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1.3 LANDSLIDES

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RESILIENCE PATHWAYS

CO-CREATING NEW KNOWLEDGE FOR UNDERSTANDING RISK AND RESILIENCE IN BC

This article is part of the Resilience Pathways Report. The report has the following objectives: a) to share knowledge about existing practices and recent advances in understanding and managing disaster and climate risk in BC, including some information on relevant federal programs, and b) to provide insights on gaps and recommendations that will help build pathways to resilience in BC.

This article belongs to *Chapter 1 Understanding and Managing Climate and Disaster Risk: Hazard Threat*. To read all articles in the report, see DRRPathways.ca.

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1.3 LANDSLIDES

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ABOUT LANDSLIDES

DESCRIPTION

Landslides are the downward movement of soil, rock, or other earth material under the influence of gravity.[1] In BC, these hazards are most common in mountain areas but also can occur in river valleys, lakes, fjords, off the coastline, or in terrain modified by human development (Figure 1). Thousands of landslides occur each year in BC, although most are small and located in remote areas.

Landslides occur when the factors that destabilize a slope overcome those that hold it in place. Complex interactions between slope topography, geologic conditions, vegetation, and human development create the conditions where landslides might arise, while triggers are external factors that can cause landslides to release.[2]

In BC, most historical landslides have been triggered by an increase in the supply of water to slopes.[3] This is typically due to rainfall or snowmelt, but can also be from anthropogenic causes, like irrigation.[4] Other common landslide triggers include freeze-thaw cycles,[5] terrain modifications from land or resource development,[6] or river erosion.[7] A less commonly occurring trigger of landslides in BC is earthquake. While these events are relatively infrequent, they could cause widespread slope failures. In the past century, no earthquake has triggered multiple landslides near a population centre in BC; however, recent events around the world indicate that impacts could be significant.[8,9]

Landslides can be classified as fast moving or slow moving.[10] Common fast-moving landslides in BC include debris flows, debris avalanches, rockslides, and rockfalls; these mainly cause impacts in runout zones and can cause life loss and secondary hazards like tsunami waves or landslide dams.[11,12] Common slow-moving landslides include earthflows and earthslides;[13] these cause progressive ground deformation that can lead to high economic loss due to long-term maintenance costs. Both fast and slow landslides cause economic loss from property destruction, infrastructure damage, and road and utility service disruption.

Climate change is anticipated to increase the frequency of landslides across much of BC.[14,15,16] These changes will mainly be driven by more frequent and intense weather systems, such as the atmospheric

[i] *The recommendations provided are solely the opinion of the authors and not the contributors or their organizations. The contributors provided very helpful insights and feedback to develop content in the article, but ultimately the authors developed the content and recommendations based on their understanding and opinion.*

