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Clear-Cut Logging and Sediment Production in the Oregon Coast Range

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Abstract. The impact of road construction, two patterns of clear-cut logging, and controlled slash burning on the suspended sediment yield and concentration from three small watersheds in the Oregon Coast Range was studied for 11 years. Sediment production was doubled after road construction but before logging in one watershed and was tripled after burning and clear-cutting of another watershed. Felling and yarding did not produce statistically significant changes in sediment concentration. Variation in the relation between sediment concentration and water discharge on small undisturbed streams was large. Conclusions about the significance of all but very large changes in sediment concentration are limited because of annual variation for a given watershed, variation between watersheds, and variation with stage at a given point.

In the Pacific Northwest commercial forests cover much of the headwater landscape. Timber harvest is the predominant land use in these forests. In Oregon alone 500,000–700,000 acres are logged annually. Logging is preceded by road construction. Clear-cutting is the principal logging technique, followed by slash burning. The change in the appearance of the landscape is dramatic and abrupt. The crucial question for water quality is: How does clear-cut logging affect erosion and sedimentation in headwater streams? In Oregon this question is crucial because salmon, steelhead, and trout use these small streams for spawning and rearing.

The purpose of this paper is to describe the effect of road building, clear-cut logging, and slash burning on suspended sediment production from three forested watersheds in the Oregon Coast Range, where precipitation averages 100 inches annually and topography is steep.

The effects of sediment on fish have been summarized by *Cordone and Kelley* [1961]. Excessive concentrations of suspended sediment (20,000 ppm) can cause gill injury or alteration of behavior patterns. The most important effects of sediment at more typical concentrations occur because of alteration and destruction of bottom organisms and because of indirect influences of sediment deposition on intragravel flow and aeration. Mineral and organic sediments in water or deposited in spawning gravels may cause mortality, delayed development, or poor condition in salmon and trout [*Brannon*, 1965; *Kramer*, 1965; *Koski*, 1966; *Shelton and Pollock*, 1966; *Servizi et al.*, 1969]. Gravel size has been related to the interchange of dissolved oxygen [*Oregon Game Commission*, 1967; *Ringler*, 1970]. Cooper found that deposition will occur in spawning gravels at moderate concentrations even though velocities are too high to permit deposition on the surface.

Public concern for pollution has led to the establishment of water quality standards. Oregon has now gone beyond interstate standards (e.g., the Water Quality Act of 1965) and has applied water quality standards to subbasins to control the quality of upstream waters directly [*Oregon Department of Environmental Quality*, 1969]. These standards have been set without a full understanding of sediment concentrations or sediment production rates from mountain streams under either natural conditions or conditions influenced by logging operations.

Forest hydrologists have often related sediment production to timber harvest operations in headwater areas. Road construction preceding logging is often the most serious cause of erosion. In the volcanic formations of the Oregon Cascades, sediment yields from three small, steep watersheds tributary to the McKenzie River seldom exceeded 200 ppm before treatment [*Fredriksen*, 1965, 1970]. Immediately after roads were constructed across one watershed, a peak sediment concentration of 1780 ppm was observed, 250 times that recorded in a control watershed. This initial effect subsided after 2 months, but concentrations remained two to three times the level predicted from the control. These results did not include samples from landslide events. In 1961 and 1964 road landslides produced average concentrations about 34 times greater than that expected from the pretreatment relationship. Mean annual sediment yield including bed load was 8000 t/mi^2 in a 9-year period, 109 times the loss from an undisturbed control watershed.

At Castle Creek in California, where the primary influence was roads, average sediment concentrations and loads from a 4-mi^2 watershed increased fivefold the first year, from 64 to 303 ppm (935–4600 t/mi^2). Concentrations and yield declined to twice the normal rate in the second year [*Rice and Wallis,* 1962; *Anderson and Wallis,* 1965]. In the Idaho granitic batholith, roads associated with jammer logging (a high density road system) in one season produced highly variable sediment yields from three logged watersheds: 12,400, 8900, and 89 t/mi^2 [*Copeland,* 1965]. Neighboring drainages without roads in this area of highly erodible granitic soil produced no sediment; in watersheds with roads high yields were attributed to inadequate cross drains.

