REGIONAL LANDSLIDE SUSCEPTIBILITY MAPPING ALONG THE YUKON ALASKA HIGHWAY CORRIDOR: A QUALITATIVE HEURISTIC APPROACH

A. Blais-Stevens, M. Kremer, A. Page, and R. Couture

Introduction

The Yukon Alaska Highway Corridor (YAHC) is a vital transportation route through which 80% of all goods in Yukon are shipped and 70% of Yukon tourists travel yearly. In addition, about 85% of Yukon's population lives along the highway and a proposed pipeline will run roughly parallel to the road. Permafrost-related landslide occurrences and ground deformation features have been observed along the YAHC.

As part of a Natural Resources Canada Program for Energy and Development (PERD), the Geological Survey of Canada in collaboration with Yukon Geological Survey, Simon Fraser University and University of Ottawa, carried out a regional geohazard assessment and slope stability studies along the YAHC. This open file report addresses one of the three main objectives of this project: to produce landslide susceptibility maps and models for debris flows and rockfall/rock slides using a qualitative heuristic method.

Figure 1. Study area within Yukon. KL: Kluane Lake, HJ: Haines Junction, W: Whitehorse

DEBRIS FLOWS
Susceptibility Index (SI)
- 0.573 - 1.0 High
- 0.423 - 0.572 Moderate
- 0.297 - 0.422 Low
- 0 - 0.296 Very Low
- Mapped debris flow deposit
- Alaska Highway

Figure 4. Modelled debris flow susceptibility overlain by mapped debris flow deposits.

Physiographic Setting

The YAHC in southern Yukon stretches linearly about 950 km with a 20 km width on each side of the highway from the Yukon-Alaska border to the British Columbia border (Figure 1). The study area covers about 27,000 km2 which includes only the area of the YAHC that runs inside the Yukon. From west to east, the corridor is situated within the Yukon Plateau, the Kaska Mountains, Liard Lowlands and Mackenzie Mountains. The area is seismically active with the Denali Fault passing through the western part of the corridor (Huscroft et al., 2004). The Kluane Ranges are found to the southwest and the Yukon Plateau to the northeast of the YAHC.

The maximum elevation within the study area is 2799 m located about 20 km south east of the southernmost point of Kluane Lake. The minimum elevation of 527 m is located about 15 km west of Haines Junction.

