Mapping and hazard assessment of large deep-seated landslides in forested landscapes

TERRY ROLLERSON, JUNE RYDER, JOHN COYLE, AND ZHONGYOU LU

Definitions and criteria for the landslide hazard ratings currently used in terrain stability mapping for forestry in British Columbia are strongly oriented toward shallow translational landslides, primarily the likelihood of initiation of debris slides and associated debris flows. However, deep-seated landslides, ranging from earthflows to slow slides in bedrock, are common in many parts of the province. We know that these can be accelerated or reactivated as a result of natural disturbances, such as climate change, seismic events and stream undercutting. Similar changes may result from forestry activities, but little is known about the potential effects of forest roads and/or various silvicultural practices. To date, deep-seated landslides have been rated by ad hoc adaptations of the existing terrain stability classification systems. Difficulties arising include mapping the extent of these features, classification of deep-seated landslides, assessment of current activity, and assignment of hazard ratings.

We discuss these difficulties, propose standard terminology for describing landslide activity, define logical hazard interpretations, and present simple criteria and rationale for hazard ratings. We also suggest modifications to the symbology used in the British Columbia Terrain Classification System to facilitate the description and classification of deep-seated landslides.

Terrain attribute studies, Vancouver Forest Region

TOM MILLARD AND TERRY ROLLERSON

Terrain attribute studies (TASS) examine previously logged and roaded terrain so that predictions can be made as to the likely locations of future forestry-related landslides. We examine the results of six TASS in the Vancouver Forest Region (VFR). Comparisons between these studies show interesting trends and contrasts. Average clearcut landslide rates vary by an order of magnitude within the VFR. Similarly, there is an order of magnitude range in the average roadfill landslide rate in the studies. However, the study location with the highest clearcut landslide rates does not coincide with the location of the highest road landslide rates. Although landslide rates vary across the VFR, there are consistent terrain characteristics that indicate higher or lower landslide hazard. This paper presents landslide rates determined by a single variable: the presence of gullies. Single gullies consistently have the highest or second highest landslide rates of any slope morphology. However, although single gullies are always some of the highest-hazard areas in each study area, landslide rates for single gully terrain still vary by at least an order of magnitude across the VFR. We speculate on the reasons why landslide rates vary across the VFR.

Flowslides and drowned, buried forests at Halden Creek, northeastern British Columbia

MARTEN GEERTSEMA AND JOHN CLAGUE

Halden Creek has been frequently impounded by flowslides. The landslides are recorded in sedimentary exposures in two ways. 1) Trees died in the resultant temporary lakes and were subsequently partially buried by alluvium. The buried portions of the trees were preserved. Bank erosion exhumed these ancient drowned forests. 2) In some cases, multiple organic layers in eroded slide debris record separate flowslide events. Using radiocarbon dates of trees and organic layers, we attempt to reconstruct flowslide history at Halden Creek.

Terrain attribute studies in the Prince George Forest Region, British Columbia

BRENT WARD, TERRY ROLLERSON, AND SID TSANG

A program of terrain stability mapping suitable for forest development purposes has been carried out in coastal British Columbia for over 20 years; however, common use in the Interior regions is limited to post-1995, since the advent of the Forest Practices Code. Terrain stability mapping assesses the likelihood of post-harvesting landslides using air photo interpretation and ground checking, usually at 1:20 000 scale. Each terrain polygon is then assigned a slope stability classification based on surficial material, texture, slope gradient, slope morphology, moisture conditions, and ongoing geomorphic processes, such as evidence of previous instability. Due to regional variations in climate, geology, soils, and other factors, few specific criteria can be applied universally across all regions of the province. Thus, this mapping is relatively subjective, being highly dependent on the experience and local knowledge of the mapper. Criteria developed on the Coast are commonly imported to the Interior, resulting in inconsistent, unreliable, or overly conservative mapping.

