Historical landslides in Canada resulting in fatalities (1771-2018)

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ABSTRACT
A map of historical Canadian landslides resulting in fatalities from 1771-2018 has been compiled using technical and scientific reports, newspaper articles, and provincial websites as sources of information. The map is regularly updated.

A total 774 people have perished in Canada historically because of landslides. British Columbia (BC) experienced the highest number fatalities at 339 (44%) and Québec (QC), the 2nd highest, at 246 (32%). These fatalities reflect the mountainous terrain in BC and sensitive glaciomarine clay areas in QC. Fatalities occurred in three other provinces and one territory: Newfoundland and Labrador (NL), 102 fatalities (13%); Alberta, 73 fatalities (9%); Ontario, 13 fatalities (2%); and Northwest Territories, 1 fatality (0.1%). The lack of fatalities in the other provinces and territories are likely related to less population and infrastructure development and fewer landslide occurrences due to physiographic conditions less prone to landslide activity.

The worst Canadian landslide disaster occurred in 1903 at Frank, Alberta, where 73 people perished from a rock avalanche that partly buried a mining town. In the sensitive clay areas of the St. Lawrence Lowlands, QC, 25 landslides caused 134 fatalities. In 1908, the village of Notre-Dame-de-la-Salettte along the Lièvre River experienced a landslide and displacement wave that resulted in 34 people perishing. In the rugged Appalachian hills of NL, rockfalls are the main cause of fatal landslides.

The greatest number of landslides and associated fatalities occurred during the 1880s to 1920s when major infrastructure corridors and cities were being developed and landslide hazards were poorly understood. Since the 1920s, a greater understanding of landslides and their potential triggers has led to mitigation measures and thus fewer fatalities per decade and per event.

RÉSUMÉ
Une carte des glissements de terrain historiques canadiens ayant causé des décès de 1771-2018 a été compilée. Cette dernière est mise à jour régulièrement en se basant sur les rapports techniques et scientifiques, les articles de journaux et les sites Web provinciaux disponibles comme sources d'information. Notre compilation a révélé que 774 personnes ont péri au Canada depuis 1771. La Colombie-Britannique (C.-B.) possède le plus grand nombre de décès à 339 (44 %). Le 2e plus élevé est le Québec (Qc) au taux de 246 (32 %) personnes. Ces décès sont dus à des glissements de terrain déclenchés surtout en montagnes en C.-B. et dans les argiles sensibles glaciomarines au Québec. Les autres décès canadiens sont survenus dans trois autres provinces et un territoire, soit : Terre-Neuve et Labrador (TN-L), 102 décès (13 %); Alberta, 73 décès (9 %); Ontario, 13 décès (2 %) et Territoires-du-Nord-Ouest, 1 décès (0,1 %). L'absence de décès dans les autres provinces et territoires est vraisemblablement liée à une plus faible population, un plus bas taux de développement et une physiographie moins susceptible aux glissements de terrain.

La pire catastrophe canadienne liée à un glissement de terrain a eu lieu en 1903 à Frank (Alberta), où 73 personnes ont péri due à une avalanche rocheuse qui a enseveli une partie de cette ville minière. Dans les basses-terres du Saint-Laurent, Qc, 25 glissements de terrain historiques ont causé 134 décès. En 1908, Notre-Dame-de-la-Salettte a été témoin d'un glissement de terrain suivi d'une vague de déplacement où 34 personnes ont péri. Dans les collines accidentées appalachiennes de TN-L, les chutes de pierres sont la principale cause d'éboulements mortels.

Le plus grand nombre de décès associés aux glissements de terrain est survenu entre les années 1880 et 1920, alors que de grands corridors d'infrastructures et des villes étaient en développement, mais les risques étaient moins bien compris. Bref, depuis les années 1920, l'étude des glissements de terrain et de leurs facteurs déclencheurs potentiels a mené à plusieurs mesures d'atténuation et à moins de décès par décennie et par événement.

