10 SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

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10.1 SUMMARY AND CONCLUSIONS

The landslide events of August 2004 had a substantial effect on the operation of Scottish trunk road network and led to wide-ranging media and political interest. The nature of these events broadly conformed to the relatively fast-moving, shallow debris flow-type of landslide with which this report primarily deals. There have since been other debris flows of a similar nature including, for example, those that affected the A9 in 2006 and the A83 in 2007, as well as a wide range of similar occurrences that affected the local road network. In general the events detailed in this report confirm that landslides typically occur in Scotland in two seasons, namely:

- Summer: July and August.
- Winter: November to January (with events sometimes occurring in October).

The work reported here forms the major component of Transport Scotland's response to the August 2004 events and builds upon an earlier report (Winter *et al*., 2005) which described the background and objectives behind the work presented. The findings from the work have already been widely presented on both nationally and internationally.

Consideration of the socio-economic aspects of landslide risk illustrates the diverse approaches taken by different societies and cultures. These considerations support the principle that the landscape itself has both a social and an environmental value and that a drive towards risk mitigation and/or reduction is only one part of the wider picture.

Notwithstanding this, the core of the work addressed by this report is the assessment and ranking of hazards presented by debris flows.

The hazard assessment process involves the GIS-based spatial determination of zones of susceptibility which are then related to the trunk road network by means of plausible flow paths to determine specific hazard locations. The approach taken, using a GIS-based assessment, enabled large volumes of data to be analysed relatively quickly and was able to rapidly deliver a scientifically-sound platform for the assessment. This desk-based approach to hazard assessment was then supplemented by site-specific inspections, including site walkovers, to give a hazard score for each site of interest.

The subsequent hazard ranking process involved the development of exposure scores predicated primarily upon the risk to life and limb, but also taking some account of the socio-economic impact of debris flow events.

Finally, these scores were combined with the hazard scores to give site-specific scores for hazard ranking from which a listing of high hazard ranking sites in Scotland was produced.

An approach to the management and mitigation of debris flow hazards has also been developed. Two approaches are described:

- Exposure reduction, which involves for example education, warning, signing and road closure.

- 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 (see Section 10.2) are based upon the reduction of the exposure of the road users to debris flow hazards as a reaction to events and utilise lower cost and less environmentally intrusive approaches rather than the typically high cost, environmentally intrusive approach of specific hazard reduction. Exposure reduction is predicated upon the simple and easily-remembered, three-part management tool, Detection-Notification-Action (DNA).

Weather and climate are clearly key influences upon the triggering of debris flows in Scotland and climate change models generally indicate that such events may become more frequent and/or more intense in the future. In the longer term the ability to forecast of debris flow from rainfall data is clearly desirable in order to allow, at least, the Detection and Notification aspects of the DNA process to be carried out in advance of events.

In support of this a variety of international approaches to the back analysis and forecast of landslide events resulting from rainfall have been researched and described. Back analysis of the rainfall associated with a selection of Scottish debris flow events has enabled a tentative debris flow trigger threshold, in terms of rainfall intensity-duration, to be proposed. This threshold, however, needs to be further validated against observations in the future and it is estimated that at least five years of data will be required prior to implementing such a system. Work is currently in progress to develop the dataset and validate the threshold. During the development period a system will also need to be put in place to allow 'real-time' capture and analysis of data to enable forecasting.

The work presented in this report gives Transport Scotland the means to apply appropriate management measures to the sites of highest risk on the trunk road network. Specific recommendations to achieve this and to further develop and improve the management process are given in the following section.

10.2 RECOMMENDATIONS

1. Recommendations in terms of the management of the effects of debris flows are, in the first instance, targeted towards reactive exposure reduction. To deliver the overall objective the following management actions (which are in effect the 'A' of the DNA, or Detection–Notification–Action, process described earlier) are considered essential:

   a) Integration of landslide-specific requirements into the VMS network.

   b) The erection of static signs to indicate the beginning, extent and end of sites of significant landslide hazard ranking (initially sites with a hazard ranking of 100 or greater). These may include flashing lights for periods of higher likelihood.

   c) The implementation of a systematic landslide patrols approach.

   d) Consideration of the need for landslide gates at locations where a physical closure may be deemed necessary. An obvious hazard area where such an approach would be appropriate is the A83 in the Rest and be Thankful area.