The climate is sub-Arctic, experiencing long, cold winters, short, mild summers and receiving low to moderate levels of precipitation. The climate in the western part of the study area is moderate, but becomes more harsh and continental towards the east. The corridor lies within the Boreal Cordillera Ecozone dominated by black and white spruce with meadows and open forests of trembling aspen (Huscroft et al., 2004).
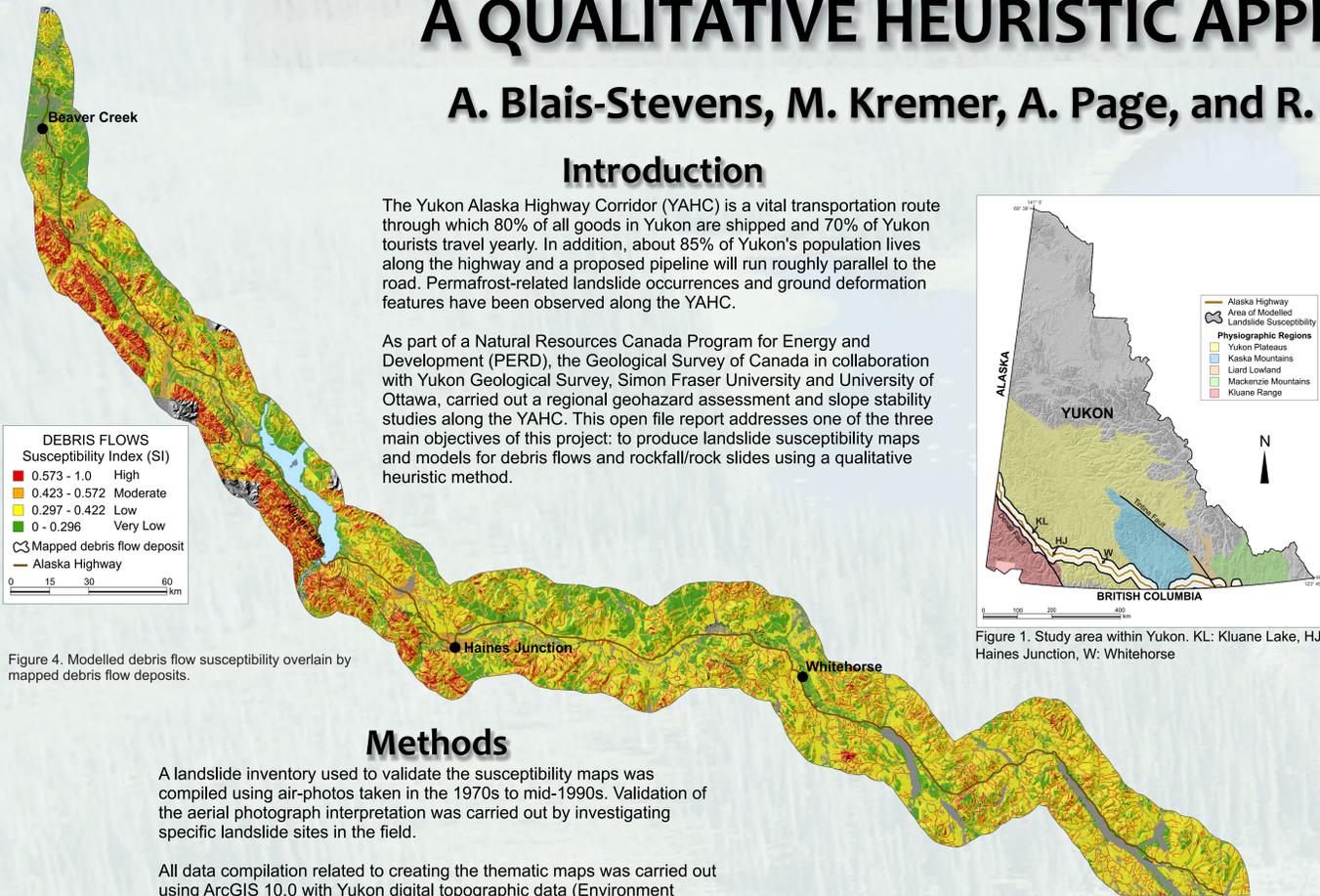
Methods

A landslide inventory used to validate the susceptibility maps was compiled using air-photos taken in the 1970s to mid-1990s. Validation of the aerial photograph interpretation was carried out by investigating specific landslide sites in the field.

All data compilation related to creating the thematic maps was carried out using ArcGIS 10.0 with Yukon digital topographic data (Environment Yukon Geomatics, 2010). The method used was a simple qualitative heuristic approach modified from Soeters and van Westen (1996). We produced susceptibility maps for debris flows and rockfalls/rock slides, using the likely landslide triggers, compiled from available documentation and/or derived from DEMs, i.e., slope angle and slope aspect (Riopel et al., 2006; Couture and Riopel, 2008; Blais-Stevens and Kung, 2009), as input layers (Figure 2). From this information, an equation was defined where the data layers served as variables, each of which was assigned a percent weight based on expert knowledge as well as geological and historical information (Table 1). Classes within each of these layers were also rated based on the potential contribution to slope failure (Table 2 and CD-ROM). The sum of the weighted variables represents a Susceptibility Index (SI) ranging between 0-1 for each pixel (25 m x 25 m). Development of the equations for the landslide susceptibility index values was carried out independently from the landslide inventory.

