HYDROLOGIC CONSEQUENCES OF LOGGING SECOND-GROWTH REDWOOD WATERSHEDS

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Abstract: Streamflow, suspended sediment, and bedload have been gauged continuously since 1962 in the 473-ha North Fork and the 424-ha South Fork of Caspar Creek on the Jackson Demonstration State Forest. From 1963 to 1967, both 90-year-old, second-growth watersheds were measured in an "untreated" condition. In 1967, logging roads were built in the South Fork. From 1971 through 1973, about 65% of the stand volume was selectively cut from the South Fork watershed. Logging began in the North Fork in 1985 and ended in 1991. The timber volume removed from the North Fork watershed approximated that cut from the South Fork in the early 1970's, but clearcutting rather than selective harvest was used. The size of clearcut blocks in the North Fork ranged from 9 to 60 ha and occupied 35% to 100% of individual tributaries. Logging-induced changes in peak flow were greatest for the first storms following lengthy dry periods. There was no significant change in large peak flows after logging. Annual runoff increased about 25% for a few years after logging, but returned to pre-logging levels within 15 years. Suspended loads in the South Fork increased by almost 400% (130 $m^3 km^{-2}$) following road building and from 100% (30 $m^3 km^{-2}$) to 500% (460 $m^3 km^{-2}$) during the five winters after logging commenced. To date, the effect on sediment loads of logging in the North Fork has been much smaller than that following logging in the South Fork. The greatest increase in suspended loads in the North Fork in the six winters since clearcutting was resumed has been 56 $m^3 km^{-2}$.

Introduction

Streamflow, suspended sediment, and bedload have been gauged continuously since 1962 in the 473-ha North Fork and the 424-ha South Fork of Caspar Creek on the Jackson Demonstration State Forest by the USDA Forest Service Pacific Southwest Research Station and the California Department of Forestry and Fire Protection.

The watersheds generally have a southwest orientation and are located about 7 km from the Pacific Ocean and about 10 km south of Fort Bragg in northwestern California. Topographic development of the area is youthful, with uplifted marine terraces deeply incised by antecedent drainages. The hill slopes are steepest near the stream channel and become more gentle near the broad, rounded ridgetops. About 35% of the slopes are less than 17° and 7% are steeper than 35°. The elevation ranges from 37 to 320 m.

The soils of the basins are well-drained clay-loams, 1 to 2 m in depth, and are derived from Franciscan graywacke sandstone and weathered, coarse-grained shale of Cretaceous Age. They have high hydraulic conductivities and subsurface stormflow is rapid, producing saturated areas of only limited extent and duration.

The climate is typical of low-elevation watersheds on the central North American Pacific coast. Winters are mild and wet, while summers are moderately cool and dry. About 90% of the average annual precipitation of 1200 mm falls during the months of October through April. Snow is rare and rainfall intensities are low.

Prior to treatment, the watersheds supported a 90-year-old, second-growth forest composed of coast redwood (*Sequoia sempervirens* [D.Don] Endl.), Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco), western hemlock (*Tsuga heterophylla* [Raf.] Sarg.), and grand fir (*Abies grandis* [Dougl. ex D.Don] Lindl.). The watersheds contained an average of about 700 $m^3 ha^{-1}$ of stem wood. From 1963 to 1967, streamflow and sediment was measured in both second-growth watersheds to "calibrate" the watersheds prior to treatment. In summer 1967, a main-haul logging road and main spurs were built in the South Fork. The road right-of-way occupied 19 ha adjacent to the stream, from which 993 $m^3 ha^{-1}$ of timber was removed. The first of three stages of logging began in the South Fork in 1971, during which 59% of the stand volume was selectively cut from 101 ha. In 1972, 69% of the stand volume was selectively cut and tractor yarded from an additional 128 ha. In 1973, 65% of the stand volume was selectively cut from the remaining 176 ha (Rice et al., 1979).

From 1985 to 1986, 67% of an 87-ha ungauged tributary was clearcut and cable yarded immediately upstream of the North Fork gauging station. Logging began in the main study portion of the North Fork in 1989 and ended in 1991. The timber volume removed from the North Fork was intended to approximate the volume cut from the South Fork in the early 1970s, but clearcutting with cable yarding was used in the North Fork rather than selective harvest with tractor yarding. The size of clearcut blocks in the North Fork ranged from 9 to 60 ha and occupied 35% to 100% of individual tributaries. New roads, landings, and skid trails occupy from 2.1% to 7.0% of individual logged watersheds. Three tributaries continue to be measured in an untreated condition. Post-logging measurements have

