



Streamline

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Summary of Landslide Occurrence on Northern Vancouver Island

Glynnis Horel

Introduction

A considerable body of literature is available on landslide occurrence related to forest development on Vancouver Island. Studies on the subject began in the mid-1980s. Various researchers have investigated landslides and their relationship to specific terrain attributes (Rollerson and Sondheim 1985; Rollerson *et al.* 1986, 1997, 2001, 2002; Millard *et al.* 2002, and others). Recently, Guthrie (2002, 2005) examined landslide frequencies in several harvested watersheds, and mass-wasting potential on Vancouver Island. Roberts *et al.* (2004) compared landslide rates for helicopter and conventional harvesting. These studies offer important information on landslides, but many questions for northern Vancouver Island remain,

particularly with the recent changes in forest management legislation from the *Forest Practices Code (FPC 1995)* to the *Forest and Range Practices Act (FRPA December 2003)*.

The *Forest and Range Practices Act* moves from a prescriptive *Forest Practices Code* to a results-based forest management regime, wherein government sets management objectives and forest companies develop strategies or methodologies to meet these objectives. The *FPC* introduced a number of key changes for forest development on steep terrain. These included the requirement to identify unstable (Class 5) or potentially unstable (Class 4) terrain at the planning stage for roads and cutblocks. If road locations could not avoid this terrain, design approaches and construction methods needed to minimize the potential for instability. In particular, full-bench and end-haul construction techniques were introduced as standard practice on steep slopes to avoid creating unstable road fills.

Higher standards were set for road drainage and culverting, and roads were required to be deactivated when not in active use. For harvesting, features with a high hazard of instability, such as gullies and escarpments, and slope areas with indicators of natural instability, were to be avoided or minimized within the cutblock.

In preparing for results-based management, Western Forest Products Inc. (WFP) began a project in 2004 to compile overview-level landslide inventories on Tree Farm Licence 6 (TFL 6) to assist with the development of results and strategies under *FRPA*. One component of the project was a landslide inventory. This paper summarizes the analysis of the landslide inventory data covering 1980 km² of northern Vancouver Island (Figure 1).

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This analysis addresses specific questions, including:

- What is the frequency of landslides from forest roads and harvested cutblocks on TFL 6?
- Has the frequency of landslides from forest roads and harvested cutblocks changed in response to changes in management practices (pre-FPC vs. practices under the FPC)?
- Since the magnitude of an event is an important component in evaluating potential consequence, what is the size distribution of landslides from forest roads and cutblocks?
- How does the occurrence of landslides from forest roads and cutblocks compare with that of natural landslides?

Study Area

The study area, located on northern Vancouver Island (Figure 1), encompasses WFP's TFL 6. The project area ranges in elevation from sea level to approximately 1220 m. The east side of the project area (east side of Vancouver Island) is typically the driest. Inlets and valleys appear to funnel and concentrate rainstorms (e.g., Port

Alice, Holberg). Overall, the entire region experiences occasional storms of greater than 100 mm rainfall in 24 hours, with the wetter parts of the region experiencing these storms several times a year. Environment Canada climate stations located near the study area are shown on Figure 1; Table 1 summarizes precipitation data for these stations. Precipitation is usually greater at higher elevations. Chatwin *et al.* (1994) noted that the hazard of landslides increases for rainfall events of 100 mm or more in 24 hours; a comparison of landslide events with precipitation data in the study area indicates the same trend. The events reported below indicate that landslide-causing storms occur several times a year in the wetter part of the study area. A thorough treatment of landslide-causing hydro-meteorological conditions for the north coast of British Columbia is given in Jakob *et al.* (2006). Actual thresholds for landslide initiation may vary by region.

Bedrock geology in the study area is highly complex. Volcanics of the Karmutsen Formation dominate the east side of the project area (Massey 1994). These are typically overlain with veneers or blankets of silty to gravelly tills on the lower and