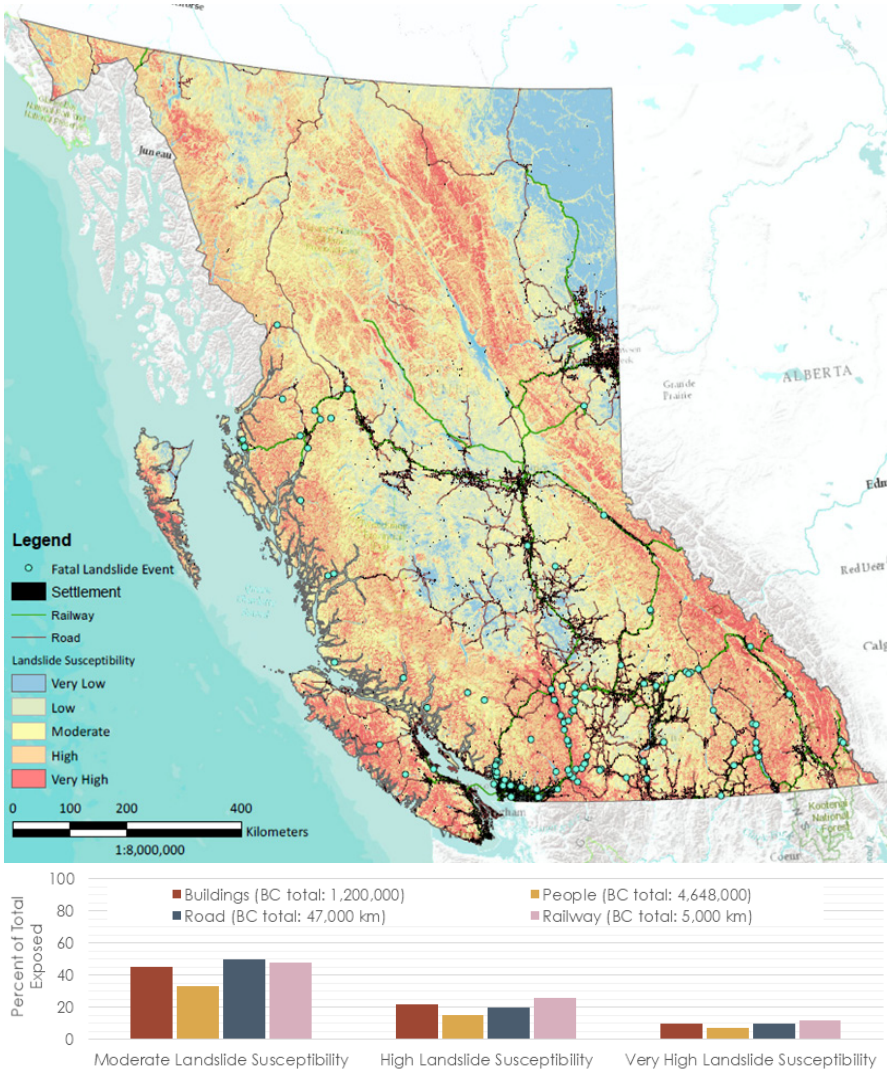

Figure 1: Landslide susceptibility in BC and the percentage of buildings, peoples, roads, and railways exposed to moderate, high, and very high levels of landslide susceptibility. Landslide susceptibility data is from NASA's global landslide susceptibility model;[17] the count of buildings and people in settlements are from NRCan;[18] railway centrelines are from GeoBC;[19] road centrelines are from BC Ministry of Transportation and Infrastructure;[20] and fatal landslide events are from NRCan.[21]

river which led to widespread flooding and landslides across southwestern BC in November 2021, more frequent wildfires, which can remove surface vegetation and increase the susceptibility to landslides, and faster deglaciation, which can expose and debuttress landslide-prone slopes.

LANDSLIDE THREAT AND PAST EVENTS

In BC, landslides mainly pose risks to public safety, infrastructure, resource development operations, forest harvestable land, agriculture, and fisheries. It is currently unclear who or what is most at risk from landslides, but there are a few apparent trends.

Landslides appear to be particularly problematic along linear infrastructure (Figure 2).[22] Commonly traversing long distances, linear infrastructure can be exposed to multiple landslide hazards at once. Impact from any one event can cause direct damages that require repair and mitigation as well as interruption of business services that can exceed direct damage costs.[23] People travelling along linear infrastructure can also be injured or killed,[24] with over half of all reported landslide fatalities in BC taking place along roads or rail lines.[25] Debris flows and debris floods also pose notable risks; these hazards terminate on alluvial fans, which form gently sloped areas among mountain terrain and have historically been favorable for residential development. Debris flows have historically caused almost 90% of reported landslide fatalities in residential areas.

Between 1880 and 2019, there have been 390 recorded fatalities caused by 123 landslide events in BC.[26] Most of these resulted in a single fatality, five events caused 10 or more fatalities, and the highest-fatality event was a rock avalanche in 1915 that killed 54 people living in a mining camp near Britannia Beach. Landslide events kill one person per year on average in BC.[27]

The total annual economic cost of landslide events in BC is unknown, but it is likely within the hundreds of millions per year.[28,29] To provide context, the costs from 32 fast-moving landslide events in BC from 1885 to 2012 have been estimated at $9 billion (2009), with most events

Figure 2: Assessing damage at Ruby Creek and Highway 7 after mudslide closes the road, November 15, 2021 (Photo: flickr/Ministry of Transportation and Infrastructure).

