Forest Resources & Practices Act

Landslide Bibliography

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**Compiled by FRPA Landslide Science/Technical Committee**

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**Presented to the Alaska Board of Forestry**

**January 2011**

Martha Welbourn Freeman, editor

Alaska Department of Natural Resources

Division of Forestry



**Forest Resources & Practices Act**

**Landslide Science & Technical Committee**

**ANNOTATED BIBLIOGRAPHY**



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November 1, 2010

Introduction

This bibliography compiles published and unpublished research relevant to landslide hazards and public safety risks associated with commercial timber harvesting subject to FRPA. In Alaska, these hazards occur primarily in the portion of FRPA Region I (coastal forests) from Cordova south.

FRPA (AS 41.17) governs forestry operations on state, municipal, and private land. The Act is designed to protect fish habitat and water quality, while ensuring that management standards are workable for landowners and operators.

In 2008, the Alaska Board of Forestry requested that the Department of Natural Resources’ Division of Forestry (DOF) address landslide hazards to public safety associated with commercial timber harvesting. DOF convened an interdisciplinary committee to do the science and technical review. The committee included scientists with expertise in soil science, geology, and hydrology, along with state agency staff experienced in forest management, road design and construction, and FRPA implementation.

This group, the Landslide Science & Technical Committee (LS&TC), was charged with assessing the geographic scope of landslide hazards to public safety associated with commercial timber harvesting regulated by FRPA, reviewing relevant literature, developing definitions for common landslide terms, and evaluating the FRPA best management practices for preventing and minimizing landslides and mass wasting.

Relevant publications included in prior FRPA bibliographies provided a foundation for the landslide bibliography. In addition, LS&TC members identified additional published documents and unpublished studies that expanded this work. The bibliography includes references on topics that are closely related to landslide risk, such as the effect of timber harvest on rainfall interception, which affects landslide response to timber harvesting. Committee members also annotated references that are commonly cited in Alaskan planning documents.

References are grouped by the geographic area in which the study occurred. The emphasis is on southeast Alaska. Relevant papers from other areas are also included, but the review of literature outside Alaska is not as exhaustive as that for literature focused within the state. Within the geographic groups, studies are listed in alphabetical order by the last name of the principal author, and by date, with the most recent papers by a principal author listed first. Documents marked with a star (★) are highlighted references that the Science & Technical Committee identified as especially relevant to the issue of landslide risks associated with commercial timber harvesting in coastal Alaska. These works generally build on earlier science, including many of the other listed references, and are frequently cited in Alaskan documents.

This document includes abstracts for the highlighted papers and many of the Alaskan papers. Abstracts for many of the other sources are available in the other bibliographical sources listed below.

Questions about this document may be directed to the DNR Division of Forestry, Forest Resources Program Manager, 555 W 7th Avenue, Anchorage, AK 99501 (907-269-8473).

**Background and sources**

This bibliography compiles information from four sources:

➀ A 2005 annotated bibliography of literature relevant to the Alaska Forest Resources & Practices Act, edited by Robert Ott, et al. The Ott bibliography includes abstracts for all references. A copy of information from the introduction to that bibliography follows.

➁ The slope stability section of a 2004 annotated bibliography prepared as part of the FRPA Region II riparian standards review, and edited by Chris Stark. Most, but not all references include abstracts prepared by the compiler. A copy of information from the introduction to that bibliography follows.

➂ A 2003 summary of monitoring studies of the effectiveness of practices under FRPA from 1990-2002 compiled by Alison Arians. These references include a summary. A copy of information from the introduction to that bibliography follows.

➃ Other publications collected by Landslide Science & Technical Committee members during the committee process. Abstracts have been prepared for some of the papers, including works that are frequently cited by Alaska planning documents. Particular recognition goes to Dennis Landwehr for compiling and annotating many of the references identified during the LS&TC process. Members of the LS&TC follow.

* Jim Baichtal USFS-Tongass National Forest, Geologist
* Bert Burkhart Columbia Helicopters
* Marty Freeman DNR Division of Forestry, Forest Resources Program Mgr.
* Kevin Hanley DEC Water Division, Environmental Program Specialist
* Adelaide Johnson USFS-PNW Forest Sciences Laboratory, Hydrologist
* Kyle Moselle ADF&G Habitat Division, Douglas Habitat Biologist
* Dennis Landwehr USFS-Tongass National Forest, Soil Scientist
* Pat Palkovic DNR Division of Forestry, SSE Forest Practices Forester
* Greg Staunton DNR Division of Forestry, Coastal Region Resource Mgr.
* Ralph Swedell DOT&PF SE Regl.Office, Regional Engineering Geologist

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| *Excerpts from:*  Relevant Literature for an Evaluation of the Effectiveness of the Alaska Forest Resources and Practices Act: An Annotated Bibliography  Compiled by:    Robert A. Ott, Ph.D.  Alaska Department of Natural Resources, Division of Forestry, and  the Tanana Chiefs Conference Forestry Program  Fairbanks, Alaska  Angie K. Ambourn, M.S.  USDA Forest Service, Alaska Region, State and Private Forestry  Forest Health Protection  Fairbanks, Alaska  Fabian Keirn  Tanana Chiefs Conference Forestry Program  Fairbanks, Alaska  Alison E. Arians, Ph.D.  Alaska Department of Natural Resources, Division of Forestry  Anchorage, Alaska  January 2005  Each abstract is identified as being an author abstract, an electronic abstract, or a compiler abstract. Author abstracts were copied verbatim from journal articles and reports that were available to us, or from electronic abstracts that were posted on websites of individual peer-reviewed journals. In a few instances, a report did not contain an abstract, but a summary, introduction, or conclusions section contained information that was adequate for summarizing the described project. In these cases, the appropriate sections were copied verbatim and labeled as an author abstract as well. Electronic abstracts are those which were obtained from the electronic key word search of the article databases identified above. From experience, we knew that many of these abstracts were not complete author abstracts, so we did not want to identify them as such. Compiler abstracts are those that were written by the compilers of this bibliography for those reports that did not contain an abstract or a suitable introduction, summary, or conclusions section. |

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| *Excerpts from:* Section 4Forestry slope and stability An Annotated Bibliography  Compiled for the  Region II FRPA Riparian Management Science & Technical Committee  by  Chris Stark  University of Alaska, Fairbanks and Bering Sea Fisherman’s Association  **July 2004**  The Region II Forest Practices Riparian Management Science and Technical Committee Literature Review and Annotated Bibliography compiles published research relevant to riparian management issues in the boreal and transitional forests of southcentral Alaska. Region II covers the Matanuska and Susitna valleys, the non-coastal part of the Copper River Basin, the western Kenai Peninsula, and the west side of Cook Inlet north of Mt. Douglas.  Volunteers from Committee conducted a broad search of publications on each topic. References for publications relevant to conditions in Region II were collected and annotated, and an introduction compiled for each section. The bibliographies and introductions were submitted to the full committee for review and editing. This document compiles the ten review topics. |

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| Summary of Monitoring Studies of the Effectiveness of Practices under the Alaska Forest and Resources Practices Act1990-2002Compiled by Alison AriansDNR Division of ForestryApril 2003 A report funded by the Alaska Coastal Management Program, Office of the Governor, pursuant to National Oceanic and Atmospheric Administration Award No. NA17OZ1113. The views expressed herein are those of the author and do not necessarily reflect the views of NOAA. This report is intended to provide a brief overview of effectiveness monitoring studies done with respect to activities under the current Alaska Forest Resources and Practices Act. It is not a review of the broad literature on riparian management, nor does it cover studies done with respect to federal best management practices for national forest land. |

# COASTAL ALASKA (FRPA Region I)

This section includes references from studies in FRPA Region I, the coastal temperate rainforest region of Alaska.

**➃Adams P.W. and R.C. Sidle. 1987. Soil conditions in Three Recent Landslides in southeast Alaska. For. Ecol. Manage. 18 (1987) 97-102.**

**Compiler abstract.**

* Soil conditions were highly variable within and between landslides.
* Organic matter was present in relatively high level and it’s contribution was from mixing of soils and from sloughing of adjacent soils.
* Due to highly variable soil conditions and presence of bedrock outcrops in the scour zone, revegetation and growth are likely to be highly variable among landslides and even within the scour or deposit area of a given landslide.