Terrain attribute studies attempt to empirically quantify which terrain units are most likely to fail following logging and road construction. This allows calibration of slope stability classifications used for terrain stability mapping and should result in more reliable mapping in the Interior. A preliminary terrain attribute study was carried out in the Prince George and Robson Valley Forest Districts in the Prince George Forest Region. The methodology for terrain attribute studies will be described and results presented. Both percentage of failed polygons and landslides per hectare data were calculated.

In the McGregor Watershed, the 56 landslides identified were concentrated in only 21 polygons, out of 268 visited (~8%). This corresponds to 0.007 landslides/ha.

Approximately 70% of the polygons that failed were silty sand glaciola-

custrine sediments. The fact that glaciolacustrine terrain makes up only 30% of mapped polygons indicates that this is a problematic terrain type. In the Dore Watershed, the 43 landslides identified occurred in 21 polygons out of 481 visited (~4%). This corresponds to 0.004 landslides/ha. Of the 21 polygons that failed, 20 were in till, reflecting the dominant surficial material in the area. The overall frequency of the two watersheds is 0.006 landslides/ha. This is considerably lower than published results from coastal British Columbia: 0.17 landslides/ha for the Queen Charlotte Islands; 0.08 landslides/ha for Vancouver Island; and 0.01–0.04 landslides/ha for the Coast Mountains.

Chi-Square Automatic Interaction Detection (CHAID) was carried out on the combined data set for clearcut landslides for both percentage of failing polygons and landslides/ha. Based on percentage of failing polygons, CHAID indicated slope group followed by terrain category as the most important variables. Slopes ≥ 31° and especially ≥ 36° and terrain types consisting of glaciolacustrine, glaciofluvial, and till were more likely to fail. Based on landslides/ha, CHAID indicated that terrain category followed by gully wall slope angle as the most important variables. Terrain types consisting of glaciolacustrine and glaciofluvial with gully wall slope angles ≥ 34° were more likely to fail. Implications of these results for terrain mapping will be discussed.

The use of SINMAP in terrain stability mapping in the Prince George region—two case studies

ROBERT PACK, DENNY MAYNARD, AND MARTEN GEERTSEMA

Terrain stability mapping for B.C. Forest Practices Code requirements follows standardized guidelines (Resource Inventory Committee [RIC] standards). Classifications resulting from these guidelines are largely based on geomorphic interpretation derived from field observation, air photo interpretation, and the assessment of regional stability criteria. Standard products include a terrain classification (base data) map, and an interpretive map that highlights terrain stability classes. A new methodology has been developed that promised to complement these conventional interpretations. SINMAP (Stability INdex MAPping) is an ArcView GIS extension that facilitates the assessment of terrain stability at the watershed scale. SINMAP has as its theoretical basis a probabilistic formulation of the infinite plane slope stability model. Digital elevation model (DEM) data are used to estimate the slope of the terrain as well as the potential soil moisture conditions as influenced by topographic flow convergence. Other parameters considered in the model include soil friction and transmissivity, root cohesion, and water recharge. Parameters can be adjusted so that the resulting stability map maximizes the "capture" of observed landslides in regions with a low stability index, while minimizing the extent of low-stability regions and consequent alienation of terrain to regions where landslides have not been observed. The utility of this method in augmenting or assisting terrain stability mapping is discussed in the

context of two study areas in the Prince George Forest Region. The subject areas include Foster Creek and Canoe Mountain in the Robson Valley Forest District.

Terrain stability mapping—practice guidelines

IRENE WEILAND, DENNY MAYNARD, AND TIM GILES

The taskforce on professional practice in terrain stability mapping was formed under the auspices of the Division of Engineers and Geoscientists in the Forestry Sector (DEGIFS) as a result of discussions during the Association of Professional Engineers and Geoscientists of British Columbia (APEGBC) conference in Whistler, B.C. in October 2000. The taskforce consisted of consultants, Ministry of Forests staff, and forest industry personnel experienced in terrain stability mapping. The taskforce objectives were to develop practice guidelines specific to terrain stability mapping (TSM) under the Forest Practices Code (FPC). The intended audience are practitioners (mappers), quality assurance reviewers, and forestry managers who administer TSM projects. The practice guidelines are intended to build on the existing FPC and Resource Inventory Committee (RIC) publications that set the current standards for TSM; and to clarify or more thoroughly explain procedures that are inadequately covered in the existing publications. The taskforce is currently producing a first draft.