costing below $50 million (2009).[30] The most expensive event was estimated to cost $8.2 billion (2009) and included a rockslide in 1914 that dammed the Fraser River causing considerable impacts to salmon stocks and BC's salmon fishery. The slow-moving Ten Mile Landslide has been impacting Highway 99 and a CN railway line since the late 1980s. It has cost the BC Ministry of Transportation and Infrastructure (MoTI) between $240,000 and $2.3 million annually and has a total mitigation expenditure of $83 million dollars.[31]

DRIVERS OF RISK

Development within landslide hazard areas leads to landslide risk. Development can cause landslides by undercutting slopes with excavations, overloading slopes with fills, removing vegetation, and increasing the water level within the slope. For example, logging and road building has been attributed to a ten-fold increase in landslide activity in coastal BC.[32] In residential areas, such as on Vancouver Island and in North Vancouver, construction of non-engineered retaining walls on slopes, decades' worth of yard waste disposal, and poorly controlled discharge of stormwater from roof drains onto slopes make up common causes for development-related slope failures.[33] On a larger scale, suburbanization is affecting groundwater levels in many areas of the Interior, which has partly led to several landslides in the Kelowna area and several slow-moving landslides in both Quesnel and Kamloops. Development also increases the exposure to landslides when buildings, roads, utilities, and other infrastructure are placed in landslide hazard zones and when the volume of traffic increases on existing roads in landslide terrain.

In most cases, the above issues can be managed using best practices for landslide risk management. For example, over the past 60 years, BC's average landslide fatality rate has dropped from five to one fatality per year, despite a five-fold population increase. This suggests that the evolution of landslide risk management has outpaced development pressures and the associated potential increase in landslide risk.[34] However, given that it was not until the late 1970s that landslide assessments were commonly used to support land and resource development projects,[35,36] a considerable amount of development was constructed within landslide-prone terrain without consistent consideration of landslide hazard. There is ongoing demand for scarce resources to manage landslide risk at these development sites.

UNDERSTANDING RISK

Current practice to understand landslide hazard and risk assessment can be grouped into three broad categories: risk identification, risk analysis, and risk evaluation.[37,38]

RISK IDENTIFICATION

Landslide risk identification primarily includes identifying and characterizing landslide-prone terrain or confirming that a potential landslide risk exists;[39] these are commonly used as screening tools to inform the scope of further study. Common practice includes using one or all of these approaches: geomorphic mapping, landslide susceptibility mapping, and priority ranking systems of landslide hazard sites.

Geomorphic maps are factual in nature and show the landforms in an area, including landslides and landslide-related features.[40] Mapping practices in BC have traditionally been based on air-photo interpretation and field visits,[41] but have since evolved to include interpretation of a variety of remotely sensed data.[42] While there are many forms of geomorphic mapping carried out in practice, terrain mapping, which uses a terrain classification system specifically developed for BC,[43] is by far the most common. Terrain mapping is publicly available for several areas of the province at various scales but there are still considerable gaps in coverage. Comprehensive guidelines for practitioners to complete terrain mapping include the *Guidelines and Standards to Terrain Mapping in British Columbia* published by the Resources Information Standards Committee.

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Landslide susceptibility maps show areas prone to landslides.[44] Common mapping practices use geographic information systems (GIS) along with available digital terrain and earth science data to estimate landslide susceptibility in the source and runout zones. There are many forms of landslide susceptibility mapping to identify source zones, ranging from slope mapping to quantitative multivariate assessments,[45,46] with terrain stability mapping being the most common in practice. Terrain stability maps have been an integral part of forest and resource development planning for several decades in BC. Most publicly available terrain stability mapping covers areas used for resource development[47] and is not often detailed enough for site-specific landslide assessments.[48] Guidelines for terrain stability mapping include *Mapping and Assessing Terrain Stability Guidebook*[49] and *Terrain Stability Mapping in British Columbia: A Review and Suggested Method for Landslide Hazard and Risk Mapping*.[50] Mapping runout areas susceptible to landslides (i.e., those at the bottom of slopes) is commonly based on simple empirical methods,[51] but more advanced terrain-based modelling techniques are starting to be used.[52,53] Maps that delineate landslide runout zones in BC are relatively scarce.