**➃ Barr, D.J. and D.N. Swanston. 1970. Measurement of creep in shallow, slide-prone till soil. Am. J. Sci. 269: 467-480, illus.**

**Compiler abstract.**

* Authors measured soil creep with strain probes and paraffin rods in the Maybeso Valley in Karta soils.
* Soil creep was measurable in the upper weather layer of the till from 0.15 to 0.457 meters deep.
* Soil creep is estimated to be on the magnitude of .0064 meters per year at the surface.
* Movement occurred throughout the year but the highest rates of movement were in the spring and fall when soil moisture contents were highest.
* The rate of creep measured was smaller than anticipated.

➁ Bishop, D.M. and M.E. Stevens. 1964. Landslides on logged areas in southeast Alaska. U.S. Dept. Agric., Northern Forest Experiment Station Res. Pap. NOR-1.

Compiler abstract: Describes and tentatively analyzes landslides on timbered slopes of mountainous southeast Alaska. Vegetation below timberline is mainly western hemlock and Sitka spruce. Recent large-scale clearcut logging of timber has accelerated avalanches and flows on steep slopes. This paper identified a 4.5 fold increase in the number of landslides in logged versus unlogged areas on Prince of Wales and Northern Revilla Island.

**➃ Burke, D. 1983. Harvesting on slopes over 75 Percent. Prepared for the USDA For. Serv. Region 10 Juneau, Alaska. Contract #53-010901000087. Doyle Burke principal investigator. Pan Sylvan Seattle-Ketchikan. 14 June 1983.**

**Compiler abstract.**

* Reviewed literature to date and affirmed that it is appropriate to avoid timber harvest on sloes over 75% in southeast Alaska.
* Author described need to minimize soil disturbance, road disturbance and vegetative disturbance when planning yarding systems on steep slopes. Ground-lead and Hi-lead are inappropriate, partial or full suspension are the preferred yarding methods. Minimize roads on steep slopes and go to longer span cable systems.

**➃ Erdman, C. F., and G. W. McInelly. 2006. Geotechnical forest practices evaluation – Petersburg slope stability assessment, Petersburg, Alaska. File No. 5242-004-00. 20 pp. + photo appendices.**

**➃ Gier, J. 2000. Mechanics Driving Landslide Occurrence in the Margaret Lake Basin (1995 to 1999). Tongass National Forest Ketchikan-Misty Ranger District March 24, 2000. unpublished report.**

**Compiler abstract.**

* Inventory and analysis of 19 landslides in the Margaret Lake basin attempted to answer 8 questions posed by the District Ranger.
* Identified heavy precipitation, including rain-on-snow events as contributing to the Margaret landslides.
* Found that most slides were related to harvest units and road drainage problems, only two of the slides initiated in unharvested areas.
* Found that harvest practices (in the past) in the Margaret watershed were not entirely consistent with 1997 Tongass Land Management Plan BMPs.

➃ Gomi, T., Johnson, A.C.,  Deal, R.L., Hennon, P.E., Orlikowska, E.H., and Wipfli, M.S., 2006. Mixed red alder-conifer riparian forests of southeast Alaska, Implications for the accumulations of woody debris, organic matter, and sediment in headwater streams. Canadian Journal of Forest Research, 36(3):325-737

➀ Gomi, T., R.C. Sidle, and D.N. Swanston. 2004. Hydrogeomorphic linkages of sediment transport in headwater streams, Maybeso Experimental Forest, southeast Alaska. Hydrological Processes 18: 667-683.

**Author abstract:** Hydrogemorphic linkages related to sediment transport in headwater streams following basin wide clear-cut logging on Prince of Wales Island, southeast Alaska, were investigated. Landslides and debris flows transported sediment and woody debris in headwater tributaries in 1961, 1979, and 1993. Widespread landsliding in 1961 and 1993 was triggered by rainstorms with recurrence intervals (24 h precipitation) of 7.0 years and 4.2 years respectively. Occurrence, distribution, and downstream effects of these mass movements were controlled by landform characteristics such as channel gradient and valley configuration. Landslides and channelized debris flows created exposed bedrock reaches, log jams, fans, and abandoned channels. The terminus of the deposits did not enter main channels because debris flows spread and thinned on the unconfined bottom of the U-shaped glaciated valley. Chronic sediment input to channels included surface erosion of exposed till (rain splash, sheet erosion, and freeze-thaw action) and bank failures. Bedload sediment transport in a channel impacted by 1993 landslides and debris flows was two to ten times greater and relatively finer compared with bedload transport in a young alder riparian channel that had last experienced a landslide and debris flow in 1961. Sediment transport and storage were influenced by regeneration of riparian vegetation, storage behind recruited woody debris, development of a streambed armour layer, and the decoupling of hillslopes and channels. Both spatial and temporal variations of sediment movement and riparian condition are important factors in understanding material transport within headwaters and through channel networks.

**➀ Gomi, T., R.C. Sidle, R.D. Woodsmith, and M.D. Bryant. 2003. Characteristics of channel steps and reach morphology in headwater streams, southeast Alaska. Geomorphology 51: 225-242.**

**Author abstract:** The effect of timber harvesting and mass movement on channel steps and reach morphology was examined in 16 headwater streams of SE Alaska. Channel steps formed by woody debris and boulders are significant channel units in headwater streams. Numbers, intervals, and heights of steps did not differ among management and disturbance regimes. A negative exponential relationship between channel gradient and mean length of step intervals was observed in the fluvial reaches (<0.25 unit gradient) of recent landslide and old-growth channels. No such relationship was found in upper reaches (0.25 gradient) where colluvial processes dominated. Woody debris and sediment recruitment from regenerating riparian stands may have obscured any strong relationship between step geometry and channel gradient in young alder, young conifer, and recent clear-cut channels. Channel reaches are described as pool–riffles, step–pools, step–steps, cascades, rapids, and bedrock. Geometry of channel steps principally characterized channel reach types. We infer that fluvial processes dominated in pool–riffle and step–pool reaches, while colluvial processes dominated in bedrock reaches. Step–step, rapids, and cascade reaches occurred in channels dominated by both fluvial processes and colluvial processes. Step–step reaches were transitional from cascades (upstream) to step–pool reaches (downstream). Woody debris recruited from riparian corridors and logging activities formed steps and then sequentially might modify channel reach types from step–pools to step–steps. Scour, runout, and deposition of sediment and woody debris from landslides and debris flows modified the distribution of reach types (bedrock, cascade, and step–pool) and the structure of steps within reaches.

**➀ Gomi, T., R.C. Sidle, M.D. Bryant, and R.D. Woodsmith. 2001. The characteristics of woody debris and sediment distribution in headwater streams, southeastern Alaska**. **Canadian Journal of Forest Research 31: 1386-1399.**

**Author Abstract:** Large woody debris (LWD), fine woody debris (FWD), fine organic debris (FOD), and sediment deposition were measured in 15 steep headwater streams with five management and disturbance regimes. Clear-cut channels logged in 1995 contained large accumulations of logging residue that initially provided sites for sediment storage. Half of the LWD in clear-cut channels was recruited during and immediately after logging. Woody debris from logging activities remains in young growth conifer channels 37 years after logging. Numbers of LWD in clear-cut and young conifer channels were significantly higher than in old-growth channels, although numbers of FWD pieces were not significantly different because of higher recruitment from old-growth stands. Channels that experienced recent (1979 and (or) 1993) and earlier (1961 and (or) 1979) scour and runout of landslides and debris flows contained less LWD and FWD, although large volumes of LWD and FWD were found in deposition zones. The volumes of sediment stored in young alder and recent landslide channels were higher than in the other channels. Because of the recruitment of LWD and FWD from young alder stands, the ratio of sediment stored behind woody debris to total sediment volume was higher in young alder channels compared with recent landslide channels. Numbers of LWD and FWD pieces in all streams were significantly correlated with the volumes of sediment stored behind woody debris. Timber harvesting and soil mass movement influence the recruitment, distribution, and accumulation of woody debris in headwater streams; this modifies sediment storage and transport in headwater channels.

