Section 4

FORESTRY SLOPE AND STABILITY

An Annotated Bibliography

**Compiled for the
Region II FRPA Riparian Management Science & Technical Committee**

**by
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SUMMARY

Though no literature or research relevant to forestry practices and slope stability in Region II was found, much has been done elsewhere; Southeast Alaska, North America and various others. The following abstracts provide some insight on the subject. No slope stability bibliography was produced during the Regions I or III riparian standards reviews.

REFERENCES

Anderson, H.W. 1957. Relating sediment yield to watershed variables *in* **M. A. M. Bell, J. M. Brown, and W. F. Hubbard, editors. Impact of Harvesting on Forest Environments and Resources. Trans. Amer. Geophysical Union 38(60):921-924. From Information Canada, Ottawa, KIA OS9 Catalogue No. F052-25.1975**

Summarizes some recent studies in which multiple regression analysis was used in relating sediment yield to watershed variables. The studies are discussed in the light of methods of selecting watersheds, data, variable and functions and the effects of neglected variables, errors in variables and exclusion of insignificant variables.

Anderson, H.W. 1970. Relative contributing of sediment from source areas and transport processes *in* J.T. Krygier and J.D. Hall, editors. Forest Land Uses and Stream Environment. Pp. 55-63.

Reports new findings, offers a re-analysis of older studies, and summarizes pertinent results in the literature. Past land use, forest fires, road building, “poor Logging” and conversion of steep lands to grass have increased sediment discharge by factors ranging from 1.24 to more than 4. Projected future use is expected to increase sediment production by a factor of 4, with 80% associated with roads and 20% with logging. Increases in turbidity of streamflow were greater in logged areas of watersheds where roads were next to streams and landings were in draws. Most landslides were associated with road development, next most with logged areas and least with undisturbed forest area. Factors affecting turbidity of streamflow (differences in silt plus clay content of silts, differences in erodibility and in percent of gravel) are predictable from geologic rock types.

Anderson, H.W. and J.R. Wallis. 1965. Some interpretations of sediment sources and causes, Pacific Coast basins in Oregon and California. U.S. Dept. Agric. Misc. Publ. 970:22-30.

Bailey, G.R. 1971. Landslide hazards related to land use planning in Teton National Forest, northwest Wyoming, U.S. Dept. Agric., Intermountain Forest and Range Experiment Station Misc. Publ.

Barr, D J. and D.N. Swanston. 1970. Measurement of creep in shallow slide prone till soil. Amer. Jour. Sci.269(12): 467-480.

Creep rates in excess of 1/4 in. per year have been noted as a result of clearcutting in shallow glacial till soils in southeastern Alaska. Creep decreases rapidly with depth.

Bethlahamy, N. 1958. Logging and surface runoff. Trans. Amer. Geophysical Union 39(3):506. (Abstract)

Modern logging techniques affect the hydrology of catchments. Investigations have shown that permanent roads improperly located and poorly constructed increase turbidity and disturb the regularity of streamflow. The effect of skidding roads is not so well understood but good planning and attention to drainage may minimize harmful effects. Severe burns reduce soil infiltration rates, but such burns normally occur on only a small portion of the logged area.

Bethlahmy, N. 1960. Surface runoff and erosion-related problems of timber harvesting. Jour. Soil Water Conserv. 15(4):158-161.

Logging affects the hydrologic characteristics and behavior of watersheds. The effect may be severe or light depending upon the methods used, the degree of planning and the attention paid to details in execution. Roads for logging are a prime source of erosion and contribute directly to stream siltation. Roads for skidding are likewise responsible for such damages but possibly to a lesser extent. The harmful effects of all roads can be minimized by good planning. Animal, tractor, and cable logging affect the land surface in different degrees of severity. The effects of tractor logging may be particularly severe in mountainous terrain. Controlled burning to eliminate debris cannot be condemned wholesale,

Bethlahmy, N. 1967. Effect of exposure and logging on run-off and erosion. U.S, Dept. Agric., Intermountain Forest and Range Experiment Station Res. Note INT-61.

