Landslide Risk Analysis of Historic Forest Development in the Interior of British Columbia—Challenges Encountered at Fall Creek

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ABSTRACT

In June 1990, the Fall Creek area east of Enderby, B.C., experienced about 66 landslides. These landslides impacted forested slopes and forestry roads, destroyed several BC Hydro transmission towers, damaged and destroyed houses, and cut off highway access to the area, resulting in the evacuation of residents. These slides also destroyed a fish farm, several licensed water intakes, and impacted on the Shuswap River (salmon spawning habitat). The total cost of the slide events is estimated to exceed $3 million. The 66 landslides occurred during a 3-day period within 12 small watersheds encompassing 3000 ha. The area has experienced logging activity since the 1940s and contains well over 100 km of active and overgrown roads and trails, many of which are no longer visible on recent aerial photographs. The task of sorting out the contribution of the historic logging activities to the landslide events was described by others as "formidable at best." The challenges in commencing such a project included (1) determination of the potential costs of the assessment work; (2) estimating if any practicable conclusions could result from such a study, given the vast network of roads and overgrown trails; and (3) conducting the fieldwork during the narrow work window of the spring freshet (the importance of which became very clear shortly after peak runoff as large streams began to disappear). The fieldwork used an observational approach, which required continuous modification as the work progressed. The fieldwork began with mapping the natural and road drainages along road corridors. The field information was plotted daily on a 1:10 000 scale base map. The plotted information revealed inconsistencies in stream volume and the location of flows. The drainages between road corridors were then traversed. The "piecing together" of the complex series of drainage diversions eventually resulted in the creation of a site drainage map, which showed the interaction between natural drainage and road/trail structures. By overlaying this map with the landslide locations, a link between many of the 66 landslides and drainage diversions was revealed. It is judged that drainage diversions were a significant contributing factor in most of the landslides that occurred in 1990. The creation of this site drainage map proved to be a valuable tool in evaluating the landslide activity associated with historic logging practices. The field studies also conclude that the Forest Practices Code and current forest practices would likely have prevented many of these slides.

INTRODUCTION

Most landslides in the southern Interior of British Columbia can be attributed to drainage diversions and concentration of surface and near-surface water flows. This paper summarizes some of the challenges encountered in assessing the landslide risks posed by historic logging activity in one area. This discussion also provides a reminder of the devastating effects that landslides can have in the Interior.

The study area contains several hundred kilometres of active and overgrown roads and trails, many of which are no longer visible on recent aerial photographs. Conducting a risk analysis within an area with so many roads and trails produced several challenges.

SITE HISTORY

The Fall Creek study area is a large face unit on the north side of the Shuswap River, located approximately 15 km east of Enderby, B.C. The area consists of about 25 small drainage basins, most of which are in the order of 100 ha. The area has been subjected to logging activities since the 1940s. In the early 1980s, the steeper forested slopes in the area of the 1990 landslides and the plateau area upslope of the 1990 landslides were subject to clearcut harvesting.

From June 11 to 13, 1990, a major spring rainstorm triggered 66 landslides in the Fall Creek area. These events occurred near the end of a long period of above-average precipitation. Most of the precipitation fell as rain, with rain on snow occurring above approximately 1300 m elevation. The landslides damaged or destroyed:

- homes and private property (vehicles and equipment)
- several BC Hydro transmission structures
- telephone lines
- water intake structures
- forested slopes
- access roads

Channel avulsion resulted in some landslides and subsequent flooding, which impacted a local fish farm and other small businesses, and delivered sediment into the Shuswap River (important fish habitat). The landslide and flooding events cut off highway access to the area. Many people left the area on foot and some were evacuated by helicopter.

On June 11, landslides destroyed three hydroelectric transmission towers, cutting off the power supply from the Revelstoke Dam. Both of the 500 kV transmission lines were down for 3 days and one line was down for 2 weeks. The loss of revenue to BC Hydro was estimated to be in the millions of dollars per hour. The total cost of the landslide damage in the Fall Creek area not including the BC Hydro revenue loss is estimated to be over $8 million.

On June 12, the same storm event had devastating effects east of Kelowna at Philpott Road, which included loss of life (Cass et al. 1992).

Following the Fall Creek landslide events, the Provincial Emergency Program (PEP) retained a geotechnical engineering consultant to assess the area.

The consultant concluded that the preferred way to protect residents at the bottom of the slopes would be to relocate some homes and construct deflection and training berms to divert future landslides. They also recommended that road structures and drainage issues related to past upslope development be assessed in the field (Thurber 1990a, 1990b).