The effects of the logging operation are often difficult to separate. In many erosion studies the sediment contributed by road construction, skid trails, and logging are measured together. One such study at Fernow Experimental Forest in West Virginia reported an average turbidity of 490 ppm (Jackson turbidity units) during tractor logging. One year later the average turbidity dropped to 38 ppm; 2 years later it was only 1 ppm. Another study at this forest illustrates the importance of planning logging operations. On a well-planned logging operation, the maximum turbidity was only 25 ppm. An adjacent watershed was logged without any plan or direction, and maximum turbidities of 56,000 ppm were recorded [*Reinhart and Eschner,* 1962].

Sediment was sampled before, during, and after clear-cut logging in the Maybeso and Harris River valleys in southeastern Alaska [*Meehan et al.,* 1969]. No significant change could be detected in the concentrations, possibly because of inadequate sampling. *Sheridan and McNeil* [1968] found small increases in the percentage of fine sediments deposited in the stream gravels after logging in this same area. The probable source of this sediment was debris avalanches, which were common in clear-cut areas.

Fredriksen [1970] reported that on a watershed clear-cut over a 3-year period with a skyline system, and thus without roads, concentrations were only modestly affected during logging. The mean concentration during storm periods remained below 10 ppm until slides triggered by the record storms of 1965 brought about 800 tons of soil and rock material into the channel. Most of this material remained trapped by logging debris.

Controlled slash burning is a common practice after clear-cutting in the Pacific Northwest. Little information exists about the effect of controlled burning on sediment production from forests. Burning after logging wtih the skyline system described above was also reported by *Fredriksen* [1970]. Resulting sediment concentrations during two subsequent years ranged from 100 to 150 ppm and were 67 and 28 times those recorded on an undisturbed watershed during the same period. Fredriksen noted that sediment had been trapped in the logging debris and was released only after burning.

THE STUDY

In 1958 Oregon State University began a cooperative study of the effects of logging on the water quality and fishery resources of three small watersheds in the Alsea basin in Oregon. These watersheds are located about 8 miles south of Toledo and about 10 miles from the Pacific Ocean (Figure 1). The watersheds were forested with Douglas fir and alder. Mean elevations are 740, 850, and 1000 feet. Mean slopes are 35, 37, and 50%. The maritime climate produces a mean annual precipitation of about 100 inches. Summers are dry, however, and most of the rainfall occurs between November and April. The soils are derived from the Tyee sandstone formation. Over 80% of the soils are from either the Slickrock or the Bohannon series. The Slickrock soils are derived from sandstone colluvium and are fairly deep. The Bohannon series, a shallow, stony soil, is derived from the sandstone residuum. Both series are moderately stable.

The sediment yield characteristics of the watersheds were monitored for 7 years before treatment (1958–1965). Suspended sediment is measured at the mouth of each watershed and at six small stream gages in Deer Creek. The gages at the mouth of each watershed are operated by the U.S. Geological Survey and integrate the effects of land use on each watershed. The small gages in Deer Creek are operated by the Oregon State University School of Forestry. These gages were installed in 1963 to evaluate the effect of each cutting unit on the tributaries within the Deer Creek watershed.

Logging roads were constructed into Deer Creek and Needle Branch between March and August 1965. Flynn Creek, a 500-acre watershed, served as a control and remained in its natural condition throughout the study. Sediment samples were collected during the winter of 1965–1966 to evaluate the effect of road building. Logging began in March 1966 and ended in November of that year. The 175-acre Needle Branch watershed was fully clear-cut. The 750-acre Deer Creek watershed was 25% clear-cut, with three small units (Figure 1). The effects of these three units were measured at four weirs. The 138-acre watershed above weir 2 was 30% clear-cut, the 100-acre watershed above weir 3 was 65% clear-cut, and the 39-acre watershed above weir 4 was 90% clear-cut. The 572-acre watershed above weir 6, which measures the combined effect of the upper watersheds, was 25% clear-cut.

The slash on Needle Branch was burned in October 1966. The upper units of Deer Creek remained unburned; the lower unit was lightly burned in October 1966. Sediment sampling on Needle Branch the following winter reflected the combined effect of road building, logging, and slash burning. Sediment measurements at the six stations on Deer Creek permitted evaluation of the first two effects; U.S. Geological Survey samples included the effect of burning the lower unit. Sediment sampling continued through the 1967–1968 and 1968–1969 storm seasons. Sediment yields will be monitored for several more years.

