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Forest Practices and Streamflow in Western Oregon

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Winters are wet, and summers are relatively dry. Precipitation, occurring mainly in long-duration, low-to-moderate intensity frontal storms, ranges from 170 to 300 centimeters (cm) in the Coast Ranges and from 70 to over 350 cm in the western Cascades. From 75 to 85 percent of annual precipitation occurs between October 1 and March 31, mostly in the form of rain. Above 900-m elevation, accumulations of snow are common.

Annual streamflow is closely correlated with annual precipitation. Runoff is usually greatest in December and January, the months of maximum precipitation. At elevations where accumulations of snow are common, annual streamflow may exhibit two peaks, one resulting from rain in December and a second one resulting from snowmelt in April or May. Maximum runoff events in western Oregon have resulted from excessive rainfall concurrent with snowmelt in December and January. Such events have caused considerable damage to stream channels, hydraulic structures, and property in much of the region (Rothacher and Glazebrook 1968).

The four study areas described here are considered representative of much of western Oregon. The Alsea study was conducted by Oregon State University in the Coast Ranges about 16 km from the Pacific Ocean (fig. 1). Soils here are derived from marine sandstone and are 60 to 140 cm deep and extremely permeable (Corliss 1973). Physiography is typical of much of the Coast Ranges; slopes are steep (40 to 110 percent), topography is highly dissected, and V-shaped drainages are common. The three other studies have been conducted by the U.S. Forest Service, Pacific Northwest Forest and Range Experiment Station. The Fox Creek study is located within the city of Portland municipal watershed 40 km east of Portland. Soils here are silt loams or gravelly loams derived from basic igneous glacial tills which overlie andesite and basalt. Soils here also exhibit rapid to moderately rapid percolation rates.[1/] Although steep slopes range up to 60 percent adjacent to streams in the lower ends of these study watersheds, the topography of this study area is relatively gentle with slopes less than 10 percent. A second U.S. Forest Service study is located in the H. J. Andrews Experimental forest 75 km east of Eugene. Slopes here are steep (55 to 110 percent), and soils are gravelly loams and clay loams derived from pyroclastic rocks. Soil permeabilities are extremely high (Rothacher et al. 1967), and runoff is rapid. Similar slope and soil conditions exist at Coyote Creek, the site of the fourth study included in this report. Soils are derived from tuffs and breccias and are quite permeable (Richlen 1973). Study areas are further compared in table 1.

[1/] Stephens, F. R. 1966. Soil management report, Bull Run-Sandy area, Oregon. 136 p. Unpublished report, USDA For. Serv., Mount Hood National Forest, Gresham, Oreg.

while another portion evaporates. In the H. J. Andrews area, about 14 percent of annual precipitation or about 30 cm is intercepted and evaporated (Rothacher 1963). The relative amount of storm precipitation "lost" to interception by a given forest vegetation depends mainly on the size of the storm. For example, Rothacher (1963) found this loss was 100 percent of storms less than 1.5 millimeters (mm) and less than 5 percent of storm precipitation in excess of 200 mm. In other words, a high proportion of precipitation from larger storms reaches the ground regardless of the presence of forest vegetation. Consequently, timber harvest would be expected to have its greatest effect on interception during smaller storm events.

In undisturbed forested areas in western Oregon, infiltration capacities are extremely high and storms are of long duration with low-to-moderate intensities. Surface soils frequently exhibit hydraulic conductivities in excess of 150 centimeters per hour (cm/h) (Dyrness 1969, Ranken 1974, Yee 1975). More important, unsaturated conductivities of at least the top meter of soil are sufficient for soils to transmit all precipitation during most storm events (Yee 1975, Harr 1975). Thus, for undisturbed soil, the overland flow component in figure 2 is virtually nonexistent; the movement of subsurface water accounts for nearly all streamflow in western Oregon. A small amount of streamflow, of course, does result from precipitation intercepted by stream channels.