High intensity (12.2cm/hr) simulated rainfall was applied to quadrats on eight steep sloped with *Pinus ponderosa/Pseudotsuga taxifolia (sic*) cover in central Idaho. Logged and unlogged sites, and N.E. and S.W. exposures were represented equally. Run-off and erosion are linearly related and are greater on S.W. than N.E. slopes. The main reason for differences in erosion rates may lie in the soil characteristics associated with slope and topography.

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.

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.

Brown, G.W. and J.T. Krygier. 1971. Clearcut logging and sediment production in the Oregon Coast Range. Water Resources Res. 7(5):1189-1198.

Calhoun, A. 1967. Stream damage *in* **California State Legislature. Man's Effect on California Watersheds, Part III 1965-66. Rept. from Assembly Committee on Natural Resources, Planning and Public Works, pp. 363-380.**

California Forest Industries Committee. 1965. An analysis of logging and the 1964 California floods. Compiled by California Forest Industries Committee, San Francisco.

Conner, A.B., R.E. Dickson, and D. Scoates. 1930. Factors influencing run-off and soil erosion. Texas Agric., Experimental Station Bull. 411.

Cope, F.G. 1966. Prevent logging damage to streams. B.C. Dept. Recreation and Conservation. Fisheries Management Rept. 52.

Describes effects of logging procedures on siltation and erosion, and their subsequent effects on stream life and future timber growth. Also includes effects of logging slash on streams and fish.

Croft, A.R. and J.A. Adams. 1950. Landslides and Sedimentation in the Northern Fork of Ogden River, May 1949. U.S. Dept. Agric., Intermountain Forest and Range Experiment Station Res. Pap. 21.

Describes landslides that occurred following heavy spring snow melt and rainstorms on the north fork of Ogden River, suggesting the causes and reports briefly on sedimentation in Pineview Reservoir.

Delberg, R.A. and J.N. Taylor. 1962. Erosion control on timberland at harvest. Jour. Soil Water Conserv. 17:177-178.

Delfs, J. *et al*. 1958. [The influences of forests and clearfellings on run-off, the water economy, and soil erosion.] Anuse dem Walds, Hannover No. 3:223 ft. (Abstract)

Report on 5 years' investigations in the spruce forest of the Harz Mountains. Water yield was higher from a clearfelled catchment than a forested catchment except during winter. No conclusion concerning flood peaks was reached. Mean annual evapotranspiration and winter storage were greater on the forested area. The clearfelled area yielded 56 tons/km2 from the forest. Runoff was 17% on bare soil, 4% on humus, 1% on needle litter, and 0.2% on *Aira Vaccinium* cover.

Dunford, E.G. 1962. Logging methods in relation to streamflow and erosion. Proc. 5th World Forestry Congress 3:1703-1708.

Reviews knowledge concerning the influence of road building and logging on forest soil erosion. Makes recommendations to decrease erosion and stream damage during and after logging.

Dyrness, C.T. 1965. Erodibility and erosion potential of forest watersheds. *In*: Proc. Internatl. Symp. Forest Hydrology, Pergamon Press, 1967, pp599-612.

Reviews some of the literature on forest soil erosion and erodibility. Particular consideration is given to resistance of soil particles to detachment and transport, and soil infiltration rate.

Fredriksen, R.L. 1970. Erosion and sedimentation following road construction and timber harvest on unstable soils in three western Oregon watersheds. USDA Pacific Northwest Forest and Range Experiment Station Res. Pap. PNW-104.

Report on erosion in three small watersheds in the western Cascades Range Province and sedimentation rate of their contributing streams after road construction, timber harvest and debris burning. Describes methods of logging and cutting used. Study suggests a minimal deterioration in water quality arising from sedimentation where disturbance from road construction is minimized by reduction of midslope road mileage through the use of specially designed yarding systems.

Froehlich, H.A. 1971. Logging debris: managing a problem *in* **J.T. Krygier and J.D. Hall, editors. Forest Land Uses and Stream Environment. Pp. 112-117.**

The frequency of major floods since 1861 was examined. They were found to occur at an average of only 8 years intervals. Studies are reviewed which indicate that logging debris often intensify flood damage. Recommendation for reducing this damage is made.