Routine suspended sediment concentrations in parts per million were obtained daily at the U.S. Geological Survey weirs by Oregon Game

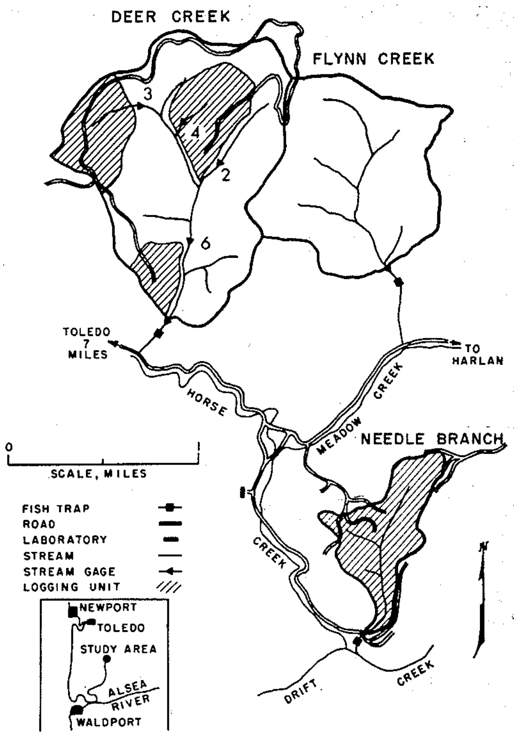

Fig. 1. Watersheds and sediment sampling stations in the Alsea watershed study.

Commission personnel. During storms samples were taken at more frequent intervals to ascertain sediment loads as stream levels changed. At the small weirs within Deer Creek, samples were taken only during storms.

CHANGES IN ANNUAL SEDIMENT LOAD

Analyses were run on two aspects of the suspended sediment data: (1) annual sediment load and (2) suspended sediment concentration. Changes in annual sediment load for the three watersheds were estimated by an averaging technique designed to reduce the variation in sediment associated with a changing streamflow regime. In streamflow studies conducted concurrently with these sediment studies, the timber harvest produced significantly increased volumes of streamflow on both treated watersheds [*Harper*, 1969; *Hsieh*, 1970].

A long-term flow-duration curve was used to estimate annual sediment yields on the basis of the flow regime during an average year. The following procedure was used in this averaging technique: (1) six years of data from the cali-

TABLE 1. Total Annual Sediment Yield in Tons per Square Mile Computed from U.S. Geological Survey Records

Water Year	Flynn Creek Normalized	Flynn Creek Actual	Deer Creek Normalized	Deer Creek Actual	Needle Branch Normalized	Needle Branch Actual
1959	92	66	114	82	74	49
1961	172	258	193	286	98	180
1962	136	84	178	97	201	115
1963	212	127	285	160	161	115
1964	223	209	231	199	181	187
1965	337	1237	308	1040	129	422
1966	246	300	577	740	270	365
1967	136	137	251	213	570	904
1968	92	59	101	84	372	490
1969	123	139	162	162	279	517

bration period were used to estimate the long-term flow-duration characteristics of each stream; (2) a relation between mean daily sediment concentration and mean daily discharge at each of the three weirs was developed for each year of the study; and (3) the sediment concentration–discharge relationship was combined with the mean flow-duration curve for each weir to obtain the mass of sediment carried in each flow class. Summing these values provided estimates of total annual sediment yield from each watershed. Thus this technique assumed that the flow each year was equal to the long-term mean in volume and distribution. This assumption normalized the effect of abnormal years by reducing the variation in sediment yield associated with annual differences in discharge. The sediment yields thus attained provide an indication of the average expectancy of a change associated with the treatments. The normalized annual sediment yield from each of the treated watersheds was then compared to that of the control by regression analysis. A similar analytical technique has been described by *Anderson* [1954].

Annual sediment yields for each watershed are shown in Table 1. Included are both normalized (weighted) yields and 'actual' yields provided from the annual sediment hydrograph analyses reported by the U.S. Geological Survey. Regressions comparing normalized annual sediment yield on Flynn Creek (the control) with that of each treated watershed are illustrated in Figures 2 and 3. Only the upper 95% confidence limits are calculated because there is no reason to suspect that treatment would reduce sediment yield.