Specifically, the taskforce has discussed the following topics: reliability and limitations of TSM; mapper qualifications and experience; standards for detailed and reconnaissance TSM; issues around map-upgrading; contract and proposal specifications; and publication of a user guide directed towards land managers, operational staff, and professionals in related disciplines.

How "risky" are old roads?

MIKE MURRELL

Road deactivation in the past has been based on the "whole watershed" approach. While this ensured that all roads were stabilized within a priority watershed, it did not address the possibility that a "high-risk" road could be present and disregarded in a non-priority watershed.

A "risk assessment" method has been developed in Squamish, B.C. to rapidly and economically identify and quantify the associated environmental risk of roads by examining them for visual signs of deterioration and considering the probable consequences to:

- people (human factor);
- the fish (in-stream factor); and
- the forest (upslope factor).

By identifying and quantifying both the hazard and the probable consequences, a simple calculation can result in a numerical risk and a subsequent ranking of all identified trouble spots. Although this reconnaissance method is limited to roads that are not completely overgrown or canopied, it quickly allows the screening of extensive road systems to help establish priority areas regardless of the tenure situation.

The method involves flying slowly over roads to recognize signs of instability, then judging when an "event" could occur (i.e., the hazard), followed by a judgement of what the damage would likely be to each of the three "factors" (i.e., the consequence). The hazards and consequences are quantified by using a chart of increasing magnitude. Five numbers are entered into a spreadsheet that computes, rationalizes, and combines the resultant risks and produces a mini-graph for each identified road section. The graphs are then pasted onto a 1:50 000 base map for display purposes.

"Decision makers" can use the spreadsheets and maps as a tool to assist them in planning and justifying road deactivation projects. Contrarily, it helps them decide if a road section's risk is too low to warrant work—that is, it has "acceptable risk."

Risk management is nothing more than examining the "risk assessment" results and deciding what to do about them. For road deactivation, this can vary from "do nothing" to "full deactivation and rehabilitation." Risk can be reduced to an acceptable level by altering one or more of the following:

- the source
- the path, and/or
- the receptor,

and can be explained by the "tipping rock" scenario.

This presentation will present the rationale leading to the present method, will explain the method itself, will present some of the results from the 1999 fieldwork in the Squamish Forest District, and will display some of the maps generated.

Landslide susceptibility from watershed and fan characteristics, Salmon Arm and Vernon Forest Districts

AXEL EICHEL AND TED FULLER

Landslide occurrence in the Salmon Arm and Vernon Forest Districts in the last 5 years has stimulated research to determine how small drainage basins might be classified into debris flow-prone, debris flood-prone, or flood-prone. Alluvial fans situated at the base of several entrenched stream systems may have people dwelling on them. In addition to safety concerns, water quality and habitat are also of importance. A procedure is presented here that uses both map-based (GIS) and field-based (fan and channel mapping) analysis to show relative risk of impact on fans. Bedrock and surficial geology

are used to type the basins that are dominated by metamorphic rocks. Basin area, aspect, slope, inner gorge, and gentle-over-steep conditions were determined. GIS-generated channel longitudinal profiles were compared between the data sets. Fan morphology and stratigraphy aided in identifying previous debris flow events and their magnitude. Historical information provided by time-series air photo interpretation, historic maps, and archival research provides clues to recurrence intervals. Some fans will have relict paraglacial deposits that include debris flows and may still support future debris flows. The methods proposed here can be used to signal special concerns for forest development. The use of this template may find application in risk assessment outside the selected forest districts.