When soil is disturbed by road construction, tractor skidding of logs, or broadcast burning, its infiltration capacity may be so seriously reduced that not all water will enter the soil. Some water may become overland flow which can move rapidly to stream channels and out of the watershed. In a few cases, the quantity entering the soil after compaction could conceivably be so small that soil drainage during the summer would be insufficient to maintain streamflow. Such cases may have been the origin of the popular but erroneous belief that clearcutting dries up springs and streams.

Water in the soil is subject to uptake and transpiration by forest vegetation and to evaporation from the soil surface. Generally, evaporation from soil under forested conditions is minimal, primarily because of small amounts of energy available for water vaporization at the forest floor and because of reduced air movement here. This energy situation can be drastically changed by timber harvest, and evaporation from soil is generally increased after removal of forest vegetation. However, this increase is greatly offset by a reduction in transpiration after timber harvest so that soil on a cut area will contain much more water at the end of a growing season than it did while forested. Water not returned to the atmosphere by evaporation or transpiration moves slowly downslope and maintains streamflow during rainless periods.

Subsurface water may be affected by construction of roads on steep slopes which may intersect relatively slow-moving subsurface water and convert it to more rapid surface flow in a ditch. This water and water flowing from road surfaces during storms moves rapidly through the ditch-culvert system and may reach the watershed outlet more quickly than it did before road construction.

With the foregoing hydrologic system in mind, let's now look at changes in streamflow which have been noted after common timber harvesting activities have been carried out in western Oregon.

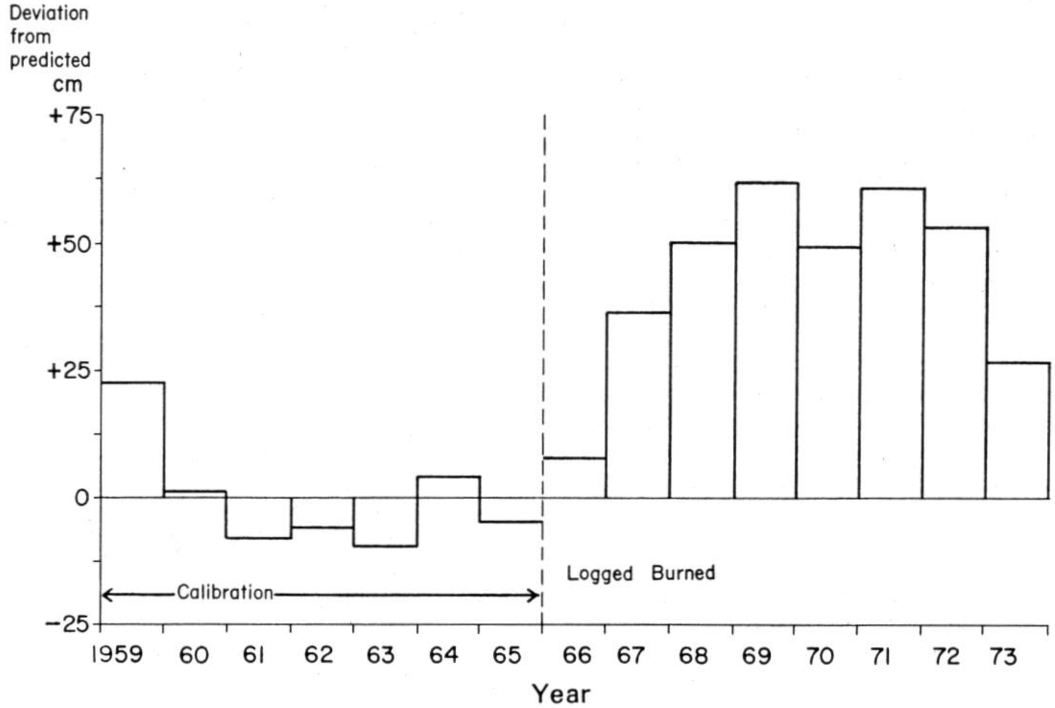

Figure 4.--Increases in annual water yield after 82-percent clearcut logging in Needle Branch watershed, Alsea watershed study.