Annual sediment yields were highly variable during the pretreatment period. There was a threefold difference between the minimum and maximum annual yields on each watershed during this period, even when normalized values were used.

Road building significantly increased sediment yield in Deer Creek (the patch cut watershed) during the 1966 water year. One road slide produced a sediment yield of 349 tons (40% of the nonnormalized yield) for the 1966 water year.

The increase in annual sediment yield after road building in Needle Branch was also statistically significant at the 95% level of probability. Road drainage and erosion of side cast materials along roads seem the most likely sources of this increase. No large slide occurred on roads in Needle Branch.

The annual sediment yield observed during the first year (1967) after logging in Deer Creek was significantly higher than that during the control period. This yield may include materials deposited by the large slide the previous year. During the two postlogging water years (1968 and 1969) sediment yields returned to prelogging levels.

Annual sediment yields in Needle Branch increased markedly immediately after the watershed was logged and burned. The normalized sediment yield increased fourfold over the pretreatment mean. The normalized yield on the control watershed dropped to three-fourths of

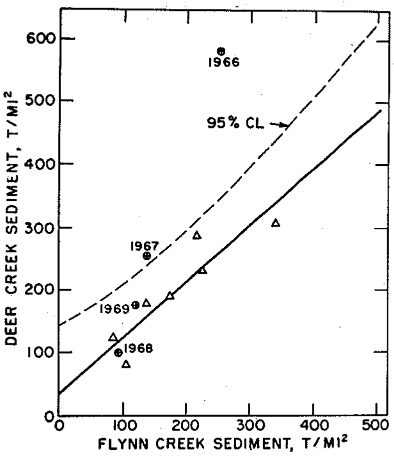

Fig. 2. Comparison of normalized annual sediment yield from Flynn Creek (unlogged) and Deer Creek (patch cut) for 7 years before treatment. Comparative yields after road building (1966) and logging (1967–1969) are shown in relation to the 95% confidence limit on the pretreatment regression.

its pretreatment mean during this year. The annual sediment yield declined during the following years as vegetation returned, but yields remained higher than those before logging and burning.

CHANGES IN SEDIMENT CONCENTRATION

A second analysis compared the instantaneous concentrations of sediment during storms with the streamflow at which the samples were obtained. This analysis was done both before and after road building and logging. Understanding how sediment concentration varies with watershed treatment is of great significance, because most of the new water quality standards for sediment are related to this relationship rather than to annual yield.

Regressions comparing instantaneous sediment concentration with the streamflow observed when the sediment sample was taken were prepared for each sampling station. Segregating the concentration data into two groups for these analyses was necessary, because the sediment–streamflow relationship for rising stages was significantly different from that for falling stages at all sampling sites. A similar procedure has been used by *Fredriksen* [1970]. The correlation coefficient r was generally much higher for rising stage data. All the concentration analyses therefore use only rising-stage data. Rising-stage data were further segregated to include only storm data with discharges greater than 5 csm (cubic feet per second square mile).

Simultaneous samples of sediment concentration and discharge were fitted to a regression equation of the form:

$$\log S = a + b \log D \qquad (1)$$

where S is the sediment concentration, D is the discharge measured when the sediment sample was obtained, and a and b are regression constants.

Evaluating the differences in sediment concentration resulting from different watershed treatments proved a difficult task. Sample sizes tend to be unequal. Variations in the sediment concentration–discharge equation can also occur because of annual changes in runoff pattern. Two additional types of variation may be imposed by treatment: Clear-cutting may change not only the variation in sediment concentration but that in discharge as well. Thus the assumption of orthogonality in the test of individual degrees of freedom may not apply, and the standard test for interaction between regression equations may not be appropriate.