In 1998, Riverside Forest Products and the B.C. Ministry of Forests approached Terratech Consulting Ltd. to conduct a joint terrain stability mapping and landslide risk analysis study of about 35 000 ha in the Hunters Range area, which included the Fall Creek area. The task was to identify and, if possible, develop remedial measures to reduce the landslide risks from historic logging activities (non-status roads) that are not covered by the current Forest Practices Code. The risk analysis of Hunters Range quickly focused most of its efforts in the Fall Creek area.

CHALLENGES ENCOUNTERED

The three main challenges encountered included (1) creating a realistic budget, (2) creating a base map, and (3) scheduling (timing) of the fieldwork.

Budgeting

At the outset, project budgets were requested for all of the stages, from the beginning office stage to the final prescription stage. During the office portion of the risk analysis,[1] the large number and extent of old roads and trails were noted and the task of assessing the influence of the past development on terrain stability appeared to be daunting. Air photos and 1:20 000 scale topographic maps provided little information regarding the present drainage conditions and could not be relied upon to prepare a budget. Drainage diversions, plugged ditches, cross-ditches, and water concentrations typically cannot be seen on air photos. With hundreds of kilometres of roads and trails, pullback and/or re-contouring all of the roads and trails was considered counter-productive (potentially creating more problems) and very expensive. It was considered unlikely that all the old roads and trails would be deactivated. Accordingly, no practical method to prepare cost estimates for assessing this face unit (multiple drainage basins) with the complex road networks was considered feasible. Cost estimates for these assessments on a per-hectare or per-kilometre basis were considered to be unrealistic. (Perhaps when dealing with a single, linear feature upslope of an identified resource, such as a mainline road upslope of a fish-bearing river, a cost per kilometre estimate could be provided.) Preliminary fieldwork was completed before preparation of a budget for field assessment.

Completion of terrain hazard and risk analysis projects in complex "face unit" areas should include budgets for a pre-field office phase, a preliminary fieldwork phase, a final fieldwork phase, and a reporting and prescription phase. The budget for subsequent phases may not be realistically estimated without the benefits of the results of the previous phase.

Base Maps

The identification of both existing and potential drainage diversion sites associated with past road and trail construction is a ground-intensive procedure. This work is often made more difficult (and time consuming) because

1 Risk Analysis: for definition see CSA (1997).

of the lack of high-quality topographic or planimetric maps showing the location of the old roads and trails and the revegetation of the trails and roads. The detail and reliability of the topographic and planimetric information on the readily available TRIM (Terrain Resource Inventory Mapping) maps is significantly less than that required to assess the impacts and potential impacts of past forest development activity on site drainage and slope stability conditions. The use of historic aerial photographs is essential for the identification of past or recent landslide activity downslope of road and trail sites. As new roads are constructed within a given area, the pattern of the older roads and trails becomes obscured. As a result, the analysis requires the use of multiple years of historic air photos. Given that the scale of most air photos is between about 1:15 000 and 1:30 000, trails associated with ground-based and selective timber harvesting become difficult to delineate. In many areas within the Fall Creek study, trails were noted to be spaced as close as 20 m apart. These issues make the analysis of the spatial relationship between the road and trail drainage issues and landslide or potential landslide sites difficult to resolve and time consuming. These problems are compounded in areas of multiple landslide events and extensive historic development activity, as in the Fall Creek area.

To address some of the challenges of assessing the existing road and trail drainage issues in the Fall Creek area, a detailed topographic map of the area was prepared. This map was prepared from both 1990 and 1994 aerial photography, with additional planimetric information on road and trail locations being obtained from older photography (dating to about 1970). This map was prepared at a scale of 1:5000 and has a contour interval of 5 m. By plotting the field information regarding road and trail drainage issues on this map, a high degree of correlation was noted between the landslide locations and the presence of upslope drainage diversions. In addition, some additional target sites (sites of potential drainage concerns that could impact on the downslope resources) were identified after the final map was prepared.

It is suggested that when performing risk analyses for face units, high-quality topographic base maps with detailed planimetric information be prepared.

Scheduling of Fieldwork

During the preliminary fieldwork (spring of 2000), site drainage information was collected along the drivable roads. This information was compiled onto a base map to form a "site drainage map" at a 1:5000 scale. As a result of this work, it was concluded that existing and potential drainage diversions posed a clear landslide risk to the downslope values considered in the study. Following the creation of a site drainage map, foot traverses of the streams and diverted drainages between the drivable roads were undertaken to tie together the drainage details. During the fall, it became apparent that fieldwork outside of the effective (freshet) work window was not reliable. Ditch and stream flows were not readily visible. Water flows noted in swales and flowing down roads earlier during the freshet had dried up. The connections between altered drainage and past instability that was obvious during the freshet became obscure in the fall. It was unclear in the fall whether a visible diversion scour path was active or an old feature that subsequent road works had corrected. The window of time for effective observation was over. In the Interior, the fall runoff conditions are generally not similar to the spring runoff conditions. Given the difficulty and uncertainty with assessing surface water flows in the late summer and early fall, some of the final fieldwork was delayed until the spring of 2001.