   e) In consultation with other stakeholder organisations, the provision of information signs in lay-bys, rest areas and at entry points to National Parks for example. Suitable sites for such provision might also include the rest areas on the A9 at Ralia and House of Bruar and the lay-by at Duck Bay on the A82.

f) The draft leaflet on 'Scottish Roads and Landslides' should form part of the material for the signs described in item (e) above. It should also be made available in electronic form (on the Transport Scotland and Traffic Scotland websites) and possibly in hard copy at the sites described in item (e) above at a later date.

g) The need for more systematic reviewing of the drainage provision in areas at risk from debris flows should be considered by Transport Scotland.

h) A strategy for dealing with land management issues in the light of debris flow potential should be considered by Transport Scotland in consultation with other stakeholders such as the Forestry Commission.

2. In addition, appropriate physical hazard reduction measures should be considered as part of the planning and design process for all sites of high hazard ranking which are scheduled for major maintenance, reconstruction and/or realignment.

3. Weather and climate are key influences on the triggering of debris flows in Scotland and climate change models indicate the potential for such events to become more frequent and/or more severe. Accordingly, the proactive detection of debris flows by means of rainfall monitoring forms a vital part of the longer term management strategy to reduce the exposure of the road using public to debris flow hazards. This then gives the potential to enable Detection, Notification and even some Actions to be undertaken prior to debris flow events. Specific recommendations to action this include the following:

a) The tentative debris flow trigger threshold that has been developed for Scotland should be tested against future observations to validate its use prior to introduction. Such work is ongoing and the first test of the threshold is reported herein. In view of the effort and the events-based data required to undertake this validation process, a period of five years is considered likely to be needed prior to its formal introduction to the management of the road network.

b) The above-mentioned work will also need to consider the most appropriate antecedent period for the forecast of conditions likely to lead to debris flow in Scotland.

c) A system to allow the 'real-time' capture and analysis of appropriate rainfall data, including forecast rainfall data, should be developed to enable the forecast of potential debris flow events. It is recommended that this work be taken forward in collaboration with the Met Office.

d) Once confidence in the threshold has been established simulations of its use should be undertaken. This will enable to lower thresholds for 'Wake-Up' and 'Warning' thresholds to be set, as well as enabling firm rules for the use and operation of the threshold to be set.

4. In addition to the implementation of the recommendations described above, other key issues should be addressed in the future. These include more detailed study of the progressive effects of climate change on debris flows in Scotland, in particular as climate change models improve. An evaluation of the economic impacts of debris flow events will also provide valuable information to aid the decision-making process in terms of management actions and priorities, particularly where higher cost actions are considered.

5. Although, the practice of clear-felling is not as widespread as it once was in Scotland, forestry practices can have a significant impact on the stability of hillsides. Learning from international best practice, particularly that from British Columbia in Canada, in terms of forestry harvesting to maintain hillside stability should be seen as a priority; this will require dialogue with the Forestry Commission.

6. The site-specific inspection programme should be extended through 2008 and subsequent years. A programme for 2008 is in place at the time of writing.

7. The GIS-based assessment should be revisited in (say) 10 years to take account of:
   a) New and improved data sets.
   b) New and improved technologies for handling such data sets.

This work would also require a reinterpretation of the GIS-based assessment.

8. Once the GIS-based assessment and interpretation has been revisited, the sites themselves should be reassessed to take account of changes in land-use and other anthropogenic factors, as well as any short-term geomorphological processes. It is recommended that those sites with a hazard score of (say) 70 should also be subject to the site-based reassessment exercise. The combination of revisiting the GIS-based assessment, interpretation and site-specific reinspection after the interval suggested, should ensure that the appreciation of debris flow hazard to the network remains soundly based in future years.

9. In respect of rock slopes, Transport Scotland is currently assessing the future actions required to address those Hazard Rating surveys and reinspections that remain to be carried out.

10. The two routes identified for 'Separate Assessment' should be the subject of specific studies designed to take into account the particular character of these sites. In particular, these studies will need to examine the wealth of information that has been accumulated on these sites in the past and also the nature of the predominantly scree slopes to assess the hazards and risk at these sites while ensuring that the outputs are broadly compatible with the outputs from the site-specific studies reported here.