7 HAZARD RANKINGS

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7.1 INTRODUCTION

The landslides study was commissioned to assess debris flow hazards on the Scottish road network and address the risks resulting from these as they affect Transport Scotland's road network and the road users. The risk to life and limb was identified at the outset of this project by Transport Scotland's senior management as the primary concern with socio-economic impacts being secondary (but nonetheless important).

Risk is classically defined in terms of landslides (Cruden and Varnes, 1996; Culshaw, 2005) as follows:

$$R = H \times E \times V \tag{7.1}$$

where R is the risk.
H is the hazard.
E denotes the elements at risk.
V is the vulnerability of the elements at risk to the hazard.

In this work the result of this equation (risk) is described as Hazard Ranking, R_H, as it is recognised that the work reported does not consider all aspects of risk.

The hazard is as determined in Section 6. The elements at risk, namely the road and the associated road users, are either present or not at a given plan location. The elements at risk may thus be represented by a binary switch that is set to unity in all cases considered (i.e. where a road and road users are present). The vulnerability equates to risk to life and limb of road users and the socio-economic impacts, including diversionary effects, of temporary closure due to landslides. The binary switch allows a simplification of Equation 7.1 and for the purposes of this study may be rewritten as:

$$R_H = H \times E_X \tag{7.2}$$

where E_X represents the vulnerability of road users to life and limb risks and the potential socio-economic impacts.

The approach taken herein mirrors that typically followed for landslide hazard and risk assessment, as described above. It builds upon the approach outlined by Winter *et al*. (2005a) in the precursor to this report and is not a modification of the approach proposed by Clayton (2001), as has been stated by Anon (2006a).

7.2 EXPOSURE SCORES

The exposure of life and limb may be represented, at a simple level, by the surrogate of traffic flow. It is accepted that sightlines and other factors that influence visibility of the road ahead could also be used to refine the exposure of life and limb (e.g. McMillan & Matheson, 1997). However, in this study two issues rendered this additional complication inappropriate: first, to a large extent traffic flows relate to the type of road alignment in place and thus to the quality of the sight lines; second, the extent of the route lengths considered meant that a simple and straightforward approach was, in this case, more suitable.

Similarly, the socio-economic aspects of exposure may be represented not only by the traffic flow and but also by the existence, length and quality of any diversion necessary.

As with the different elements that make up the GIS-based hazard assessment (Section 4), the different elements of exposure must also be added together in order to achieve an overall score. Relevant categories were determined and scores then assigned for both traffic flow and diversionary aspects of exposure for each site. The scores for these individual factors were then weighted to reflect their relative importance and then summed to produce the overall exposure score.

The traffic categories used by Transport Scotland reflect the traffic flows over the entire network. The lowest flow category comprises those roads with an Annual Average 2-way 24-hour Daily Flow (AADF) of less than 10,000 vehicles per day. It was apparent at the outset of the work to define the traffic flow scores that this lowest category would cover a large proportion of the vulnerable sites identified in Section 5. This would mean that the use of the standard traffic flow categories would not effectively differentiate between the various sites and a decision was therefore made to use alternative categories. These new categories and their associated exposure scores (E_{XT}) were defined as follows:

AADF $\leq$ 2,500 vehicles per day, $E_{XT} = 1.0$.
2,500 < AADF $\leq$ 7,500 vehicles per day, $E_{XT} = 1.5$.
7,500 < AADF $\leq$ 25,000 vehicles per day, $E_{XT} = 2.0$.
AADF > 25,000 vehicles per day, $E_{XT} = 2.5$.

Traffic data was sourced from the Scottish Road Traffic Database operated by Transport Scotland.

The diversion scores (E_{XD}) were based upon an informed judgement of the potential consequences of a closure on the network within a given location section. Where the diversion was short and effective (e.g. by other trunk and/or ‘A’-roads) then the consequences were defined as ‘Limited’. Where the diversion was long, by difficult means (e.g. ‘C’, ‘D’ and/or unclassified road) or does not exist (in practical terms) the consequences were defined as ‘More significant’. ‘Significant’ represents the middle ground between these two extremes and the diversion scores were defined as follows:

Limited, $E_{XD} = 0$.
Significant, $E_{XD} = 1$.
More significant, $E_{XD} = 2$.