An application of risk analyses in the forest sector using judgemental probability and decision (fault) tree analysis

DOUG NICOL

Judgemental probabilities and fault tree analyses have been used to estimate the risk associated with specific forest road segments to downslope resources. An example is reviewed showing its application.

The example arises as a result of 1960's and early 1970's logging practices. Two small creeks located in the northern portion of the Arrow Forest District in southeastern British Columbia contained debris from the construction of old trails and roads. Some of this debris/fill is now failing as a result of diverted water and rotting organics. One of the creek channels is within a domestic watershed while the other is located above a residence. Adjacent gullies have experienced road-related fill slope failures as a result of the old skid trails/roads. The identified hazards entailed debris slides and debris flows that would potentially mobilize to the valley bottom. A traditional forest sector risk analysis would consist of identifying the hazard qualitatively (hazard simply consisting of likelihood of landslide) multiplied by a qualitative consequence (low, moderate, or high).

For comparison purposes, the risk was estimated using a decision tree (fault tree) analysis through the application of judgemental probabilities. The decision tree analyses provided additional clarity with respect to the level of risk and allowed the resource managers to better evaluate the risk and determine the level of required remedial works.

Potential consequences of logging and road building upslope of unstable terrain: Planning implications

DAVID TOEWS

Logging and road building above potentially unstable terrain can increase the probability of landslides. There are several guidelines that address this situ-

ation. In the Forest Practices Code (FPC) Guidebook for community watersheds there is a guideline that limits the extent of logging above potentially unstable terrain to 20% of the drainage area. Also, in the Kootenay-Boundary Land Use Plan there is a similar guideline that applies to all areas in the Nelson Forest Region in southeastern British Columbia. Professional hydrologists and geoscientists are frequently asked to investigate individual situations to determine if this guideline can be safely exceeded. This presentation will discuss a number of field situations that have been investigated in the Kootenays. The roads associated with development pose a greater risk than the logging itself. The strategy should be to maintain natural drainage patterns. Logging also poses an incremental risk, although a smaller one, and should also be limited in these situations. In order to produce a credible analysis of the risks and options available, the professional geoscientist or hydrologist must work closely with the development forester.

Promoting better management through stumpage incentives

JIM SMITH

Road density and, to a lesser extent, Equivalent Clearcut Area (ECA), are directly associated with the risk of landslides and sediment production. This is particularly important when operating in consumptive watersheds and areas with high-value fisheries. As the forest industry begins to move into these contentious areas, incentives to reduce risk factors should be developed. The stumpage appraisal system is designed to assess costs associated with the average efficient operator in most conventional forest industrial development. The system presently promotes road building and is commonly used as a mechanism to reduce stumpage rates on cutting permits. Access alternatives that have less impact, such as long skidding or forwarding, are discouraged by the system. As well, cost allowances for silvicultural systems, which minimize ECA, should be encouraged. The appraisal system is a powerful tool that should be used by government to promote development options that reduce risks to water resources in these valuable watersheds.

Managing the Coldstream Creek landslide: An example of applying incremental landslide stabilization techniques

KEVIN TURNER, JOHN DONNELLY, AND DRUM CAVERS

The Coldstream Creek valley is a community watershed located just east of Vernon, B.C. Besides supplying water for the Coldstream Irrigation District, the watershed is managed for forestry and range operations, and, being proximate to a major population centre and to Silver Star Provincial Park, it has an intensive level of public and recreational use. In the spring of 1996, a

3.6-ha slump initiated in a narrow canyon at the outlet of the valley, effectively cutting off access into the watershed. The landslide occurred following an extended period of above-normal annual precipitation. The high rate of slump movement (i.e., some 30–40 mm per day) precluded the typical "fix and forget" management technique. The steep terrain and private property that exists around the landslide made bypassing the slump a risky, difficult, and expensive option. Accordingly, attempts to stabilize the slide using a variety of techniques were undertaken between 1996 and 1999. These techniques involved survey monitoring, slope buttressing, site drainage alteration, trench drain installation, bank stabilization, subgrade ballasting, and horizontal drain installation. The project underscores the value of approaching landslide stabilization projects using a planned geotechnical investigation process, open communication and cooperation amongst the watershed stakeholders, and a program to monitor the results.