Fujiwara, K. 1970. [A study on the landslide by aerial photographs.] Hokkaido Univ. Experimental Forest Res. Bull. 27(2):297-345. (Abstract)

There was a marked increase in the number of landslide scars per hectare a few years after clearfelling. Complete renewal of vegetation cover takes 10 to 15 years.

Gilmour, D.A. 1971. The effects of logging on streamflow and sedimentation in a North Queensland rainforest catchment. Commonwealth Forest Review 50(1): 39-48.

In stream water samples collected during logging operation, analysis indicated that sedimentation occurred after almost every fall of rain and became severe after rain of even moderately low intensity.

Gleason, C.H. *et al*. 1955. Watershed damage – its signs and causes. American Forests, June 1955.

Describes the kind of watershed damage that can be caused by fire, overgrazing, poor road building, mining operations and poor logging practices.

Gorsenin, N.M. 1959. [Soil erosion in the montane forest of the Carpathians.] Pocvoved. 11:26-36. (Abstract)

Gully and sheet erosion took [lace after clearfellings. Subsurface erosion of humus and fine soil predominated on soil with large stones.

Gray, D.H. 1969. Effects of forest clearcutting on the stability of natural slopes. Dept. of Civil Engineering, National Science Foundation, Grant No. GK-2377.

Forest cover appears to affect the deep seated stability of soils in two principal ways (viz. by modifying the hydrologic regime in the soil mantle and by mechanical reinforcement from its root system). Studies are described which report theoretical slope stabilities, and quantitative data on soil moisture stress and soil mantle creep before and after clearcutting.

Haupt, H.F. and Kidd, W.J. 1965 Good logging practices reduce sedimentation in central Idaho. J. For. 63:644-670.

Sedimentation was checked fairly well in 16 small watersheds in the Boise Basin Experimental Forest during ponderosa pine harvesting by advance planning, close supervision of logging, and application of intensive control measures for erosion promptly after harvest. It was found that the width of buffer strips directly affected sedimentation: 8 ft. strips permitted free sediment flow, 30 ft. strips did not permit any flow. After 3 years, sediment flow had almost halted.

Hesmer, H. and Feldmann, A. 1953. [Surface run-off on forested and unforested slopes in southern Sauerland.] Forstarchiv. 24(11/12):245-256. (Abstract)

(1) Forest soils showed a very high infiltration capacity on most plots studied and run-off, when it occurs at all, accounts for a very small percent annual precipitation and is far from being as significant as is sometimes supposed. (2) Under coppice, run-off is normally nonexistent even in very heavy rain. A very small run-off was observed only with very heavy rain on coppice areas clearfelled 2 years previously where the scanty litter had decomposed and plant cover was not yet re-established; and even this run-off appeared to be mostly absorbed by the loosed soil around the stumps or on areas where there were patches of litter or plant cover. (3) On clearfellings of spruce, whether in the first few years with litter cover or after plant cover had been established, infiltration was similar to that under spruce stands. Even with heavy rain after severe drought areas with only litter and/or raw humus cover differed little. A heavy cover of slash in one instance kept the litter moist enough to prevent run-off in heavy rain after 30 days drought. (4) The all important factor causing run-off appears to be exposure of mineral soil or topsoil poor in humus i.e. by skidding or fire. Especially high run-off was found for skidding trails running up and down slopes.

Hornbeck, J.W. and K.G. Reinhart. 1964. Water quality and soil erosion as affected by logging in steep terrain. Jour. Soil Water Conserv. 19(1):23-27.

The influence of different forestry practices on streamflow was investigated on the Fernow Experimental Forest in West Virginia. On clearcut, tractor skidded areas, maximum turbidity was found to be 56,000 ppm, while the maximum was only 25 ppm on an intensive selection cut watershed.

Jeffrey, W.W. 1968. Timber harvesting and other land use activities as related to water quality in the Okanagan Basin. Brief presented to B.C. Pollution Control Board, July 31, 1968.