1 INTRODUCTION

As part of the Natural Resources Canada's Public Safety Geoscience Program within the Geological Survey of Canada, a database of the historical landslides that resulted in fatalities from 1771-2018 has been compiled and mapped on the Canadian physiographic regions (Bostock 2014). A previous version was published by Blais-Stevens et al. (2015). The version discussed in this paper

dates to 2018 (Blais-Stevens et al. 2018a and b; Figure 1), but still requires updating as two more events took place in 2018.

Two decades ago, Evans (1999) published a Canadian landslide disasters map from 1840-1998, which included historical events with three or more casualties. In addition to being updated, the new map compilation has been expanded to include events with one to two fatalities and associated table of events. Landslides that triggered tsunamis or displacement waves that caused fatalities are now also included (Blais-Stevens et al. 2018a and b).

This paper provides an overview of landslides in Canada that have resulted in fatalities between 1771-2018 by province and territory including physiographic region, by decade, and by landslide type. A brief description of some of the disastrous events is presented.

The objective of the mapping project was to raise awareness of historical Canadian landslide fatalities to stakeholders and decision-makers.

2 METHODOLOGY

The starting point to the database compilation was the Evans (1999) Canadian landslides disasters map. Moreover, provincial government websites as well as internet searches provided well-documented references. Scientific and technical reports also provided detailed information. Colleagues studying landslides, who reviewed preliminary versions of the map and associated table, provided additional information.

In some reported landslide cases, there is only an approximate location recorded for the event. It was mapped and labeled as such. Moreover, the descriptions of events may be short and rather general. Therefore, some interpretation was needed. Where the reported information on the slope process or type of failed material was not detailed enough, the event was labeled with the term “landslide” in the generic sense.

The fatal landslide events were mapped using ArcGIS v.10.1 on a Digital Elevation Model (DEM) of the Canadian landmass at a 1:6,000,000 scale, overlain on the physiographic regions (Bostock 2014).

3 RESULTS AND DISCUSSIONS

3.1 Fatal landslides per province or territory

At the time of writing, there have been 774 landslide fatalities in Canada between 1771-2018 (Figure 2). British Columbia with its mountainous terrain experienced the highest number of fatalities at 339 (44%). Québec has the 2nd highest at 246 (32%). Sensitive glaciomarine clay failures in the St. Lawrence Lowlands are responsible for 25 fatal landslides and 134 fatalities in Québec. Landslide fatalities occurred in three other provinces and one territory. The 3rd highest number occurred in Newfoundland and Labrador’s rugged Appalachian terrain at 102 fatalities (13%), mainly due to rockfalls. All 73 fatalities in Alberta perished in a single catastrophic landslide, the Frank slide, which is Canada’s worst landslide disaster (see Section 3.5.1). Ontario experienced 13 fatalities (2%); caused by landslides, mainly from railway embankment failures. The Northwest Territories witnessed one (0.1%) fatality at Fort Smith due to a landslide triggered in sediment by erosion along the along the Slave River (Figure 2).

The other provinces and territories with no reported fatal landslides likely reflect less population, less infrastructure development and physiographic conditions less susceptible to slope failure.

3.2 Number of landslides and fatalities by landslide type

There were 21 different terms used out of the 157 slope failures that were responsible for the 774 fatalities. Some terms in the information sources are informal, but they are those often used in newspapers (e.g., shifting soil for a debris slide; Figure 3). ”Landslide”, in a generic sense, is also used frequently in reports as mentioned above. This category has a high number of events and fatalities at 34 and 117, respectively (Figure 3). In many cases, there is uncertainty in the nature of the failed material when the term landslide is used.

Four rock avalanches caused the highest number of fatalities in Canada (=135) in BC and Alberta. Slope failures triggered in bedrock such as rockfalls, rock slides, rock avalanches, collectively represent the highest number of events and fatalities at 46 and 316, respectively. Of these events, two catastrophic rock slides took place in Québec City in the 1880s wiping out dwellings and killing a total of 82 people. In addition, Newfoundland and BC’s rugged coastline have witnessed several bedrock triggered fatal landslides, many as rockfalls or rock slides (Blais-Stevens et al., 2018 a, and b).

