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SOCIO-ECONOMIC SIGNIFICANCE

Canadian Technical Guidelines and Best Practices related to Landslides: a national initiative for loss reduction

R. Guthrie

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Note to Reader

This is the eighth in a series of Geological Survey of Canada Open Files that will be published over the year. The series forms the basis of the *Canadian Technical Guidelines and Best Practices related to Landslides: a national initiative for loss reduction*. Once all Open Files have been published, they will be compiled, updated and published as a GSC Bulletin. The intent is to have each Open File in the series correspond to a chapter in the Bulletin.

Comments on this Open File or any of the Open Files in this series should be sent before the end of March 2013 to Dr. P. Bobrowsky at pbobrows@NRCan.gc.ca

1. INTRODUCTION

Landslides can result from either natural processes or anthropogenic activity, but their socio-economic significance is typically the result of a human-landslide interface. The socio-economic significance of landslides in Canada is a function of the country's unique geographical landscape. At 9.98 million km^2, Canada is the world's second largest country by area; yet with only 34.8 million people, it ranks 37th in global population and 224th by population density (Statistics Canada, 2012). Canada is largely a hinterland, rich in resources, but with few people. Eight of ten of the country's major cities lie and the majority of Canadians reside, within 160 km of the US border (Figure 1).

Canadians are connected to one another by an extensive infrastructure network of roads, rails, pipelines, telecommunication and power lines that are the lifeblood of the country. The network is vast; it is 7314 km between St. John's, Newfoundland on the east coast, and Victoria, British Columbia on the west coast. Transporting goods and resources to cities and ports is a unique challenge in an affluent country that supports a low tax base per unit area. Landslides not only threaten lives, but the infrastructure upon which Canadians rely.

Canada's settlement patterns mimic its physiographic regions (Figure 2). Most Canadians live in the St. Lawrence Lowlands. But the southern part of the Canadian Cordilleran is also highly settled, as are the southern parts of the Interior Plains. The rest of Canada, comprising the northern Canadian Cordillera, the northern Interior Plains, the Canadian Shield, the Appalachian Mountains, the Arctic Lowlands and the Inuittian Mountains support lower population densities. Population densities are illustrated in Figure 1.