For any given site, weightings were then applied to the two exposure scores. The two weighted scores were then added together to give a total score for exposure. The weightings applied reflect the paramount importance of reducing the exposure to risks related to life and limb of the travelling public, and for this reason the traffic score was weighted more heavily than the largely disruption-focused diversion score. It should however be noted that the traffic score does itself include significant elements that relate to the potential disruption to road users.

The score of the final exposure score is thus given by:

$$E_X = (E_{XT} \times 1.0) + (E_{XD} \times 0.5) \qquad (7.3)$$

Accordingly, Equation (7.2) may thus be rewritten as follows:

$$R_H = H \times [(E_{XT} \times 1.0) + (E_{XD} \times 0.5)] \quad (7.4)$$

The final exposure scores are detailed in Appendix D.1.

It could be argued that either the hazard or the exposure (and therefore hazard ranking) should be influenced by the length of the section in question in a very direct sense by, for example, taking the Elements at Risk part of Equation 7.1 to be the length of road. This type of approach is suited to risks such as that of a tanker over-turning on a straight road – that is, risks that are entirely uniform along the full length of the section (see also Section 5.2.2). However, there are a number of factors that count against this approach, and these are as follows:

1. The relation between length and the probability of event occurrence is not a constant. The hazards contained within a given section length are variable in terms of their spacing and magnitude and the profile of any hazard score along a given length is therefore also variable. It would therefore not be correct to proportion the exposure according to the length of the section in question.
2. Effects of length have already been accounted for appropriately in the process in which priorities were assigned to the lengths (see Section 5.2.2). Thus, hazard scores should be viewed as providing aggregate scores over the length of the identified hazard rather than average scores at any given point within the length.
3. The purpose of the work was also to rank hazards rather than to perform an all-encompassing risk assessment.
4. The hazards and hazard rankings are intended to apply to each likely point of potential incident on a route length and therefore it would be inappropriate to undertake a length-based approach.
5. A length-based approach does not lend itself readily to spatial assessments (such as those relating to debris flows) as opposed to purely linear hazards (such as that of a fuel tanker overturning).

7.3 HAZARD RANKINGS

The overall hazard ranking scores were thus able to be computed by taking the results presented in Section 6 and applying them, along with the exposure scores, to Equation 7.4. The detailed final hazard ranking scores obtained are then able to be set-out and are presented in tabular form in Appendix D.2. A truncated form of the table, detailing sites with final hazard ranking scores of 100 or greater, is presented as Table 7.1 and the geographical distribution of the sites is illustrated in Figure 7.1.

In Section 3, Figure 3.1 identified site rankings in terms of Low, Medium, High and Very High Hazard Ranking. An explanation of these categorisations was given in the text.

The distinction that was made between Low and Medium Hazard Ranking sites (Winter *et al*., 2005a) has been superseded by the development of Traffic Scotland's Emergency Standard Diversion Routes (ESDR) (see also Section 8.3.1). This means that the actions planned for Medium Hazard Ranking sites are in the process of being implemented for all sites, including Low Hazard Ranking sites; the 'do nothing' scenario thus becoming redundant.

Table 7.1 – Sites with a hazard ranking score of 100 or greater.