Furthermore, debris flows occurring on BC’s steep mountainous river channels have been responsible for 22 fatal landslide events out of 23. A total of 96 people perished because of debris flows triggered during periods of heavy rains mainly in the fall and winter. One fatal event happened in a Québec mine in 1946 resulting in one fatality.

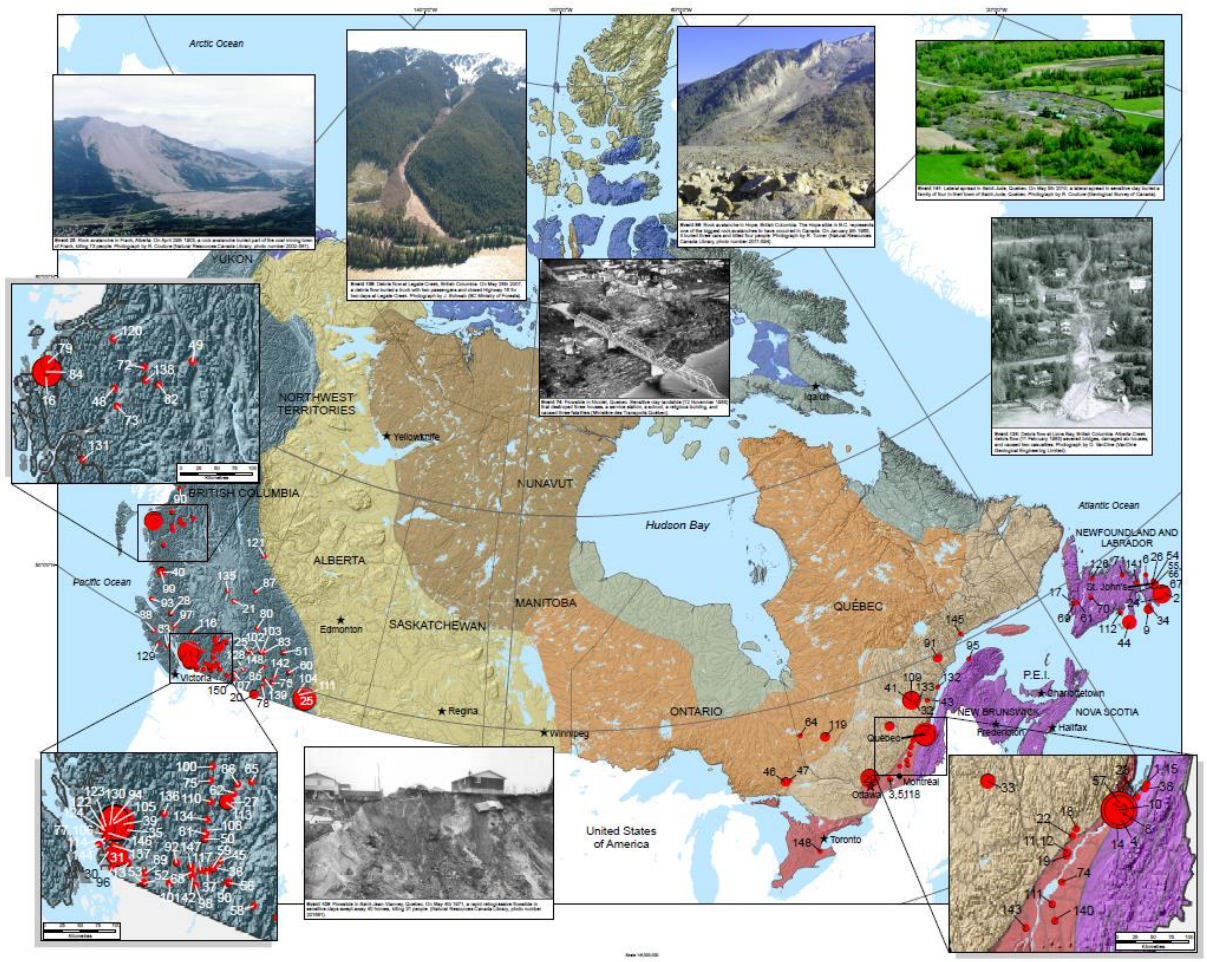

Figure 1. The historical fatal landslides in Canada between 1771-2018 map (Blais-Stevens et al. 2018 a and b). The Geological Survey of Canada Open File map 8392 (English) and 8391 (French) also include a table of events (not shown) in chronological order.