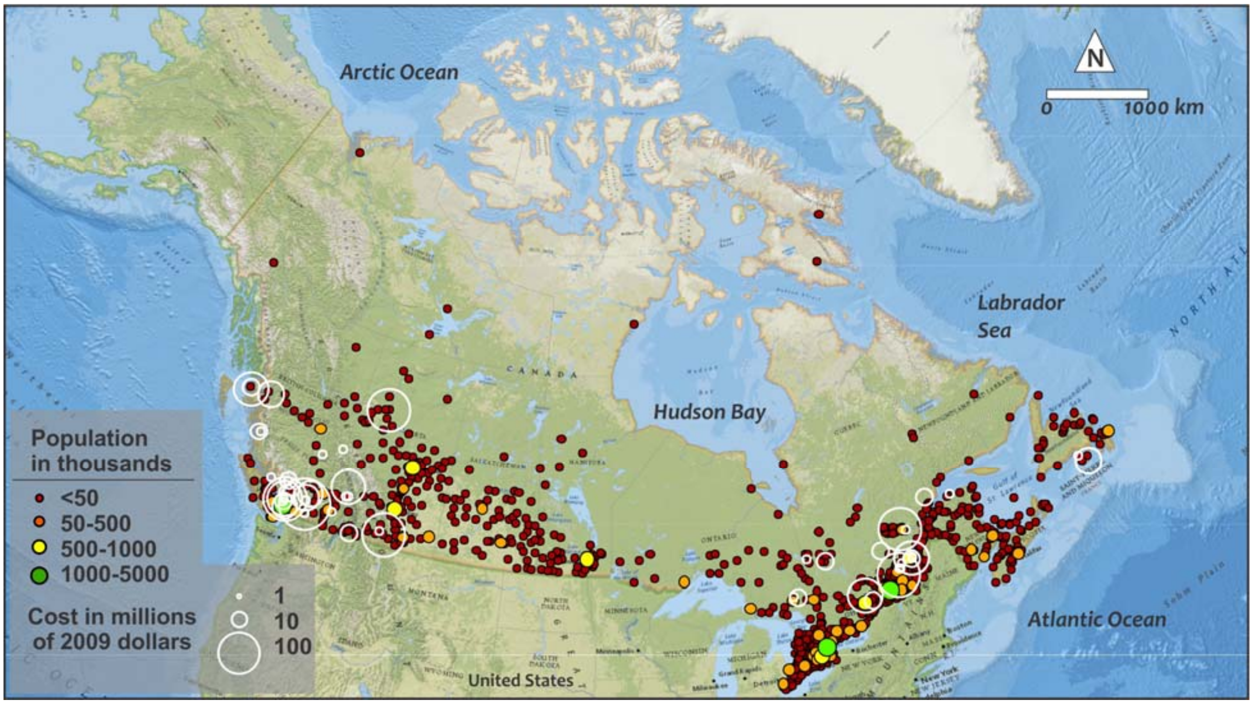

Figure 1. Population distribution (2000) and damaging landslides in Canada (1841-2010). Open circles represent major historic landslides and their approximate costs. Costs are largely direct (loss of lives, infrastructure and measurable resources), but may include some indirect costs. See Table 4 for specific details and references.

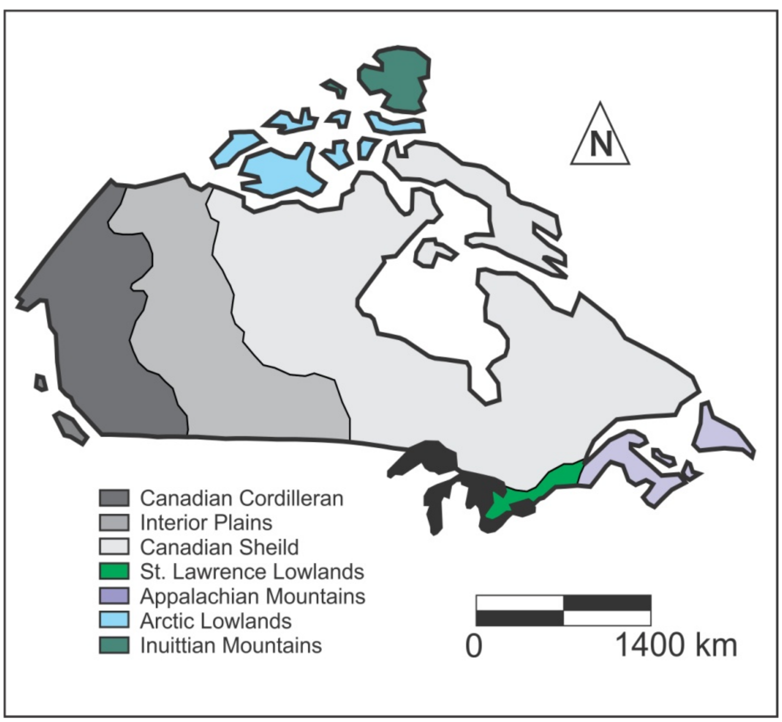

Figure 2. Major physiographic regions of Canada (Bostock, 1967).

Whereas landslides occur in all physiographic regions, the Canadian Cordilleran and the St. Lawrence Lowlands are especially prone to landslides. In addition these two physiographic regions contain the largest cities and greatest population densities. Even so, the vast majority of landslides in Canada have little effect on people and their built environment.

The socio-economic significance of landslides considers both direct and indirect costs. Direct costs include injury or loss of life, damage to infrastructure and property, and the loss of resources, and are relatively straightforward to calculate and quantify. Indirect costs include items such as lost wages, added costs for redirecting traffic, and so on and although just as important as direct costs, are much more difficult to calculate and quantify. For example, a landslide that buries a stream may immediately destroy fish and fish habitat – a measurable direct cost. But the fish habitat may be lost for many years, and a slow recovery can affect fish stocks for decades. If the river is an important fish habitat, the indirect costs of the suppressed fishery industry could exceed the direct costs. Such are the challenges when estimating the cost significance of landslides.

A further complicating measure of socio-economic significance is the scale of the landslides themselves. Landslides can occur catastrophically and completely overwhelm the geomorphic system in which they occur (Guthrie and Evans, 2007), or they can be relatively small and are simply part of the background "noise" of a geomorphic system. Whereas catastrophic landslides can have devastating effect, the deaths of 76 persons in the 30 Mm^3 Frank Slide for example, such landslides occur relatively infrequently. Small landslides occur with much more regularity, often thousands each year, and depending on their location, can be equally as devastating.