The test statistic selected to circumvent this

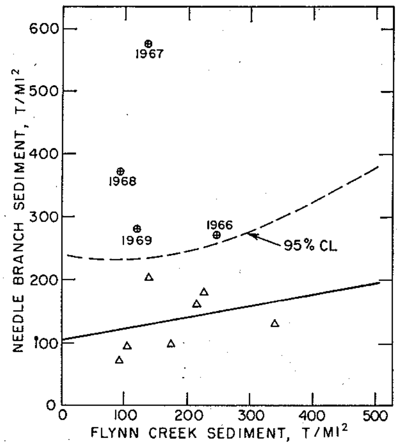

Fig. 3. Comparison of normalized annual sediment yield from Flynn Creek (unlogged) and Needle Branch (clear-cut) for 7 years before treatment. Comparative yields after road building (1966) and logging and burning (1967–1969) are shown in relation to the 95% confidence limit on the pretreatment regression.

difficulty was:

$$F_2^{\,2} = \frac{SSB_p - (SSB_1 + SSB_2)}{SSA_p - (SSA_1 + SSA_2)} \qquad (2)$$

where SS_p is the error sum of squares obtained by combining or pooling the sediment concentration–discharge data for the (1) pretreatment period and (2) each treatment year for each watershed (A or B), SS_1 is the error sum of squares for the pretreatment period, and SS_2 is the error sum of squares for the posttreatment period. Watershed A represents the control watershed (Flynn Creek) and watershed B represents either of the treated watersheds (Deer Creek or Needle Branch).

Mean streamflow and sediment concentrations are shown in Table 2 for the U.S. Geological Survey weirs and in Table 3 for the small weirs within Deer Creek for each year of the study. Only 2 years of pretreatment data were used in this analysis because more data were not available from the small weirs in Deer Creek. Notation of a significant increase is the result of testing regressions by equation 2 rather than by simple tests on the mean values.

Some interesting differences can be drawn from analysis of separate samples and annual yield. In Deer Creek the road slide in 1966 produced an increased annual yield that was significant at the 95% level of probability. The relative significance dropped in the analysis of sediment concentration. The increase was not significant at 95% but was significant at 90%. The annual yield in the subsequent water year (1967) was still significantly higher than that in the pretreatment period (at the 95% level of probability). The comparison of sediment concentrations during the 1967 water year with those during the control period revealed no significant differences. The reason for this discrepancy is that there was a significant shift in the sediment–discharge relationship of the control watershed during this year.

The shift in the sediment concentration–discharge relationship of the control likely occurred as a result of the flood of December 1964–January 1965 and was produced by residual materials deposited during those major events. Before the floods the maximum concentration of suspended sediment recorded on Flynn Creek (the control) was 682 ppm, compared to 969 ppm on Needle Branch. During the

TABLE 2. Analysis of Simultaneous Sampling of Suspended Sediment Concentration and Streamflow at U.S. Geological Survey Stations during Rising Stages and Discharges Greater than 5 csm

Water Year	Sample Size	Sediment Concentration, ppm		Streamflow, cfs	
		Range	Mean	Range	Mean
		Flynn Creek (Control)			
1964–1965	72	1–205	194	4.2–148	32
1966	64	1–718	128	4.2–66	22
1967	28	38–439	148	4.2–69	32
1968	18	32–256	109	11–44	26
1969	17	1–200	57	7–44	20
		Deer Creek (Patch Cut)			
1964–1965	71	1–1610	267	6–204	58
1966	66	1–6960	337*	6–115	32
1967	32	53–670	233	20–105	59
1968	20	35–345	115	10–46	40
1969	49	6–381	90	8–76	37
		Needle Branch (Clear-Cut)			
1964–1965	88	1–969	116	1.6–45	13
1966	68	1–892	179*	1.6–27	9
1967	89	1–6300	589	1.6–25	11
1968	44	20–7670	640†	1.9–32	10
1969	38	70–738	280†	3.1–24	12

* Significant increase at 90% level of probability.
† Significant increase at 95% level of probability.

TABLE 3. Analysis of Simultaneous Sampling of Suspended Sediment Concentrations and Streamflow at Stations on Deer Creek during Rising Stages and Discharges Greater than 5 csm

Water Year	Sample Size	Sediment Concentration, ppm		Streamflow, cfs	
		Range	Mean	Range	Mean
		Deer Creek 2			
1964–1965	45	1–716	85	1.0–34	8.3
1966	15	2–178	32	1.0–9	3.7
1967	14	3–242	67	1.0–30	11.3
		Deer Creek 3			
1964–1965	43	1–793	99	0.8–19	4.6
1966	15	1–410	117	1.2–18	4.9
1967	14	4–194	72	0.8–18	7.1
		Deer Creek 4			
1964–1965	16	1–99	18	0.3–10	2.1
1966	14	1–10	2	0.3–8	1.8
1967	13	1–8	4	0.3–7	2.0
		Deer Creek 6			
1964–1965	15	3–462	152	4.5–136	34.1
1966	15	1–720	176*	4.5–108	27.3
1967	19	1–366	122	6–84	33.5