Mass wasting events associated with a large-magnitude rain-on-snow event, November 1999, Columbia and Rocky Mountains, southeastern British Columbia

JOE ALCOCK

In November 1999, a large-magnitude rain-on-snow event occurred in the Kootenay Region of British Columbia. In the Columbia Forest District, tens of debris flow, water erosion, and other mass wasting events occurred. Many of the in-block debris flows, water events on pre-and post-Code roads, and natural events were investigated and site-specific causes determined. Generally, the mass wasting and water erosion events generated by the rain-on-snow were different than typical spring snowmelt-caused events. Surface and subsurface drainage volumes were often beyond ditch and culvert flow capacity. Surface water flow occurred in new, untested locations. Debris flows occurred in the uphill portions of cutblocks and in reactivated gully wall failures. Ice and slush avalanches were observed in alpine areas. This major precipitation event served to pinpoint the locations of inadequate drainage structures and unstable sidecast and road gully fills. The adequacy of drainage structures in new and disused forestry roads is evaluated. The effects of snowpack distribution, cutblock boundaries in relationship to terrain stability polygons, and other factors are discussed.

Causes of gentle-over-steep landslides in Arrow Forest District

PETER JORDAN AND DOUG NICOL

In the southern Interior of British Columbia, many landslides related to forest development occur on steep slopes below roads and cutblocks that are on

relatively gentle terrain. An important problem in planning forest development is that Forest Practices Code requirements for terrain stability assessments and road design are based on conditions at the site, not on the often more hazardous slopes below.

We have investigated a number of landslide incidents throughout the Nelson Forest Region, including many below cutblocks and roads. Some of these have occurred below "post-Code" roads (those built since the introduction of the Forest Practices Code in 1995). This presentation will focus on several landslides in the Arrow Forest District that illustrate the hydrological and geotechnical processes involved in landslide initiation, as well as the forest planning implications. Two main mechanisms will be discussed: drainage concentration and diversion by roads, and enhanced snowmelt due to clearcuts above potentially unstable slopes.

Coffee Creek landslides and flood event of November 1999

NICHOLE BOULTBEE, DOUG NICOL, PETER JORDAN, AND DWAIN BOYER

On November 11 and 12, 1999, an unusual rainstorm caused flooding and landslides in several areas of the Kootenay region of British Columbia. The area most affected was the Coffee Creek drainage near Balfour, on Kootenay Lake, where serious damage occurred to Highway 31. Several landslides occurred in the watershed, and the Forest Service road along the creek was washed out at many locations.

The relative importance of natural processes, and of landslides and erosion caused by forest development, is an issue that is always raised whenever a damaging hydrologic event occurs. In Coffee Creek, a large landslide in an old cutblock was caused by the rainstorm, and a large natural debris flow occurred in an undeveloped area nearby. Both events added large quantities of sediment to the creek channel, and, downstream from these slides, the channel experienced severe bank erosion and aggradation.

Severe fall rainstorms are very unusual in the Kootenays, where almost all peak flows, as well as landslide and erosion events, occur during spring snowmelt. Information on the climatic and hydrologic causes of the event, and the natural and forestry-related landslides, will be presented.