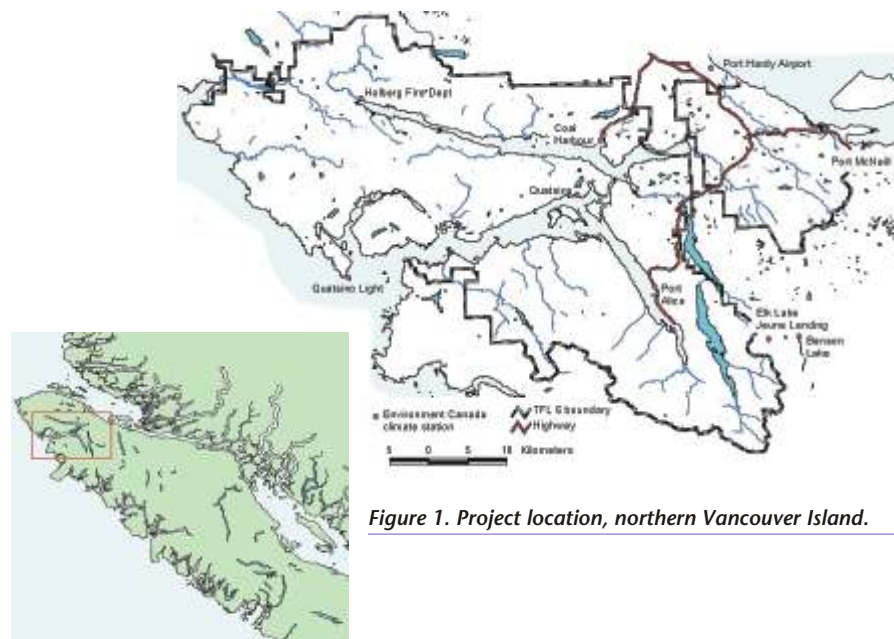


Figure 1. Project location, northern Vancouver Island.



Table 1. Environment Canada climate stations – precipitation summary

Station	Elevation (m)	Period of record	Mean annual precipitation (mm)	Maximum 1-day rainfall (mm)
Benson Lake	145	1959–1972	3554	182
Coal Harbour	57	1968–1996	1960	120
Elk L. Jeune Landing	110	1924–1938	2900	146
Holberg Fire Dept.	46	1967–1991	3963	223
Port Alice	21	1924–2002	3148	234
Port Hardy Airport	22	1944–2003	1795	154
Port McNeill	91	1974–1983	1892	157
Quatsino	8	1895–2002	2418	162
Quatsino Light	21	1978–2002	2569	118

mid-slope areas, and on moderate terrain between Port Alice and Port Hardy. In steeper terrain around the Benson Lake area, the mid- and upper slopes have veneers or blankets of silty to gravelly colluvium. Between Port Alice and Benson Lake, narrow bands of Parson Bay and Quatsino Formation sedimentary units include limestone with karst features. The narrow band of Cretaceous sedimentary units of the Nanaimo Group along the east coast from Port McNeill to the Port Hardy Airport is typically overlain by silty to clayey tills and deep glaciofluvial deposits with minor glaciolacustrine and glaciomarine sediments.

Bonanza Group volcanics dominate the west side of the area. There are occurrences of Queen Charlotte Group sedimentary units and minor occurrences of Kyoquot Group sedimentary units. In this area as well, bedrock is typically overlain by silty tills in moderate terrain and on lower valley slopes. Mid- and upper valley slopes have colluvial veneers or blankets. There are wetlands (mostly swamp forests or forested swamps) in the moderate terrain west of Holberg. Glaciofluvial deposits are found in many of the larger valley floors, especially at valley confluences. Occurrences of Island Plutonic Suite intrusives are scattered throughout the study area.

No specific intersection of bedrock units with landslides has been done

for this study but visual observations of landslide distribution and bedrock types suggest no strong correlation to bedrock units. Landslide occurrence is strongly correlated to steep slopes (>60%) regardless of bedrock type, except in the Parson Bay limestone units where very few slides occur.

Analysis Methods

The landslide inventory was compiled from interpretation of 1995 colour airphotos at an approximate scale of 1:20 000, and from WFP landslide event reports compiled to June 2004. A 2003 georeferenced satellite image (resolution = 10 m) of the study area was reviewed for landslides that may have been missed on event reports. Landslides include events of about 500 m² (0.05 ha) and larger; smaller landslides are not identifiable on the scale of airphotos used in this study. Small landslides (i.e., <0.25 ha) are often not detectable on airphotos after about 10 years because regenerating forests conceal them. The airphoto inventory, therefore, is not a record of all landslides that may have occurred pre-1995, but rather focuses on those that were discernible on the 1995 airphoto series. It is likely that a significant number of small landslides occurred in the past that are not in this inventory because they are no longer detectable. As well, small landslides in unharvested timber may not be detectable under the forest

canopy from airphotos or from the air (Robison *et al.* 1999).

Since 1995 (and in some operations before that), landslides have been recorded in event reports. Landslides were identified via helicopter overflights and in road-based inspections. Some operations do this regularly after major storms; other operations combine landslide inspections with flights for other work. Because forestry activities continue in cutblocks until the stand is free to grow (and often beyond), reporting of events in harvested areas is thorough. Roads under permit receive similar scrutiny. Unharvested timber is reviewed during helicopter inspection flights but may not receive the same attention unless a landslide has reached a road or cutblock. Therefore, it is not certain that all natural landslides occurring after 1995 were found and recorded in event reports. Landslides large enough to be visible on the 2003 satellite image but not recorded in event reports were captured. Small landslides may not have been visible on the satellite image because of the low resolution.