This contribution first discusses landslides in the context of geological hazards, followed by the socio-economic significance of landslides worldwide. It then presents the socio-economic significance of landslides in Canada by physiographic region and by industry sector, and finally summarizes 56 notable landslides that have occurred between 1841 and 2012.

2. LANDSLIDES AND GEOLOGICAL HAZARDS

Landslides are part of a family of geological hazards that affect every continent. Geological hazards include: earthquakes, tsunamis, volcanoes, floods (including glacial lake outburst floods and floods related to ice jam and landslide dam failures), surface erosion, subsidence, and landslides.

Whereas global awareness of geological hazards, and especially their associated disasters, has increased dramatically in recent years, the challenges to fully understand the socio-economic significance of such hazards and disasters remain. The monetary cost of geological hazards tends to be concentrated in industrialized and developed countries because of the relative concentration of wealth (Table 1). In terms of numbers of displaced or affected persons, however, geological hazards and the associated disasters are most severe in densely populated less developed countries (Table 1). Note in Table 1, that Canada is only represented in the left-hand column and is 19/20 with respect to direct and indirect costs.

Table 1. Top 20 countries affected by geological disasters for the period 1900-2009 by direct and indirect costs (in billions of $CAD) (left columns) and by number of individuals killed or presumed killed (right column) (from Guthrie, 2013 and EM-DAT, 2010).

Country	**Cost (billions of $CAD**	**Country**	**Persons killed & presumed killed**
United States	556	China	11,148,689
China	322	Former Soviet Union	6,368,439
Japan	213	India	4,570,345
Italy	67	Bangladesh	2,588,666
India	49	Korea	611,875
Korea	39	Ethiopia	404,456
Germany	35	Indonesia	235,555
France	33	Japan	221,699
Australia	29	Pakistan	169,777
United Kingdom	29	Iran	155,495
Spain	26	Sudan	150,785
Mexico	26	Myanmar	145,687
Turkey	25	Italy	140,049
Indonesia	23	Mozambique	102,768
Iran	21	Turkey	90,754
Former Soviet Union	21	Niger	85,132
Taiwan	20	Cape Verde Is	85,035
Bangladesh	18	Peru	84,195
Canada	17	Guatemala	83,083
Brazil	13	Chile	60,619

Highlighted countries are in both columns.

2.1 Landslides around the World

Landslides occur on every continent but are historically under-reported in remote, sparsely-populated areas or in less developed countries where such events are frequently grouped with other natural hazards such as floods, earthquakes and volcanoes (Petley, 2012). Nevertheless, generalizations can be made regarding the requisite conditions for wide-spread landslides.

Convergent fault boundaries tend to produce complex geology, steep mountainous terrain, active seismicity and volcanism. The Asia-Pacific region combines the features of convergent fault boundaries coupled with intense and high rainfall (e.g. typhoons) to produce landscape conditions particularly susceptible to landslides. Countries, including China, Taiwan, India and Indonesia are amongst the most frequently affected countries by landslides in the world (see Nadim et al., 2006).

North and South America are bound along their western edge by the Cordillera, ranges of mountains formed by the subduction of the Pacific plate beneath the North American and Nazca plates, respectively. Landslides occur within these steep rugged ranges, further exacerbated by moist air flowing off the Pacific Ocean and falling as snow or rain.

In Europe, the high mountains of the Alps and Caucuses form conditions for landslides that are similar to those in the North and South American Cordillera.

Landslide disasters have taken lives, and resulted in untold injuries and massive economic losses worldwide. Records of landslide disasters date back to at least 373 BC with the total loss of the population in the town of Helice, Greece (Seed, 1968).