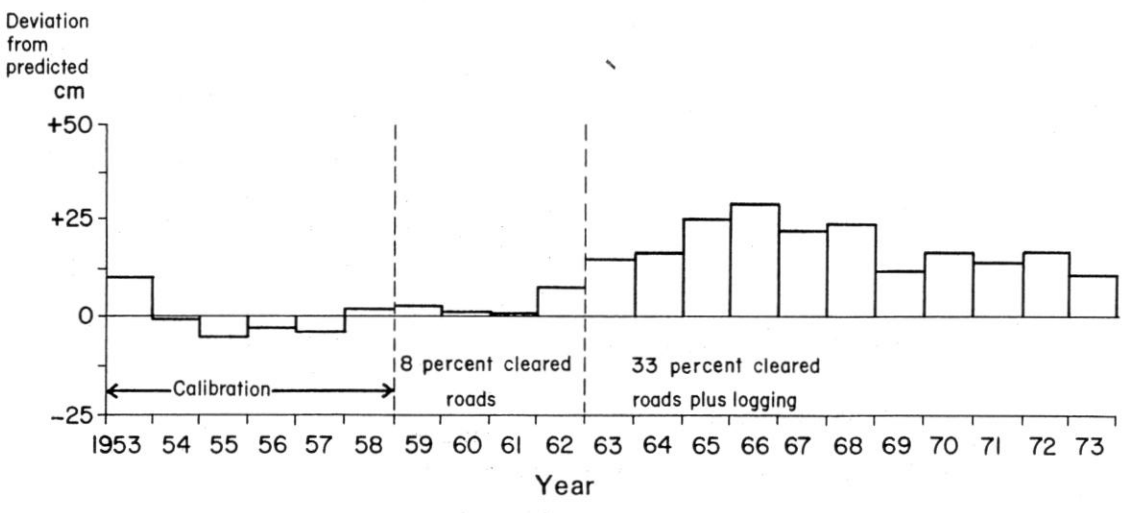

Figure 5.--Increases in annual water yield after roadbuilding and patch-cut logging in watershed 3, H. J. Andrews Experimental Forest.

proposed by Hibbert (1967). In most cases, yield increases have been 25 to 35 percent of predicted streamflow.

SEASONAL YIELDS

Often the distribution of increases in water yield through the year are of more interest than the size of the annual increases. Analyses of seasonal increases in water yield have been made in three of the watershed studies in western Oregon; results are sufficient to describe, at least relatively, seasonal increases that can be expected in much of western Oregon.

The most complete analysis of seasonal water yields was made by Rothacher (1970) and later updated (Rothacher 1971). Increases in yield were noted for all seasons after a 96-ha watershed (HJA-1) was clearcut and burned. In much of the western Cascades and elsewhere in western Oregon, largest increases have occurred during fall months when soils on the cutover areas are wetter than they were under forested conditions. Thus, a smaller proportion of fall rains is required for soil moisture recharge and a larger proportion can go to streamflow. Smaller increases in yield observed during winter months generally have reflected differences in interception between cut and uncut areas, although in some cases differences in soil moisture may exist between cut and uncut areas because of winter transpiration. Increases noted in spring months have been due primarily to differences in soil moisture content as a result of transpiration. Summer increases have been small in absolute terms but large in relative terms. For example, minimum flow during the week of lowest flow doubled after watershed HJA-1 was clearcut, and tripled after this watershed was burned (Rothacher 1971). Two years after burning, however, increases had diminished as riparian and other vegetation returned.

Increases in minimum flows were also observed in the Oregon Coast Ranges. Harr and Krygier (1972) used the number of low-flow days, i.e., days with average flow below 0.011 cubic meter per second per square kilometer ($m^3/s \cdot km^2$) (1 csm[2]) as a criterion for evaluating changes in minimum flows. A significant reduction in number of low-flow days was observed for 5 years after a 71-ha watershed (AL-1) was 82 percent clearcut and burned (fig. 6). As regrowth has proceeded, the trend has been toward the prelogging numbers of low-flow days. Effects were initially most pronounced in spring and fall. Because average daily flow during the summer was generally less than 0.011 $m^3/s \cdot km^2$ on even the 82-percent-clearcut watershed, an increase in streamflow during summer months could not be detected by this method of analysis even though an increase in streamflow undoubtedly did occur. A nearby watershed (AL-3) that was 25 percent clearcut showed a less consistent reduction in number of low-flow days, again primarily during spring and fall months.