* Significant increase at 90% level of probability.

flood the maximum concentration on Flynn Creek was 2050 ppm, compared to 476 ppm on Needle Branch. Most pools in Flynn Creek were filled with sediment (R. C. Williams, unpublished report, 1965). Thus the control watershed responded differently to the same storm event from the other two watersheds, which were treated the next year. *Anderson* [1968, 1970] has noted the dissimilar responses of other watersheds to the same large event. He has also shown that materials deposited during these events provide a sediment reservoir for many subsequent years. Thus the classical concept of a single 'control' watershed for sediment studies of this type may not always be valid.

The same pattern appears on Needle Branch. The difference during the first water year after logging (1967) is even more profound. A fivefold increase in mean sediment concentration was not significant at the 90% level of probability because of the upward shift in the sediment–discharge regression of the control watershed during this same year. The increase on Needle Branch is significant at about 87%, but the difference in statistical significance is still surprising.

The comparison of changes in sediment concentration for the small weirs in Deer Creek is shown in Table 3. Road building produced significant changes only at station 6. Station 3, immediately below the road slide, showed no increase in sediment concentration because samples were not taken during this event. Logging did not produce significant increases in sediment concentration at any of the sampling stations in Deer Creek.

A frequency distribution of mean daily sediment concentration during low flow periods is shown in Table 4. Mean daily flow of less than 5 csm occurred during 60–70% of the year on these coastal watersheds. Even with the severe treatment given Needle Branch during the 1967 water year, mean daily concentrations were less than 10 ppm during about 97% of these low-flow days. These data substantiate the fact that in mountain watersheds the majority of the sediment load is carried during a few large storms. The best indication of treatment effect is shown in the increased maximum concentration at low flow on Needle Branch from the 1966–1969 water years. The pattern is similar to that of sediment yield shown in Table 1.

DISCUSSION

The results of this intensive study of sediment yield and land use clearly illustrate the

TABLE 4. Frequency Distribution of Mean Daily Suspended Sediment Concentrations during Days with Mean Flow of Less than 5 csm

Water Year	Concentration Class, ppm					Maximum Concentration, ppm	Days per Year
	0–5	5–10	10–20	20–30	>30		
			Flynn Creek				
1959–1965	91.9	5.4	2.1	0.3	0.3	26	231
1966	84.4	11.0	4.2	0.4		21	263
1967	97.4	2.2	0.4			13	237
1968	98.1	1.1	0.4	0.4		26	267
1969	92.8	6.8	0.4			12	251
			Deer Creek				
1959–1965	89.3	7.7	2.5	0.3	0.2	28	237
1966	84.7	11.5	3.4	0.4		28	261
1967	77.1	16.7	1.2	3.8		52	240
1968	79.3	17.9	0.8	0.4	1.6	53	257
1969	89.4	4.6	4.2	0.9	0.9	37	216
			Needle Branch				
1959–1965	94.4	4.7	0.8	0.1		15	235
1966	89.8	9.0	0.4	0.4	0.4	74	256
1967	96.6	0.8	1.4	0.4	0.8	220	238
1968	93.2	2.4	2.0		2.4	413	250
1969	93.4	3.5	1.3	1.4	0.4	230	230

Values are percentage of days in each class when flow was less than 5 csm.

effect of several forest management practices on water quality. The influence of roads on sediment yield has again been demonstrated by this study. Our results substantiate the conclusions drawn by *Fredriksen* [1970]. The road system in Deer Creek, for example, was carefully located, constructed, and used. The roads were located near the ridges. They entered the watershed from the back of the ridges; thus road mileage within the watershed was minimized. The roads were well graveled and were not used during the winter months. Even with these precautions, one slide occurred and its effect was quite significant. A large volume of material still remains trapped behind a logjam in the upper part of the watershed and provides a potential source for additional sediment yield at some later date.

About 1.5 miles of road were constructed within the Needle Branch watershed. This construction, together with the landings for logs, exposed mineral soil over about 7% of the watershed. This exposed soil was undoubtedly the source of sediment in the 1966 water year.