Timber harvesting has an effect upon water resources. By returning evapotranspirative losses, total water yield is increased on certain sites. By creating a different mesogeometry in the landscape, snow accumulation and melt are affected. Operations associated with timber realization, particularly road building and timber extraction, have a potential for sediment production. Recent work suggests that land denudation may affect chemical water quality through release of ecosystem nutrients.

Jordan, P. 2000. Regional Incidence of Landslides. Ministry of Forests Research Program. Watershed Assessment in the Southern Interior of British Columbia: Workshop Proceedings, Working Paper 57. March 9-10, 2000. Penticton, British Columbia, Canada

A regional study was made of landslides in portions of the Arrow Forest District and the Kootenay Lake Forest District, which permits some preliminary conclusions to be made about the areal frequency of landslides, their causes, and their importance as sediment sources to streams. The study covered all or parts of 100 map sheets, totaling about one million hectares. Approximately 1700 landslides were inventoried by air-photo interpretation. A subset of about one-quarter of this study area, centered on the Slocan Valley, is discussed in this paper.

The data show that landslide frequencies are typically increased by roughly 10 times by forest development (depending on how one defines the land base for calculation of areal frequencies). The landslide frequency on private land is higher than on Crown land. About 95% of development-related landslides are due to roads or skid trails. On older roads, road fill failures are apparently the most common cause. However, on newer roads, the most common cause is drainage concentration and diversion by roads. An important category of landslides occurs some distance below roads, below a culvert or a point of accidental drainage discharge. In many of these cases, the road itself is on gently sloping, low hazard terrain, and the landslide occurs on steeper terrain below. This is known as the "gentle-over steep" situation. The Forest Practices Code does little to reduce landslide hazard in this situation, because the need for professional engineering involvement in road design is triggered by the hazard at the road location, not the road.

The terrain type most frequently involved in landslides, on an areal basis, is deep glaciofluvial or other stratified glacial deposits in valley bottoms. Otherwise, there are few generalizations that can be made about terrain factors contributing to landslide hazard, or about contributions of landslide sediment to streams. Landslides, like other geomorphic and hydrologic processes, tend to follow magnitude-frequency relations. Small landslides are most frequent, and often do not reach a stream. Large landslides are much less frequent, but often enter streams. In most watersheds, landslides are not a major component of the sediment budget, but in the rare cases where a large landslide occurs, it can dominate the sediment regime for 1 or several years

Knaebel, C.J. 1950. Forestry and flood control in Japan. Natural Resources Section, C.H.C., S.C.A.P., Tokyo, Preliminary Study 39. (Abstract)

The problem of erosion is discussed, figures for flood damage are given in tables and graphs, and recommendations are made on co-ordination of flood control, watershed improvement, upstream control, research and training, and, more specially, on restriction of clearfelling, planting immediately after felling, improvement to roads and cableways to reduce log skidding on steep slopes, restrictions on the collection of litter, management of treeless grasslands, control of conversion of forest to grass, and cultural practices in cleared areas.

Kotok, E.I. 1931. Erosion: a problem in forestry. J. For. 29(2):193-198.

The necessity of maintaining a soil cover to check erosion, aside from its effect on water conservation requires careful study by the forester. On badly eroded land the forester has the dual job of devising means to check erosion and starting a new forest. Reference is made to experimental determinations of the influence of soil cover upon run-off and erosion.

Leaf, C.F. 1966. Sediment yields from high mountain watersheds, Central Colorado. USDA Rocky Mountain Forest and Range Exp. Station Res. Pap.RM-23.

Study of comparative annual sediment yields from a carefully logged watershed and 2 undisturbed watersheds in the Fraser Experimental Forest showed good correlation between peak streamflow and accumulated sediment volume. The relationships indicate that a major part of the sediment volume is derived from channel erosion.
Keywords: erosion, logging, sedimentation, streamflow, watersheds, Colorado.

Leaf, C.F. 1970. Sediment yields from Central Colorado snow zone. Amer. Soc. Civil Engineers, Jour. Hydraulics Division 96(HYI):87-93.