Minimum flows at Coyote Creek were also increased after a 50-ha watershed (CC-3) was 100 percent clearcut. However, no significant changes were detected either on the Coyote Creek watersheds cut in small patches or by the shelterwood method or on the two patch-cut Fox Creek watersheds.

In summary, increases in seasonal water yield after timber removal are greatest in fall and spring when maximum differences in water storage (interception + soil water) exist. Largest relative increases occur during minimum flow in the summer.

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[2] csm = $ft^3/s \cdot mi^2$.

the proportion of the parent watershed which exhibits increased stormflow, and the travel time of water from the various subwatersheds to the point of potential flooding. Only increases in stormflow of major runoff events are instrumental in downstream flooding; increases during frequent and minor runoff events are of little consequence.

An attempt has been made to isolate the effects of roads on storm runoff from other timber harvesting activities in several small watersheds. Changes have generally been minor, inconsistent, and in most cases, statistically nonsignificant at the 95-percent level of probability. Statistical nonsignificance has been due in part to the small number of runoff events suitable for inclusion in the analysis and to the high degree of variation in both pretreatment and posttreatment periods. Watershed studies have generally followed the same sequence. First, after watersheds were calibrated for 6 to 10 years, roads were constructed on certain watersheds, and their effect on streamflow was evaluated for 1 to 3 years. Then timber was harvested and the effects of its removal evaluated for several years. The calibration periods, because they have been longer, have had the greatest probability of containing large runoff events, those with a return period of 5 years or more. On the other hand, effects of roadbuilding can be evaluated for only 3 years; after 3 years the areas are altered by logging. Thus, there is generally a shortage of runoff events with which to evaluate the effect of roads alone. Where a sufficient number of events has been available, these events have been small with return periods less than that of the mean annual runoff event.

There has been much the same type of difficulty in assessing changes in storm runoff after timber harvest. The effects of logging and burning should be greatest the first winter after harvest. As the watershed is revegetated, the effects of these activities are ameliorated so that the condition of the watershed is somewhat improved. Consequently, the period of time a watershed is in a clearcut or burned condition is rather short, and the number of storm runoff events suitable for analysis again is generally small. Also, the size of these suitable events tends to be small.

Peak Flows

In the Alsea study in the Coast Ranges, the effects of roads alone on peak flow were variable. A significant increase in peak flow was noted only on a 40-ha watershed (AL-33) where roads occupied 12 percent of total watershed area (Harr et al. 1975). Here average peak flow was increased 0.055 $m^3/s \cdot km^2$ (5 csm) in both fall and winter. Both increases were highly significant. No significant increase in average peak flow after roadbuilding was noted in either the H. J. Andrews study or the Fox Creek study where roads occupied 8 percent and less than 2 percent of the respective watershed areas. In fact, in the H. J. Andrews study, a slight unexplained decrease in peak flow was noted after roadbuilding. At Coyote Creek, an increase in average peak flow occurred on a watershed (CC-1) in which roads and skid trails occupied about 15 percent of the watershed. In all four of the above cases, the runoff events used in analyses were generally less than 0.33 $m^3/s \cdot km^2$ (30 csm), and were of little consequence in potential damage to stream channels or hydraulic structures. Thus, for western Oregon, analyses of changes in peak flows have failed to reveal any consistent increase caused by roads alone.