Priority rating includes creating a ranked inventory of landslide hazard sites, with the purpose of informing resource allocation and risk management actions. Priority rating systems have been used in planning and management of linear infrastructure in BC for decades,[54,55,56] and recent studies have used this approach to prioritize landslide hazards across some regional districts.[57] Landslide rating systems commonly used in BC are often semi-quantitative, are hazard- or risk-based (i.e., consider both hazard and consequences), and are typically tailor-made for specific projects or stakeholders. One of the main drawbacks is that creating priority rankings to meet the needs of multiple stakeholders simultaneously is challenging and sometimes not practicable.

RISK ANALYSIS

Landslide risk analysis involves estimating the level of hazard or risk from a landslide[58] and is used to gather information required for evaluating whether risks can be tolerated and for implementing risk reduction measures. In this step, hazard analysis involves estimating factors related to landslide occurrence (e.g., landslide mechanisms, the likelihood or probability of the landslide, frequency-magnitude relationships, the slope factor of safety, slope activity) or landslide runout (e.g., runout extents, landslide flow depth and velocity). Risk analysis involves estimating the probability of

certain consequences from landslides (e.g., the probability of fatality). There are a variety of approaches that can be used to assess landslide hazard and risk and several resources are available for practitioners (see Resources section). The level of effort, type of assessment, and assessment outcomes depend on the project objectives, landslide characteristics, available background information, and level of exposure.[59] In many cases, estimating landslide risk is not needed nor is carried out in current practice, and risk management decisions can be based on hazard assessments alone.

Landslide hazard and risk analyses are routinely performed by qualified professionals (engineers and geoscientists) as part of the application processes for proposed land development, forestry, and other resource use projects[60] or to inform landslide risk reduction where existing development is exposed. Engineers and Geoscientists of British Columbia (EGBC) publishes guidelines for professionals carrying out landslide hazard or risk assessments in BC, such as the *Legislated Landslide Assessment for Proposed Residential Development in BC*.[61,62] However, there are ongoing challenges in current practice. For example, qualified professionals conducting these studies are not always landslide specialists, so assessments can lack consistency and important aspects of professional practice guidelines. Also, understanding the magnitude of very-low-probability events, the mechanisms of large slow-moving landslides, and the impacts of climate change on landslide frequency and magnitude are challenging and prone to considerable uncertainty.

RISK EVALUATION

Landslide risk evaluation includes comparing the estimated level of hazard or risk to tolerance criteria. In BC, governments and infrastructure owners define these criteria; it is not the role of landslide professionals. For land development planning, qualified professionals are responsible for evaluating if a development is "safe" from the effects of landslides; however, no defined level of landslide safety has been adopted province wide. A few incorporated jurisdictions have defined landslide safety standards, and MoTI provides guidance for unincorporated areas, but there are differences between regulations that have been adopted.[63] As examples, the Fraser Valley Regional District has used a hazard-based standard since the early 1990s that depends on hazard type and size of development,[64] and the District of North Vancouver uses a risk-based standard that considers the probability of death of a person in individual homes.[65] Despite the lack of broad regulatory guidance on landslide hazard or risk tolerance criteria, current practice in risk analysis seems to be trending away from fundamental geomorphological interpretation and experience-based judgment and towards quantitative risk assessments. Quantitative risk assessments are powerful tools to support landslide risk management decision making, but can also be complex, expensive, and in some cases no more effective than simpler approaches at leading to good risk management decisions.

REDUCING RISK

WHAT SOURCES HELP US REDUCE RISK

In BC, there is no single entity responsible for coordinating and overseeing landslide risk management. Instead, the province, local governments, infrastructure owners, and resource development companies are responsible for managing landslides on their own lands or that pose a risk to their assets or to worker and public safety. Many entities are involved to support risk management activities (Table 1).

There are benefits and drawbacks with the current governance model for landslide risk management in BC. Different organizations can adopt plans, policies, and risk reduction strategies that are suitable to their context and based on resources available. However, issues related to consistency, coordination, and disparity in available resources for landslide risk management arise between different organizations and jurisdictions.