Recent large-magnitude landslides, Prince Rupert Forest Region

JAMES SCHWAB

Large-magnitude landslides occur on an infrequent basis within the interior portion of the Prince Rupert Forest Region, British Columbia. Where these large landslides occur they have considerable impact to forest land. Four recent large landslides were investigated:

1. Windfall main landslide (Mezidian Lake) was caused by the diversion of creek 300 m down a logging road (7000 m^3 / 20 hr period). Water flowed into a bedrock fault in sedimentary rock. The failure initiated as a bedrock slide of 100 000 m^3 that triggered a debris avalanche, which travelled 900 m to the valley flat. It carried boulders the size of pickup trucks. Total volume transported is in the order of 160 000 m^3. Land area covers 14 ha.
2. Rock avalanche Howson Range (Telkwa pass) originated as a rock topple failure (1×10^6 m^3) from a rock ridge. The rock fell about 150 m onto glacial ice, expanded to cover the ice valley glacier, to a width of 300–400 m, continued down the ice valley, and avalanched into the Limonite Creek valley. The rock avalanche travelled a total distance of 2.6 km, dropping 1300 m in elevation, and severed the Pacific Natural Gas pipeline. The avalanche path through mature forest covered an area 1200 m long by 400 m wide. This area was scheduled for harvest through the Small Business Forest Enterprise Program (SBFEP). Historical rock avalanches have occurred in the Limonite Creek valley. The level of acceptable risk must be considered for forestry operations in potential rock avalanche zones.
3. A retrogressive slide-flow occurred on relatively gentle, completely forested, seemingly benign terrain proposed for timber harvesting (Goat Mountain, Harold Price watershed east of Smithers). Failure was within a deep compact basal till. The landform was dissected by a few minor ephemeral stream channels. There was no evidence of previous large landslides. The landslide covers an area of 6.1 ha. Volume is in the order of 250 000 m^3. The headscarp of the failure bowl is 24–28 m deep. Sliding occurred along an assumed failure plane of 24%. Morphological features resemble failures in sensitive clays. The till is similar to glacial tills found throughout the Bulkley Valley (Liquid Limit 33.5, Plastic Limit 12.1, Plasticity Index 21.4, sand 41.8%, silt 31.0%, clay 27.2%, and bulk density 1.85). The gentle slope and the lack of discernible field indicators suggest that a failure at this site may not have been anticipated through a routine terrain stability field assessment.
4. A large underwater landslide (3×10^6 m^3) occurred off the steep slope of a fan-delta on Troitsa Lake. The visible portion of the landslide measures 400 m by 60 m. A displacement wave 1.5 m high hit the opposite side of the lake 1 km away. A backwash wave 2 m in height crashed back over the head scarp. The north end of the lake (10 km from the landslide), experienced an initial sharp swell about 60 cm in height; bays and shallows were then sucked empty. A large return wave 2 m high crashed through a shallow bay, tearing sunken logs and debris from the bay floor and hurling the debris onto the beach and into the forest surrounding the bay. Boats and floating wharves were ripped from their moorings. The instability of fans and fan-deltas in freshwater fjord-type lakes is mentioned briefly in published literature. However, little documentation exists of known sites and landslide-tsunami events in British Columbia.

Dendrochronology of debris flows on the British Columbia north coast

JAMES SCHWAB

In selected study areas on the British Columbia north coast, debris flows were identified on air photographs and mapped. The identification of failures was repeated for available photo coverage to determine the year of photography when the failure first appeared. A field-sampling program was then undertaken on Graham Island (Queen Charlotte Islands) and in the Prince Rupert area. Failures greater than 1.0 ha in area or large enough to extend into the valley bottom were sampled to determine the possible date of the event. Tree sampling for tree ring analysis was done on slide deposits in the depositional zone or on levees within torrent channels. Generally, 10–15 core samples were obtained for each slide. Scarred trees and trees showing vigorous or suppressed growth that were located along the edge of a slide were also cored or a cross-section disk taken to look for slowing of or release in growth. A search for events recorded in newspapers, journals, technical reports, ship logs, diaries, and company documents was also undertaken to find records and written accounts of storms and landslides. The ages of trees sampled on landslides were then compared and linked to known events. Most of the landslide volume transported occurred during major storm events. Data collected for Graham Island and the Prince Rupert area indicate that six storms over the last 150 years transported 76% of the landslide volume: 9.5%, 14%, 30.9%, 6.5%, 6.4%, and 9.1%, respectively, for the years 1875, 1891, 1917, 1935, 1957, and 1978. This documentation of landslide ages suggests that forest management activity on the north coast has yet to experience the "big storm" similar to the 1917 event.