As noted elsewhere, landslides are commonly undercounted because they tend occur in conjunction with other natural hazards such as earthquakes, volcanoes and floods. For example, in 1556, in the Shanxi province of China, an earthquake was reported with a death toll of ~830,000 (Gu, 1989). Many of those deaths resulted directly from landslides, massive debris flows in unstable loess deposits, but have not been reported as such. Volcanic debris flows (lahars) can extend many kilometres beyond the blast of a volcano, and threaten lives and property. The deaths in the Colombia volcanic disaster of 1985 (21,800) are largely attributable to the lahars associated with the event (Evans, 2006). Floods are especially linked to, and often confused with, landslides. High amounts of, or intense, rainfall produces both floods and landslides that can blend as part of a continuum depending on the concentration of sediment in the flow. In addition, floods can result from the failure of landslide dammed lakes, often to devastating effect. For example, in 1786, a landslide dam burst on the Dadu River in the Sichuan province of China causing flooding as far as 1,400 km downstream which in turn resulted in approximately 100,000 deaths (Shuster and Wieczorek, 2002).

The distribution of landslide disasters relates to both their proximity to people and the population density. Consider the contrast, for example, between North and South America; in Canada the population density within the Canadian Cordilleran is approximately 4 persons/km^2, whereas within the Peruvian Andes the population density is approximately 23 persons/km^2. Not surprisingly, landslide-related disasters have greater significance in Peru.

Two of the most well-known landslide disasters began in the Huascarán Mountains in the Yungay province of Peru in 1962 and again in 1970. Both events began as rock/ice falls and transformed into high velocity (up to 85 m/s in 1970) debris flows (which continued downstream for 180 km in 1970). About 7,000 people were killed during the two events (Evans et al., 2009).

Worldwide, deaths due to landslides represent only a small number of the reported deaths from geological hazards (Table 2).

Table 2. Top 21 countries by number of reported deaths or presumed deaths from landslides and all geological hazards for the period 1900 – 2009 (EM-DAT, 2010).

Country	Reported deaths or presumed deaths		Approximate % of deaths by landslides
	from landslides	from all geological disasters	
Former Soviet Union	12,427	6,368,439	<1
Peru	10,454	84,195	12
India	4,843	4,570,345	<1
China	3,532	11,148,689	<1
Colombia	2,988	31,747	9
Honduras	2,810	28,188	10
Philippines	2,696	55,499	5
Italy	2,585	140,049	2
Indonesia	2,250	235,555	1
Nepal	1,738	17,890	10
Ecuador	1,099	13,374	8
Japan	1,002	221,699	<1
Turkey	680	90,754	1
Pakistan	627	169,777	<1
United States	615	41,037	1
Papua New Guinea	520	6,653	8
Russia	463	5,279	9
Tajikistan	368	1,898	19
South Korea	346	8,619	4
Viet Nam	330	24,340	1
Canada	305	1,287	24

Countries in which landslides have resulted in >5% of deaths from all geological hazards are highlighted.

In Canada, landslide deaths account for approximately 24% of the total deaths from geological hazards, the largest percentage of any of the 21 countries listed. This is a result of population concentration in the two most landslide prone regions of the country, and the low population densities that limit not only the effect of landslides, but of all geological hazards.

Smaller landslides can also be significant. For example, the small landslides caused by earthquakes, such as the 1994 Northridge Earthquake in the United States, or by precipitation, hurricanes and extreme storms, such as the 1999 storms that caused hundreds of debris flows and debris floods near Caracas, Venezuela. In Canada, landslides associated with storms can be widespread and destructive (Guthrie et al., 2010). Indeed the risk from rock fall is most acute for small (10 m^3) events (Hungr et al. 1999).

2.2 Landslides in Canada

Canada can be divided into seven major physiographic regions (Figure 2) and landslides occur to some extent in each region. Northern Canada, including portions of the Canadian Cordilleran, Interior Plains and Canadian Shield, is subject to instability as a result of melting permafrost, either naturally or exacerbated by human settlement and industry. Including alpine regions, permafrost underlies almost half of Canada. As climate warms, the landslide hazard associated with the perennially thawing portions of permafrost will increase. Rocky slopes in the Canadian Shield and the Appalachian Mountains are prone to rock fall and toppling that can impact people and infrastructure. The east coast is, in addition, subject to landslides in marine clays. Coastlines on both sides of the country are affected by landslides when storm-induced waves undercut post-glacial sediments. River valleys throughout much of Canada, but especially the Interior Plains and the St. Lawrence Lowlands, widen by successive landslides occurring along their banks.

The greatest landslide hazards occur in the Canadian Cordilleran and the St. Lawrence Lowlands. In addition, as discussed in Section 1, both regions intersect Canada's highest population densities (Figure 1). The following sections consider the properties of both regions more closely. Hungr and Locat (in preparation) further discuss examples of common Canadian landslide types in all the physiographic regions.