**➃ Hartsog, W. 1990. Summary of Slope Stability and Related Problems on the Tongass National Forest. Unpublished white paper. October, 1990.**

**Compiler abstract.**

* Author reviewed numerous landslides associated with road construction and timber harvest.
* Recommended road locations to avoid steep slopes.
* Full bench and end-haul may be needed in some areas.
* Timing of pioneer road construction and subsequent blasting and deposition of rock embankment could have prevented some road related failures.
* Identified a need for long-range planning on timber sales.

**➃ Johnson, A.C. Edwards, R. and Erhardt, R., 2008, Reply to discussion by Amod S. Dhakal and Roy C.Sidle: “Ground water response to forest harvest: Implications for hillslope stability”, *Journal of American Water Resources Association*, 44(4):1062-1065.**  
**★➃ Johnson A.C., R.T. Edwards, and R. Erhardt. 2007. Ground-water Response To Forest Harvest: Implications for Hillslope Stability. Journal of American Water Resources Association, 43(1):134-147.**

**Compiler abstract.**

* Authors studied ground-water response to timber harvest using wells in the alternatives to clearcutting study sites.
* The influence of timber harvest varied greatly with location and local site characteristics.
* One site showed statistically significant maximum soil saturation increases of 0.14, 0.12, and 0.11 following 100%, 75%, and 25% harvest (*p*<0.05).
* At the chosen field sites the differences in saturation did not dramatically affect hillslope stability, but could do so in nearby areas with greater slope and/or greater soil depth.

➃ Johnson, A.C. and Edwards, R.T. 2002. Physical and chemical processes in headwater channels with red alder. In: Johnson, A.C., Haynes, R.W., Monserud, R.A, (eds). Congruent Management of Multiple Resources: Proceedings from the Wood Compatibility Workshop. *Gen. Tech. Rep. PNW*-GTR-563. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station: 101-108.

**➀ Johnson, A.C., and P. Wilcock. 2002. Association between cedar decline and hillslope stability in mountainous regions of southeast Alaska. Geomorphology 46: 129-142.**

**Author abstract:** Old-growth forests experiencing widespread decline of yellow-cedar (*Chamaecyparis nootkatensis* ) in southeast Alaska have a 3.8-fold increase in the frequency of landslides. We report here on an investigation of the cause of this increased slope instability. Time since death of cedar was assessed using surveys around landslide sites. Root decay on dead trees was used to estimate the decline in the apparent soil strength provided by roots. Changes in soil hydrology were measured with 120 piezometers located in areas of healthy cedar, healthy spruce/hemlock, and sites with cedar decline. Relative influences on slope stability by changes in soil moisture and root strength were evaluated with a simple stability model. At most sites, soil depth is <0.7 m, and the loss of root strength has an important and possibly dominant influence on slope instability. In soils deeper than 1 m, changes in pore pressure have a proportionately larger influence on slope stability. Landslides appear most likely when cedar decline reaches snag class IV (approximately 50 years after tree death), when most of the cedar root strength is lost and root strength from secondary growth has yet to develop.

**★➀ Johnson, A.C., D.N. Swanston, and K.E. McGee. 2000. Landslide initiation, runout, and deposition within clearcuts and old-growth forests of Alaska. Journal of the American Water Resources Association 36: 17-30.**

**Electronic Abstract**: More than 300 landslides and debris flows were triggered by an October 1993 storm on Prince of Wales Island, southeast Alaska. Initiation, runout, and deposition patterns of landslides that occurred within clearcuts, second-growth, and old-growth forests were examined. Blowdown and snags, associated with cedar decline and "normal" rates of mortality, were found adjacent to at least 75 percent of all failures regardless of land use. Nearly 50 percent of the landslides within clearcuts occurred within one year following timber harvest; more than 70 percent of these sites had hydrophytic vegetation directly above failures. In following the runout paths of failures, significantly more erosion per unit area occurred within clearcuts than in old-growth forests on slopes with gradients from 9 to 28 degree (16 to 54 percent). Runout length, controlled by hillslope position within deglaciated valleys, was typically longer in old-growth forests than in second growth and clearcuts (median values were 334, 201, and 153 m, respectively). Most landslides and debris flows deposited in first- and second-order channels before reaching the main stem channels used by anadromous fish. Slide deposits in old-growth forests were composed of a higher proportion of woody debris than deposits derived from slides in second growth or clearcuts.

**➃ Karl, Susan M.; Haeussler, Peter J.; McCafferty, Anne E., 1999, Reconnaissance Geologic Map of the Duncan Canal-Zarembo Island Area, Southeastern Alaska. Open-File Report 99-168, Map Sheet: 54 x 36 inches; Pamphlet: 30 p.**

**Author abstract.** The geologic map of the Duncan Canal-Zarembo Island area is the result of a multidisciplinary investigation of an area where an airborne geophysical survey was flown in the spring of 1997. The area was chosen for the geophysical survey because of its high mineral potential, a conclusion of the Petersburg Mineral Resource Assessment Project, conducted by the U.S. Geological Survey from 1978 to 1982. The City of Wrangell, in southeastern Alaska, the Bureau of Land Management, and the State of Alaska provided funding for the airborne geophysical survey. The geophysical data from the airborne survey were released in September 1997. The U.S. Geological Survey conducted field investigations in the spring and fall of 1998 to identify and understand the sources of the geophysical anomalies from the airborne survey. This geologic map updates the geologic maps of the same area published by David A. Brew at 1:63,360 (Brew, 1997a-m; Brew and Koch, 1997). This update is based on 3 weeks of field work, new fossil collections, and the geophysical maps released by the State of Alaska ( DGGS, Staff, and others, 1997a-o). Geologic data from outcrops, fossil ages, radiometric ages, and geochemical signatures were used to identify lithostratigraphic units. Where exposure is poor, geophysical characteristics were used to help control the boundaries of these units. No unit boundaries were drawn based on geophysics alone. The 7200 Hertz resistivity maps (DGGS, Staff, and others, 1997k-o) were particularly helpful for controlling unit boundaries, because different stratigraphic units have distinctive characteristic conductive signatures (Karl and others, 1998). Increased knowledge of unit ages, unit structure, and unit distribution, led to improved understanding of the nature of unit contacts. Northwest- to southwest-directed thrust faults, particularly on Kupreanof Island, are new discovery. Truncated faults and map patterns suggest there were at least 2 generations of thrusting, and that the thrust faults have been folded. Subsequent right-lateral strike-slip NW-SE faults, have offset thrust faults, and these in turn are offset by N-S right-lateral strike-slip faults. Our fieldwork raised as many questions as it answered, and we see this map as a progress report at a reconnaissance level. The main contributions of this map are 1) the greater distribution of Triassic rocks, 2) increased fossil age information, and 3) the identification of thrust faults within and between units. <http://pubs.usgs.gov/of/1999/of99-168/>

**★➃ Landwehr D.J. 1999. The Inventory and Analysis of Landslides Associated with the 89-94 KPC LTS Units and Roads on the Thorne Bay Ranger District. Ketchikan Area Watershed Group. February, 1999. Final. unpublished monitoring report.**

**Author abstract.**

* The author took field measurements of all landslides associated with timber harvest and road construction completed as part of the implementation of the 89-94 KPC operating period on the Thorne Bay Ranger District. Implementation of the project took 6 years and the inventory was completed with an aerial survey of all harvest units and roads in 1998.
* The inventory includes 162 landslides, 54 of which occurred during the October 1993 storm event. The average size of landslides associated with timber harvest activities is about 0.5 acres.
* The average initiation angle during the 1993 storm event was 71% versus the average initiation angle for all other slides was 77 percent. This is significant at the 70 percent probability level.
* Sixty of the 162 slides were associated with 222 miles of road construction. Forty-seven of the road and rock pit related slides occurred during construction or pit development.
* The 162 landslides covered 76.4 acres of land. The associated timber harvest covered 18,429 acres and 222 miles of road construction. The slides impacted 0.4 percent of the land harvested.