This overview study has two possible uncertainties related to the timing of landslides following harvesting. The first is the actual time of the landslide. For example, if a landslide was discovered and reported in January 2002 but the date of the slide was unknown, this analysis assumed it to have occurred January 2002. If it had in fact occurred in late 2001, the data summary would show the landslide to be a year later than it actually was, relative to the year of cutblock harvest. Second, the year of logging recorded in WFP's inventory is the year in which yarding is completed. If yarding was started in one year but completed the next, the data summary would show the logging to be in the year it was completed.

As noted above, this overview-level inventory did not include field verification of landslides, except via

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helicopter reconnaissance by WFP operations staff for identification of slides recorded in event reports.

For landslides identified from airphoto interpretation, the following information was recorded:

- size class (Table 2)
- point of origin (Table 3)
- vegetation condition apparent on the 1995 airphotos (vegetated, nonvegetated, partly vegetated).

For landslides identified from event reports, the following information was recorded:

- date of occurrence, as close as known
- point of origin (Table 3)
- slide length and area.

Table 2. Landslide size classes

Size class	Landslide surface area
1	<1000 m ² (<0.1 ha)
2	1000–2500 m ² (0.1–0.25 ha)
3	>2500–5000 m ² (>0.25–0.5 ha)
4	>5000–10 000 m ² (>0.5–1.0 ha)
5	>10 000 m ² (>1.0 ha)

In the airphoto inventory, if a landslide within a cutblock was vegetated, it was not possible to tell whether the slide predated the cutblock. These landslides were assumed to be associated with harvesting (OS, G, ESC, CB).

The data were captured spatially in Arcview™ shapefiles as a point theme, with the point positioned at the top of the landslide. A point theme is a convenient and economical way to capture many landslides. It lends itself well to data analysis including intersections with other spatial data such as harvested cutblocks, terrain stability or slope polygons, watershed polygons, or other management units.

The accuracy of landslide size estimates from airphotos depends on when the landslide occurred relative to the date of photography. The spatial extent of landslides that are partly

or fully vegetated is uncertain; for this reason the size of landslides identified on airphotos and appearing partly or fully vegetated may be underestimated. Landslide sizes from event reports are more accurate than those estimated from airphotos. The starting

ellipse images were digitally measured as a spot check against the event reports. For the data summaries in this paper, the following points of origin are grouped together as slides in harvested cutblocks: OS, G, ESC, CB, and WT.

Table 3. Landslide origin

Point of origin	Definition
N	Slide originates in unharvested timber. Includes all types of natural slides (debris slides or flows, rockfalls, etc.).
OS	Slide originates on open slope in harvested cutblock.
G	Slide originates in harvested gully (headwall, sidewall, or gully bottom). Includes torrented or severely eroded gullies.
ESC	Slide originates in frontal slope of escarpment or sidewall of inner gorge (harvested).
CB	Slide originates in harvested cutblock, gully, or escarpment (not differentiated).
WT	Slide originates in windthrow patch.
RC	Road cut failure.
RF	Slide originates at road fillslope.

point of landslides identified from airphotos was plotted on the 2003 satellite image. Size was estimated by digitally measuring the slide length (or for large landslides, the landslide area) on the satellite image. The resolution of the satellite image, and the vegetation condition of the landslides apparent on the airphotos limited the accuracy of these size estimates.

Landslide lengths and areas given on event reports usually include the entire disturbed area, including the gully transport zone in channelized debris flows. Landslide event reports often include a 1:5000 map showing the limits of the slide sketched from aerial observations and from photographs taken of the slide. Landslide areas presented in the event reports are usually measured from these maps. In some event reports, only a 1:20 000 map is included and the estimate of landslide area is less accurate. Landslides from the event reports were also plotted on the 2003 satellite image, but the areas recorded were taken from the event reports. Some areas of large slides visible on the sat-

Landslide Occurrence

The region experiences both natural landslides and landslides associated with forest development. Natural landslides are an important part of the physical watershed processes in this region. Landslides have formed fans on the larger valley floors, and along lake and ocean shorelines. Natural landslide deposits influence or even control valley-bottom and stream morphology. Sediment from landslides is important for the replenishment of spawning gravels, both in streams and along shorelines. The largest events in the study area are natural rockslides. These rare events are not within the scope of forest management, but should be considered in the overall watershed processes and are recorded in the inventory.

The magnitude of an event is an important component of consequence (Wise *et al.* [editors] 2004). Small events (≤ 0.25 ha) may not significantly affect forest productivity (BC Forest Practices Board 2005) but may, for example, have a high consequence

to a fish stream or water intake, depending on location. Data on probable landslide size help in assessing acceptable risks to downslope resources. In the following data tables and discussions, “pre-FPC” refers to the period before 1995; “post-FPC” refers to 1995 and later. The “post-FPC” data in this paper are for the period 1995 to 2004.

