Landslide susceptibility mapping along existing and proposed pipeline corridors in Canada

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ABSTRACT: The Canadian Energy Pipeline Association (CEPA) measures approximately 580,000 km of pipeline in Canada with the longest crude oil pipeline in the world. In 2007, approximately 2.65 million barrels per day of crude oil and roughly 17.1 billion cubic feet of natural gas per day traveled through Canada’s pipeline networks. There are several proposed new pipeline routes including the Yukon Alaska Highway Pipeline (YAHP) Project and the Mackenzie Valley natural gas Pipeline project (MVP) located in Canada’s sub-Arctic region. This paper compares two examples of regional landslide susceptibility mapping studies along an existing pipeline corridor in southern British Columbia (BC) and a proposed pipeline (MVP) in Canada. Both methods are semi-quantitative and rely on expert judgment. Landslide inventory information overlain on the resulting landslide susceptibility maps indicates good correlation with potential for improvement. The paper also discusses the federal government’s role in providing geoscience information for environmental assessments of the MVP and YAHP projects.

1 INTRODUCTION
1.1 Pipelines in Canada

The Canadian Energy Pipeline Association (CEPA, 2008) counts roughly 580,000 km of pipeline in Canada which includes the longest crude oil pipeline in the world (Figs 1, 2a). In 2007, crude oil and natural gas net exports were estimated at $41.5 (CND) and $24.3 billion, respectively. Since pipelines are thought to be the safest and most efficient means of transporting crude oil and natural gas, several new pipeline routes have been proposed, e.g., Yukon Alaska Highway Pipeline (YAHP) and Mackenzie Valley Pipeline (MVP; Fig. 2). When a pipeline is proposed, the National Energy Board (NEB) is charged with the responsibility of regulating the construction and operation of inter-provincial and international pipelines. In determining whether a pipeline project should proceed, the NEB reviews, among other things, its economic, technical and financial feasibility, and the environmental and socio-economic impact of the project. Under the Environmental Assessment Act, several factors are considered, such as, the types of environmental impacts, which include slope stability. The approval process may take several years (perhaps decades) before a pipeline project gets implemented. During the process, the NEB seeks geoscientific advice from the private sector as well as from Natural Resources Canada (NRCan) and other federal agencies.

The objectives of this paper are to present two examples of landslide susceptibility studies for existing and proposed pipelines, such as the MVP and the YAHP, and to discuss the federal government’s role in providing geoscience information.
2 LANDSLIDE SUSCEPTIBILITY MAPPING

2.1 Landslide susceptibility mapping for an existing pipeline, southern British Columbia.

Regional studies for landslide susceptibility, hazard and risk mapping are rare for pipeline networks in Canada (or at least not necessarily available to the public). However, one carried out by BGC Engineering Ltd. for an existing pipeline in southern British Columbia stands out (Leir et al. 2004). The purpose of the study was to identify slow, progressive subsurface deformation along a buried gas pipeline that could potentially result in leakage and affect 88 surrounding communities (see Fig. 2b, Terasen Gas pipeline). The main concerns in terms of types of subsurface deformations were earth and debris slides, earth and rock flows, and earth and rock creep.

Identifying the causal factors in their methodology, Leir et al. (2004) were restricted to those that were consistent across the region, such as bedrock type, surficial geology, slope angle, proximity to water bodies, and proximity to faults. A compilation of number and types of landslides was also carried out, but with some difficulty. Information on landslides was limited for two reasons. Information is not always transmitted to the public domain and landslides with extremely slow velocities (< 16 mm/yr) are not always identified. Because of the limited information available, a landslide inventory was used strictly as a guide for qualitatively calibrating the GIS model.

Once the data sets were defined, each class within the causal factors was subjectively scored based on expert knowledge. Following the data assembly, an algorithm was developed using fuzzy logic. The fuzzy logic approach was selected because it offered a probabilistic framework without the direct integration of a landslide database. This method is also considered an indirect method because it uses a statistical approach to predict landslide prone areas (van Westen et al. 2003).