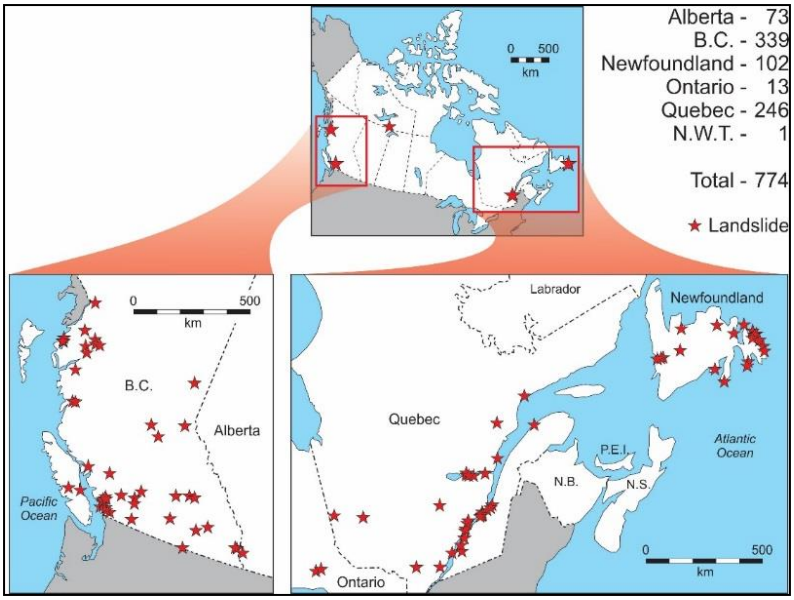

Figure 2. Total number of landslides that have resulted in fatalities in Canada from 1771-2018 per province and territory. No fatal events have been reported for the other provinces and territories. Red stars indicate landslide distribution.

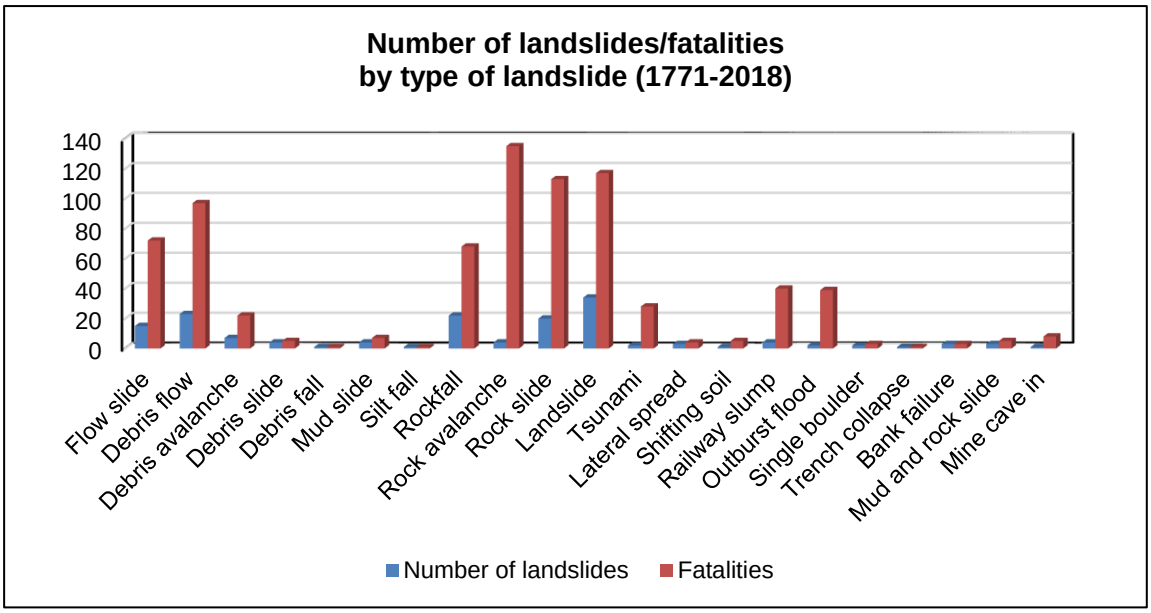

Figure 3. Number of landslides (blue columns; N= 157) and fatalities (red columns; N=774) in Canada from 1771-2018.