The debris flow equation for the susceptibility map was:
$$SI = 0.3DD + 0.3S1 + 0.2G + 0.15P + 0.05S2$$
Where parameters were defined as DD= Distance to drainage, S1= Slope angle, S2=Slope aspect, G=Surficial deposit type, and P=Permafrost distribution (Table 1a). DD and S1 were given the highest weights given the channelized nature of a debris flow (Dai and Lee, 2001) and that most debris flows in the area are initiated in steep streams (Thurber Consultants, 1983; Blais-Stevens and Septer, 2008).

The equation for the rockfall/rock slide susceptibility map was:
$$SI = 0.25R + 0.5S1 + 0.1S2 + 0.15DF$$
Where parameters were R=rock type, S1= Slope angle, S2=Slope aspect, DF=Distance to fault (Table 1b). Slope angle was considered to be the most important variable in this region (Moreiras, 2005; Ruff and Czurda, 2008; Kamp et al., 2008), followed by rock type. Distance to fault was considered important as the YAHC is crossed by seismic faults.

We tested three ways of displaying the the SI results (natural breaks, 4, and 6 equal intervals). We overlaid the inventory on each map product to look for correlation with susceptibility zones. For the final map products, we chose to divide into four colour-coded categories using Jenks natural breaks classification (Jenks, 1967) because of better validation results with the landslide inventory.
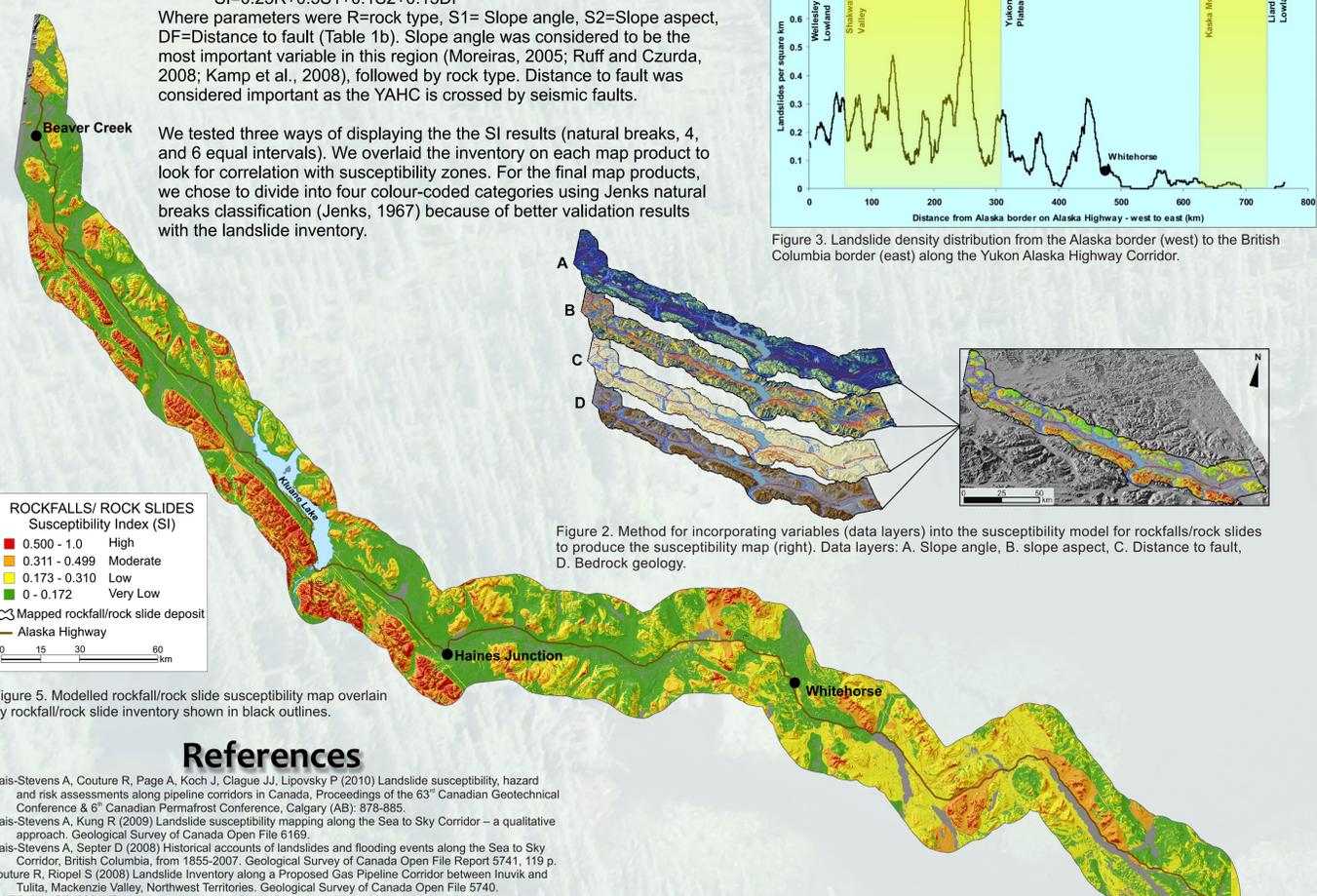
Table 1. Susceptibility index equation parameters and their assigned weights. a: Debris flows, b: Rockfalls/Rock slides.