PRACTICE AND CAPABILITIES

Landslides impacts are the result of a chain of events where a landslide occurs, reaches an element (e.g.,

Table 1: Organizations involved in landslide risk management (overview)

Organization	Type	Role
Academics/Researchers	Community of practice	Researches landslide fundamentals and produces tools.
Emergency Management BC	Provincial ministry	Leads landslide emergency response for events occurring on Crown land, except for those that affect highways, or when a local government requests provincial support with a landslide emergency.
Engineers and Geoscientists BC	Non-profit	Regulates practicing engineers and geoscientists, sets and maintains the academic, experience and professional practice standards for its members, and publishes professional practice guidelines.
BC Ministry of Transportation and Infrastructure	Provincial ministry	Manages landslide hazards that affect or potentially affect highway infrastructure and public safety, plans new infrastructure in respect of landslide hazards, considers improvements to network reliability and resiliency, and is the approving authority for residential development in unincorporated areas.
BC Ministry of Forests, Lands, Natural Resource Operations and Rural Development	Provincial ministry	Conducts post-wildfire landslide assessments and preliminary assessments of landslide hazards on Crown land where there is potential risk to public safety, private property, or ministry infrastructure (e.g., forest service roads). Supports EMBC in emergency landslide response, and researches causes and impacts of landslide processes in BC.
Local governments	Municipalities, regional districts	Responsible for managing landslides on their own lands/leases or that pose a risk to their assets or public safety, including landslide mapping, community planning, policy development, bylaw development and enforcement, assessing and controlling landslide risks, emergency management, and public communication when hazards are identified.
Crown or private infrastructure owners and resource development enterprises	E.g., forestry, mining, utilities, hydroelectric	Responsible for managing landslides on their own lands/leases or that pose a risk to their assets or worker/public safety, including hazard and risk assessment, risk control, emergency management, and stakeholder engagement.
Professional Engineers and Geoscientists	Community of practice	Are employed or contracted by governments, private organizations, or landowners to lead or support with landslide risk management.

asset, person), and causes a loss depending on the element's vulnerability. Interventions in this event chain will reduce landslide risk. Interventions include: 1) reducing exposure to landslides, 2) reducing the potential for a landslide to release, 3) controlling the landslide impact zone, and 4) reducing the vulnerability of elements to landslide impacts. Many methods are used to achieve these outcomes, which can be implemented individually or in combination. The appropriate risk reduction strategy for a particular landslide risk is highly specific, depending on the type of consequence (e.g., loss of life, service disruption, or economic loss), landslide characteristics (e.g., fast moving or slow moving), risk reduction objective (e.g., tolerable life-loss risk, economic loss reduction, infrastructure protection, or economic risk transfer), and available resources.

REDUCING EXPOSURE TO LANDSLIDES

Methods that reduce exposure to landslides aim to prevent elements from being within the path of a

landslide should one occur. Common approaches include landslide hazard zone avoidance and landslide monitoring and evacuation systems.

Landslide avoidance is applicable to all landslide types, consequence types, and risk reduction objectives, and is the first line of defense against landslide hazards. Avoiding landslide hazard zones is achieved by prohibiting development, restricting certain types of development, setting back infrastructure from landslide hazard zones, or relocating existing properties and infrastructure away from identified hazard zones. In residential development, landslide hazards are avoided through community planning and the subdivision approvals process.[66] Approving authorities rely on qualified professionals to: prepare maps that help define landslide development permit areas (DPAs); assess landslide hazards and risks if a proposed development or subdivision falls within a landslide DPA; and declare that development areas are "safe for the use intended" in landslide DPAs. However, the definition of "safe" remains undefined in many municipalities, and landslide hazard maps that can be used to define landslide DPAs are inconsistent and not widely available. In jurisdictions where landslide mapping is unavailable, simple rules are used to identify landslide DPAs (e.g., based on slope percentage or degree), but these often do not capture the full extent of landslide-prone terrain.[67] Acquisition of existing property and sterilization of land in developed landslide hazard areas has been rare in BC and is often neither practical nor economically viable.[68]

Landslide monitoring (e.g., using rainfall, groundwater pressure, or slope displacement) and evacuation or road closure systems are used to remove people and elements from harm's way when a landslide appears likely to occur. As such, they can reduce safety risks and some economic risks, such as those related to pipeline spills, but do not reduce economic risks related to repair and service disruption. While these approaches are often the only feasible methods of risk reduction from low-probability, high-consequence landslides (e.g., rock avalanche), they are challenging to implement due to technical uncertainties about landslide triggers, a commonly high rate of false alarms, and concerns about legal liability to the entity that owns the monitoring equipment and signals the evacuation.[69] Furthermore, evacuations tend to be incomplete, imperfect, and require a population that is well educated in how to respond to an evacuation notice.[70] Regional landslide early warning systems can be useful tools for improving situational awareness and are less prone to issues associated with site-specific systems described above,[71] but cannot be used to detect an imminent landslide.