**★➃ Landwehr D. J. 1998. The Effectiveness of Standards and Guidelines in Preventing Additional Mass Movement. An 89-94 KPC FEIS Monitoring Report. Ketchikan Area Watershed Group. Final February, 1998. unpublished monitoring report.**

**Author abstract.**

* The author used multiple sets of air photos taken every 5 years to conduct a comprehensive landslide inventory for the 89-94 Long-term timber sale operating period. The landslide inventory spans a 20 year time frame from 1971 to 1991. No field measurements were taken, landslide size was scaled from topographic maps. Landslide analysis was conducted for the 20 year time period and each five year time period within the 20 years.
* The frequency of landslides in harvested areas is higher than the frequency of landslides in unharvested areas for all time periods.
* The frequency of landslides harvested areas in the most recent time period (1985 to 1991) is less than all previous time period, even though timber harvest is progressively occurring on steeper slopes.
* The average age of second-growth in which landslides occurred between 1975 and 1991 is 9 to 13 years.
* Current timber harvest (late 1990s) is occurring on steeper ground than any previous operating period.
* The average size of 541 landslides in unharvested commercial forest land is 3.1 acres.
* The average size of 197 landslides occurring in second-growth is 0.6 acres.
* The average size of 55 road and rock pit related landslides is 0.55 acres.
* On average, over the 20 year time period one landslide was caused per 19 miles of road construction.
* On average, one landslide occurred in 6,239 acres of unharvested commercial forest land over the 20 year time period. This equates to one landslide per 124, 788 acres of unharvested commercial forest land per year.
* On average, one landslide occurred in 1,373 acres of harvested areas per 20 years. This equates to one landslide per 27,467 acres of harvested land per year.
* Landslides in harvested areas at a rate 4.5 times that of unharvested areas over the 20 year time period.

**➃ Landwehr D. J. 1994. Inventory and Analysis of Landslides Caused by the October 25, 26, 1993 Storm event on the Thorne Bay Ranger District. Ketchikan Area Watershed Group. January 10, 1994. Unpublished report.**

**Author abstract.**

* The author documented 140 landslides (through aerial survey) as the result of a single storm event.
* Frequency analysis showed more slides occurred in recently harvested areas than in unharvested areas or in areas of older second-growth.
* Older second-growth (8 to 30 years old) had more landslides per unit area than stands less than 8 years old but more landslides than unharvested (old-growth).
* The author recognized the possibility of not detecting small landslides under the forest canopy and analyzed landslide frequencies with and without small landslides.
* Landslides in recently harvested areas were smaller than landslides in unharvested areas and in second-growth.

**➃ Lemke, R.W., 1975, Reconnaissance engineering geology of the Ketchikan area, Alaska, with emphasis on evaluation of earthquake and other geologic hazards. U.S. Geol. Survey Open-File Report 75-250, p. 65.**

<http://www.dggs.dnr.state.ak.us/pubs/pubs?reqtype=citation&ID=11073>

**➃ Lemke, R.W., 1974, Reconnaissance Engineering Geology of the Wrangell area, Alaska, with Emphasis on Evaluation of Earthquake and Other Geologic Hazards. US Geological Survey, Open-File Report 74-1062, pp. 19-27.**

<http://www.dggs.dnr.state.ak.us/pubs/pubs?reqtype=citation&ID=11017>

**➃ Landwehr, D. J. and G. Nowacki. 1999. Summary of statistical review of Ketchikan Area soil disturbance. Unpubl.**

**➃ Lemke, R.W. and L.A. Yehle, 1972a, Reconnaissance Engineering Geology of the Haines Area, Alaska, with Emphasis on elevation of Earthquake and other Geologic Hazards. US Geological Survey, Open-File Report 72-229, 109p.**

<http://www.dggs.dnr.state.ak.us/pubs/pubs?reqtype=citation&ID=10950>

**➃ Lemke, R.W. and L.A. Yehle, 1972b, Regional and other general factors bearing on evaluation of earthquake and other geologic hazards to coastal communities of southeastern Alaska. U.S. Geological Survey open-file report 72-230, 99 p.**

<http://www.dggs.dnr.state.ak.us/pubs/pubs?reqtype=citation&ID=10951>

**➂ Martin, D.J. 1996b. Monitoring the effects of timber harvest activities on fish habitat in streams of coastal Alaska. 1997 Status Report, 1992-1997**.

**Compiler abstract:** Results:

* 55% of landslides (in both managed and unmanaged forests) delivered coarse sediment to headwater or larger stream channels.
* 67% of landslides from unmanaged forests reached stream channels (unstable steep areas).
* 12% of clearcut/road landslides reached channels.
* 45% of the landslides originated above timberline.
* Clearcuts and roads were 11% of landslides, but only 2% of the landslides that reached stream channels.
* Low gradient channels in basins with high sediment influx responded to sediment load: channel migration, braiding, bar formation.

Further Study Recommendations:

* Future studies will link these results to fish habitat. Further studies will examine relationships between sediment supply, pool development, and spawning gravel conditions.
* Field observations may be required to determine sediment delivery and landslide activity in some areas where aerial photographic evidence is inconclusive.

**➂ Martin, D.J., and J.A. Kirtland. 1995. An assessment of fish habitat and channel conditions in streams affected by debris flows at Hobart Bay. Project 16-004 report written by Pentec Environmental, Inc., Edmonds, Washington. Written for Goldbelt, Inc., Juneau, Alaska. 40pp. plus Appendix.**

Compiler abstract: Background:

* In 1993, several debris flows occurred in basins flowing into Hobart Bay. Three debris flows were triggered by forest practices activities (roads and clearcuts) on steep and unstable slopes. Sediment went into Gypo Creek.
* Two debris avalanches were initiated by natural causes: Nancy Creek and Salt Chuck Creek basins. The avalanches became debris flows passing through clearcuts and depositing sediment.
* 1994, they were on the list of impaired water bodies (EPA 303(d) list).

Results:

* 26 landslides: 13 delivered sediment. 6 originated in harvest areas. Most were in steep inner gorges along channels.
* Thin soils, also evidence of other debris flows pre-harvest.
* Clearcutting creates instability, decreases tree root strength, increases soil saturation by increasing snow pack depth. Forest roads redirect surface and subsurface water.
* Management activities may have altered the timing of the landslides, but can’t conclude that they increased the rate. All were in areas that already have landslides.
* Landslide sediment delivery: most landslides were confined to small tributaries, not larger-order channels.
* Fish habitat
  + Channel characteristics described.
  + Barriers to fish migration formed at some locations, but were passable at most locations.
  + Spawning gravel comparison:
* No significant difference between managed and unmanaged areas.
* Sedimentation does not appear to be affecting spawning habitat.
* Rearing habitat:
* Fewer pools: debris flows caused
* Less LWD: past harvests without buffers.
* Extra sedimentation creates channel braiding.
* Standing timber would have minimized lateral spread of debris flow, then quicker habitat recovery.

Conclusions

* Future management activities on naturally unstable areas may increase the probability of initiating landslides during storm periods.
* Debris flows have had positive and negative effects. Magnitude of effect depends on length of time since last debris flow.

**➃ Miller, R.D., 1975, Surficial geologic map of the Juneau urban area and vicinity, Alaska. U.S. Geological Survey, Miscellaneous Geologic Investigations Map I-885.**

<http://www.dggs.dnr.state.ak.us/pubs/pubs?reqtype=citation&ID=12956>

**➃ Miller, R.D., 1973, Gastineau Channel Formation, a Composite Glaciomarine Deposit Near Juneau, Alaska: A description of the depositional environment and lithology of diamictons of late Pleistocene and early Holocene age. Geological Survey Bulletin 1394-C, United States Department of the Interior, pp. C1-C20.**

<http://www.dggs.dnr.state.ak.us/pubs/pubs?reqtype=citation&ID=3686>

**➃ J. H. Patric and D. N. Swanston. 1968. Hydrology of Slide-Prone Glacial Till Soil in Southeast Alaska. Jour. of Forestry, January 1968.**

**Compiler abstract. A**uthors attempted to create a soil mass movement through intensive irrigation of a Karta soil, discovered that soil pore water pressure at a local site is dependent on pore water pressure of surrounding soils.