Route Code	OC Unit	Start-NGR	End-NGR	Length (m)	Priority	Hazard Score	Exposure Score	Hazard Ranking (Risk) Score = Hazard × Exposure	Locality
A82-17	NW	NN 28766 96227	NN 21391 85632	13,400	**1**	**100**	**2.5**	**250**	Loch Lochy
A85-09	NW	NN 50672 28326	NN 38766 25266	12,900	**2**	**100**	**2.5**	**250**	Glen Dochart
A82-08	NW	NH 45761 19182	NH 43486 16747	3,410	**1**	**90**	**2.5**	**225**	N of Invermoriston
A82-37	NW	NN 34026 00456	NS 34556 97686	3,300	**1**	**90**	**2.5**	**225**	Inverbeg and N
A9-12	NW	ND 02175 14804	NC 93895 09663	10,200	**1**	**90**	**2.5**	**225**	S of Helmsdale
A9-35b	NW	NN 66562 72101	NN 69762 71546	3,310	**1**	**90**	**2.5**	**225**	N Glen Garry
A82-09	NW	NH 42981 16557	NH 42451 16667	581	**1**	**80**	**2.5**	**200**	Invermoriston
A82-26	NW	NN 05220 59568	NN 07550 58357	2,720	**2**	**80**	**2.5**	**200**	E of Ballachulish
A82-34	NW	NN 33296 20776	NN 31776 09196	13,500	**1**	**100**	**2.0**	**200**	N Loch Lomond
A85-08	NW	NN 58437 24970	NN 55677 29396	5,480	**1**	**100**	**2.0**	**200**	Glen Ogle
A9-11	NW	ND 08775 20794	ND 02860 15349	11,200	**1**	**100**	**2.0**	**200**	N of Helmsdale
A83-02	NW	NN 26901 03861	NN 23021 07837	6,310	**1**	**90**	**2.0**	**180**	Ardgarten to Rest & be Thankful
A83-04	NW	NN 23421 09592	NN 19096 09927	4,360	**1**	**90**	**2.0**	**180**	Glen Kinglas
A9-44	NW	NO 00212 47141	NO 00472 43871	3,320	**1**	**90**	**2.0**	**180**	N of Dunkeld
A87-19	NW	NG 64039 23632	NG 48718 29902	26,100	**Separate Assessment**	**90**	**2.0**	**180**	Southern Skye - N of Broadford
A82-36	NW	NN 31916 04456	NN 34026 00456	4,610	**2**	**70**	**2.5**	**175**	S of Tarbet
A9-35a	NW	NN 63982 83957	NN 64987 73046	11,900	**2**	**70**	**2.5**	**175**	S of Dalwhinnie
A83-06	NW	NN 19221 12717	NN 11260 08848	9,170	**2**	**85**	**2.0**	**170**	Clachan to Strone Point
A82-05	NW	NH 52566 28987	NH 49631 23632	6,770	**2**	**65**	**2.5**	**163**	S of Drumnadrochit
A77-11	SW	NX 05214 72439	NX 08694 63338	9,990	**2**	**80**	**2.0**	**160**	S of Glen App
A82-02	NW	NH 60696 39243	NH 57346 34993	5,520	**1**	**100**	**1.5**	**150**	N end of Loch Ness
A83-05	NW	NN 18406 11247	NN 19406 12512	1,620	**1**	**100**	**1.5**	**150**	Cairndow
A87-12	NW	NH 03370 12016	NG 96289 14946	8,620	**1**	**100**	**1.5**	**150**	E Glen Shiel
A87-15	NW	NG 94469 21121	NG 88269 26106	8,650	**1**	**100**	**1.5**	**150**	Loch Duich
A87-09	NW	NH 11495 10731	NH 09725 11731	2,080	**1**	**95**	**1.5**	**143**	W Loch Cluanie
A830-05	NW	NM 90195 80853	NM 76679 82314	15,500	**2**	**70**	**2.0**	**140**	Glenfinnan to Lochailort
A9-45	NW	NO 03452 41486	NO 04062 40886	877	**2**	**70**	**2.0**	**140**	S of Dunkeld
A82-27	NW	NN 10700 58212	NN 27671 52992	19,900	**Separate Assessment**	**90**	**1.5**	**135**	Glen Coe
A828-01	NW	NN 05175 59653	NM 99145 54983	8,540	**2**	**90**	**1.5**	**135**	W of Ballachulish
A835-07	NW	NH 38284 70387	NH 28554 73906	11,400	**1**	**90**	**1.5**	**135**	Lubfearn to W Loch Glascarnoch
A85-15	NW	NN 13191 28352	NN 03135 29863	12,400	**1**	**90**	**1.5**	**135**	Dalmally to W Pass of Brander
A86-12	NW	NN 25591 81307	NN 22966 81947	2,770	**1**	**90**	**1.5**	**135**	Inverroy to Spean Bridge