a Parameters	Code	Weight	b Parameters	Code	Weight
Slope angle	S1	30%	Slope angle	S1	50%
Slope aspect	S2	5%	Slope aspect	S2	10%
Surficial geology	G	20%	Rock type	R	25%
Permafrost type	P	15%	Distance to fault	DF	15%
Distance to drainage	DD	30%	Total	SI	100%
Total	SI	100%			

Table 2. Examples of the classes and ratings set for two variables used in the debris flow susceptibility model. See accompanying CD-ROM for all the classes and ratings used in the equation.

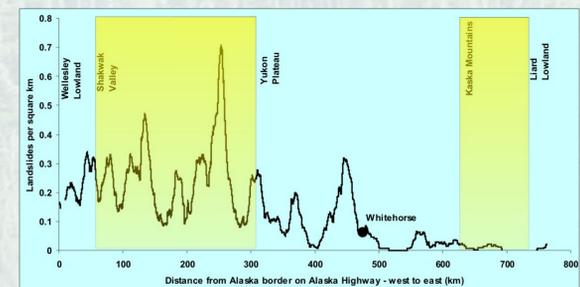| a Slope Angle	Class	Rating	b Distance to Drainage	Class	Rating
0-15	L	0.1	0 - 50 m	H	1.00
16 - 25	M	0.5	51 - 100 m	M-H	0.75
26 - 45	H	1.0	101 - 150 m	M	0.50
46 - 55	M	0.5	151 - 200 m	M-L	0.25
56 - 90	L	0.1	> 200 m	L	0.10

Figure 3. Landslide density distribution from the Alaska border (west) to the British Columbia border (east) along the Yukon Alaska Highway Corridor.
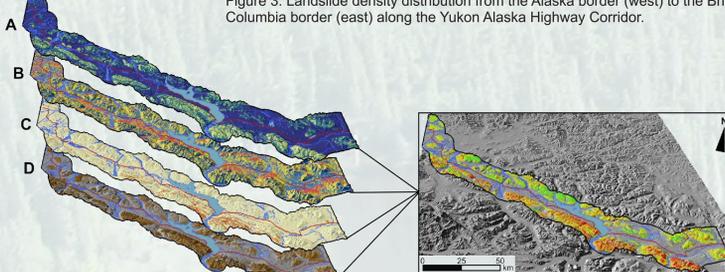

Figure 2. Method for incorporating variables (data layers) into the susceptibility model for rockfalls/rock slides to produce the susceptibility map (right). Data layers: A. Slope angle, B. slope aspect, C. Distance to fault, D. Bedrock geology.

ROCKFALLS/ ROCK SLIDES
Susceptibility Index (SI)
- 0.500 - 1.0 High
- 0.311 - 0.499 Moderate
- 0.173 - 0.310 Low
- 0 - 0.172 Very Low
- Mapped rockfall/rock slide deposit
- Alaska Highway

Figure 5. Modelled rockfall/rock slide susceptibility map overlain by rockfall/rock slide inventory shown in black outlines.