3.3 Number of landslides and fatalities per decade

The number of landslide events is plotted by decade on Figure 4. From the 1770s, there was a steady increase in fatal landslide events until the 1960s after which there was a steady decrease until the 2010s. The steady increase is likely the result of increasing infrastructure development, expansion of settled areas and increasing population. With time, understanding of landslide hazards also improved, which helped the development of mitigation measures in high risk zones (e.g., Sea-to-Sky highway; Blais-Stevens and Hungr 2008). The 2010s have experienced an increase in fatal landslides similar to those of the late 1800s and early 1900s. The number of fatalities per landslides, however, is far lower with the 2010 events (Figures 4 and 5).

A histogram of the number of landslide fatalities plotted per decade is shown on Figure 5, which shows that the number of fatalities for the 1900s was especially high. This decade is strongly skewed by the 73 fatalities of the 1903 Frank slide, Alberta, which is Canada's worst landslide disaster. (See section 3.5.1).

The number of fatalities per decade was elevated from 1880s to 1920s at more than 50 fatalities per decade. Similarly, the 1960s and 1970s experienced more than 50 fatalities each. The 1960s saw 21 events with 57 fatalities and the 1970s, 12 events with 54 fatalities. After the 1920s, there was only one very large catastrophe where more than nine people perished in one landslide event. This occurred in 1971 in Saint-Jean-Vianney (discussed in Section 3.5.5.). It is thought that a better understanding of landslide triggers, i.e., recognizing the hazards and risk and developing associated mitigation measures has contributed to the decreased numbers since the 1970s.

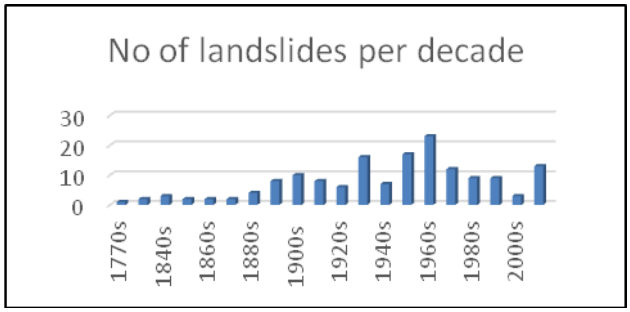

Figure 4. Number of fatal landslide events per decade (N=151) since 1771.

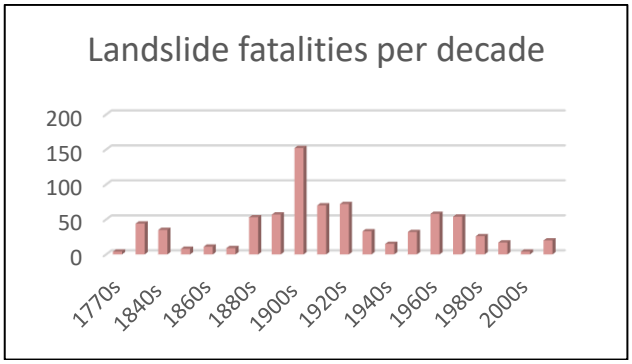

Figure 5. Landslide fatalities per decade (1771-2018; N=774).

3.4 Number of landslides and fatalities per month

A histogram of the number of fatalities and landslides per month shows that the summer months, June to August, have fewer fatal landslides. Fall, winter and spring months

show a relatively steady number of fatal landslides that average about 14 events. This is likely due to climate related factors that cause slope instability, such as freeze-thaw cycles, periods of increased precipitation in the fall and spring, and snow melt in the spring.

