Decrease in stream gravel permeability after clear-cut logging: an indication of intragravel conditions for developing salmonid eggs and alevins

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Abstract

Average gravel permeabilities decreased significantly in an Oregon, U.S.A., stream after 82% of the drainage basin was clear-cut. Patterns remained statistically normal in a stream of an unlogged drainage basin and in a stream in a drainage area that was 25% clear-cut, but with riparian buffer strips about 30 m wide left along the stream. It is cautioned that decreases in yearly permeability values can reflect adverse intragravel conditions for developing salmonid eggs and alevins, even if other environmental changes, particularly the amount of sediment fines in gravel, are not as apparent.

Introduction

Permeability of stream gravel is related to porosity, hydraulic gradient, and the size, shape, depth, and arrangement of the gravel particles (Vaux 1962; McNeil & Ahnell 1964; Cooper 1965). During logging operations, intrusion of excess sediment can have a profound effect on gravel permeability (McNeil & Ahnell 1964; Peters 1965; Moring 1975). This sediment is principally from logging roads in mountainous or steep-sloped areas (Brown & Krygier 1971; Beschta 1978; Gurtz *et al.* 1980). However, it can also originate from soil erosion that results from removal of logging slash or vegetation with heavy equipment (Beschta 1979).

A reduction in gravel permeability may affect developing salmon and trout. Gravel permeability is inversely related to the percentage of sediment fines in the gravel (McNeil & Ahnell 1964), and directly related to survival of young salmonids (Wickett 1958; Cloern 1976; Turnpenny & Williams 1980; predicted by Coble 1961). Excess sediment in spawning gravel may physically entrap emerging salmonid alevins (Cooper 1965; Phillips *et al.* 1975; Hausle & Coble 1976; Turnpenny & Williams 1980) or cause mortalities of eggs and alevins by reducing intragravel flow and dissolved oxygen (Wickett 1954; Coble 1961; McNeil 1962, 1966; Ringler & Hall 1975; Woods 1980). However, the proportion of sediment fines in the gravel may be extremely variable (Adams & Beschta 1980), and the potential changes in the intragravel environment may not always be reflected in the analysis of sediment fines in stream gravel (Moring 1975). Gravel permeability is a function not only of sediment fines, but of all sizes of gravel and cobble (Platts *et al.* 1979). Hence, it is theorized that another method of detecting intragravel changes due to land use practices in the drainage basin – measurement of gravel permeability – might be more useful than determination of sediment fines.

Three small tributary streams of the Alsea River, Oregon, were studied from 1962 to 1973 to analyze the effects of logging on stream gravel permeability. The drainage basin of one stream was almost completely (82%) clear-cut; that of the second was partly (about 25%) clear-cut in three blocks, none of which was adjacent to the stream; and that of the third (the control) was uncut. Changes in gravel permeabilities were monitored over a 4-year pre-logging period and a 7-year post-logging period.

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Materials and methods

Three Order 2 streams (Horton 1945) were used in the study. One experimental stream, Deer Creek, is about 2300 m long and has a mean summer width of 1.8 m, a gradient of 18 m/km, and a drainage area of 304 ha. The stream provides spawning and rearing habitat for coho salmon (*Oncorhynchus kisutch*), cutthroat trout (*Salmo clarki*), and steelhead trout (*Salmo gairdneri*). Three blocks in the drainage were clear-cut in 1966; and 75% of the drainage basin was left uncut, including buffer strips 30 m wide adjacent to the stream.

The second experimental stream, Needle Branch, is 1000 m long and has a mean summer width of 1.1 m, a gradient of 14 m/km, and a drainage area of 75 ha. The stream provides spawning and rearing habitat for coho salmon and cutthroat trout. Most (82%) of the drainage basin was clear-cut in the summer of 1966. No buffer strips were left along the stream.

The control stream, Flynn Creek, is about 1400 m long and has a mean summer width of 1.7 m, a gradient of 25 m/km, and a drainage area of 202 ha. It provides spawning and rearing habitat for coho salmon and cutthroat trout.

Gravel permeabilities were measured at 2-week intervals throughout the year at three permanent Mark VI standpipes (Terhune 1958) in each stream. A plastic cylinder pump brought water from the subgravel environment under a 2.5-cm head, and flow was measured in units of milliliters per second, following the general methods of Coble (1961). Using calibration curves, these values were converted to permeabilities and expressed as centimeters per hour, following the methods of Terhune (1958).

Results

Average permeability in Needle Branch decreased markedly after the drainage basin was logged (Fig. 1). Permeabilities dropped from a prelogging average of about 4900 cm/h to an average of 1100 cm/h for the first year after logging, and then remained relatively constant, but depressed, at an average of 2400 cm/h for the next 6 years. Both the first-year and later changes were highly significant ($P < 0.01$). Average permeabilities in Flynn Creek and Deer Creek remained fairly stable throughout the study; values during postlogging years were not significantly different from those of prelogging years.