Sediment yields were measured from two undisturbed watersheds and one watershed from which one-half of the merchantable timber was removed by careful timber harvesting. The necessary logging roads on the harvested watershed were planned and built to minimize erosion. Results indicate that sediment yield need not be excessive after harvest cutting on small forested watersheds in Central Colorado provided that reasonable control measures are applied during logging and road construction.

Lewis, A.B. and S.A. Newstein. 1971. A Preliminary study of soil erosion following clearfelling. Scottish Forestry 25(2):121-125 (Abstract)

After clearfelling Norway spruce, there appeared to be no appreciable amount of water run-off. Sheet erosion was very small, but was greater on steep sloped.

Lieberman, J.A. and M.D. Hoover. 1948. Uncontrolled logging damages water quality. USDA Southeast Forest Exp. Station Res. Note 1.

In a typical southern Appalachian logging operation, during a 3 month period in 1942, 250 cu. ft. of eroded material were collected from a portion of skid road 450 ft. long and 5 ft. wide on a 30% gradient. Water samples collected daily from the logged area were compared with those collected from an adjacent undisturbed catchment area. Analysis of turbidity determination for the period June 10 – Sept. 21, 1946, gave the following results: logged area, avg. turbidity 93.7 ppm, maximum turbidity 3.500 ppm and modal value 36 ppm; the corresponding values for the undisturbed area were 4.3, 80 and 2.0, respectively.

Lowdermilk, W.C. 1934. Studies in the role of forest vegetation on erosion control and water conservation. Proc. 5th Pacific Sci. Congress, 1933. 5:3963-3990.

Baring soil of its protective mantle of vegetation, especially in rain belts, accelerates erosion above the geologic norms to important degrees – even to rates far in excess of soil formation.

McArdle, R.E. 1960. Watershed Management on Wild Lands. J. For.58(4):259-316.

Full use of land resources while maintaining an optimum supply of usable water requires acceptance of 4 basic objectives that should govern integral use and management of land and water resources: maintenance of an effectual plant cover, maintenance of soil stability, maintenance of maximum infiltration rates, and control of surface run-off. Coordination of timber harvesting with protection of watershed values begins with the plans to open up new cutting roads. Selection of logging methods must give attention to probable disturbance of the soil mantle.

McCallie, S.W. 1922. Deforestation and erosion. Amer.Forester 28:394-396.

Describes the destructive effects of erosion caused by rainwash after removal of forest cover. Examples are given of area in Georgia.

McRorey, R.P. et al. 1954. A guide to erosion reduction on national forest timber sale areas. USDA California Forest and Range Exp. Station.

Detailed guide to prevention of erosion from logging on U.S. National Forests. Includes a fairly comprehensive description of the adverse effects of some logging practices as well as recommendations to improve the situation.

Marston, R.B. 1958. Parrish Canyon, Utah: a lesson in flood sources. Jour. Soil Water Conserv. 13(4):165-167.

Run-off was measured for 11 years on plots of stunted *Populus tremuloides* cover. Summer precipitation totaled 34.08 in. for this period, and of this total only 0.07 in. was measured as surface run-off and no sediment was eroded. In 1947, the trees were felled, the litter removed and the herbaceous cover burnt. For the next 11 years the total summer rain was 42.23 in. and surface run-off was 4.56 in., causing a soil loss of 3.24 acre-ft. of sediment per $mile^2$/year.

Merseneau, R.C. and C.T. Dyrness, 1972. Accelerated mass wasting after logging and slash burning in western Oregon. Jour. Soil Water Conserv. 27(3):112-114.

Clear-cut logging and slash burning in a steep 237 acre watershed in western Oregon resulted in increased rates of soil movement, especially on sloped unprotected by organic debris. During the first growing season after burning, soil movement which largely occurred as dry gravel, was most pronounced on 80% slopes (vs. 60%), on south aspects (vs. north), and in areas having little plant cover. By the second growing season after burning, rapid invasion by vegetation essentially halted soil movement on all slopes except extremely stony talus areas.

Newman, F.S. 1939. The forest and its effect on streamflow. For. Chron. 15(4):200-206.

A discussion of the effects of the forest on precipitation and erosion of related to streamflow. Species useful in the management of streamflow and prevention of erosion are given.