REDUCING POTENTIAL LANDSLIDE RELEASE

Methods that reduce the potential for landslide release aim to increase slope stability. Methods include: following best design and construction practices for development in landslide terrain; protecting existing vegetation and promoting growth of new vegetation in landslide terrain; and designing and constructing measures that stabilize slopes or reduce displacement rates (e.g., drainage systems, erosion protection, buttresses, anchors, removal of destabilizing loads, and head scarp stabilization).[72,73] These methods are employed by qualified professionals. Best practices for design are defined in local government design standards, professional practice guidelines prepared by EGBC, and informal guidebooks from various Canadian and international government agencies, such as the *Forest Road Engineering Guidebook*[74] and the *Washington State Department of Transportation, Geotechnical Design Manual.*[75] These methods for reducing the potential for landslide release are generally successful at reducing landslide risk from engineered slopes and from land development, except when the designers lack sufficient experience and expertise. It is generally not feasible nor cost effective to fully stabilize large natural slopes and large existing landslides, although drainage measures and re-vegetation can improve some landslide types (Figure 3).

CONTROLLING THE LANDSLIDE IMPACT ZONE

Methods that control the landslide impact zone aim to stop or redirect a landslide away from harm after it has released. These methods are applicable primarily to fast-moving landslides like rockfalls, debris flows,

and debris avalanches that tend to pose life-loss and service disruption risk. Methods include rockfall barriers and nets (commonly used along highways and railways), debris flow barriers, basins, diversion berms, and engineered channels.[76]

Local governments have a political mandate to protect citizens, yet they often lack the financial resources to undertake large engineering design and construction projects and to pay the long-term operation and management costs.

Highways and railways tend to have the land tenure and allocated resources needed to protect against high-frequency landslides, particularly at sites with a documented history of landslide activity. Local governments, however, particularly in rural areas, struggle to design and construct large protection structures that reduce landslide risk to "safe" levels,[77] despite such structures being technically feasible. Local governments have a political mandate to protect citizens, yet they often lack the financial resources to undertake large engineering design and construction projects and to pay the required long-term operation and maintenance costs. Local governments compete for funding of capital costs from a variety of provincial and federal grants, but the grants can take years to secure without a guarantee of success and often have a maximum value that is insufficient and unrelated to the cost of reducing risk to a tolerable level. Winning a grant is a function of many factors (e.g., number of applicants, timing of submittal, availability of grant money, quality of application) that are unrelated to the urgency of need for a particular community, and ultimately there is not enough funding to meet the requests of all applicants. Although funding is available through Emergency Management BC for imminent landslide threats during and following disasters, historically this funding stream has not been available for construction of proactive landslide protection measures.

Figure 3: Church Road slide at Highway 97, May 17, 2021. The spring freshet resulted in flooding and damage at over 90 road sites in the Cariboo (Photo: flickr/Ministry of Transportation and Infrastructure).

REDUCING VULNERABILITY TO LANDSLIDES

Methods that reduce vulnerability to landslides aim to reduce the level of consequence that could arise if a landslide were to encounter an element. Commonly used methods include constructing impact-resistant structures and proactive emergency response and recovery planning.

Winning a grant is a function of many factors . . . that are unrelated to the urgency of need for a particular community, and ultimately there is not enough funding to meet the requests of all applicants.