Natural and Development-related Landslides: Total Occurrence and Size Distribution

Table 4 and Figure 2 show the total landslide inventory by size-class distribution for the three major origin categories over the entire study area (1980 km²). These data include events

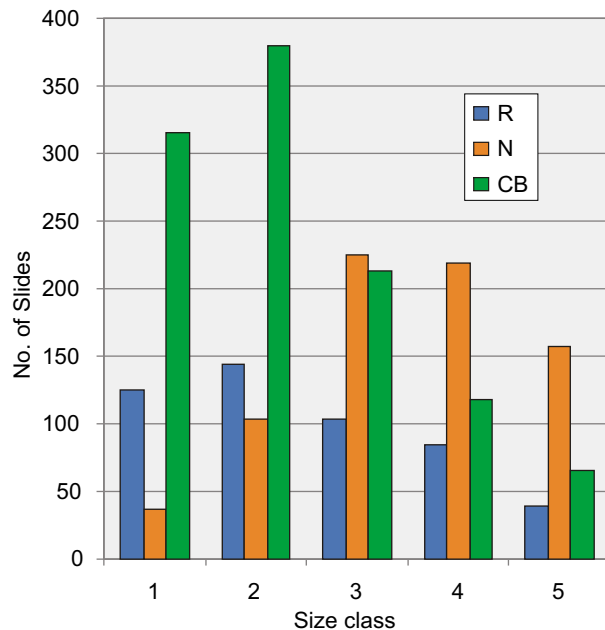


Figure 2. Landslide distribution for all types of slides.

Further, landslides on post-FPC roads are typically smaller than those on pre-FPC roads.

For ease of analysis, this paper compares the pre- and post-FPC landslide frequency for roads and cutblocks that was compiled for a study of 56 watersheds within the project area. These watersheds comprise a total area of 1506 km² and include all primary watersheds in the study area with a drainage area of 100 ha or larger. For these 56 watersheds,

WFP’s inventory data show the length of road constructed on steep terrain before 1995 to be 371km, and the number of slides from these roads was 319. The length of road constructed on steep terrain from 1995 to the end of 2003 was 102 km, and the number of slides was 23. “Steep terrain” for this analysis was taken to be Stability Class 4 and Class 5 terrain, plus slopes steeper than 60% that fall outside the Class 4 and 5 terrain polygons.

The landslide frequency for pre- and post-FPC roads constructed on steep terrain, then, is:

- Pre-FPC roads (constructed before 1995): 0.9 slides per kilometre of road on steep terrain.
- Post-FPC roads (constructed 1995 or later): 0.2 slides per kilometre of road on steep terrain.

Fifty percent of landslides for the post-FPC roads are in the smallest size class (<1000 m²) compared with 24% for pre-FPC roads. However, the pre-FPC roads span a much longer time frame than the post-FPC roads. Small slides that may have occurred more than 10 years before the 1995 airphotos may not have been cap-

Origin	No. of slides by size class					Total	% of overall total
	1	2	3	4	5		
Road cut or road fill (R)	125	144	104	84	39	496	21%
Unharvested timber (N)	37	104	225	219	157	742	32%
Harvested cutblock (CB)	315	380	213	118	65	1091	47%
Total	477	628	542	421	261	2329	100%
Percentage (%)	20%	27%	23%	18%	11%	100%	

for pre- and post-FPC roads and cutblocks as well as landslides in unharvested timber.

Both natural and development-related landslides vary across the region, with greater concentrations in some areas than others. Compiling the data across smaller units (such as watersheds) is beyond the scope of this study. Nevertheless, even at the TFL scale, the results are informative.

For landslides originating at roads or in harvested cutblocks, most are in the two smallest size classes. For roads, 54% of landslides are in size classes 1 and 2; for harvested cutblocks, 64% of landslides are in these two size classes. Landslides originating in unharvested timber comprise 32% of the total slide inven-

tory and have a larger size distribution; only 19% are in the two smallest size classes. However, as noted, reporting of natural landslides may be incomplete, especially for small events under the forest canopy. The number of natural landslides may be underestimated.

Landslides from Roads

Table 5 and Figure 3 summarize landslide size distribution originating at road cuts and fills by era of road construction. Roads appearing on the 1995 airphotos were considered pre-FPC; roads in WFP’s inventory not appearing on the 1995 airphotos were considered post-FPC. The data indicate that the frequency of landslides decreased four-fold on post-FPC roads compared with pre-FPC roads.

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Era of construction	No. of slides by size class					Total
	1	2	3	4	5	
Built before 1995	111	137	102	81	37	468
	24%	29%	22%	17%	8%	100%
Built 1995 or later	14	7	2	3	2	28
	50%	25%	7%	11%	7%	100%
Total	125	144	104	84	39	496

Landslides from Harvested Cutblocks

Table 6 and Figure 4 show the size-class distribution of landslides in pre-FPC and post-FPC cutblocks to 2004. The frequency of landslides in harvested cutblocks for pre-FPC cutblocks is almost double that of post-FPC cutblocks. Unlike road landslides, the size distributions of landslides in pre- and post-FPC cutblocks are similar.