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.

Large areas of forested steepland are clearfelled annually by high lead logging. The effects of clearfelling on slope stability has not been extensively studied in B.C. It as found that large landslides were more frequent on clearfelled areas than on undisturbed slopes. road construction, which was responsible for 14 large landslides and more than100 smaller failures appeared to be more detrimental to the stability of Coast /range slopes than other activities carried on by man. Much of the influence of logging is attributed to the decreased tensile strength of the roots of cut trees. Concludes that logging and road construction are not compatible with protection of soil resources.

Packer. P.E. and G.F. Christiansen. 1964. Guides for controlling sediment from logging roads. USDA Intermountain Forest and Range Exp. Station Misc. Publ. 42.

Roads have a definite influence on sedimentation of watersheds. Emphasizes the necessity of proper logging and road building, and goes over factors affecting erosion and sedimentation, particularly improper road position. Many recommendations for control are made.

Reigner, I.C. 1951. Erosion studies on the Scholhanie watershed, New York. Dept. Agric., Northeast Forest Experiment Station Sta. Pap.44.

More than 80% of moderately eroded land was in grass and only 18% in forest cover. Most of the logging sites examined shoed little or no erosion damage.

Reinhart, K.G. 1964. Effect of a commercial clearcutting in West Virginia on overland flow and storm run-off. J. For. 62(3):167-171.

Presents data from 74 acres, clear-cut leaving 17 $ft.^2$b.a./acre. Skid roads were chosen by the loggers and not drained. Infiltration rates after logging were well above maximum rainfall intensities except on portions of the skid roads, where surface run-off occurred, combined with subsurface flow, intercepted by the road cuts. It is suggested that road condition and forest floor disturbances have as much influence on the hydrology of logged areas as do intensity of fellings and stand conditions.

Reinhart, K.G., A.R. Eschner and G.R. Trimble, Jr. 1963. Effect on streamflow of four forest practices in the mountains of West Virginia. USDA Northeast Forest Exp. Station Res. Paper NE-1.

Four intensities of forest management, ranging from commercial clear-cutting to an intensive selection cutting, were applied on calibrated watersheds. Increases in annual flow were related to volume cut and water quality clearly reflected care in the logging operation. Maximum turbidities ranged from 56,000 ppm on watersheds with unplanned skid roads to 25 ppm on watersheds with carefully planned skid roads.

Rice, R.M., J.S. Rothacher and W.F. Megahan. 1972. Erosional consequences of timber harvesting: an appraisal. National Symposium on Watersheds in Transition. Pp. 321-329.

Summarizes our current understanding of the effects of timber harvesting on erosion. Rates of erosion on mountain watersheds vary widely but the relative importance of different types of erosion and the consequences of disturbances remain fairly consistent. Therefore these conclusions seem to be valid for most circumstances: most of man's activities will increase erosion to some extent in forested watersheds, erosion rarely occurs uniformly; sediment production declines rapidly following disturbance; landslides and creep are the chief forms of natural erosion in mountainous regions; cutting of trees does not significantly increase erosion, but clear-cutting on steep unstable slopes may lead to increased mass erosion; accelerated erosion is a possible undesirable side effect of used of fire in conjunction with logging; the road system built for timber harvesting far overshadows logging or fire as a cause of increased erosion; and potentially hazardous areas can be identified in advance of the timber harvest.

Rothacher, J.S. 1959. How much debris down the drainage? Timberman 60(6):75-76.

On the basis of theoretical consideration it is possible to estimate the amount of water that a given watershed is capable of producing and depths that can be expected in the stream channel during high flow; but more information is needed to better estimate maximum flows and how large a stream is required to move logging.

Rothacher, J.S. and T.B. Glazebrook. 1968. Flood damage in the national forests of Region 6. USDA Pacific Northwest and Range Exp. Station.

Discusses floods with particular reference to logging in increasing soil instability on steep slopes and to the accumulation of logging debris in stream channels.

Rothwell, R.L. 1971. Watershed management guidelines for logging and road construction. Canada Forest Service, Forest Research Lab., Edmonton. Inform. Rept.A-X-42.