There are only two instances where watersheds were clearcut (or nearly so) in the absence of logging roads. In the H. J. Andrews study, average peak flow increased 30 percent

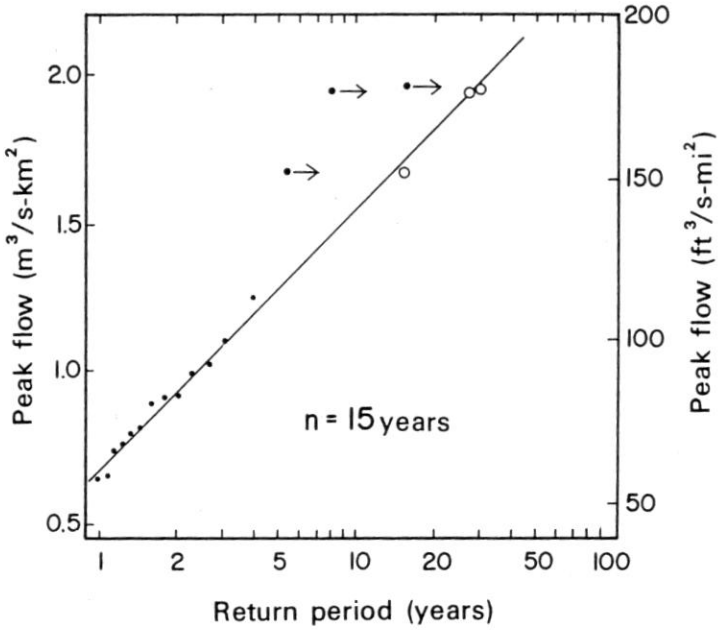

Figure 8.--Peak flow frequency analysis for control watershed, Alsea watershed study, 1958-73. The return periods of the three largest events were arbitrarily increased to be consistent with return periods of simultaneous peak flows on nearby streams of longer record.

In the watershed (AL-1) where only 5 percent of the area was occupied by logging roads and skid trails, no significant increase in peak flows above 0.55 $m^3/s \cdot km^2$ (50 csm) was observed (Harris 1973). In another watershed (AL-33) of this study where roads occupied 12 percent of total watershed area, the increase in peak flow appeared to exist for even the larger runoff events. Similarly, in the Coyote Creek study, where compacted soil from logging roads and tractor windrowing of slash occupied 13 percent of a watershed (CC-3) that was clearcut, the predicted increase in a peak flow of 1.1 $m^3/s \cdot km^2$ (100 csm) was 25 percent. Where compacted area occupied 15 percent of a watershed (CC-1) in which 30 percent of the forest was removed in a shelterwood cut, the predicted increase in a peak flow of 1.1 $m^3/s \cdot km^2$ (100 csm) was 27 percent.

Thus, the amount of a watershed in forest roads and skid trails appears to increase the size of larger peak flows as well as the smaller peak flows during the rainy season. This contrasts with clearcutting alone which appears to have

Average peak flows can be increased, but the peaks to which these increases apply correspond to only 0.33 to 0.55 $m^3/s \cdot km^2$ (30 to 50 csm), well below the estimated 25-year peak of about 1.7 to 1.9 $m^3/s \cdot km^2$ (150 to 175 csm) (see Figs. 7 and 8). Analyses of larger runoff events (Harris 1973, Rothacher 1973) suggest that the effect of clearcutting decreases with increasing magnitude of the runoff event.

Design implications, potential onsite damage, and damage to hydraulic structures resulting from the effects of roads and other severely compacted areas on peak flows are much more serious than those of clearcutting. Roads are more permanent than clearcuttings and, unlike the situation with clearcutting, differences between watersheds with roads and watersheds without roads appear to exist even for large runoff events. In western Oregon, four experimental watersheds had at least 12 percent of their areas in roads, skid trails, and other areas of heavily compacted soil. For three of these watersheds, regression analyses indicate marked increases in peak flows with estimated return intervals of 3 to 5 years--peak flows larger than the mean annual runoff event. Using data from the Alsea watershed study, Harr et al. (1975) suggested that a 10-year runoff event might be increased to a 25-year event, and a 25-year event might be increased to a 90-year event on a watershed with 12 percent of its area in roads.