For the 56 watersheds in the study area, the total area of steep terrain logged before 1995 was 8711 ha, and the number of cutblock slides was 746. The total area of steep terrain logged from 1995 to 2004 was 1690 ha, and the number of cutblock slides was 82. "Steep terrain" is defined here the same as above; that is, the combined area of Stability Class 4 and 5 terrain plus the area of slopes steeper than 60% that fall outside the Class 4 and 5 polygons.

For these 56 watersheds, then, the frequency of landslides from cutblocks is as follows:

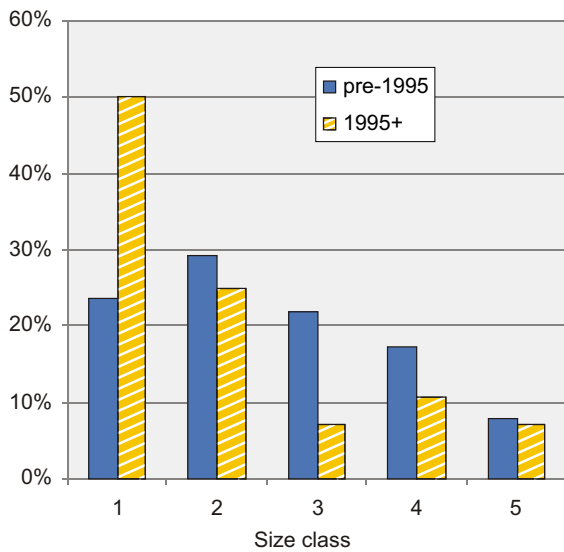


Figure 3. Size-class distribution of landslides from pre- and post-FPC roads.

tured in the inventory. Had these been captured, the size-class distribution may show a somewhat higher distribution of slides in the two smaller size classes for the pre-FPC roads. It would also increase the overall frequency of slides per kilometre of road on steep terrain for the pre-FPC case.

Arguably, the older roads have been more fully tested than the post-FPC roads, because road fills supported on

logs or stumps can fail many years after construction as the wood decays and yields. Event reports show that this still occurs on old roads. However, the FPC introduced the principal change of end-haul construction as standard practice on steep terrain. Therefore, it is unlikely that a significant number of these types of failures would appear on post-FPC roads over a longer time frame. Failures that might occur on both pre- and post-FPC roads could be asso-

ciated with alterations to road drainage or failure of drainage structures. But the typically old, oversteepened fills on pre-FPC roads would still be more vulnerable to slides caused by road drainage, so this is unlikely to significantly change the relative frequencies of pre- and post-FPC road landslides.

Period of harvest	No. of slides by size class					Total
	1	2	3	4	5	
Pre-1995 harvest	282	349	192	103	54	980
	29%	36%	20%	11%	6%	100%
1995 and later harvest	33	31	21	15	11	111
	30%	28%	19%	13%	10%	100%
Total	315	380	213	118	65	1091

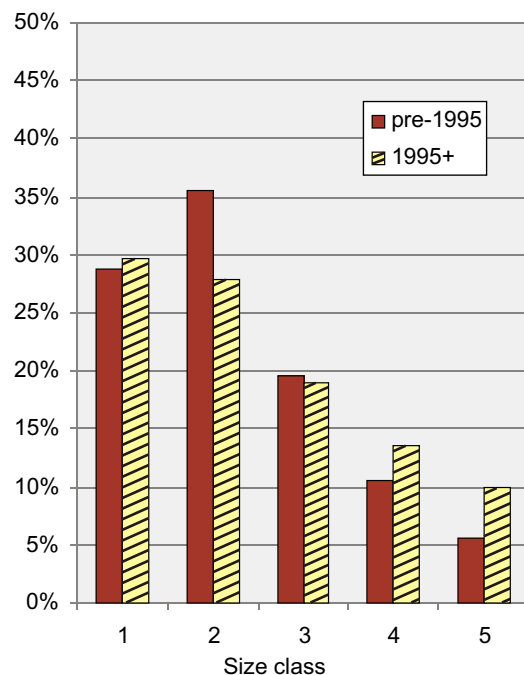


Figure 4. Size-class distribution of cutblock landslides pre- and post-FPC.

- Pre-FPC cutblocks (harvested before 1995): 8.6 slides per 100 ha logged of steep terrain.
- Post-FPC cutblocks (harvested 1995 or later): 4.9 slides per 100 ha logged of steep terrain.

Recent cutblocks, and especially those harvested within the last 5 years, may not have been fully tested, and might experience further landslides (see below for a discussion on the timing of landslide occurrence following harvesting). As with roads, small landslides occurring more than 10 years before the 1995 airphotos may not have been captured. Accounting for these landslides would probably increase the landslide frequency in pre-FPC cutblocks.