A87-13	NW	NG 96259 14951	NG 94614 17946	3,790	**2**	**90**	**1.5**	**135**	W Glen Shiel
A82-07	NW	NH 47461 21012	NH 46411 19822	1,620	**3**	**50**	**2.5**	**125**	N of Alltsigh
A82-16	NW	NN 29996 98177	NN 28981 96572	1,960	**3**	**50**	**2.5**	**125**	Loch Oich to Loch Lochy
A82-23	NW	NN 04505 66337	NN 03765 65377	1,260	**3**	**50**	**2.5**	**125**	N of Corran Ferry
A82-24	NW	NN 02295 63258	NN 02645 62728	688	**3**	**50**	**2.5**	**125**	S of Corran Ferry
A82-38	NW	NS 34556 97686	NS 35196 87156	11,100	**3**	**50**	**2.5**	**125**	N & S of Luss
A83-18	NW	NR 84819 80506	NR 86284 74006	7,040	**3**	**50**	**2.5**	**125**	S of Inverneill
A83-20	NW	NR 86794 69696	NR 86529 69066	687	**3**	**50**	**2.5**	**125**	N Tarbet
A9-24	NW	NH 72341 35783	NH 75841 34579	4,040	**3**	**50**	**2.5**	**125**	N of Loch Moy
A9-27	NW	NH 82171 26569	NH 87652 24074	6,660	**3**	**50**	**2.5**	**125**	Slochd
M90-09	NE	NO 14377 13430	NO 13887 15335	3,200	**3**	**50**	**2.5**	**125**	N of Glen Farg
A82-04	NW	NH 52391 30037	NH 50831 30172	1,590	**1**	**80**	**1.5**	**120**	Drumnadochit
A86-03	NW	NN 67317 95722	NN 67162 95417	357	**1**	**80**	**1.5**	**120**	Glentruim House
A86-09	NW	NN 48856 87552	NN 47661 86407	1,730	**1**	**80**	**1.5**	**120**	Aberarder (Loch Laggan)
A86-10	NW	NN 47516 86247	NN 37536 81267	11,600	**2**	**75**	**1.5**	**113**	Loch Laggan and Reservoir
A86-11	NW	NN 33266 80957	NN 27646 81067	6,180	**2**	**75**	**1.5**	**113**	Tulloch to Roy Bridge
A7-06	SE	NT 40762 02692	NY 38842 96252	7,160	**2**	**70**	**1.5**	**105**	S of Teviothead
A835-09	NW	NH 19553 80586	NH 18168 85540	5,320	**2**	**70**	**1.5**	**105**	S of Loch Broom
A1-06	SE	NT 79571 67434	NT 85681 62704	8,630	**3**	**50**	**2.0**	**100**	Penmanshiel to Howburn
A7-01	SE	NT 48882 32523	NT 48142 31013	1,840	**3**	**50**	**2.0**	**100**	N of Selkirk
A76-04	SW	NS 85832 04117	NS 81022 07857	6,570	**3**	**50**	**2.0**	**100**	S of Sanquhar
A77-10	SW	NX 09284 77378	NX 05214 72439	6,640	**3**	**50**	**2.0**	**100**	Glen App
A83-01	NW	NN 29616 05036	NN 28391 03881	1,760	**3**	**50**	**2.0**	**100**	W of Succoth
A83-07	NW	NN 11260 08848	NN 11395 10083	1,260	**3**	**50**	**2.0**	**100**	E Loch Shira
A83-10	NW	NN 04495 04203	NN 02915 03179	1,910	**3**	**50**	**2.0**	**100**	E of Auchindrain Folk Museum
A83-12	NW	NS 01725 99834	NR 98995 97649	3,550	**3**	**50**	**2.0**	**100**	W of Furnace
A83-21	NW	NR 86034 68451	NR 85284 68076	839	**3**	**50**	**2.0**	**100**	W of Tarbet
A830-04	NW	NM 90855 80478	NM 90205 80848	867	**3**	**50**	**2.0**	**100**	Glenfinnan
A830-06	NW	NM 76679 82314	NM 71574 84404	6,080	**3**	**50**	**2.0**	**100**	Lochailort to Prince's Cairn
A835-04	NW	NH 43565 58802	NH 40650 59367	3,110	**3**	**50**	**2.0**	**100**	S of Garve
A84-03	NW	NN 57047 14530	NN 58487 13465	1,900	**3**	**50**	**2.0**	**100**	N Loch Lubnaig
A9-09	NW	ND 15325 29325	ND 13145 25995	4,350	**3**	**50**	**2.0**	**100**	S of Dunbeath
A9-10	NW	ND 12010 23055	ND 11670 22435	1,110	**3**	**50**	**2.0**	**100**	Berriedale
M74-09	M74	NS 95997 16852	NS 96337 16502	492	**3**	**50**	**2.0**	**100**	Elvanfoot