Results/Discussion

In the YAHC, a total of 1743 landslides were identified on air-photos, representing approximately 1 landslide per 17 km² (Figure 3). The dominant landslide types were: debris flows and fans (28%), debris slides (31%), earth slides/flows (5%), rock slides (11%), rock falls and topples (4%), karstic depressions (5%), solifluction (8%), and combined retrogressive thaw flows and active layer detachments (1%). Rock glaciers were also identified (6%). A landslide distribution map reflects dominant landslide activity in unconsolidated sediments at 64% and 36% in bedrock (Blais-Stevens et al., 2010).

The debris flow susceptibility map showed SI values varying from 0-1.0. For validation, the debris flow deposit inventory was overlain on the susceptibility map, and we observed a very good correlation between the debris flow inventory and the susceptibility zones. A total of 69% of the mapped debris flow deposits occur downstream from a high (red) susceptibility zone, and 28% occur downstream from the moderate (orange) susceptibility zone (Figure 4). For this area, only 6% of the YAHC is classified as high susceptibility, 17% as moderate susceptibility, 45% as low susceptibility, and 32% as very low susceptibility.

The rockfalls/rock slides susceptibility map showed SI values ranging from 0-1.0 (Figure 5). Similarly, we overlaid the rockfall and rock slide inventory on the susceptibility map for validation and also observed a very good correlation between the two. A total of 64% of the rockfalls and rock slides are located within the high (red) and 20% within the moderate (orange) susceptibility zone. For this area, only 0.03% of the YAHC is classified as high susceptibility, 6% as moderate, 15% as low, and 20% as very low. The remaining 59% is built on sediment, therefore no data are available.

Conclusions

An inventory of landslides within the YAHC showed that most activity from the dominant landslide types occurs within unconsolidated sediments. The qualitative heuristic method has produced regional debris flow and rockfall/rock slide susceptibility maps with good validation with the landslide inventory and a preliminary hazard assessment for the YAHC. The susceptibility models could be improved by trying more quantitative methods or by increasing the resolution of some of the parameters, e.g., the permafrost distribution map, which is presently a 1:1,000,000 scale map (Heginbottom and Radburn, 1992). Additional parameters could be included such as forest fire occurrence because forest fires degrade the insulation effect of the vegetation layer above frozen ground and therefore change the thermal regime of permafrost. Climate data could also be included in the model. Moreover, the landslide inventory could be updated with recent high resolution satellite imagery. Nevertheless, the landslide susceptibility maps display a preliminary assessment of potential landslide activity.

In this proposed pipeline corridor, slope failures are prominent. Most landslides that could affect the pipeline corridor have been initiated in steep bedrock terrain. Thus, our preliminary investigations indicate that there is a slope hazard to be considered during development of the pipelines.