The size distribution of landslides in pre- and post-FPC cutblocks follow similar trends. For pre-FPC cutblocks, 65% of landslides were in the two smallest size classes. For post-FPC cutblocks, 58% were in the two smallest classes.

Timing of Cutblock Slides Following Harvesting

For landslides recorded on event reports, the date of landslide occurrence is usually known to within a few months, and sometimes linked to a specific storm. This information allows a comparison between the time of landslide occurrence and the time of harvest. Figure 5 illustrates the number of cutblock landslide events for time periods following harvesting. These data include slides from both pre- and post-FPC cutblocks.

These data show the greatest frequency of landslides (76%) to be within the first 5 years immediately following harvesting. Figure 6 breaks down the distribution of slides within the first 10 years following harvesting

to examine more closely the landslide occurrence during this time frame.

These data still show a strong trend in occurrence of cutblock landslides in the first few years following harvesting. Forty-eight slides (27%) occurred in the same year as harvest, some in the first storm after harvesting.

Root strength deterioration is a factor in the occurrence of shallow rapid debris slides following harvesting (Ziemer and Swanston 1977; O’Loughlin and Ziemer 1982; Abe and Ziemer 1991). Rates of root strength deterioration vary with root size, tree species, and region. Small roots can lose strength within a few months of harvesting while large roots can take years. Investigators have found that total root strength typically reaches a minimum between 4 and 10 years following harvest (depending on species and other factors), after

declines, the rate of landslides increases correspondingly. One would expect landslide occurrence to peak at the same time as total root strength reaches a minimum.

Studies have recorded significantly increased rates of landslides in the 10 years after harvesting (O’Loughlin and Ziemer 1982). Gray and Megahan (1981) found an increase in landslides in the 4–10 years following vegetation removal in the Idaho Batholith. Using slope stability and hydrology models and assuming root strength decay, modelling by Dhakal and Sidle (2003) of landslide occurrence in Carnation Creek predicted clustering of landslides in the 5- to 17-year period following harvesting,

However, the data in TFL 6 do not follow this trend. Most landslides occur soon after harvest, and decline sharply with time. In particular, the number of

landslides that occur in the same year as harvest suggests that root strength decay may not be the most important factor in the occurrence of post-harvest open-slope landslides. Keim and Skaugset (2003) question the role of root strength as the primary influence of forest cover on stability.

Differences in terrain conditions (for example, glaciated vs. unglaciated) could be a factor in the different trends in TFL 6 compared with other areas studied, and the relative importance of root

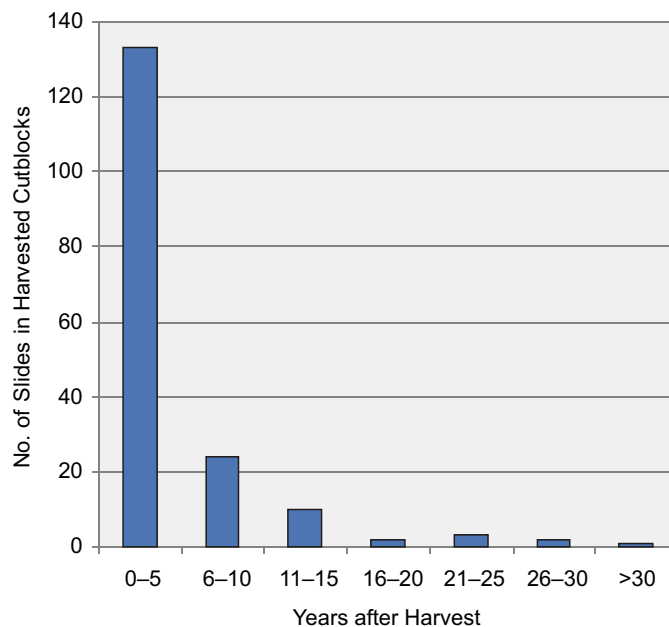


Figure 5. Time of cutblock slides after harvesting.

which root strength increases with the regenerating forest. Within the rooting zone, roots supply a component of soil shear strength. The decline of root strength decreases the shearing resistance of the soil mass in this zone. It follows that, as root strength

strength in slope stability. Landslide investigations by the author as well as others on Vancouver Island have found that the failure surface is most often at an interface—between soil and rock, or between weathered and unweathered soil horizons—and is

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usually below the root mat. Investigators in other regions explain the role of root strength by shear planes extending through the rooting zone. Root strength here might only be a factor at the tear point where the slide initiates, and not along the failure surface.