Potential physical damages caused by landslides can be reduced by impact-resistant construction. Owners of linear infrastructure like pipelines, powerlines, roads, and railways have many methods for reducing physical damage caused by landslides, such as using heavy walled pipe, changing the depth of burial, using lightweight backfill, or using erosion-resistant materials for road surfacing and subgrades.[78] These practices are well established in BC and regularly applied. For residential development, physical damages can be reduced with elevated construction levels, reinforced walls, careful window and door placement, and building-specific protection berms and barriers. Although common in the European Alps, few landslide-resistant buildings have been constructed in Canada. Restrictive covenants and indemnity covenants are used by local governments to establish design requirements under which a property can be safely developed (e.g., flood construction level on a debris flow fan) and to provide a waiver of liability in favour of the local government or the Province.[79] The requirements can reduce physical damages that occur due to a landslide, but the waiver of liability transfers the financial risk from the government to the property owner. The liability transfer may be a necessary means of limiting liability exposure for governments and third-party consulting firms. Landslide insurance may offer homeowners some protection from the related financial risks; unfortunately, landslide insurance is not currently available in BC. From the insurance industry's perspective, it is not practicable to insure a relatively small group of potential high-risk policy holders.[80]

Proactive emergency response and recovery planning can reduce non-physical vulnerabilities to landslides. For economic risks, this can be done by reducing the duration of service disruption and optimizing the recovery and repair method by, for example, writing contracts with maintenance and repair contractors, establishing detours, developing maintenance designs in advance, and staging equipment. For safety risks, this can be done by developing emergency response plans, improving response coordination, and increasing public awareness of landslide hazards.[81] Local authorities in BC lead response activities in their jurisdictions and receive support for significant events through Emergency Management BC.[82] As soon as local authorities, the Province, and/or qualified engineers and geoscientists become aware of existing developments within landslide hazard areas, they are required to notify leaseholders or landowners of the landslide risk.[83]

> Province-wide guidance on the level of tolerable landslide risk is not available, and government authorities are developing their own definitions of "safe."

GAPS

While considerable strides have been made to reduce landslide risk in BC, gaps in practice remain, including:

1. **Hazard event record keeping** – Records of landslide events that include information such as impact intensity, duration, lives lost, injuries, service disruptions, direct economic losses, and indirect economic losses (e.g., business interruption losses) are limited, incomplete, or privately held by infrastructure owners. The lack of publicly available records introduces large uncertainties into consequence estimation for risk assessments, which impedes accurate risk estimation, the use of cost-benefit assessment for resource allocation, and comparison of risks between hazard types and hazard sites.

2. **Education of professionals** – In BC, there are examples of landslide risk management projects completed by practicing engineers and geoscientists that do not meet important aspects of professional practice guidelines. Continual education of practicing engineers and geoscientists, as well as knowledge sharing within the community, is ongoing through EGBC and is important for maintaining and improving professional practice standards.

3. **Public awareness of landslide hazards** – A lack of public awareness about landslides has

led to landslide damages in BC. For example, non-engineered slope modifications have caused landslides in the past, and people have been killed by landslides due to inappropriate reactions to events. Improving public awareness of landslide hazards is important for helping individuals manage their own landslide risk. Public education of landslide hazards has been an important part of landslide risk management within the District of North Vancouver for years and provides a good example of the associated benefits and challenges.

4. **Landslide susceptibility mapping** – Landslide susceptibility mapping in BC is not available for much of the province, including in many developed areas. Understanding the location of areas prone to landslides is one of the first steps in managing landslides, as it provides a basis for land-use regulation, development planning, and risk reduction planning.

5. **Landslide risks in context** – Currently, it is unclear which hazard types pose the highest risk, and which risks can be tolerated in BC. Furthermore, it is unclear which landslide sites pose the greatest risk relative to other landslide sites within BC. Comparing all hazard sites (regardless of hazard type) in a common risk-based framework would facilitate communication and better resource allocation decisions.

6. **Guidance on landslide safety levels** – Province-wide guidance on the level of tolerable landslide risk is not available, and government authorities are developing their own definitions of "safe." In the absence of overarching guidance, BC is becoming a patchwork of different policies that challenges the consistency of provincial reporting and planning. Establishing provincial guidance on landslide safety levels will be a difficult task that requires dedicated resources and collaboration between governments, qualified professionals, and the planning community. There are many challenges to overcome, including: developing guidelines for different development types (e.g., existing/proposed, developments of different sizes), managing inconsistency between jurisdictions that have existing policies, and implications for development in existing landslide hazard zones. These challenges will be easier to overcome the sooner they are addressed.