**➃ Patric J.H. and W.J. Walkotten. 1967. Elevation effects on rainfall near Hollis, Alaska. USDA For. Serv. Res. Note PNW-53. May 1967.**

**Compiler abstract.**

* Studied rainfall across an elevation gradient in the Maybeso valley near Hollis.
* For each inch of rain at sea level the average rainfall increase was 0.02 inches per hundred feet of elevation rise.

**➃ Patric J.H. 1966. Rainfall Interception by Mature Coniferous Forests of Southeast Alaska. J. of Soil and Water Conservation. November-December Issue, 1966.**

**Compiler abstract.**

* Studied rainfall interception near Juneau Alaska.
* Interception loss of about 25 percent of annual rainfall must be accounted for in the forest water budget of southeast Alaska.

**➀ Perkins, S.J. 1999. Landslide inventory and sediment response study for monitored Sealaska streams. Report by Martin Environmental, Seattle, Washington to Sealaska Corporation, Juneau, Alaska. 27pp plus Appendices and maps.**

**Author Abstract (Author Introduction):** This report presents the results of a landslide inventory and sediment-response study of twelve streams that are the subject of ongoing studies of forest practices effectiveness by Sealaska and the Alaska Forest Association. The purpose of this was to 1) estimate relative sediment supply levels to the study streams, 2) determine the relative importance of landslides in supplying sediment to each stream, and 3) compile a history of sediment supply changes and historic channel responses to changes in bedload. The results of this study will provide the context for a second study phase: analysis of monitoring data to examine the effects of sediment supply changes on channel substrate and morphology.

The scope of this study consisted of inspection of aerial photographs, topographic maps, and supplemental information from timber harvest managers.

**➃ Saviers, Aimee. 2008. Flooding and mass wasting along the Lynn Canal Corridor in Southeast Alaska – October 1998. http://aprfc.arh.noaa.gov/pubs/newltr/pub6/SE\_flood.html**

**➃ Schroeder W.L. and D.N. Swanston. 1987. Application of Geotechnical Data to Resource Planning in Southeast Alaska. USDA For. Ser. PNW Gen. Tech. Rep. PNW-198, January, 1987.**

**Compiler abstract.** Report discusses application of Geotechnical data and meteorological data to slope stability analysis and land management planning in southeast Alaska

**➃ Schroeder W.L. 1983. Geotechnical properties of southeast Alaskan Forest Soils. Oregon State University, Civil Engineering Department. 1983.**

**Compiler abstract.**

* A wide variety of soil types exists in the Tongass National Forest. Generally the soils are fine-grained, but may be coarse grained with high fines content. Soil fines are generally silty in nature, although some clays exist. Soil densities may be quite low or reasonably high. In the field the soils’ degree of saturation usually exceeds about 90 percent.
* Tongass soils have relatively high angles of internal friction. There is a modest (but important for slope stability) degree of cohesion available. Angle of internal friction is related to plasticity index.
* Water has an important influence on the behavior of these soils. Increasing saturation reduces undrained strength. Change in water level within a slope is a prime driving mechanism for slope instability.

**➃ Schroeder W.L. and G. Filz. 1981. Engineering Properties of Southeast Alaskan Forest Soils. Oregon State University, civil Engineering Department.**

**Compiler abstract.**

* Due to high organic colloid content the plasticity of many soils in southeast Alaska decreases if the soils are dried before testing.
* The effective angle of internal friction of the soils studied tends to increase with increasing dry density and with decreasing plastic index.
* Specimens from a single site exhibited significant variability in their shearing behavior.
* Due to the variability, slope stability analysis based on a single set of strength parameters should be used with caution. In particular, the stability of thin soil on slopes is sensitive to small changes in cohesion.

**➃ Sidle R. C. 1984a. Shallow Groundwater Fluctuations in Unstable Hillslopes of Coastal Alaska. Zeitschrift Fur Gletscherkunde and Glazialgeologie Band 20 (1984) S. 79 -95.**

**Compiler abstract.**

* Author measured groundwater in two hillslope hollows.
* Groundwater responds rapidly with very little lag to major rainfall inputs in confined hillslope depressions.
* Typically rates of groundwater rise were an order of magnitude higher than rainfall intensity. The rates were higher than could be predicted from vertical infiltration.
* Subsurface water is apparently channeled through discontinuous macropores and pipes within the hillslope soil mantle. Another possible explanation is the displacement of previously stored water upslope.
* Disruption of the system of macropores may lead to high pore water pressures antecedent to landslides.

**➃ Sidle R. C. 1984b. Relative Importance of Factors influencing Landsliding in Coastal Alaska.**

**Compiler abstract.**

* Sensitivity analysis of the infinite slope model indicates that cohesion and soil depth are two most important variables influencing factor of safety for conditions typical of coastal Alaska. The influence of soil depth is greatly diminished on low cohesion soils.
* Slope gradient and angle of internal friction affected factor of safety by almost one order of magnitude less than did typical ranges of cohesion and soil depth.
* Groundwater exerts a dynamic influence on slope stability because water tables can develop in hillslope soils.
* Removal of vegetation can substantially reduce site stability through loss of root cohesion.
* The effects of groundwater fluctuations and loss of root strength would be the most important factors influencing the initiation of landslides.
* Caution should be exercised when the infinite slope model is used to quantitatively predict stability of natural slopes because of the inherent variabilities of soil and site factors.

**➃ Sidle, R.C. and D.N. Swanston. 1982. Analysis of a small debris slide in coastal Alaska. Canadian Geotechnical Journal Vol. 19 No. 2 pp 167-174. 1982.**

**Compiler abstract.**

* A small slide occurred in a study area where piezometers were installed.
* The authors applied the infinite slope model to the available slope, soil and water table data.
* It must be remembered that the use of such models, based on theoretical soil mechanics, greatly oversimplifies the complex field situation. Rooting strength was assumed to be negligible.
* The authors note the evidence of recent soil creep days and months before the slide occurred.

**➃ Swanston, D.N. 2006a. Assessment of landslide risk to the urban corridor along Mitkof Highway from planned logging of Mental Health Trust lands. Unpubl. 19 pp.**

**➃ Swanston, D.N. 2006b. Critique of “Geotechnical forestry practices evaluation – Petersburg slope stability assessment, Petersburg, Alaska File Number 5342-004-00”. August 30, 2006. 3 pp.**

**★➃ Swanston, D. N. 1997. Controlling Stability Characteristics of Steep Terrain with Discussion of Needed Standardization for Mass Movement Hazard indexing: A resource Assessment. In assessments of Wildlife Viability, Old-growth Timber Volume Estimates, Forested Wetlands, and Slope Stability. Conservation and Resource Assessments for the Tongass Land Management Plan Revision. Charles G. Shaw III Technical Coordinator, Kent R. Julin Compiler. USDA For. Serv. PNW-GTR-392. March 1997.**

**Compiler abstract.**

* Author reviews the stability factors and data for southeast Alaskan and defines four mass movement index ratings.
* A numeric mass movement index form is presented for forest-wide application.
* A critical slope angle of 72% is identified.

**➃ Swanston, D.N. 1995. Overview of controlling stability characteristics of steep terrain in southeast Alaska with discussion of needed standardization for mass movement hazard indexing on the Tongass National Forest. Unpubl.**

**➀ Swanston, D.N., and R. Erhardt. 1993. Short-term influence of natural landslide-dams on the structure of low-gradient channels: An extended abstract. In: Proceedings of Watershed ‘91: A conference on the stewardship of soil, air, and water resources, 16-17 April 1991, ed. T. Brock. USDA Forest Service, Alaska Region, R10-MB-217. Pages 34-38.**

**Author abstract:** Landslides, one of the principal processes of sediment and large woody debris transport from uplands to anadromous fish streams in southeast Alaska, tend to enter low-gradient channels at nearly right angles. Rapid deceleration from impact of debris with the opposing bank, coupled with a substantial reduction in gradient, causes dewatering and deposition of a debris wedge at and immediately downstream from the point of entry of the landslide. The persistence of the wedge, both as a dam and temporary base-level for the channel, is largely determined by composition of material and the size of flows carried by the channel during storms. Subsequent flows over and around the deposit tend to be sediment poor and energy rich, resulting in more rapid downcutting, increases in downstream channel scour, and the frequent shifting of the channel bed for several hundred meters downstream. In this dynamic environment, the large woody debris piles downstream of the wedge serve as focal points for formation and persistence of habitat elements such as pools, riffles, and side channels. These habitat elements remain viable until occurrence of additional landslides or flood flows with power great enough to remobilize the debris.