In terms of the High and Very High Hazard Ranking sites the primary intention is to concentrate on exposure reduction and a mixture of exposure and hazard reduction respectively. The distinction between these two approaches is more fully described in Section 8, but, in summary, the key issue is one of cost, with hazard reduction generally being significantly more expensive than exposure reduction.

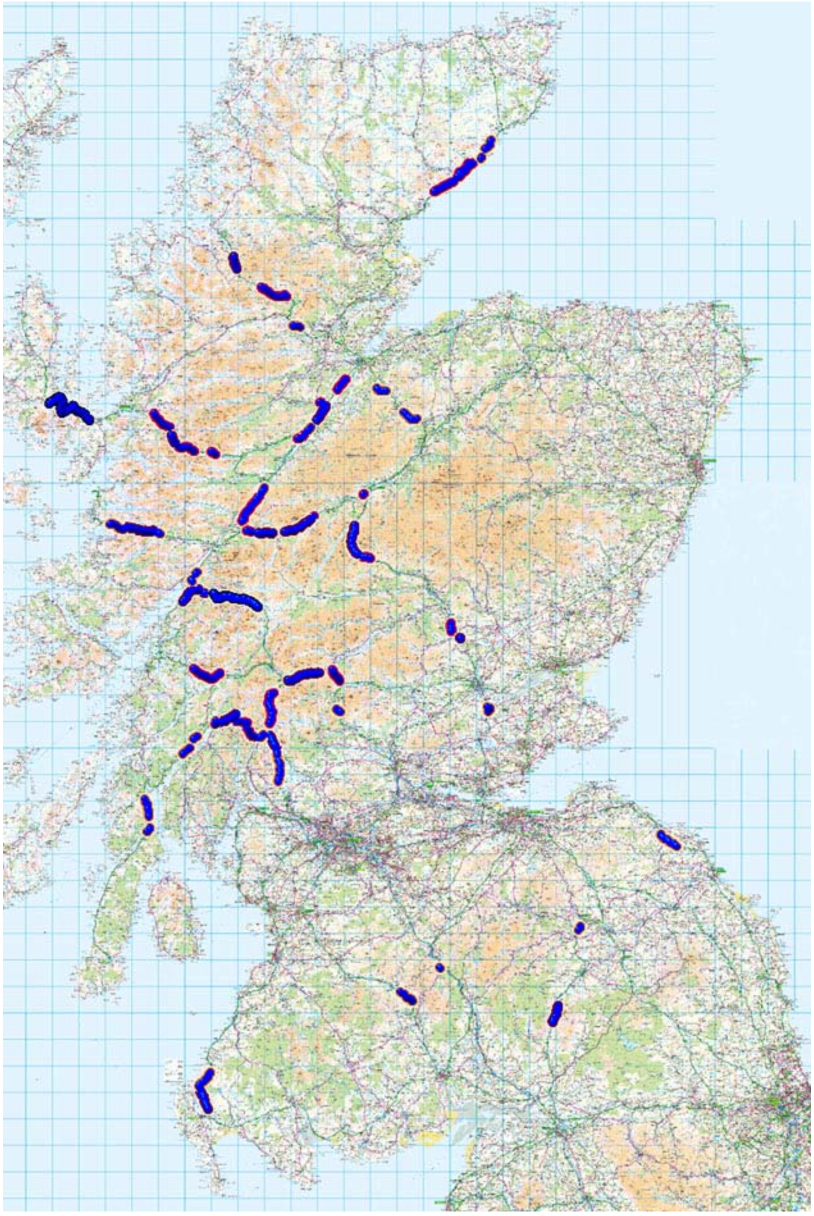

Figure 7.1 – Sites with a hazard ranking score of 100 or greater. (© Crown Copyright. All rights reserved Scottish Government 100020540, 2008.)

The cost of hazard reduction measures, beyond routine drainage maintenance and improvement measures, is such that embarking upon such work needs to be considered very carefully. Indeed, the costs need to be set within the context of the overall maintenance and construction budgets operated by Transport Scotland. Additionally, any intended work should be reviewed in terms of existing programme plans for significant upgrading and/or realignment of existing routes (see also Section 8.2).

Table 7.1 details those sites determined to be of High and Very High Hazard Ranking.

7.4 RE-INSPECTION PROGRAMME

In Section 3, Figure 3.1 indicates a Monitoring and Feedback activity in the flowchart. An essential component of that activity is having in place an effective programme for re-inspection of slopes identified as being hazardous or potentially so. As an overall consideration, the GIS-based assessment should be re-visited in (say) 10 years to take account of:

1. New and improved data sets.
2. New and improved technologies for handling such date sets.

This work would also require reinterpretation of the GIS-based assessment (either manually as reported here or automatically if technology, including processing power, allows).

In terms of re-inspection of the sites themselves, those with a hazard score of (say) 70 (i.e. Priority 2 sites with the 10 uplift added for site-specific inspection) and above, should also be subject to a reassessment exercise. This would go some way towards taking account of temporal changes to the volume and nature of material available for triggering debris flows.