7. **Unavailable landslide insurance for private property owners** – There is currently no means to insure properties against landslide hazards in BC. Landslide insurance could provide the incentive for implementing risk reduction measures through rate control and could help distribute economic risks more evenly. The business case for landslide insurance in Canada is likely only practical if risk from multiple hazards is pooled. New Zealand and Norway have functional multi-hazard insurance schemes available for homeowners that cover landslides.

8. **Information sharing** – Most information that describes, or that could be used to understand, landslide hazard and risks in BC is not publicly available. This is primarily information collected by consultants for individual homeowners or the private sector, but also includes information collected by public agencies or university researchers. There are legal and practical barriers to sharing this information, such as copyright and limitation of liability, which are reducing public access to this information.

9. **Coordinated risk management activities** – Landslide risk management decision making and resource allocation is currently spread among many entities, including multiple provincial government agencies, local governments, private companies, and individual professionals. Coordination between the entities can improve consistency, data sharing, and resource allocation as well as reduce potential duplication.

OPPORTUNITY

RECOMMENDATIONS

The gaps described above are opportunities to improve the efficiency of landslide risk

Table 2. Recommendations

Recommendation	Description of Impact	Capabilities Needed
1. Assign responsibility to a single entity, task force, or working group to provide provincial leadership on landslide management issues in BC, and coordinate sactivities to address gaps.	Gaps identified in this article, as well as other potential issues not listed here, are much more likely to be addressed.	Funding; interagency coordination; leadership.
2. Establish a single responsible entity to maintain a landslide event database for BC that records quantitative information about landslide location, type, size, movement rate, economic loss, damages, injury, and life loss.	Provides a basis for better understanding and assessing landslide risks in BC and how they compare to other risks.	Funding; interagency and research coordination; leadership.
3. Investigate opportunities to improve education of professionals related to landslide risk and risk management practice.	Improves quality and consistency of professional practice.	Funding and leadership.
4. Investigate opportunities to develop a landslide hazard and risk awareness program for the public that educates about where and when landslides occur and how to respond.	Reduces vulnerability and increases resilience to landslides.	Funding and leadership.
5. Complete province-wide landslide susceptibility mapping, with a priority on developed areas. (The State of Washington Landslide Inventory Mapping Protocol[84] is a good example.)	Provides a basis for: identifying landslide-prone areas across the province; province-wide landslide risk reduction planning; and understanding landslide risk across BC.	Funding; provincial lidar coverage; interagency and research coordination.
6. Develop provincial guidance for landslide safety evaluation. As a first step, different policy options should be developed and their benefits/drawbacks assessed.	Improves consistency in the level of landslide risk to manage across the province; reduces inconsistency in how qualified professionals define "safe."	Funding; collaboration between all levels of government, EGBC, qualified professionals, owners, and researchers; leadership.
7. Investigate the feasibility of: 1) establishing landslide insurance for homeowners in BC; 2) improving data sharing between public and private entities; and 3) improving coordination of risk management activities in BC.	Provides a basis for potentially overcoming these complex gaps in current practice, which would likely require governance reorganization or new legislation.	Funding, interagency coordination; leadership.

management practice and reduce landslide risk in BC. The recommendations in Table 2 are more immediate steps that can be taken to address those gaps. The recommendations provided above are solely the opinion of the authors and not the contributors or their organizations.

THE CHALLENGE

When considering gaps listed in this article, overcoming information-sharing barriers presents a complex challenge with no clear path forward. In the current context, sharing information about landslide hazards and risks can lead to litigation, economic damages, or opportunity losses for the parties involved. In extreme cases, this has led to situations where owners of different infrastructure that cross the same landslide hazard zone won't share data. There are also cases where data collected by researchers through publicly funded grants is not shared due to limitations in data sharing infrastructure, is only shared to obtain co-authorship rights, or is not shared at all. Overcoming data sharing challenges will likely require specific legislation or significant changes to provincial organization and input from many groups, including professional engineers and geoscientists, the legal community, all levels of government, researchers, and the private sector.

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