An important factor in the occurrence of cutblock landslides may be changes in the soil pore pressure regime. Site investigations (by the author and others) have found that fairly minor changes to surface water flow can cause landslides. Road drainage onto slopes below the road can be a significant factor; but, for the open-slope slides in the event reports, 54%

patterns from yarding; minor changes to the near-surface macropore structure due to falling and yarding (Ziemer 1992); and loss of canopy interception that would allow more rapid pore pressure spiking during intense storms. Keim and Skaugset (2003) refute the concept that a forest canopy has a maximum capacity beyond which all precipitation is transferred to the ground; they suggest that the forest canopy has an intensity smoothing effect that could be relevant to slope stability.

Landslides do not occur uniformly through time; they tend to be clustered around specific severe storm events. However, storm intensity can-

the cutblock from new harvesting or new road construction, or to root strength decay.

In summary, the factors contributing to post-harvest open-slope failures are complex and probably vary from site to site and region to region. However, in this data set, the temporal distribution of slides following harvesting is inconsistent with root strength decay being the major factor.

Summary of Key Observations

- For landslides originating at roads or cutblocks, most slides (both pre- and post-FPC events) are smaller than 0.25 ha. Natural events occur relatively more frequently in larger size classes.
- The occurrence of landslides from roads on steep terrain built in 1995 and later compared with roads built before 1995 has decreased four-fold. As well, the size of landslides from post-FPC roads tends to be smaller than those on pre-FPC roads.
- Bearing in mind that recent cutblocks have not been fully tested, there has been almost a two-fold reduction in landslides from cutblocks on steep terrain harvested in 1995 and later compared with cutblocks harvested before 1995.
- Changed management practices have resulted in fewer landslides for both roads and cutblocks.
- The greatest frequency of landslides from harvested cutblocks occurred in the first 5 years following harvesting, with 27% occurring in the same year as harvest and some landslides occurring in the first storm following harvesting. This result suggests that root strength decay may not be the most important factor in these types of landslides.

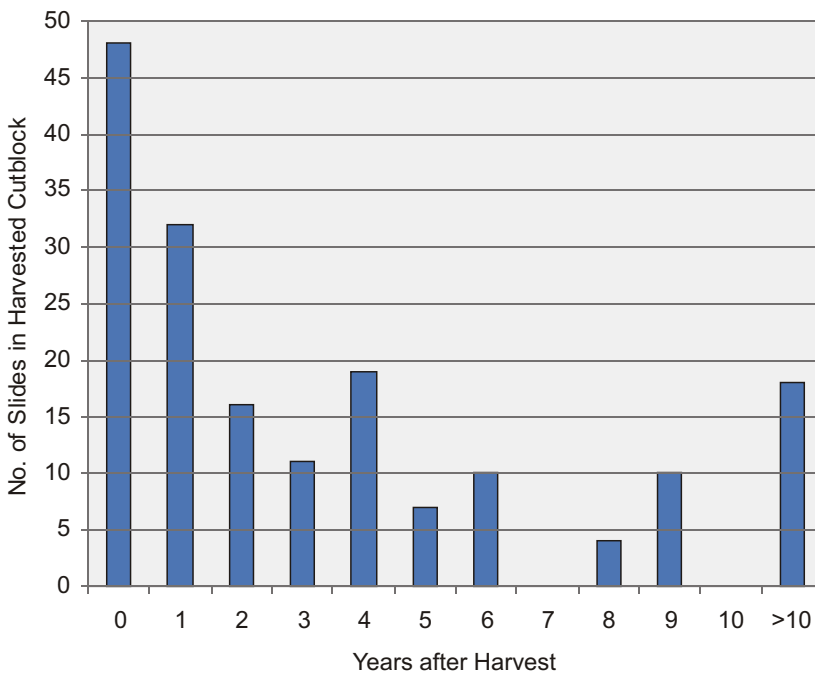


Figure 6. Distribution of landslides after harvesting.

occurred below roads and 46% occurred where no roads were present upslope, so this factor alone does not account for the trend. Some boundary-edge slides are associated with windthrow, which allows more rapid ingress of water at the upturned root wads. Other factors may include minor changes in surface drainage

not be the sole factor because this would flatten the trends shown in Figures 5 and 6. Cutblocks of various ages would experience slides in the same storm. Storm patterns could contribute to scatter beyond the first few years. Some of the longer-term scatter could be due to other factors such as changes in the slopes above

