination activities that have been undertaken in order to raise awareness of landslides and their consequences are listed along with the main target audience, generally the membership of relevant professions, the public and politicians. Such activities promote the work undertaken both nationally and internationally in support of Transport Scotland's approach to professional excellence. Section 3 also explores landslide risk issues in a socio-economic context using international examples.

The first key objective of the work commissioned was to assess and rank debris flow hazards. Section 4 describes the methodology used to undertake this pan-Scotland, GIS-based, assessment of debris flow hazards (further details are given in Appendix A). The results from this are also presented in summary form in Section 4. This assessment presents information, essentially on debris flow susceptibility, in the form of a virtual map that can be viewed in three dimensions with the addition of a suitable digital elevation model (DEM).

The interpretation of the GIS-based assessment was then achieved by examination of this, and other, imagery to evaluate plausible flow paths from zones of susceptibility to the road. Sections of road alignments subject to hazards were thus able to be determined. The process undertaken and the results obtained are presented in Section 5. At this point initial hazard scores were assigned to each site at which a hazard had been determined (the detailed results are presented in Appendix B).

The work presented in the sections described above is, however, purely desk-based. To complete the hazard assessment site-specific inspections, including site-walkovers, formed an essential concluding part of the process. The methodology for this process is described in Section 6 and the results of the site inspections carried out during 2007 are reported in Appendix C. The outputs from the site inspections were then used to modify the hazard scores assigned in Section 5.

The hazard scores were then further modified by the use of scores related to the exposure of road users to debris flow hazards and the socio-economic impact of the events to give a hazard ranking. This hazard ranking is considered to be an analogue for risk. This whole process is described in Section 7 and final hazard scores, exposure scores and hazard ranking scores are presented in Appendix D. Also included is a listing of high hazard ranking sites in Scotland.

The second key objective of the work presented herein was to develop an approach to the management and mitigation of such debris flow hazards. Section 8 describes risk reduction techniques for sites of high and very high hazard. Two approaches are described:

- Exposure reduction which includes education, warning, signing and road closure for example.
- Hazard reduction which includes engineering measures that protect the road, reduce the opportunity for debris flow to occur, or involve realignment of the road.

Most of the recommendations are based upon the reduction of exposure as a reaction to events, using lower cost and more environmentally acceptable approaches rather than the generally high cost, environmentally intrusive approach of specific hazard reduction. A review of international approaches to the signing of landslides in a road environment is presented in Appendix E, while Appendix F presents the draft content of a proposed educational leaflet for road users which is intended to be made available online initially and possibly at key locations on the network at a later date.

In the longer term it is proposed that the approach to exposure reduction should use proactive techniques and Section 9 describes climatic influences on landslides, including the potential impacts of climate change on both the prevalence and intensity of debris flow in Scotland. Methods for forecasting landsides from rainfall data are described and a series of international case studies is presented in Appendix G. Progress towards the development of a rainfall trigger threshold for debris flow in Scotland is set out and a tentative threshold described in terms of rainfall intensity-duration is included (the background and detail to this work is given in Appendix H). It is anticipated that the development of adequate data and confidence in its application to forecast landslides from such rainfall thresholds in Scotland will take some significant time.

Section 10 draws conclusions from the work presented and makes recommendations for action at a number of different levels including aspects relating to the design, construction, operation and maintenance of the trunk road network. Recommendations for work to further develop the understanding of debris flow events in Scotland and the management of their effects form part of Section 10.