**★➃ Swanston D.N. and D.A. Marion 1991. Landslide Response to Timber Harvest in Southeast Alaska. Proceedings of the Fifth Federal Interagency Sedimentation Conference. March 18-21, 1991 Las Vegas Nevada.**

**Compiler abstract.**

The authors documented all landslides over 77 cubic meters in size on the Tongass national Forest from 1963 and 1983 aerial photos.

* The landslide occurrence rate in harvested areas is 3.5 times greater than in undisturbed areas.
* As a general rule, landslides in harvested areas are significantly smaller, occur at lower elevations, develop on gentler slope gradients, and tend to travel shorter distances.
* Under natural undisturbed conditions most failures are associated with shallow linear depressions. Only about 10% of slides occur in gullies.
* In contrast in harvested conditions about 30% of landslides occur in gullies. The number of landslides occurring at sites underlain by glacial till also is also substantially increased in harvested areas.
* Three quarters of all failure regardless of management initiate on slopes of 34 degrees or greater, that approximates a critical angle of stability for these hillslope soils.
* Eighty-six percent of failures occurred on warmer southerly aspects suggesting that aspect may substantially influence slope stability, possibly through its effect on hillslope water balance consditions.

**★➀ Swanston, D.N. 1974. The forest ecosystem of southeast Alaska. 5. Soil mass movement. USDA Forest Service, Pacific Northwest Forest and Range Experiment Station, General Technical Report PNW-17. 22pp.**

**Author Abstract:** Research in southeast Alaska has identified soil mass movement as the dominant erosion process, with debris avalanches and debris flows the most frequent events on characteristically steep, forested slopes. Periodically high soil water levels and steep slopes are controlling factors. Bedrock structure and the rooting characteristics of trees and other vegetation exert a strong influence on relative stability of individual sites.

Timber harvesting operations have a major impact on initiation and acceleration of these movements. The cutting of timber itself has been directly linked with accelerated mass movements, and the accumulation of debris linked with accelerated mass movements, and the accumulation of debris in gullies and canyons has been identified as a major contributor to the formation of large-scale debris flows or debris torrents. The limited road construction on steeper slopes thus far has had a relatively small impact.

Effective management practices on such terrain consist of identification and avoidance of the most unstable areas and careful control of forest harvesting operations in questionable zones.

➁ Swanston, D.N. 1970. Mechanics of debris avalanching in shallow till soils of southeast Alaska. USDA Pacific Northwest Forest and Range Exp. Station Res. Pap. PNW-103.

Compiler abstract: A study of 3 logged areas with recent debris avalanches indicated that a combination of complete saturation, naturally unstable slopes (>34 degrees) and the loss of the anchoring effects of tree roots were the principal causes of the landslides.

**➀ Swanston, D.N. 1969. Mass wasting in coastal Alaska. USDA Forest Service, Pacific Northwest Forest and Range Experiment Station, Research Paper PNW-83. 15pp.**

**Author abstract:** Mass wasting, a dominant form of erosion in coastal Alaska, is common where slopes are oversteepened by glacial erosion, soils are newly developed and shallow, and there is abundant rainfall. Presently, the most practical policy for the forest-land manager is avoidance of susceptible areas during timber harvest. Old debris avalanche and flow scars are visible on aerial photos, but a more accurate identification of these areas can be made from a slope-gradient map, which can be used to (1) delineate potential slide areas, (2) determine percentage of slide-prone ground, and (3) establish cutting patterns causing minimum disturbance.

**➃ Swanston, D. N. 1967a. Debris Avalanching in thin soils derived from bedrock. USDA For. Serv. Research Note PNW-64. September 1967.**

**Compiler abstract.**

* Destruction of the root system would greatly increase susceptibility of the slope soil to slides.
* Windthrow can be a triggering force.

**➃ Swanston D.N. 1967b. Geology and slope Failure in the Maybeso Valley, Prince of Wales Island, Alaska. Douglas N. Swanston, Ph.D. Michigan State University, 1967.**

**Compiler abstract.** Rising pore water pressures in weathered till, frequently in excess of 124 pounds per cubic foot, is the most important factor in debris avalanche development.

**➃ Swanston, D. N. 1967c. Soil-water Piezometry in a southeast Alaska Landslide Area. USDA Forest Service Research Note PNW-68. November 1967.**

**Compiler abstract.**

* A close relationship exists between rainfall and pore-water pressure development.
* Shear Strength of till soils decreases 65% at total saturation.
* The arrival of the first fall snows may terminate the season of maximum slide activity.

**➃ Swanston D.N. and W.J. Walkotten. 1967. Progress report, The effectiveness of rooting as a factor of shear strength in the Karta soil. Study No. FS-PNW-1604:26 November 21, 1969.**

**Compiler abstract.**

* Hydraulic excavation of two Sitka spruce stumps showed extensive lateral root system with numerous sinker roots.
* Root decay is visible 5 years after clearcutting.

**➃ US Forest Service. 2008. Soil and Water Forest-wide Standards and Guidelines. Tongass Forest Plan. January 2008. pp. 4-64 t- 4-66.**

**➃ Wu T.H., D.P. Bettadapura, and P.E. Beal. 1988. A statistical model of root geometry. Forest Science, Vol. 34. No. 4, pp 980-997.**

**Compiler abstract.** Developed a model of root geometry based on measures at three sites in southeast Alaska and other sites across the US.

**➃ Wu T.H. and D.N. Swanston. 1980. Risk of Landslides in Shallow Soils and its relation to clearcutting in southeast Alaska. Forest Sci. Vol 26. No. 3, 1980 PP 495-510.**

**Compiler abstract.**

* Modeled infiltration and seepage of water into a shallow soil over bedrock based on measurements taken with Piezometers in the Maybeso valley near Hollis Alaska.
* Piezometric rise and fall was rapid and directly related to rainfall.

**➃ Wu T.H., W.P McKinnell III, and D.N. Swanston. 1979. Strength of tree roots and landslides on Prince of Wales Island, Alaska. Can. Geotech. J. Vol 16, 1979.**

**Compiler abstract.**

* Continued development of the pore-water and root strength model reported in 1976.
* Calculated safety factors based on the models and determined that loss of root strength following clear-cutting can seriously affect slope stability.

**➃ Wu, T.H. 1976. Investigation of Landslides on Prince of Wales Island, Alaska. Geotechnical Engineering Report No. 5. Dept of Civil Engineering, Ohio State University, Columbus, Ohio.**

**Compiler abstract.**

* Field and laboratory investigations of pore-water pressure and infiltration and the influence of tree roots on shear strength and slope stability.
* Used piezometers at numerous field sites to model pieziometric rise in virgin forests and clearcut areas.
* Tree roots elongate under soil creep and can stretch as much as 3 inches before failure.

**➃ Yehle, L.A., 1978, Reconnaissance Engineering Geology of the Petersburg Area, Southeastern Alaska, Petersburg Area, Southeastern Alaska, with Emphasis on Geologic Hazards. US Geological Survey, Open-File Report 78-675.**

<http://www.dggs.dnr.state.ak.us/pubs/pubs?reqtype=citation&ID=11205>

**➃ Yehle, L. A., 1974, Reconnaissance Engineering Geology of Sitka and Vicinity, Alaska, with Emphasis on Evaluation of Earthquake and other Geologic Hazards. United States Department of the Interior Geological Survey, Open-file Report 74-53.**

<http://www.dggs.dnr.state.ak.us/pubs/pubs?reqtype=citation&ID=11000>

**➃ Yehle, L.A., and Lemke, R.W., 1972, Reconnaissance engineering geology of the Skagway area, Alaska, with emphasis on evaluation of earthquake and other geologic hazards, US Geological Survey, Open-File Report 72-454. 108 p., 4 sheets, scale 1:96,000.**

<http://www.dggs.dnr.state.ak.us/pubs/pubs?reqtype=citation&ID=10971>

**➀ Ziemer, R.R., and D.N. Swanston. 1977. Root strength changes after logging in southeast Alaska. USDA Forest Service, Pacific Northwest Forest and Range Experiment Station, Research Note PNW-306. 10pp.**

**Author abstract:** A crucial factor in the stability of steep forested slopes is the role of plant roots in maintaining the shear strength of soil mantles. Roots add strength to the soil by vertically anchoring through the soil mass into failures in the bedrock and by laterally tying the slope together across zones of weakness or instability. Once the covering vegetation is removed, these roots deteriorate and much of the soil strength is lost.