To calibrate and validate their model, Leir et al. (2004) overlaid the landslide inventory information with 66% of the landslide points having a rating greater than the threshold at 0.54. Leir et al. (2004) considered their landslide susceptibility model successful as it predicted greater than 60% of the observed landslides falling above the threshold value (Guzzetti et al. 1999). Leir et al. (2004) further developed their susceptibility map by ranking the susceptibility rating for each community based on the proximity of the pipeline and number of cells with a high rating.
2.2 Landslide susceptibility mapping for the proposed Mackenzie Valley Pipeline project.

After more than 30 years of negotiations, public hearings, and environmental impact studies, the Mackenzie Valley natural gas Pipeline is scheduled to begin operations in 2011 (Mackenzie Gas Project 2004). One pilot study carried out by the Geological Survey of Canada (GSC, a branch of NRCan) was on landslide inventory and susceptibility for the northwest portion of the Mackenzie Valley Pipeline corridor (Riopel et al. 2006; Couture & Riopel 2008). The initiative’s main goals were to provide basic geoscience information and fill knowledge gaps in terms of landslides susceptibility, but also in assessing the potential influence of environmental factors on magnitude and frequency of landslides for the proposed pipeline corridor.

The study area comprised a 40 km wide corridor over a 540 km distance between Inuvik and Tulita (Fig. 4). The area is covered by unconsolidated sediments (99%) and encompasses three zones of permafrost (continuous, extensive discontinuous and intermediate discontinuous). The first part of the study was to compile the number and types of landslides from new and existing data. More than 1800 landslide events were characterized (Riopel et al. 2006; Couture & Riopel 2008). The most abundant types of landslides were retrogressive thaw flows (29%) and active layer detachments (26%). Less abundant were rock falls (10%), debris flows (10%), earth slides (9%), and retrogressive thaw slides (5%).

A qualitative parametric method was selected because of i) its flexibility to evaluate different datasets, ii) possibility to evaluate different data sets as individual parameters, iii) the ease at which one can combine the data sets, iv) opportunity to consult with several GSC scientists familiar with the area.

The parametric method was described in five steps (Fig. 5) and in detail in Riopel et al. (2006). In step 3, once the six raster layers were selected (land cover, slope angle, slope aspect, surficial geology, permafrost type, and permafrost ice content) the relative susceptibility to landsliding of each unit within those six layers was reclassified. The layers were either reclassified from their original units into three (low, moderate, or high) or five (very low, low, moderate, high, or very high) landslide susceptibility classes. The reclassification was based on the judgment of GSC scientists familiar with the terrain.

In step 4, ranks were assigned to the reclassified units for mathematical computations at the pixel level. The reclassified units of each layer were ranked to a common scale between 1 and 10. A standard class – rank association was applied for the six layers allowing a linear and homogeneous rank value distribution. The 5-class ranking system was given the values 1, 3, 5, 7, and 10 respectively for the classes very low (VL), low (L), moderate (M), high (H), and very high (VH), whereas, the 3-class ranking system was given the values 1, 5, and 10, for L, M, H respectively.

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relative importance in influencing terrain susceptibility to landsliding.

A parametric equation (Equation 1) was defined in which the six layers were the variables and weights were factors:

\[
SI = 0.3S_1 + 0.05S_2 + 0.30G + 0.05P_1 + 0.20P_2 + 0.10L
\]

The variables were: S1, slope angle; S2, slope aspect; G, surficial deposit; P1, permafrost type; P2, ice content; and L, soil type. Pixels of the factorised variables were spatially added (vertical integration) to obtain the susceptibility index (SI). The resulting susceptibility indices, values ranging from 1 to 10, were classified in three landslide susceptibility zones (low, moderate, and high), by grouping SI values 1 to 3 as low, 4 and 5 as moderate, and SI values from 6 to 10 as high to create the landslide susceptibility map.