It is suggested the fieldwork for conducting risk analyses not be undertaken outside of the spring freshet season in the Interior.

RESULTS

A total of 66 landslides were noted to have occurred during a 3-day period. Landslides in 10 of the 25 watersheds impacted resources or values in the valley bottom. By superimposing the site drainage information onto the landslide location information, it became apparent that a significant number of the landslide sites appeared to be linked to drainage diversions. Some diversions were judged to be linked to three or more landslides as the diverted flows cascaded down the slope across roads and trails. For example, it is possible that the loss of drainage control in the upper reaches of Newman Creek contributed to between 10 and 15 of the reported 66 landslides that occurred in June 1990. These particular landslides contributed to debris flow activity within existing drainages, which impacted several houses, private property, the Mabel Lake Road, and Shuswap River. Had properly placed culverts, cross-ditches, and swales been incorporated into the road network, a significant number of observed diversions may have been prevented. Note that most of the landslides, which initiated at higher elevations (> 1100 m), appeared to be natural events (i.e., they were not linked to development activity). Some of the landslides on the steeper slopes in the developed areas also appear to have been natural events.

DISCUSSION

The risk analysis work carried out within the Hunters Range (Fall Creek area) identified a number of sites and areas that pose a significant risk to one or more of the resources considered within this study. The risks posed by most of these sites are related to the existence of, or potential for, surface water or near-surface water flow concentration and diversion onto unconditioned, moderately steep to steeply sloping terrain. The field review of a number of the existing landslides located within, and downslope of, past areas of forest development (typically where roads and trails change natural drainage patterns) suggests that ≥ 60% of the landslides can be attributed to one or more of the following site conditions:

- a lack of a coordinated drainage system;
- poorly installed drainage structures;
- improperly located drainage structures; or
- poorly maintained drainage structures.

As many of the landslides noted in the field could be readily linked to drainage problems, the risk analysis focused on the identification of existing and potential drainage diversions or concentrations. These situations are judged to represent a short-term[2] risk, where landslide activity could be initiated as a result of the next spring freshet or significant rainfall event. It was concluded that repairs to drainage problems would significantly reduce the likelihood of landslide activity and should be undertaken prior to considering long-term[2] issues such as perched fills (oversteepened road fill reinforced by organic debris).

In recent years, wood-supported fills have been pulled back and in many cases the materials have been end-hauled to dump sites. This approach to landslide hazard mitigation and risk management is expensive. Significant funds are required for the pullback of wood-supported fills to reduce the landslide hazards and risks within a given area. A more cost-effective risk-mitigation strategy would be to address drainage problems. In many cases, landslide hazard mitigation projects requiring drainage works often include extensive fill pullback programs. This significantly increases the cost estimates of most projects, resulting in the deferral of both the drainage and fill pullback work. This leaves the "short-term" hazards (and risks) related to drainage not mitigated.

SUMMARY

The risk analysis work conducted within the Fall Creek study area has illustrated the importance of establishing and maintaining good drainage control on all roads and trails. The loss of control on a single stream channel can lead to extensive landslide activity and damage to forest land and other downslope resources. Depending on the location of the diversion and the extent and condition of the roads and trails downslope of the diversion site, a single diversion can result in multiple landslide events.

Based on the results of the Fall Creek risk analysis work, it is suggested that the following procedure be considered for landslide risk analysis projects in areas of past forest development in the Interior:

1. Identify the areas where high-value resources are located. This may be considered to be the point or area of interest (AI).
2. Identify areas or zones upslope of the AI that include slope stability class III, IV, or V terrain and that have been subjected to past forest development activity or have had forest development upslope. This will require the use of existing maps and both recent and historic aerial photographs.
3. Collect or prepare high-quality maps of the area that show the existing road and trail locations and existing stream channels.
4. Conduct field mapping of the site drainage conditions during the spring freshet and collect detailed information on the existing road/trail drainage network. This should include, but not necessarily be limited to:
   - road grade (adverse vs. favourable), swale locations, drainage divide locations, and cross-ditch and water bar (and reverse water bar) locations;
   - culvert locations and conditions, and ditch locations and conditions;
   - direction of ditch line flow, seepage locations, stream channel locations, and location of ponded water;
   - evidence of water diversion, stream erosion or deposition, and scour on road surface, cutslope, or fillslope;

2 Short-term risk is used to describe a higher level of risk associated with a short return period event. Long-term risk is used to describe a lower level of risk, associated with a long return period event. See RIC (1996).