The combination of revisiting the GIS-based assessment, interpretation and site-specific re-inspection after the interval suggested, should also ensure that the appreciation of debris flow hazard to the network remains soundly-based in future years.

7.5 ROCK SLOPES

Clearly debris flows are not the only hazards that may affect roads in Scotland and amongst the others are those presented by falls of geological material from rock slopes and cliffs alongside the network. Between 1994 and 1999 Transport Scotland (in a previous guise) initiated and operated a structured programme of rock slope risk assessment and management on the trunk road network (McMillan, 1995; McMillan & Matheson, 1997). The process involved the computation of a Hazard Index that then determined the actions required in terms of further inspections and more detailed surveys to determine Hazard Ratings.

The Hazard Index categories that were developed are as follows:

- Urgent detailed inspection (hazard rating survey).
- Detailed inspection (hazard rating survey).
- Review in five years.
- No action.

In recent years, a review of progress with both inspections and recommended remedial works was undertaken (Blair & McMillan, 2004). This review identified the sites at which urgent detailed inspections had been required to be undertaken as part of the Hazard Rating process. Whilst most of those had been, indeed, undertaken prior to the review, some outstanding inspections were identified, as follows:

- A82 Tyndrum to Fort William (one outstanding Hazard Rating survey).
- A87 Invergarry to Cluanie (two outstanding Hazard Rating surveys).
- A887 Invermoriston to Moriston Bridge (one outstanding Hazard Rating survey).
- A86 Newtonmore to Spean Bridge (two outstanding Hazard Rating surveys).
- A82 Fort William to Fort Augustus (one outstanding Hazard Rating survey).

The 2004 review is, of course, unable to detail how many of the sites flagged for detailed inspection have now been inspected.

Transport Scotland is currently assessing the future actions required to address those Hazard Rating surveys and re-inspections that remain to be carried out.