References

Blais-Stevens A, Couture R, Page A, Koch J, Clague JJ, Lipovsky P (2010) Landslide susceptibility, hazard and risk assessments along pipeline corridors in Canada, Proceedings of the 63rd Canadian Geotechnical Conference & 6th Canadian Permafrost Conference, Calgary (AB): 878-885.
Blais-Stevens A, Kung R (2009) Landslide susceptibility mapping along the Sea to Sky Corridor – a qualitative approach. Geological Survey of Canada Open File 6169.
Blais-Stevens A, Septer D (2008) Historical accounts of landslides and flooding events along the Sea to Sky Corridor, British Columbia, from 1855-2007. Geological Survey of Canada Open File Report 5741, 119 p.
Couture R, Riopel S (2008) Landslide Inventory along a Proposed Gas Pipeline Corridor between Inuvik and Tulita, Mackenzie Valley, Northwest Territories. Geological Survey of Canada Open File 5740.
Dai FC, Lee CF (2001) Terrain-based mapping of landslide susceptibility using a geographical information system: a case study. Canadian Geotechnical Journal 38: 911–923.
Environment Yukon Geomatics (2010) 30m DEM. [online] Available: ftp://ftp.geomaticsyukon.ca/DEMs/
Heginbottom JA, Radburn LK (compilers) (1992) Permafrost and ground ice conditions of northwestern Canada; Geological Survey of Canada, Map 1691A, scale 1:1,000,000. Digitized by S. Smith, Geological Survey of Canada, Boulder, CO, National Snow and Ice Data Center/World Data Center for Glaciology, Digital Media.
Huscroft CA, Lipovsky PS, Bond JD (2004) A regional characterization of landslides in the Alaska Highway corridor, Yukon. Yukon Geological Survey, Open File 2004-18, 65 p., report and CD-ROM.
Jenks GF (1967) The Data Model Concept in Statistical Mapping, Intern Yearb Carto 7: 186-190.
Kamp U, Growley BJ, Khattak GA (2008) GIS- based landslide susceptibility mapping for the 2005 Kashmir earthquake region. Geomorphology 101: 631–642.
Moreiras SM (2005) Landslide Susceptibility Zonation in the Rio Mendoza Valley, Argentina. Geomorphology 66: 345-357.
Riopel S, Couture R, Tewari K (2006) Mapping susceptibility to landslides in a permafrost environment: case study in the Mackenzie Valley, Northwest Territories. GeoTech Event 2006, Ottawa, 13 p.
Ruff M, Czurda K (2008) Landslide susceptibility analysis with a heuristic approach at the Eastern Alps (Vorarlberg, Austria). Geomorphology 94: 314-324.
Soeters R, van Westen CJ (1996) Slope instability recognition, analysis, and zonation. In: Turner AK, Schuster RL (eds) Landslides, investigation and mitigation, Transportation Research Board, National Research Council, Special Report 247. Washington, National Academy Press: 129–177.
Thurber Consultants Ltd (1983) Debris torrent and flooding hazards Highway 99, Howe Sound. Report to B.C. Ministry of Transportation and Highways, 25 p.

Disclaimer

Her Majesty the Queen in right of Canada, as represented by the Minister of Natural Resources ("Canada"), does not warrant or guarantee the accuracy or completeness of the maps and other data and information ("Data") contained in this report and does not assume any responsibility or liability with respect to any damage or loss arising from the use or interpretation of the Data.

The Data in this report are intended to convey regional trends and should be used as a guide only. The Data should not be used for design or construction at any specific location, nor are the Data to be used as a replacement for the types of site-specific geotechnical investigations.

Clause de non-responsabilité

Sa Majesté la Reine du chef du Canada, représentée par le ministre des Ressources naturelles (« le Canada »), ne garantit ni l'exactitude ni l'exhaustivité des cartes et des autres données et renseignements (« les données ») contenus dans le présent rapport, et n'assume aucune responsabilité à l'égard de tout dommage ou de toute perte découlant de l'utilisation ou de l'interprétation de ces données.

Les données contenues dans le présent rapport visent à esquisser des tendances régionales et ne doivent servir qu'à titre indicatif. Elles ne doivent pas être utilisées à des fins de conception ou de construction dans un endroit spécifique ni remplacer les études géotechniques propres au site.

Recommended Citation

Blais-Stevens, A., Kremer, M., Page, A., and Couture, R., 2011. Regional landslide susceptibility mapping along the Yukon Alaska Highway Corridor: A qualitative heuristic approach; Geological Survey of Canada Open File 6946, 1 CD-ROM. doi:10.4095/288986

OPEN FILE
DOSSIER PUBLIC
6946
2011

This publication is available from the Geological Survey of Canada Bookstore (http://gsc.nrcan.gc.ca/bookstore_e.php). It can also be downloaded free of charge from GeoPub (http://geopub.nrcan.gc.ca).

© Her Majesty the Queen in Right of Canada 2011

Natural Resources Canada   Ressources naturelles Canada

Study Area