2.2.1 Canadian Cordilleran

The Canadian Cordillera (Figure 2) comprises most of British Columbia and the Yukon Territory and represents in excess of 1.5 million km^2 of steep hazardous terrain (Clague, 1989). The Canadian Cordillera formed over millions of years as a series of crustal fragments called terranes, which accreted to the North American lithospheric plate. As with convergent zones elsewhere, this activity caused the uplift of parallel mountain chains. Associated volcanism along the continental margin further resulted in mountain building. Quaternary glaciations deepened and steepened mountain valleys, and the retreat of glacial left behind over steepened, unstable slopes. From the highest peaks to the west coast fjords, from the incised glacial deposits of the interior plateaus to the permafrost-supported landscapes in the north, landslides are common in the Canadian Cordillera.

Slide or flow-like movements occur throughout the Canadian Cordillera, triggered by rain, melting snow and less frequently by seismic activity. Landslides can also occur with little or no perceptible trigger as the result of ongoing weathering and erosion under the harsh mountain conditions. Such landslides frequently block roads, affect fisheries and waterways, dam streams, and isolate communities. As debris flows or debris slides they can extend the hazard farther downstream to alluvial fans where they can affect communities.

Bedrock falls and topples triggered by freeze-thaw, precipitation or seismic activity are common in high relief areas throughout the Canadian Cordillera, and frequently disrupt road and rail traffic as well as take human lives.

Rotational slides often occur in areas with deep Quaternary sediments. Large deep-seated failures in bedrock are less common, but still important. For instance, mitigation of the Downie Slide, a slow rock slide in the Columbia River Valley has cost more than $52 million (Piteau et al., 1978; Cruden et al., 1989).

Historical landslides in the Canadian Cordillera range in volume from less than 1 m^3 to almost 50 M m^3. Guthrie and Evans (2007) determined that moderate volume (ca. 10,000 m^3) flow-type landslides on the west coast affected the landscape the most, and that the average volume event was even smaller (ca. 3,000 m^3). Hungr et al. (1999) determined that along major transportation corridors in the region, the greatest threat to life came from rock falls of about 10 m^3. Both of these studies demonstrate the important coupling of landslide frequency and volume. Smaller landslides occur much more frequently than large ones. Although small individual landslides occupy less physical space, taken together they are a pervasive and substantial threat to life, the environment and infrastructure. Larger landslides in contrast, while exceedingly dangerous, occur infrequently. Nevertheless, when large landslides interact with humans, the results can be devastating. For example, the 1903 rock fall-debris flow that buried the town of Frank, Alberta, killing 76, and the 1915 Jane Camp rock fall-debris flow, near Britannia Beach, British Columbia, that buried a mining camp and killed 56 people.

2.2.2 St. Lawrence Lowlands

The Saint Lawrence Lowlands (Figure 2) is a small region centered on the Saint Lawrence River Valley, underlain by gently dipping rocks that form a deceptively benign terrain. The glacial history of the Saint Lawrence Lowlands, however, includes the formation of several glacial lakes, and the inland Champlain Sea. The sensitive glaciomarine clay deposited in the Champlain Sea throughout this region has resulted in some of the worst landslide disasters in Canadian history, including the the Nicolet landslide in 1955 and St. Jean-Vianney landslide in 1971. Although the region is dominated by glaciomarine slides, three rock falls in a densely populated area of Quebec City in the 1800s (1841, 1852 and 1889) also had devastating effects (Occhietti, 1989; Evans, 2001, 2003).

2.2.3 Landslide Significance by Sector

A complete accounting of the significance of landslides to Canadian industry is impossible to achieve. The burden is borne by many organizations across many industries. Direct costs are often imprecisely recorded, and like many areas world-wide, costs may not be differentiated between the damage from landslides and related geological hazards. As previously discussed, indirect costs are particularly challenging to record with any accuracy, however, in some cases they may substantially exceed the direct costs. Despite the challenges, Hungr (2004) assembled an estimate of annual direct losses and prevention expenditures by various sectors for landslides in western Canada between 1880 and 2001 (Table 3).