Figure 6 shows that there were fewer fatalities in the winter months and in June and August. In winter months, the ground is frozen in most of Canada and there is less construction activity. Higher numbers of fatalities are observed in the spring and fall months and in July. The month with the greatest number of fatalities is April where two catastrophes took place (Frank and Notre-Dame-de la Salette).

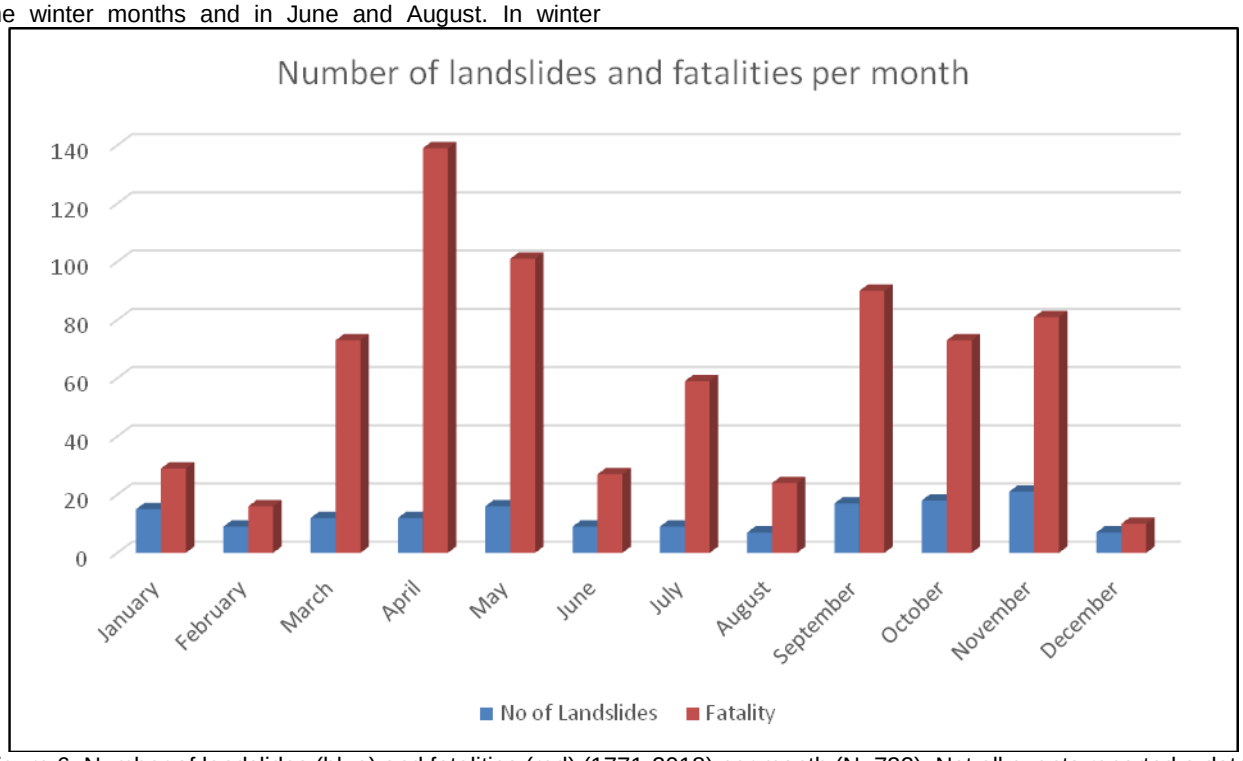

Figure 6. Number of landslides (blue) and fatalities (red) (1771-2018) per month (N=722). Not all events reported a date.

3.5 Notable disasters

3.5.1 Frank Slide, April 29, 1903

This event is the worst Canadian landslide disaster and resulted in 73 fatalities after a rock avalanche destroyed part of the mining town of Frank, Alberta, on April 29, 1903. This rock avalanche was triggered on the north peak of Turtle Mountain, located close to the BC border (Figures 1 and 7). The landslide volume was 30M m^3. It is thought that the triggers were weakness in bedrock structure (anticline) of Mesozoic coal-bearing, sedimentary rocks, freeze-thaw cycles, and mining activity. As mentioned above, this is Alberta's only fatal landslide. At present, the south peak (Figure 7) is being monitored as it has shown signs of slope deformation (Froese et al. 2009).