It is doubtful that normal clearcutting practices in the headwater areas of western Oregon have any appreciable effect on downstream flooding. Similar conclusions were reached for forested watersheds of the Eastern United States (Lull and Reinhart 1972, Hornbeck 1973). Such flooding results from extremely large, low-frequency runoff events. These are termed wet-mantle floods and are caused by such great amounts of precipitation that differences in soil moisture and interception between cut and uncut areas become insignificant. If a cable yarding system is used, soil disturbance is light (Dyrness 1967) and infiltration capacity largely unchanged on the clearcut area; cut and uncut areas should respond nearly the same during large storms. In addition, whatever differences do exist between cut and uncut areas are further masked downstream by water flowing from uncut areas. To illustrate this point, Harr et al. (1975) assumed a 100-year rotation, an initial increase in stormflow of 10 percent, and that increases in stormflow would not disappear until 20 years after timber harvest. They estimated that the maximum increase in total storm flow at the outlet of a typical large drainage in western Oregon would be about 1 percent; for a 50-year rotation, the increase would be about 2 percent, hardly enough to cause downstream flooding.

The effects of clearcutting on storm runoff also may be overshadowed by other hydrologic phenomena sometimes related indirectly to timber harvest. Road failures, natural slope failures, natural organic debris, and logging debris can temporarily dam streams and cause extreme peak flows when such dams eventually fail and release large quantities of water and debris. Culverts and bridges adequate to accommodate design flows have failed when plugged with debris (Rothacher and Glazebrook 1968). In addition, snow accumulation and melt rate in the ephemeral snow zone may be altered by clearcutting.

A potential application of results of watershed studies in western Oregon involves the relationship between increases in water yield and in peak flow. National Forests in the northern Rocky Mountains, for example, are regulating timber harvesting activities to minimize channel erosion (USDA Forest Service 1971, Delk 1972, Galbraith 1973) because increases in peak flow (and thus channel erosion) supposedly are related directly to increases in annual water yield.

However, in western Oregon there is no consistent relationship between increases in water yield and increases in peak flow after timber harvesting activities. Type of watershed treatment and whether or not increases occurred in annual yield, average peak flows, and large peak flows are shown in table 3. As can be seen, every possible combination of increases has been observed. Six experimental watersheds exhibited increases in annual yield and average peak flows. (Increases in water yield have been assumed for the three Deer Creek subwatersheds although annual yield data are not available.) Three watersheds showed an increase in water yield but none in average peak flow, and two showed no increase in yield, but an increase in average peak flow. The only consistency here is that all watersheds that were at least 65 percent clearcut showed increases in both water yield and average peak flows.

In terms of damage to stream channels by increases in peak flows, it seems improbable that these average peaks are very effective. Sediment concentrations are frequently high during initial fall runoff events, nearly all of which are smaller than the average peak flow; but this sediment most likely is soil that fell into the stream channel during the summer. Thus, even if a strong relationship did exist between increases in water yield and increases in average peak flow (it doesn't) it would be of little consequence in channel erosion.

Of considerably more importance to channel erosion are increases in larger peak flows, i.e., peaks with return intervals in excess of that of the mean annual peak (2.33 years). Peaks of this size appeared to have increased on only three experimental watersheds in western Oregon. Each of these watersheds had at least 12 percent of its area occupied by heavily compacted soil, mainly as a result of logging roads, tractor skidding, and tractor windrowing of slash. Thus, soil disturbance and its location relative to stream channels appear to offer a basis for developing a method for regulating timber harvesting to minimize channel erosion. However, the dynamics of channel erosion and sediment transport are insufficiently understood at this point to allow assessment of the effects of timber harvest activities on this type of erosion.

Summary

Results of four studies show certain aspects of stream flow in small watersheds in headwater areas in western Oregon were changed by roadbuilding, clearcutting, and other timber harvesting activities. Annual yields and summer low flows were increased significantly after clearcutting. Such increases, however, have only onsite importance, because under sustained yield forest management, increases in water yield from clearcut areas are greatly overshadowed by water flowing from uncut areas. Thus, yield increases in a large basin are extremely small. Both roadbuilding and clearcutting increased small peak flows. Large peak flows appeared to be increased where at least 12 percent of a watershed was seriously compacted by roadbuilding, tractor skidding, or tractor windrowing of slash.

Timber harvesting practices that do not severely modify soil properties on more than about 5 percent of headwater basins in western Oregon probably do not have any appreciable effect on large, low-frequency runoff events which cause extensive downstream flooding. These large events are wet-mantle floods caused by such

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