The year to year variability of the landslide costs may be high, but most interesting are the opportunity costs. Land sterilization occurs when population growth pushes development into less stable regions. However, increased demand on the land does not remove the threats to lives and livelihood. Judicious planners are forced to take a sober look at the areas that are prone to landslides and plan accordingly (see Porter and Morgenstern, 2013). The opportunity costs continue to rise as a direct result of unstable land being identified and the relative value of stable land as it becomes scarcer.

In 1973, in a landmark Canadian decision, the Honourable Justice Berger upheld the decision of a BC senior approving officer to disallow the development of 126 lots on the Rubble Creek Fan in the Cheakamus Valley, British Columbia. This despite the fact that construction had started and some residential development had already progressed on the fan (Supreme Court of BC, 1973). The issue was the credible threat of a massive rock fall-debris flow that could bury the proposed subdivision in its entirety. Since that decision was made, it has guided planners and landslide professionals in the province.

In their own way, landslides that remove timber and soil from slopes also sterilize land by marginalizing the productive capacity of that land for up to 80 years (Smith et al., 1986). The loss in harvestable timber can be significant. The recent Mount Meager rock slide-debris flow resulted in an estimated $10 million in lost timber (Guthrie 2013). Sterilization also affects agricultural and urban land as it removes soil or makes development, expansion and renewal dangerous.

Table 3. Annual direct losses and prevention expenditures by various sectors for landslides in western Canada between 1880 and 2001 (Hungr, 2004).

Sector	Typical landslide type	Annual direct losses in millions of $CAD	Annual prevention expenditures in millions of $CAD
Residential	debris flows; earth and rock slides	2.5 – 3.5	1 – 2
Roads and bridges	debris flows; rock falls; earth and rock slides	4	5.5
Railways	debris flows; rock falls; earth and rock slides	2.5 – 3.5	2 – 4
Hydro power	rock slides	1	4
Pipelines	earth and rock slides	1 – 2	2 – 4
Forestry	debris flows; earth and rock slides	2 – 3	1
Sub-total		**12 – 16**	**16 – 21**
Land sterilization			10 – 50
Loss of harvestable timber		16 – 48	
Total in 2004 $CAD		**29 – 65**	**25 – 71**
Total in 2011 $CAD		**34.5 – 77**	**30 – 85**

In Canada, railways are an industry dominated by two companies (CN and CP Rail), and closely watched by the Canadian Transportation Research Board. Extending Table 3 to central and eastern Canada, an estimated $8-25 million/year is spent on stabilization and mitigation of landslides and related natural hazards along railways. Most of those costs are dominated by a few large events where the rail line has to be closed for an extended period of time. For example, the 1997 Conrad derailment in BC cost CN approximately $50,000/hour for the first few hours, but then costs escalated substantially to millions of dollars after two days (Transportation Research Board, 1997). Single events routinely cost several million dollars in direct costs, but indirect costs such as insurance claims can range from $150 million to $500 million.

Fisheries impacts are especially hard to quantify. Only one example is included in Table 4 but in total costs, it overwhelms the cost of all other landslides. A rock fall at Hell's Gate in the Fraser Canyon, BC, in 1914, that occurred during the construction of the rail line, blocked the Fraser River and had an effect on the salmon fishery that lasted decades (Cruden et al., 1989). Many other landslides affect fisheries values but their total cost (direct and indirect) is rarely calculated.

2.2.4 Notable Historical Landslides

Hundreds of landslides occur each year in Canada. Most go largely unnoticed in spite of the fact that small landslides are typically more destructive per unit volume than large landslides (Hungr et al., 1999; Evans, 2003; Guthrie and Evans, 2007). Table 4 tabulates the socio-economic significance of 56 notable Canadian landslides for the period between 1841 and 2012. The geographic distribution of those landslides is shown as white circles in Figure 1. The landslides tabulated occurred in the provinces of Newfoundland and Labrador, Quebec, Ontario, Alberta and BC. Taken together they account for almost $10 billion in direct and indirect costs (2009 $CDN).

3. SUMMARY

Landslides continue to have significant socio-economic effects in Canada, as they do elsewhere in the world. In Canada, landslides disrupt roads, natural resources, power, energy and communication infrastructure. Less frequently they take lives, injure people, and damage other forms of infrastructure. Fifty six notable landslides recorded since 1841 are estimated to have resulted in direct and indirect costs of approximately $10 billion, killed an estimated 581 individuals, and destroyed or buried homes, roads and highways, bridges, rivers, pipelines and other infrastructure vital to the well-being of all Canadians.