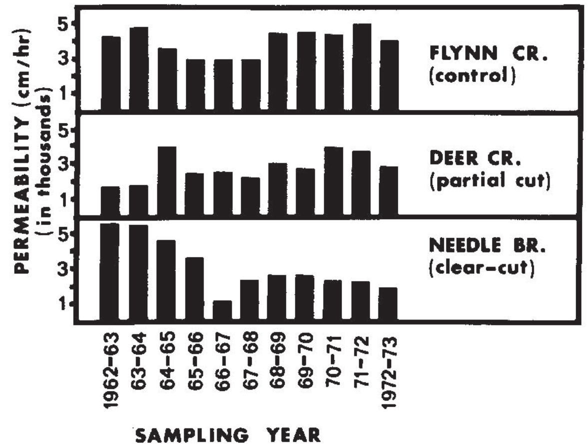

Fig. 1. Annual average gravel permeability in three tributaries of the Alsea River, Oregon, U.S.A., 1962-1973. In Deer Creek and Needle Branch watersheds, road construction was completed after the 1964-65 season, and logging after the 1965-66 season.

Individual permeability measurements varied among stations and among sampling dates within a season. Coble (1961) found different permeability values in stations only 15 cm apart in Needle Branch in studies made in 1959, before the present study began. The intragravel invironment at any one location is continually shifting, but average permeabilities over a season (Fig. 1) gave a relative indication of changes over the years. Among the three streams, the gravel in Needle Branch was most permeable before the drainage area was logged and least permeable after the logging. Permeability of the control stream was intermediate before the logging operations in the other two drainage basins, and was the highest thereafter.

Discussion

One of the principal factors influencing permeability of stream gravel is sediment. Sediment discharge was shown by Moring (1975) and Beschta (1978) to increase significantly in the two streams with logging activity in their drainage basins. Sediment discharge in Needle Branch increased from 40 to 121 metric tons/y (an increase of 203%). Sediment discharge on Deer Creek increased from an average of 293 metric tons/y before road construction to 451 metric tons/y (an increase of 54%) after road construction. Both changes were significant at the 95% confidence level (Moring 1975; Beschta 1978). Sediment discharge increased only 0.1% in Flynn Creek over the same period.

Beschta (1978) and Paustian & Beschta (1979) indicated, however, that the rate of sediment discharge inadequately characterizes the sedimentation. The extreme variability in sediment discharge, and the increase in streamflow after logging, may obscure the actual impact of sedimentation. Moring (1975) reported that streamflow increased by 27% in Needle Branch after intensive logging, but only 4.9% in Deer Creek (partial clear-cutting), and 1.6% in Flynn Creek (the control). But, peak streamflows increased after 12% of one of the Deer Creek cutting blocks was occupied by roads (Harr *et al.* 1975). The increased flow compounded the problem of estimating the sedimentation. High flows made available more sediment for deposition in the gravel. Flushing of such excess sediment occurs naturally only about 20 days each year in western Oregon streams (Beschta & Jackson 1979), so during disruptive land use, streamflow may have a more significant role in depositing excess sediment than flushing it from the system. Despite a significant increase in streamflow in Needle Branch after logging, gravel permeabilities significantly decreased.

This decrease in gravel permeability can be used as an indicator of inferior intragravel rearing conditions for developing eggs and alevins. Although studies have shown that high levels of sediment fines are detrimental to emerging alevins (Phillips *et al.* 1975; Hausle & Coble 1976; Turnpenny & Williams 1980), field analysis of gravel in Needle Branch and Deer Creek were inconclusive following logging in the drainage basins, despite large increases in sedimentation (Moring 1975).

Adams & Beschta (1980) indicated that the amount of sediment fines in the gravel of western Oregon streams is extremely variable, and is naturally broad enough to obscure the possible effects of land use alterations. Gravel permeabilities, however, declined in Needle Branch, and the long-term post-logging impacts on populations of cutthroat trout (Hall & Lantz 1969; Moring & Lantz 1975) and reticulate sculpins, *Cottus perplexus* (Moring 1981), in Needle Branch may be related back to sub-optimal and critical rearing conditions during early development. Changes in average gravel permeabilities may be a more important indicator of such intragravel conditions than are changes in sediment fines, as natural fluctuations in the latter parameter can be quite variable.

Summary

Gravel permeability is directly related to survival of developing salmonid eggs and alevins. Gravel permeabilities decreased significantly in an Oregon stream after clear-cut logging of the drainage basin. No statistical distinctions were noted between pre-logging permeabilities (1962–66) and post-logging permeabilities (1967–73) in a stream where the drainage area was partially cut (25%), or in a stream where the drainage basin was uncut. A principal result of logging activities, particularly road building, is an increase in sediment in the stream. Various investigators have shown this increased sediment tends to decrease gravel permeability and emergence survial of salmonids, but natural variability of stream gravel is quite high. Hence, the monitoring of gravel permeabilities during land alteration activities may be a more useful environmental tool for assessing intragravel rearing conditions.

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