3.5.2 Jane Camp, March 23 1915

Canada's second worst landslide disaster occurred on March 23, 1915, killing 54 people at Jane Camp of the Britannia copper mine, southwestern BC (Blais-Stevens and Septer 2008).

The landslide was triggered in the middle of the night as a rock avalanche that developed into a debris flow as it traveled down slope and hit the bunkers of Jane Camp, where women and children were sleeping. The volume was about 100,000 m^3. It is believed the landslide was triggered by repetitive freeze-thaw cycles and blasting due to mining activity (Figure 8).

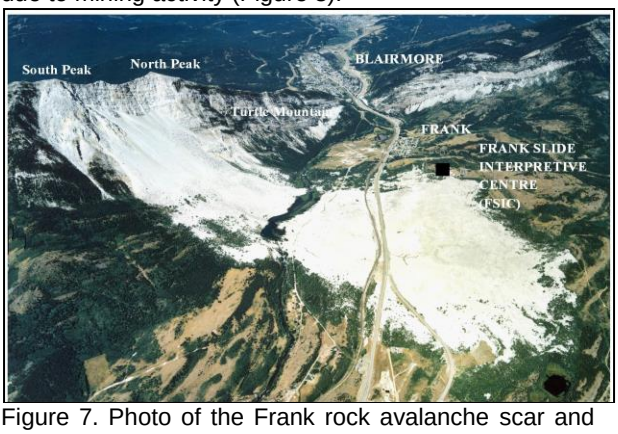

Figure 7. Photo of the Frank rock avalanche scar and deposit showing the north and south peaks at the top of Turtle Mountain. The road across the deposit is the Trans-Canada highway.

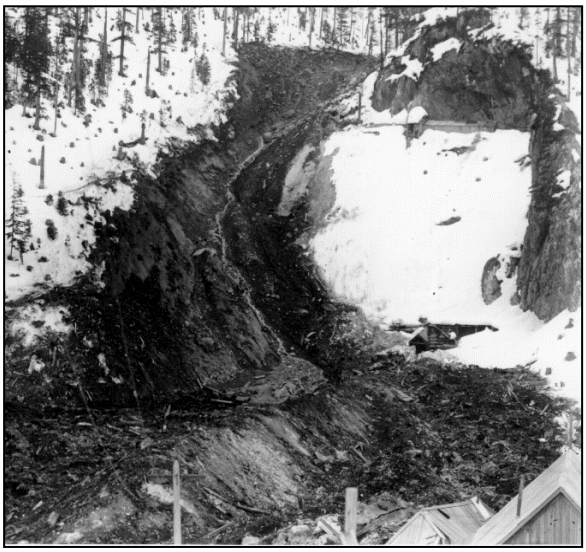

Figure 8. Photo of the head scarp of Jane Camp landslide, which took place in March 1915 and caused 54 fatalities (Photo: Vancouver Public Library).

3.5.3 Sea-to-Sky corridor, southwest BC

Jane camp is considered part of the Sea-to-Sky corridor (Blais-Stevens and Septer 2008). Since 1915, this corridor has experienced 111 fatalities due to 11 fatal events including rockfalls, rock slides and avalanches, landslide dam outburst flood, and debris flows (Blais-Stevens and Septer 2008). Several mitigation measures have been undertaken to stabilize the slopes and steep streams along the highway since the 1980s (Blais-Stevens and Hungr 2008), and especially for widening of the highway for the 2010 Winter Olympics (Sea-to-Sky Highway Improvement project 2004). Some of the mitigation measures carried out are: shot crete or wire mesh covering steep slopes, drainage pipes at the base of slopes, replacing wood trestle bridges with ones made of steel and moving them farther away from the steep slopes, highway status broadcasting system, 24-hour road patrols, BC Ministry of Transportation adopted a rock fall hazard rating system, concrete debris basins and shooting channels controling stream flow and debris along Howe Sound among others (Blais-Stevens and Hungr, 2008).