In general, Canada's most damaging landslides are found in the Canadian Cordillera with their steep mountains and high relief, an area accompanied typically by high precipitation, and in the St. Lawrence Lowlands, where sensitive clay dominates the landscape. Landslides also occur in the other five physiographic regions of Canada.

Damaging landslides occur where the natural landscape intersects a socio-economic landscape, and most historical landslides of significance have occurred at the human-landslide interface. However, as Canadians continue to expand settlement into less stable areas, we need to be ever more cognizant of the landscape in which we live, and carefully manage our exposure to unnecessary risks that threaten our livelihood, lives, and the infrastructure upon which we rely.

4. ACKNOWLEDGEMENTS

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Table 4: Notable Historical Landslide in Canada from 1841-2012

Date	Location	Province	Landslide type	Reported volume (m^3)	Reported deaths	Damage	Total estimated costs (2009)	Sources
1841	Champlain Street, Quebec City	Quebec	rock slide	-	32	houses destroyed	$48,000,000	2,3
1852	Champlain Street, Quebec City	Quebec	rock slide	-	7	houses destroyed	$10,500,000	2,3
1885/1886	Rubble Creek	BC	rock fall-debris flow	30-36 M	0		$17,000,000	4
1864	Champlain Street, Quebec City	Quebec	rock slide	-	4	houses destroyed	$6,000,000	2,3
1877	Ste-Genevieve-de-Batiscan	Quebec	earth flow	-	5	house and attached mill destroyed	$7,500,000	5,3
1889	Champlain Street, Quebec City	Quebec	rock slide	53 k	50	7 houses destroyed	$77,240,000	2,3
1891	North Pacific Cannery	BC	debris flow	-	35	houses destroyed	$52,500,000	3
1894	St-Alban	Quebec	earth flow	185 M	4	farmhouses destroyed	$6,320,000	2,3
1895	St-Luc-de-Vincennes	Quebec	earthflow	-	5	house destroyed	$7,652,000	5,3
1897	Sheep Creek	BC	debris flow	-	7	maintenance camp struck by debris	$10,500,000	3
1898	Quesnel Forks	BC	earth slide/ debris flow	1.7 M	3	damaged homes, farms and a highway	$4,500,000	6,3
1903	Frank	Alberta	rock fall-debris flow	30 M	76	town partially buried	$114,000,000	3
1905	Spences Bridge	BC	earthflow	-	15	victims swept away by wave	$22,500,000	3
1908	Notre-Dame-de-la-Salette	Quebec	earthflow	-	33	12 houses destroyed by wave	$49,500,000	3
1909	Burnaby	BC	soil slide	-	22	railway damaged, train derailed	$33,000,000	3
1910	St-Alphonse-de Bagotville	Quebec	earth flow	-	4	construction camp buried	$6,000,000	3
1910	Coucoucache	Quebec	soil slide	-	6	railway damaged, train derailed	$9,000,000	3
1914	Hell's Gate	BC	rock fall	-	0	damage to fish migration corridor resulting in massive losses to fish stocks	$8,215,000,000	7