Measurements of change in strength of roots remaining in the soil after logging at Staney Creek on Prince of Wales Island, southeast Alaska, indicate that loss of strength in smaller roots occurs rapidly for all species the first 2 years. Western hemlock (*Tsuga heterophylla* (Raf.) Sarg.) roots are more resistant to loss of strength than are Sitka spruce *(Picea sitchensis* (Bong.) Carr.) roots. By 10 years, even the largest roots have lost appreciable strength.

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## OTHER Alaska REFERENCES

This section includes state-wide references and references in which the location of the study area was not identified.

**➀ Everest, F.H., and R.D. Harr. 1982. Silvicultural treatments. In: Influence of forest and rangeland management on anadromous fish habitat in Western North America, ed., W.R. Meehan. USDA, Forest Service, Pacific Northwest Forest and Range Experiment Station, Corvallis, Oregon. General Technical Report PNW-134. Pages 1-18.**

**Electronic Abstract:** Distribution of anadromous salmonids and coniferous forest coincides along much of the Pacific Slope; consequently, the habitat of anadromous fish is subject to a wide variety of silvicultural treatments required to establish and nurture young forests. The silvicultural activities include: cutting prescriptions to improve natural regeneration; preparing sites for planting; removing slash to reduce fire hazard; seeding and planting; reducing competition to enhance growth of young trees. Anadromous salmonids have exacting habitat requirements and most production in forested watersheds occurs in small (first-order to third order) streams. Some silvicultural treatments, such as broadcast burning and machine scarification and piling, can degrade water quality and fish habitat in small streams, but seldom do so because of the low spatial and temporal intensity of the activities. The highest risk of habitat damage from silvicultural activities occurs in areas with erosive soils and high annual precipitation, or high summer solar radiation and low streamflow. Maximum risk from solar heating occurs in western and northeast Oregon, western and central Washington, northwest California, and central Idaho. High-risk areas for decreased water temperatures are located in northern and central Idaho, northeastern Oregon, southeastern Washington, northern British Columbia, and Alaska. Areas of central Idaho; northwest California; western Oregon, Washington, and British Columbia; and southeast Alaska are vulnerable to surface erosion and mass wasting.

**➀ Everest, F.H., and W.R. Meehan. 1981. Forest management and anadromous fish habitat productivity. In: Transactions of the Forty-Sixth North American Wildlife and Natural Resources Conference, ed., K. Sabol. Wildlife Management Institute, Washington, D.C. Pages 521–530.**

**Electronic Abstract:** The anadromous fishery resources of western North America are produced largely within forested watersheds. Forest and rangeland management activities that can influence the quality of anadromous fish habitat include timber harvest, road construction, and livestock grazing. Organic debris from forested watersheds of the Pacific Northwest and Alaska enters streams through direct litterfall, landslides, debris torrents, timber felling, and streambank erosion, plus blowdown of trees and branches. Large woody debris can create habitat for rearing salmonids, but may cause sedimentation in spawning areas. Large, naturally occurring debris can promote streambank stability and reduce streambed scour. Large accumulations of fine organic debris can adversely affect habitat by reducing dissolved oxygen and producing toxic leachates. Total removal of debris can result in a completely open channel, promoting streambed sour, streambank instability, and loss of fish habitat productivity. Debris torrents, a common mass erosion event in the Pacific Northwest, have a negative impact on habitat and production of anadromous salmonids in small streams immediately downstream from the torrent egress. Studies within a 1-mile reach of Knowles Creek, however, indicate that the total effect of debris torrents in that sediment-poor watershed tends to be positive. Preliminary results of a livestock grazing study do not show profound effects on fish populations among various grazing systems or between one to three years of season-long grazing and ungrazed controls.

**➃ Mason, Owen, W.J. Neal, and O. H. Pilkey, with J. Bullock, T. Fathauer, D. Pilkey, and D. Swanston. 1997. Living with the coast of Alaska. Duke University Press. 348 pp.**

**➃ State of Alaska. 2007. All-Hazard Risk Mitigation Plan – October 2007. Section 5.9 Ground Failure. Pp. 185-199.**

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## Canada

★**➃ Banner, A, P. LePage, J. Moran, and A. deGroot (editors). 2005. The HyP3 Project: pattern, process and productivity in hypermaritime forests of coastal British Columbia – a synthesis of 7-year results. B.C. Min. For., Res. Br., Victoria, B.C. Spec. Rep. 10.**

**Author abstract:**

* At the two study sites, the canopy intercepted 20 to 25% of the average annual rainfall (during the snow-free period).
* If areas are clearcut the amount of water that must be removed by the existing hydrological processes can be expected to increase.
* Possible consequences: a decrease in the time to peak flows after a storm, an increase in peak flow volumes, an increase in water table height, an increase in erosion as natural drainage pipes reach capacity sooner and more overland flow occurs.
* Soil pipes were identified at most study sites. Soil pipes contribute to stability in two ways. 1) by increasing the rate of soil drainage, and 2) by limiting development of perched groundwater conditions.
* If soil pipes become mechanically damaged and blocked, the increase in pore water pressure could trigger landslides.

**➃ Beaudry P.G. and R.M. Sagar. 1995. The water balance of a coastal cedar-hemlock ecosystem. Presented at the joint meeting of the Canadian Society for Hydrological Sciences and the Canadian Water Resources Association: Mountain Hydrology, Peaks and Valleys in Research and Applications, May 17 -19, 1995, Vancouver British Columbia, Canada.**

**➀ Bovis, M.J., and M. Jakob. 1999. The role of debris supply conditions in predicting debris flow activity. Earth surface Processes and Landforms 24: 1039-1054.**

**➀ Brardinoni, F., M.A. Hassan, and H.O. Slaymaker. 2002. Complex mass wasting response of drainage basins to forest management in coastal British Columbia. Geomorphology 49: 109-124.**

**➀ Clague, J.J., R.J.W. Turner, and A.V. Reyes. 2003. Record of recent river channel instability, Cheakamus Valley, British Columbia. Geomorphology 53: 317-332.**

**➃ Chatwin, S.C., and R.B. Smith. 1992. Reducing soil erosion associated with forestry operations through integrated research: an example from coastal British Columbia. In Erosion, debris flows, and environment in mountain regions, proc. of the Chengdu Symp. IAHS Publ. no. 209**

★**➃ Chatwin, S. C. 1994. Measures for Control and management of unstable terrain. Pp. 92-105 in A guide for management of landslide-prone terrain in the Pacific Northwest. 2nd ed. Land management handbook #18. B.C. Ministry of Forests**

**Author introduction.** *A Guide for Management of Landslide-Prone Terrain in the*

*Pacific Northwest* has been prepared for agency and industry personnel who are operating in areas with existing or potential stability problems. The document is intended for use

in the coastal areas of the Pacific Northwest, even though the principles may be applicable to other locations in North America. The guide addresses four topics:

• Slope movement processes and characteristics.

• An office/field technique for recognizing landslide-prone ter-

• Measures to manage unstable terrain during forestry activities.

• Road deactivation and revegetation of unstable terrain.

The region referred to as the Pacific Northwest extends from southern Alaska to northern California, and includes the province of British Columbia, and the states of Washington and Oregon. It is an area of high relief and varied bedrock comprised of several mountain systems fronting the Pacific Ocean.