The final step was to overlay the landslide inventory on the landslide susceptibility map. Results showed a good correlation between landslide occurrence and landslide susceptibility zones. The method was especially effective in identifying low and high zones of landslide susceptibility but less so for the moderate zone. Too many landslides (42%) fell into the moderate zone whereas they should likely have fallen into the high landslide susceptibility zone (Riopel et al. 2006; Couture & Riopel 2008).

2.3 Landslide susceptibility mapping for the proposed Yukon Alaska Highway Pipeline project

As part of the NRCan Program on securing Canadian energy supply, the GSC (e.g., authors) is involved in compiling landslide inventory and developing a method for landslide susceptibility mapping for the Canadian portion of Yukon Alaska Highway Pipeline project (Fig. 2). The GSC is working in collaboration with other federal and provincial government agencies as well as university scientists and the private sector to fill knowledge gaps in terms of slope stability information. The purpose of this project is to contribute to the environmental impact assessment and also to provide a “Best practices guide” to influence pipeline regulations and risk management. Presently, the project is at the preliminary stage of data compilation. Nevertheless, as with MVP, it is expected that one of the most obvious causal factors in triggering landslides in that region will be the potential environmental impacts on permafrost.

3 SLOPE STABILITY STUDIES FOR ENVIRONMENTAL ASSESSMENTS

Other types of slope stability studies for existing or proposed pipeline corridors in Canada have contributed to filling the knowledge gaps in terms of understanding slope processes, slope monitoring, and risk management. They have also contributed to the necessary environmental assessments related to the implementation of pipelines.

At the beginning of the MVP proposed project, McRoberts & Morgenstern (1973; 1974) and Code (1973) studied slope stability processes in permafrost terrain as well as provided landslide inventories. In later years, Aylsworth et al. (2000a, b; GSC) carried out an extensive landslide inventory and permafrost thaw sensitivity studies. In addition, for a proposed pipeline corridor in west central British Columbia, Geertsema et al. (2008) provided an inventory of catastrophic large landslides.

Moreover, slope monitoring studies along an existing pipeline in northeast British Columbia by Sladen & Dyke (2004) and Dyke & Sladen (2007) (GSC) identified the importance of slow slope movement on colluvial aprons in river valleys as well as the influence of pore pressure variations controlling slope movement.

Landslide risk management studies have also been carried out, but mainly in the private sector, not at the federal level. One example worth noting is by Leir & Reed (2002) where they developed a natural hazard database management tool to help pipeline decision-makers.

4 DISCUSSION AND CONCLUSIONS

When comparing the two landslide susceptibility methods, the one for southern British Columbia (Leir et al. 2004) has a more quantitative (fuzzy logic) approach than the one for the proposed MVP (Riopel et al. 2006; Couture & Riopel 2008). Both studies relied on expert judgement, which made the results somewhat subjective. However, both mentioned that their choice for the landslide susceptibility method was dependent on the initial availability and quality of the data. Both also mentioned how their approach could be improved by considering other causal factors.

Very few Canadian regional landslide susceptibility studies along pipeline corridors seem to be available to the public. This could reflect the fact that pipelines are privately owned and information is proprietary. However, other types of slope stability studies seem more available (e.g., slope monitoring, landslide inventory, and pipeline
risk management) in contributing to environmental assessments.

The National Energy Board of Canada is charged with the responsibility of regulating the construction and operation of inter-provincial and international pipelines. It will seek advice when necessary from NRCan (including GSC scientists) among other federal and provincial agencies during the Environmental Assessment. Working in conjunction with Environmental Assessment, NRCan has a mandate to secure Canadian energy supply. One of its activities is to fill knowledge gaps on slope stability issues along pipeline corridors in order to influence pipeline regulations and risk management. This knowledge is especially useful when NRCan is called upon to evaluate the environmental assessment of the project proponents.

REFERENCES