High-lead logging alone did not produce amounts of sediment significantly different from those in the calibration period. This result also coincides with those observed elsewhere [*Fredriksen,* 1970; *Lull and Satterlund,* 1963; *Meehan et al.,* 1969; *Packer,* 1967]. The maximum sediment concentration observed at weir 4 in Deer Creek was less than 20 ppm. The watershed was 90% clear-cut but unburned. This concentration can be compared with a maximum sediment concentration of over 7000 ppm observed after logging and burning in Needle Branch.

Slash burning after clear-cutting is a common management practice in the Pacific Northwest. Arguments both for and against burning are numerous. A review of this controversy is clearly beyond the scope of the present paper. The sediment data collected during the study, however, indicate the effect of burning on water quality.

The slash fire in Needle Branch was extremely hot; mineral soil was exposed throughout most of the watershed. High sediment yields can be expected when mineral soil is subjected to more than 100 inches of rain during a 6-month period.

The cause of increased sediment yield after logging in Deer Creek is somewhat obscure and may be the result of interacting factors. Upstream, the sediment contribution of the two clear-cuttings, as indicated by changes in the sediment concentration–discharge regressions, was not significant. Downstream, two possible sources of sediment exist: (1) materials that accumulated in the stream channel as a result of the road slide the previous year (the mean concentration of sediment at station 6 in Deer Creek, though not statistically significant, remained high, some residual source thus being indicated) and (2) the clear-cutting farthest downstream, (the fact that the clear-cutting between station 6 and the U.S. Geological Survey station was lightly burned after logging could have contributed to increased sediment yield).

The data indicate that sediment yields should approach pretreatment levels 5–6 years after complete clear-cutting and burning. Two important concepts must be understood about this recovery: (1) These results pertain to a case study conducted in an area in which vegetation grows rapidly and returns to unoccupied sites very quickly. Exposure time for mineral soil is thus minimized. (2) Erosion is significant for both terrestrial and aquatic habitats. Although the supply of sediment from the slopes may decline rapidly, the presence of this material in the stream gravels may persist. Such an accumulation of fine materials in spawning gravel can significantly reduce the emergence of salmonid fry [*Hall and Lantz*, 1969].

What inferences about sediment sampling or monitoring can be drawn from the data? This question is crucial, not only from the point of view of studying sediment transport processes, but from that of water quality as well. The Oregon water quality standards [*Oregon Department of Environmental Quality*, 1969], for example, specify that no activities will be permitted that cause 'any measurable increases in natural stream turbidities when natural turbidities are less than 30 Jackson Turbidity Units (JTU) or more than a 10 percent cumulative increase in natural stream turbidities when stream turbidities are more than 30 JTU . . .'

The important question is how to obtain the best standard of comparison. What, in other words, is a 'natural' sediment concentration for small streams? Our data indicate that rather large annual variations in the sediment–discharge relationship can occur on undisturbed watersheds. Variations between watersheds may also be large. Variation in the sediment–discharge relationship is stage dependent. A much better correlation between sediment concentration and discharge was observed during rising stages. Thus one concludes that a great deal of experience, together with an intensive, rigidly standardized sampling scheme based on flow regimes, is required before a judgment with a precision of 10% can be made.

Our ability to make accurate judgments about changes in the sediment concentration–discharge relationship in this study would have been greatly improved by replicating the control. The assumption that neighboring watersheds respond in similar fashion to similar events, regardless of magnitude, is certainly questionable. Thus it would seem that any sediment monitoring system would require more than one control for comparison.

A further constraint in sediment sampling or monitoring is imposed by the influence of a few large storms on annual sediment yields. If these events are not sampled adequately or are missed, conclusions about the treatment effect are likely to be erroneous. This problem is compounded by the treatment itself, which imposes a greater variation on the sediment–discharge relationship, particularly at high flows. Thus monitoring a specific stream to detect a 10% change in sediment concentration will require more than just a few random samples.

We have shown that clear-cut logging may produce little or no change in sediment concentrations in small streams. The greatest changes were associated with the road building operation that preceded logging and the controlled slash burning afterward. We have also shown that unless these changes are large, it may be very difficult to separate man-caused changes in sediment concentration from those imposed by natural variation, particularly if very large runoff events occur within the measurement period.

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