**➀ Dhakal, A.S., and R.C. Sidle. 2003. Long-term modelling of landslides for different forest management practices. Earth Surface Processes and Landforms 28: 853-868.**

**➃ Fannin, R.J., G.D. Moore, J.W. Schwab, and D.F. VanDine. 2007. The evolution of forest practices associated with landslide management in British Columbia, Parts I and II. Watershed Mgmt. Bull. 11(1):5-16**

**➀ Guthrie, R.H. 2002. The effects of logging on frequency and distribution of landslides in three watersheds on Vancouver Island, British Columbia. Geomorphology 43: 273-292.**

**➀ Guyette, R.P., and W.G. Cole. 1999. Age characteristics of coarse woody debris (*Pinus strobus*) in a lake littoral zone. Canadian Journal of Fisheries and Aquatic Sciences 56: 496-505.**

**➀ Hartman, G.F., J.C. Scrivener, and M.J. Miles. 1996. Impacts of logging in Carnation Creek, a high-energy coastal stream in British Columbia, and their implication for restoring fish habitat. Canadian Journal of Fisheries and Aquatic Sciences 53(Suppl. 1): 237-251.**

**➀ Hogan, D. 2001. Stream channel assessment in the interior of British Columbia. In: Watershed Assessment in the Southern Interior of British Columbia, D.A.A. Toews and S. Chatwin (eds.). Workshop proceedings, 9-10 March 2000, Penticton, British Columbia, Canada. British Columbia Ministry of Forests, Research Program, Victoria, Working Paper 57. Pages 112-133.**

**➀ Hogan, D.L. 1989. Channel response to mass wasting in the Queen Charlotte Islands, British Columbia: temporal and spatial changes in stream morphology. In: Proceedings of Watershed ‘89: A Conference on the Stewardship of Soil, Air, and Water Resources, 21-23 March 1989, Juneau, Alaska, E.B. Alexander (ed.). USDA Forest Service, Alaska Region, R10-MB-77. Pages 125-142.**

**➀ Jordan, P. 2001a. Regional incidence of landslides. In: Watershed Assessment in the Southern Interior of British Columbia, eds., D.A.A. Toews and S. Chatwin. Workshop proceedings, 9-10 March 2000, Penticton, British Columbia, Canada. British Columbia Ministry of Forests, Research Program, Victoria, Working Paper 57. Pages 237-247.**

**➀ Jordan, P. 2001b. Sediment budgets in the Nelson Forest region. In: Watershed Assessment in the Southern Interior of British Columbia, eds., D.A.A. Toews and S. Chatwin. Workshop proceedings, 9-10 March 2000, Penticton, British Columbia, Canada. British Columbia Ministry of Forests, Research Program, Victoria, Working Paper 57. Pages 174-188.**

➁ O’Laughlin, C.L. 1972. An investigation of the stability of the steepland forest soils, in the Coast Mountains, British Columbia. Ph.D. Thesis, Univ. B.C. Faculty of Forestry.

**★➃ 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(2004) 337-346.**

**Author abstract:** A comparison of landslide rates following helicopter and conventional, cable-based, clear-cut logging was carried out using results from two independent terrain attribute studies in the Eldred and Lois River watersheds in the Southwest Coast Mountains of British Columbia. Landslides initiating from directly within a road prism were excluded from the study in order to focus the comparison on landslides related primarily to conventional versus helicopter yarding methods. A landslide rate of 0.02 landslides/ha was observed in 162 terrain polygons logged by helicopter f8 years prior to this study. Landslide rates in 38 gullied polygons were 0.06 landslides/ha. No landslides were observed in 124 open-slope polygons. Over a similar 8-year   
average period, 0.03 landslides/ha were observed in 142 cable-yarded terrain polygons; 0.06 and 0.02 landslides/ha occurred in gullied and open-slope polygons, respectively. t-Tests indicate that total landslide rates are not significantly different following helicopter and conventional logging; however, a dichotomy exists between gullied and open-slope terrain polygons. Landslide rates are not significantly different in gullied terrain but are significantly higher on open-slopes following conventional cable logging. Consequently, landslides appear to have a greater potential to occur in open-slope terrain following conventional logging, but differences in gullied polygons are less likely. Increased post-logging landslide rates in conventionally logged, open slopes are more likely the result of undetected road-related drainage changes than differences between helicopter and conventional yarding-related ground disturbance.   
  
**➀ Tripp, D.B., and V.A. Poulin. 1992. The effects of logging and mass wasting on juvenile salmonid populations in streams on the Queen Charlotte Islands. Land Management Report Number 80. Prepared by Tripp Biological Consultants, Ltd., Nanaimo, British Columbia, and V.A. Poulin & Associates, Ltd., Vancouver, British Columbia, for the Fish/Forestry Interaction Program, Research Branch, B.C. Ministry of Forests, Victoria. 38pp.**

★➃ **Wilford, D.J., Sakals, M.E., Grainger, W.W., Millard, T.H., Giles, T.R., 2009, Managing forested watersheds for hydrogeomorphic risks on fans, B.C Ministry of Forests and Range, Forest Science Program, Land Management Handbook 61, Victoria, B.C, 62 pp.   
          
Author abstract:** Fans are linked to their watersheds by hydrogeomorphic processes-floods, debris floods, and debris flows. These processes move water, sediment, and debris from the hillslopes of a watershed through channels to the fan.  Fans in British Columbia are often the site of residential developments, and transportation and utility corridors, as well as high-value habitat for fish and high-productivity growing sites for forests.   Collectively, these features are termed “elements-at-risk” because they may be vulnerable to watershed-generated hydrogeomorphic processes that issue into the fan.  These processes may be natural or result from land use activities, and can cause the partial or total loss of some or all of the elements on the fan.     
        In British Columbia, forest harvesting and road building is associated with increased hydrogeomorphic hazards.  The downstream effects of these forestry activities in source areas may be far-reaching and extend beyond the scope of conventional site-oriented planning.  A five-step approach is presented to assist land managers undertake risk analyses and assessments that place their proposed developments within the watershed-fan system.  The five steps are:  1) identify fans and delineate watersheds; 2) identify elements-at-risk on fans; 3) investigate fan processes; 4) investigate watershed processes; 5) analyze risks and develop plans.  This scheme is applicable to watersheds throughout British Columbia.

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**Author Abstract**: Erosion and sedimentation are natural geomorphic processes characterized by large temporal and spatial variability. Recent radionuclide studies suggest that rare episodic events, such as large wildfires, produce massive sediment yields over time scales of thousands of years, thereby causing long-term average sediment production to exceed present-day average erosion rates by a factor of about 10. Even today, in undisturbed forested watersheds, sediment production is highly variable. Early studies of the effects of grazing and wildfire and surveys of river basins provided a foundation for much of the subsequent research on the effects of forest   
practices on erosion and sedimentation. The erosional and sedimentation effects of wildfire have been documented in many locations - ranging from none to minimal for low-intensity burns to catastrophic for high intensity burns. Management of forestlands to regulate the risk of wildfire   
effects on erosion and sedimentation is an important present-day concern throughout the region.   
  
Research consistently has shown that roads have the greatest effect of all practices associated with forest management on both surface and mass erosion. A large body of research shows, however, that much of the erosional impact of roads is manageable through proper land-use planning, location, design, construction, maintenance, and road closure. Considerable empirical data exists to illustrate surface erosion rates on roads, including time trends following construction as well as the effectiveness of a variety of erosion control practices. Effects of harvesting and associated site preparation activities on surface erosion are generally minimal   
and usually are controlled by providing downslope buffers. An exception is broadcast burning on harsh sites with highly erodible soils. Mass erosion, usually in the form of debris avalanches and torrents, is managed through risk assessment that uses inventory data and/or slope stability models to identlfy high-hazard site conditions. The primary management option for minimizing mass erosion resulting from roads or timber cutting is avoiding high-risk sites. Where avoidance is not possible, special design features are used, in the case of roads, or cutting and site preparation practices are modified, in the case of timber harvesting.   
  
Several empirical and process-based models have been developed to predict surface erosion rates, the effectiveness of a variety of erosion control practices, and downslope sediment delivery. Empirical data are the primary source of information for occurrence, magnitude, and downslope delivery of landslide material. Examples of downstream cumulative effects have been documented in terms of sediment delivery and associated channel responses. Methods to predict downstream cumulative effects are crude, however, limited primarily to sediment delivery, and are more applicable to smaller basins. Linkages between downstream cumulative effects and the impacts on beneficial uses, especially fish habitat, are poorly defined.   
  
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