Guidelines based on an extensive literature survey of research results and practices in North America and on a broad reconnaissance of forest conditions in Alberta. Most serious erosion and sedimentation problems in forested lands originate from logging operations and forest roads. Main causes of erosion are logging on steep slopes, skidding straight up and down slope roads that change or disturb the natural flow of drainage channels and roads with steep gradients and inadequate drainage to direct water from road surfaces. It is not the cutting of trees that results in damage but the methods of log removal. In general, however, the potential for erosion increases with the number of stems or volumes removed per unit area. Tractor logging usually causes more soil disturbance, exposure and compaction than other methods.

Schiecchtel, H.M. 1954. [The consequences of deforestation as instanced by the Fisingtal in the North Tirol.] Zbl.ges.Forstw.73(1/2):13:28. (Abstract)

Forest cover of the Trillertal, a 17 km long side valley, was reduced from 33% to 25% between 1873 and 1951 through overcutting and avalanche. Faulty location of clearfelling along the feeder valleys and the damage done to their stream beds by skidding aggravated the effect of a 20% annual overcut and turned them into torrents carrying masses of stone and gravel.

Schurholz, G. 1971. Adverse side effects of commercial logging practices in British Columbia. Canada, Dept. Environment, Translation OOENV-124.

Deals with the four logging methods best known in North America and their adverse effect on water management including clear-cutting, diameter limit cutting, extensive selection management and intensive selection management. Emphasis is on erosion caused by roads, skid trails and tracks causing extensive stream pollution.

Shirai, J., M. Kondo and C. Ohara. 1954. [Experiments in water conservation at Tatsunokochi. Vol.4. The difference in run-off before and after felling.] Meguro Forest Exp. Station Tokyo, Bull. 68:95-122. (Abstract)

Measurements on rainfall, run-off and water retention by the soil show that flood control and water conservation in the two area already examined were decreased by clearfelling.

Silen,R.R. and H.J. Gratkowski. 1953. An estimate of the amount of road in the staggered-setting system of clear-cutting. USDA Pacific Northwest Forest and Range Exp. Station Res. Note 92.

Measurement of 8800 acres suggest that ca 6.2% of total forest area will be disturbed by road building and 3.6% by the construction of log dumps; loss of productive land through failure of regeneration on cuts and fells and on roadbeds is estimated at 2.9% and on log dumps at 1.2%.

Swanston, D.N. 1969. Mass wasting in coastal Alaska. USDA Pacific Northwest Forest and Range Exp. Station Res. Pap. PNW-83,

Mass wasting 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 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.

Swanston, D.N. 1980. Influence of Forest and Rangeland Management on Anadromous Fish Habitat in Western North America -- Impacts of Natural Events USDA Forest Service Anadromous Fish Habitat Program, USDA Forest Service Pacific Northwest Forest and Range Experiment Station General Technical Report PNW-104.

Natural events affecting vegetative cover and the hydrology and stability of a stream and its parent watershed are key factors influencing the quality of anadromous fish habitat.

High intensity storms, drought, soil mass movement, and fire have the greatest impacts. Wind, stream icing, and the influence of insects and disease are important locally.

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.
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.

Swanston, D.N. 1971. Principal mass movement processes influences by logging, road building and fire *in* **J.T. Krygier and J.D. Hall, editors. Forest Land Uses and Stream Environment.**

Dominant natural soil mass movement processes active on watersheds of the western United States include (1)debris avalanches, debris flows, and debris torrents; (2) slumps and earth flows; (3) deep seated soil creep; and(4) dry creep and sliding. A dominant characteristic of each is steep slope occurrence, frequently in excess of the angle of stability of the soil. All but dry creep and sliding occur under high soil moisture conditions and usually develop or are accelerated during periods of abnormally high rainfall. Further, all are encouraged or accelerated by destruction of natural mechanical support on the slopes. Logging, road building and fire play an important part in initiation and acceleration of these soil mass movements. Road building stands out at the present time as the most damaging activity, with soil failures resulting largely from slope-loading, back-slope cutting, inadequate slope drainage. Logging and fire affect stability primarily through destruction of natural mechanical support for the soils, removal of the surface cover, and obstruction of main drainage channels by debris.