A handbook for management of snow-avalanche–prone forest terrain

PETER WEIR, PETER JORDAN, AND STEVE CHATWIN

In mountainous regions of British Columbia, forest harvesting is moving onto steeper, potentially avalanche-prone terrain. The B.C. Ministry of Forests has produced a Land Management Handbook aimed at foresters, forest technicians, engineers, engineering technicians, geoscientists, harvest supervisors, and others responsible for managing forests in avalanche-prone terrain. It assists in identifying avalanche-prone terrain and offers principles useful for planning silvicultural operations, cutblock configuration, and harvesting systems to minimize resource losses to snow avalanches.

The handbook highlights:

- appropriate avalanche safety programs where winter harvesting may expose workers to avalanches, providing guidance for the scheduling of winter operations to identify, control, or avoid unacceptable risks; and
- the need to identify areas where avalanches may occur after forest harvesting, with the potential to damage timber or other resources, or to interfere with reforestation.

The handbook employs a risk-based approach. A planning matrix is developed that combines the Canadian avalanche size system, which embodies concepts of vulnerability and consequence, with an estimate of the likelihood of avalanches (using three order-of-magnitude frequency classes) to produce a risk ranking system.

Some operators working in avalanche-prone terrain in British Columbia have developed avalanche risk management programs to proactively "manage with residual risk," a subtle difference from the traditional risk-avoidance approach. A key challenge has been to establish risk management objectives to provide guidance for avalanche practitioners employed by forest companies.

Assessing snow-avalanche risk on harvestable terrain

KEVIN STITZINGER, PETER WEISINGER, AND DAVID MCCLUNG

Each winter there are more than 300 000 avalanches ≥ size 2 (based on the Canadian Classification System) in the mountains of western Canada, 80% of which occur in the Coast and Columbia Mountains of British Columbia. Virtually all of these avalanches occur in forested zones where tree removal can uncover terrain prone to snow avalanche initiation and where existing avalanche paths can be laterally and longitudinally extended if adjacent tree cover is lost.

Our poster will present information on the progress of two current graduate studies from the University of British Columbia's Avalanche Research Group. The goal of both studies is the development of risk-based methods to aid decision-making when harvesting in avalanche-prone terrain. One study focuses on identifying terrain prone to avalanche initiation and estimating risk prior to logging; the second study focuses on issues of risk management where runout zones enter harvestable terrain. The poster will highlight methods and preliminary results.

Identification of natural and logging-related landslides in the Capilano River basin (coastal British Columbia): A comparison between remotely sensed survey and field survey

FRANCESCO BRARDINONI

In the Pacific Northwest, landslide inventories are routinely compiled by means of aerial photo interpretation. When examining photo pairs, the forest canopy, notably in old-growth forest, hides a population of "not-visible" landslides. The present study attempts to estimate the contribution of landslides not detectable from aerial photographs, to the global mass of sediment production from mass failures on forested terrain of the Capilano River basin. To achieve this, aerial photo interpretation has been coupled with intensive fieldwork for identification and measurement of all landslides. In order to minimize bias in the comparison and integration of field-collected and air photo–collected data, it was decided to define a 30-year time window. Results show that not-visible landslides can represent up to 85% of the total number of failures and can account for up to 30% of the total volume of debris mobilized. Rate of sediment production differs greatly (one order of magnitude) between two sub-basins of the study area, suggesting that such figures should be generalized with care within a physiographic region—Pacific Ranges of the Coast Mountains. Discrepancies in denudation rate are explained qualitatively by GIS-based analysis of slope frequency distributions, drainage density, and spatial distribution of surficial materials.