3.5.4 Notre-Dame-de-la-Salette, QC, April 1908

This fatal landslide event is the worst landslide disaster in Québec in sensitive glaciomarine clays within the St. Lawrence Lowland's Champlain Sea sediments.

The event took place in the middle of the night on April 26, 1908, when a slope failure was triggered by bank erosion along the Lièvre River bank during high spring run-off. The rapidly moving landslide displaced river water and generated a large wave that carried blocks of ice into the village of Notre-Dame-de-la-Salette on the opposite side of the river. The ice and water catastrophically destroyed more than 20 buildings (Figure 9). Thirty-four people died during this event (Réseau du patrimoine 2018).

3.5.5 Saint-Jean-Vianney, QC, May 1971

This event took place in the middle of the night on May 5, 1971, along the Saguenay Valley because of a failure of sensitive glaciomarine clay deposits (Figure 10). Thirty-one people perished as the landslide engulfed 42 houses. It is thought that the landslide was triggered by heavy rains.

Soon after, it was discovered that this landslide occurred within the scar of a very large landslide (Tavenas et al. 1971). This older landslide is believed to have been triggered by the AD1663 M7 Charlevoix earthquake (Locat 2008).

Figure 9. Destroyed houses due to a landslide and displacement wave (April 1908) in Notre-Dame-de-la Salette, QC, located roughly 40 km north of Ottawa (Photo: GSC Library).

Figure 10. Photo of the back scarp area of the Saint-Jean-Vianney landslide, which engulfed more than 40 houses (Photo: GSC Library).

3.5.6 Harbour Breton, Newfoundland, August 1973

This debris slide/torrent occurred in Harbour Breton, southern Newfoundland on August 1st, 1973 after several weeks of heavy rains. It took place in the middle of the night, sweeping four houses into the harbour situated along the shoreline. Four children from the same family perished.

Notably, this site experienced a landslide in 1953, but there were no houses at that time (Department

of Natural Resources of Newfoundland and Labrador 2018).

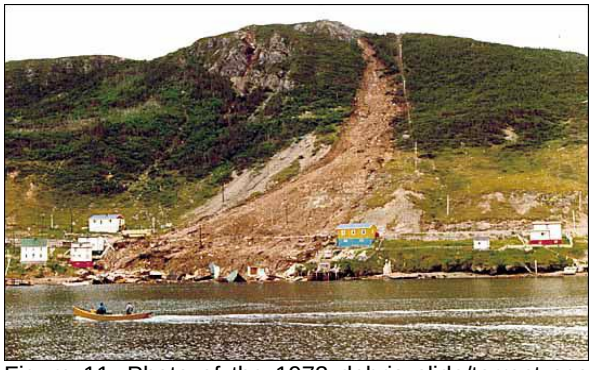

Figure 11. Photo of the 1973 debris slide/torrent scar Harbour Breton, NFLD that destroyed four houses and killed four children. (Photo: M. Batterson).

4 CONCLUSIONS

From 1771 to 2018, there were 774 reported historical landslide fatalities in Canada. Certain physiographic regions are more prone to landslide activity, especially mountainous terrain of BC, and the sensitive clay areas in the St-Lawrence Lowlands, Quebec. British Columbia experienced 339 fatal landslide fatalities, Québec, 246, Newfoundland and Labrador, 102, Alberta 73, Ontario, 13, and Northwest Territories, 1. The lack of fatalities in the other provinces and territories likely relates to less population and infrastructure development and fewer landslide occurrences due to physiographic conditions less prone to landslide activity.

The most important landslide triggers are described as heavy precipitation, freeze-thaw cycles, river erosion during spring thaw, and earthquakes. These are often combined with construction or mining activities such as blasting.

Over time, mitigation has decreased the number of landslide fatalities because of a better understanding of landslide hazards and processes. Nowadays, when there is a fatal landslide, the number of fatalities is usually much lower than it was in the late 1800s to early 1900s.

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