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Literature Cited

- Abe, K. and R.R. Ziemer. 1991. *Effect of tree roots on shallow-seated landslides*. United States Department of Agriculture Forest Service, General Technical Report PSW-GTR-130.
- Chatwin, S.C., D.E. Howes, J.W. Schwab, and D.N. Swanston. 1994. *A guide for management of landslide-prone terrain in the Pacific Northwest*. Second edition. BC Ministry of Forests, Victoria, BC. Land Management Handbook Number 18.
- British Columbia Forest Practices Board. 2005. *Managing landslide risk from forest practices in British Columbia*. Victoria, BC. Special Investigation FPB/SIR/14.
- Dhakal, A.S. and R.C. Sidle. 2003. *Long-term modeling of landslides for different forest management practices*. *Earth Surface Processes and Landforms* 28(8):853–868.
- Gray, D.H. and W.F. Megahan. 1981. *Forest vegetation removal and slope stability in the Idaho Batholith*. United States Department of Agriculture Forest Service, Research Paper INT-127.
- Guthrie, R.H. 2002. *The effects of logging on frequency and distribution of landslides in three watersheds on Vancouver Island, British Columbia*. *Geomorphology* 43(3–4):275–294.
- _____. 2005. *Geomorphology of Vancouver Island: mass wasting potential (includes maps)*. BC Ministry of Environment, Victoria, BC. Research Report Number RR01.
- Jakob, M., K. Holm, O. Lange, and J.W. Schwab. 2006. *Hydrometeorological thresholds for landslide initiation and forest operation shutdowns on the north coast of British Columbia*. Landslides, DOI 10.1007/s10346-006-004-1. Springer-Verlag.
- Keim, R.F. and A.E. Skaugset. 2003. *Modelling effects of forest canopies on slope stability*. *Hydrological Processes* 17:1457–1467.
- Massey, N.W.D. 1994. *Geological compilation, Vancouver Island, British Columbia (NTS 92B, C, E, F, G, K, L, 102I)*. BC Ministry of Energy, Mines and Petroleum Resources, Victoria, BC. Open File 1994-6. 1:250,000 scale.
- Millard, T., T.P. Rollerson, and B. Thomson. 2002. *Post-logging landslide rates in the Cascade Mountains, southwestern British Columbia*. BC Ministry of Forests, Vancouver Forest Region, Research Section, Nanaimo, BC. Forest Research Technical Report TR-023/2002.
- O'Loughlin, C. and R.R. Ziemer. 1982. *The importance of root strength and deterioration rates upon edaphic stability in steepland forests*. In *Proceedings, IUFRO Workshop, August 2–3, 1982, Corvallis, Oregon*, pp. 70–78.
- Roberts, B., B. Ward, and T. Rollerson. 2004. *A comparison of landslide rates following helicopter and conventional cable-based clear-cut logging operations in the Southwest Coast Mountains of British Columbia*. *Geomorphology* 61:337–346.
- Robison, E.G., K.A. Mills, J. Paul, L. Dent, and A. Skaugset. 1999. *Storm impacts and landslides of 1996: Final report*. Oregon Department of Forestry, Forest Practices Monitoring Program, Salem, Oregon. Forest Practices Technical Report Number 4.
- Rollerson, T., T. Millard, and B. Thomson. 2002. *Using terrain attributes to predict post-logging landslide likelihood on southwestern Vancouver Island*. BC Ministry of Forests, Vancouver Forest Region, Research Section, Nanaimo, BC. Forest Research Technical Report, TR-015/2002.
- Rollerson, T., T. Millard, C. Jones, K. Trainor, and B. Thomson. 2001. *Predicting post-logging landslide activity using terrain attributes: Coast Mountains, British Columbia*. BC Ministry of Forests, Vancouver Forest Region, Research Section, Nanaimo, BC. Forest Research Technical Report, TR-011/2001.
- Rollerson, T. and M. Sondheim. 1985. *Predicting post-logging terrain stability – a statistical-geographical approach*. In *Proceedings, Joint Symposium of the IUFRO Mountain Logging Section and the Sixth Pacific Northwest Skyline Symposium*, Vancouver, BC.
- Rollerson, T.P., D.E. Howes, and M.W. Sondheim. 1986. *An approach to predicting post-logging slope stability for coastal British Columbia*. In *Proceedings, NCASI West Coast Regional Meeting, Portland, Oregon*.
- Rollerson, T.P., B. Thomson, and T.H. Millard. 1997. *Identification of coastal British Columbia terrain susceptible to debris flows*. In *Proceedings, 1st International Conference, Debris-Flow Hazards Mitigation: Mechanics, Prediction and Assessment*. American Society of Civil Engineers. August 7–9, 1997, San Francisco, Calif.
- Wise, M.P., G.D. Moore, and D.F. VanDine (editors). 2004. *Landslide risk case studies in forest development, planning and operation*. BC Ministry of Forests, Research Branch, Victoria, BC. Land Management Handbook Number 56.
- Ziemer, R.R. 1992. *Effect of logging on subsurface pipeflow and erosion: coastal northern California, USA*. In *Proceedings, Chengdu Symposium: Erosion, Debris Flows and Environment in Mountain Regions*. IAHS Publication Number 209, pp. 187–197.
- Ziemer, R.R. and D.N. Swanston. 1977. *Root strength changes after logging in southeast Alaska*. United States Department of Agriculture Forest Service, Pacific Northwest Forest and Range Experiment Station, Portland, Oregon. Research Note PNW-306.