1915	Jane Camp	BC	rock fall-debris flow	100 k	56	mining camp partially destroyed	$84,000,000	3
1921	Britannia Beach	BC	railway fill failure; debris flood	-	37	outburst flood destroyed >50 houses damaged or destroyed	$74,200,000	3,8
1922	Elcho Harbour	BC	debris slide	-	5	logging camp destroyed	$7,500,000	3
1929	Grand Banks	Newfoundland & Labrador	submarine slide-flow	200 M	28	generated a tsunami; 12 telegraph cables broken	$42,640,000	10
1930	Capreol	Ontario	soil slide	-	4	railway damaged, train derailed	$6,000,000	3
1930	Crerar	Ontario	soil slide	-	8	railway damaged, train derailed	$12,000,000	3
1938	St-Gregoire-de-Montmorency	Quebec		-	4	apartment building destroyed	$6,000,000	3
1946	Beattie Mine	Quebec	debris flow	-	4	mineshaft overcome with debris flow	$6,000,000	3
1955	Nicolet	Quebec	earth flow	-	3	destruction of a church complex	$85,800,000	3
1957	Peace River	BC	soil slide	-	0	destruction of the peace river bridge, shut down natural gas cleansing plant	$146,000,000	11
1957	Prince Rupert	BC	debris slide	-	7	3 houses buried	$10,500,000	3,12
1959	Revelstoke	BC		-	4	house destroyed	$6,372,000	3,13
1960	McBride	BC	debris flow	-	3		$4,500,000	3
1962	Riviere Toulnustouc	Quebec	earth flow	-	9		$13,500,000	3
1963	St-Joachim-de-Tourelle	Quebec	earth flow	-	4		$6,000,000	3
1964*	Downie	BC	rock slide	1.5 G	0		$52,000,000	7
1964	Ramsay Arm	BC	debris flow	-	5	logging camp struck by debris flow	$7,500,000	3
1965	Hope	BC	rock slide-debris flow	48 M	4	3 vehicles and 3 km of highway buried	$6,000,000	3
1965	Ocean Falls	BC	debris flow	-	7	community struck by debris flow	$10,500,000	3
1968	Camp Creek	BC	debris flow	76 k	4	car struck by debris flow	$6,000,000	3,9
1969	Porteau	BC	rock fall	-	3	car struck by rock fall	$4,500,000	3
1971	St-Jean-Vianney	Quebec	earth flow	6.9M	31	40 houses destroyed	$93,930,000	3

1971	Boothroyd	BC	rock fall	-	3	train derailed by rock fall	$4,500,000	3
1972	Michel	BC	debris flow	-	3	maintenance crew struck by debris	$4,500,000	3
1973	Attachie	BC	soil slide	24 M	0	dammed Peace River for ~10 hours	-	3
1973	Breton Harbour	Newfoundland & Labrador	debris slide	-	4	4 houses destroyed	$6,000,000	3
1975	Devastation glacier	BC	rock fall-debris flow	13 M	4	survey crew buried	$6,000,000	3,9
1980	Belmoral Mine	Quebec	earth flow	-	8	mine cave in	$12,000,000	3
1981	M Creek Bridge	BC	debris flow	20k	9	bridge destroyed	$13,500,000	3,8
1983	Alberta Creek	BC	debris flow	15 k	2	3 houses destroyed	$3,000,000	8
1990	Joe Rich	BC	debris slide-flow	-	3	house destroyed	$4,960,000	3
1993	Lemieux	Ontario	earth flow	2.8 M	0	17 hectares of farmland destroyed	$12,500,000	8
1997	Conrad Siding	BC	debris slide-flow	-	2	train derailed, 2 locomotives and 14 railcars destroyed. 400 m of track replaced. 260.5 hours out of service.	$22,000,000	8, 14
2002	Zymoetz River	BC	rock slide-debris flow	1.4 M	0	ruptured a pipeline, triggered a forest fire, dammed the Zymoetz river, and destroyed a bridge	$33,400,000	8
2005	Berkley Escarpment	BC	debris slide	-	1	300 people evacuated, destruction of 2 homes	$4,200,000	15
2010	Mt Meager	BC	rock slide-debris flow	48.5 M	0	1,500 people evacuated	$10,000,000	16
2010	Saint-Jude	Quebec	Earth flow	520 k	4	1 home destroyed, 200 m of road destroyed an aqueduct and power lines damaged.	$6,500,000	17
2012	Johnsons Landing	BC	debris flow	-	4	3 homes destroyed	$7,000,000	5
Totals					**580**		**$9,538,214,000**	

*Downie Slide was first noted in 1964, it initiated sometime before that date

Sources: 1) Bank of Canada (2011); 2) Canada Home Listings (2011); 3) Evans, 2003; 4) Supreme Court of BC, 1973; 5) Canadian Mortgage and Housing Corporation, 2011; 6) Bichler et al., 2004; 7) Cruden et al., 1989; 8) Natural Resources Canada, 2009; 9) BC Ministry of Mines, Energy and Petroleum Resources, 1993; 10) Fine et al., 2005; 11) Thomson, 2010; 12) Conroy, 2010; 13) Okanagan Mainline Real Estate Board, 2011; 14) Transportation Research Board, 1997; 15) Canadian Disaster Database, 2012; 16) Guthrie et al., 2012; 17) Locat et al., 2012

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