Swanston, D.N. 1972. Judging impact and damage of time harvesting to forest soils in mountainous regions of Western North America. Proc. Western Reforestation Co-ordinating Committee, 1971. Pp. 14-19

Slope disturbance produced by forest operations on mountainous terrain has been identified as a major contributor to initiation and acceleration of erosion by soil mass movement processes. Road building is the most damaging operation, but timber cutting may be effective as an initiator in local areas. Forest operations in mountainous regions have a major impact on soil erosion processes. Forest vegetation protects the soil surface, and internal soil strength is adequate to resist the downward pull of gravity on the soil mass. Any disrupting influence, whether it be a natural catastrophe, such as fire, earthquake, or large storm, or the activities of man, is a potential initiator of a more active erosion cycle.

Swanston, D.N. 1974. The Forest Ecosystem of Southeast Alaska -- Soil Mass Movement. USDA Forest Service General Technical Report PNW-17

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 tree 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 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 sloped 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.

Ujari, F. 1969. [The effect of forest sediment formation.] Erdesz Kutatas. 65(1):133-136. (Abstract)

On an experimental catchment area of the Hungarian Forest Research Institute at Kisnana, water yield and sedimentation were measured on 2 X 10 m plots. Removal of tree and/or shrub vegetation greatly increased run-off; the remaining ground cover, however, prevented an increase in sedimentation. This is interpreted as indicating that the erosion risk of clearfelling on such sites is not great. Erosion of a bare plot was considerable.

USDA. 1950. How forest conditions affected the 1948 Columbia flood. USDA Forest Service, Agric. Info. Bull.10.

Analysis of the available data indicates that the primary cause of the flood was excess precipitation over the catchment area, but that denuded and eroded forest slopes contributes more than their share of flood water and debris. In particular, snow melt was much slower on the forested areas.

USDA. 1971. Erosional effects of timber harvest *in* "Clearcutting" practices on national timberlands, hearings before Subcommittee on Public Lands, Committee on Interior and Insular Affairs, U.S. Senate, 92nd Congress, 1st Session. Pp. 1202-1223.

USDA Int. F.R.E.S. 1964. Good logging practices reduce sedimentation in central Idaho. Rept., USDA Intermountain Forest and Range Exp. Station, 1963. Pp. 45-46.

Describes results after 11 years of logging on a group of small catchments in a ponderosa pine granite soil zone. There was no relation between the area of logging disturbance and the frequency of sediment flows reaching a channel. Haul road disturbance produced surface sediment reaching a channel more often than did skidding trail disturbance. Mean annual yield of sediment downstream in settling ponds was low, owing to the provision of protective strips, logging supervision, prompt application of soil-conserving measures, and the small number of perennial streams.

USDA Pacific Northwest Forest and Range Experiment Station. 1951. Douglas fir region old growth management (Streamflow and erosion studies). Rept. USDA Pacific Northwest Forest and Range Exp. Station, 1950. Pp 29-31.

Studies indicate that most stream sedimentation came from road building and road use. In logging, most erosion damage resulted from using heavy equipment during periods of surface run-off. Previously logged areas caused serious turbidity only during the heaviest rains. Yarding across streams, in the few cases where this was essential, was an important source of sedimentation even in dry weather. Recommendations are made for road planning and construction to reduce sedimentation. A trial has begun on the effect of streamside treatment in logging when (1) a wide strip of timber is left between the first road level and the stream, (2) and (3) trees are felled right to the bank on steep and gentle slopes respectively and (4) a narrow belt of trees is left along the bank. Conclusions at the end of the first year were that all four methods successfully prevented interference with the stream either by turbidity or by the accumulation of logging debris.

USDA Rocky Mt. Forest and Range Experiment Station. 1949. Partial timber cutting did not change quality of water. Rept., USDA Rocky Mountain Forest and Range Exp. Station, 1948. Pp3-4.

There is definite indication that erosion subsequent to logging is almost entirely absent in the high altitude country of the Rocky Mountains area.