- landslide activity from cutslope or fillslope, excessive flows down ditch line, and excessive (particularly unconfined) flows over the cutslope and fillslope;
- evidence of recent repairs to culvert or other structures, and additional or replaced culverts; and
- dry channel locations with evidence of past flow, and natural swale or gully location (that presently may not have flows).

5. Compile this site drainage information onto the base map and determine if other areas (perhaps with more difficult access) should be assessed in the field.
6. Traverse all stream channel reaches (including non-classified drainages) that extend through the areas of past development.
7. Assess in the field the potential for drainage diversions to occur and the likelihood that landslides will be triggered.

CONCLUSION

Drainage concentrations and diversions are responsible for most of the development-related landslides in the southern Interior. Understanding the interaction between natural and development-related drainage is critical in analyzing landslides within and downslope of development. Figure 1 illustrates the relationship between resource values, development, and terrain, and how these components should be addressed in landslide risk analyses.

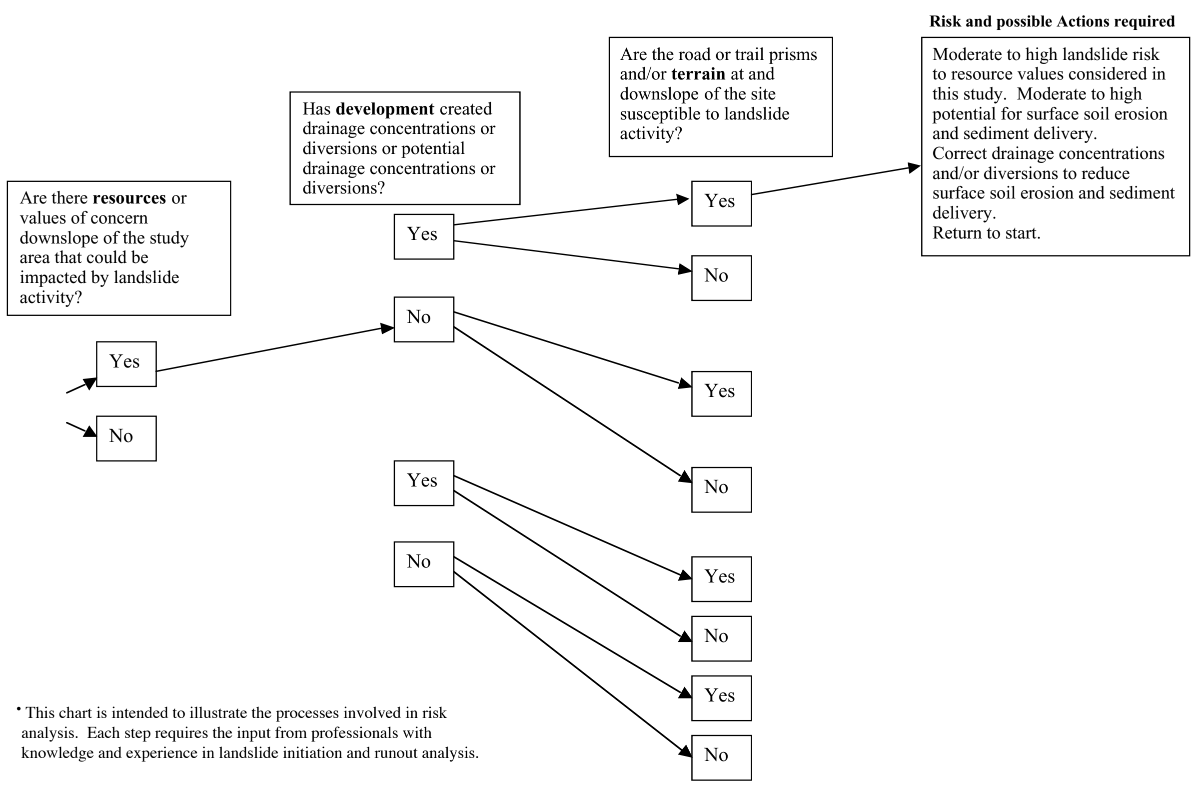

FIGURE 1 *Method of analyzing landslide risk in areas of historic forest development.*

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