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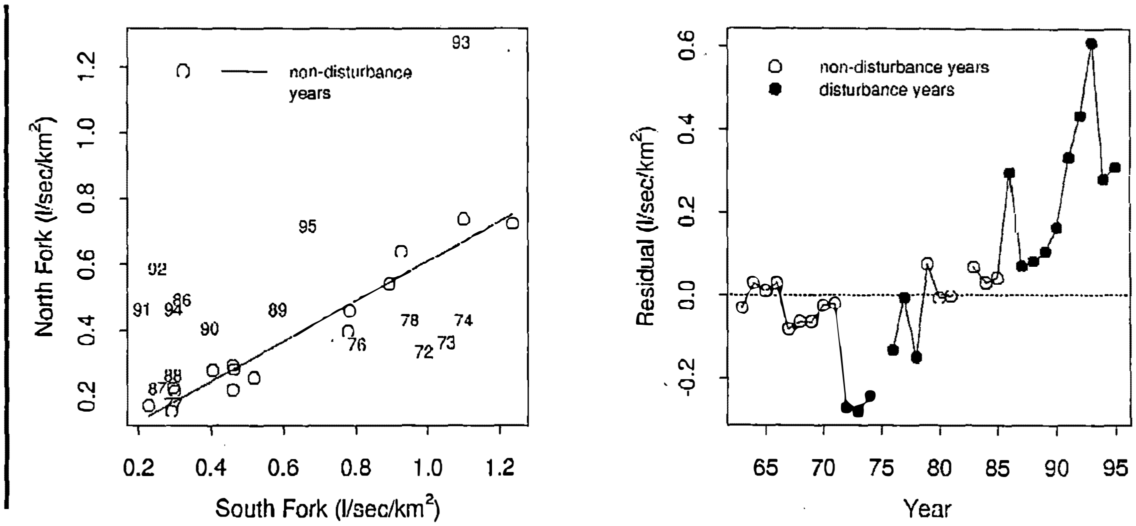

Figure 1. Relation between minimum summer streamflow in the North and South Forks of Caspar Creek, 1963-1995, the regression line is based on non-disturbance years; and residuals of observed streamflow from the non-disturbance regression.

continued in the North Fork and South Fork watersheds to the present.

Summer Lowflow

Throughout much of the arid west the lack of water during the summer growing season has been a severe constraint on agriculture, power production, urbanization, and virtually all forms of human enterprise. An extensive folklore has developed concerning the effect of cutting trees that ranges from "cutting trees dries up rivers and springs and causes deserts" to "cutting trees causes large floods." In the early 1900s, serious scientific thought began to be directed to evaluating the effect of forest manipulation on water yield with the establishment of the Wagon Wheel Gap studies in Colorado. Hewlett (1982) summarized the results of 94 catchment experiments world-wide. They reported that although there was extreme variation between areas, in no case did cutting trees reduce streamflow. Conversely, in no case did a regrowth of the forest cause an increase in water yield. They concluded that the potential for vegetation treatment to increase water yield was greatest in coniferous forests, less in deciduous hardwoods, and least in brush and grassland areas. In addition, water yield increases following vegetation treatment have been found to be greatest in high rainfall areas, and, within a given area, tend to be greater in wet years than in dry years (Ponce and Meiman, 1983). These small watershed studies indicate that there is no potential for increasing water yield bye manipulating vegetation in areas having less than aboute 380 mm of annual precipitation, and marginal potentiale when precipitation is between 380 and 500 mm (Hibbert,e 1983).e

Caspar Creek is within a climate zone where logging might result in an increase in streamflow during the summer. The selective tractor logging in the South Fork increased the 1972 summer lowflow by about 0.44 $l\text{-}s^{-1}\text{-}km^{2}$ or an increase of about 80% from that predicted by the pre-logging regression. This increased summer flow declined with regrowth of the vegetation so that within 7 to 8 years after logging the summer streamflow had returned to pre-logging levels. When 12% of the North Fork was clearcut near the weir, summer streamflow in 1986 increased about 0.30 $l\text{-}s^{-1}\text{-}km^{-2}$ (about 150%) for one year, then returned near prelogging levels (Fig. 1). In late summer 1989, logging began in the upper third of the North Fork. Logging continued in 1990 and 1991. Minimum flow during the four summers from 1990 to 1993 averaged about 0.38 $l\text{-}s^{-1}\text{-}km^{-2}$ (172%) larger than predicted. A maximum increase of 277% greater than predicted streamflow occurred during summer 1992. The increased flow declined in 1994 and 1995 after the completion of logging (Fig. 1) and is projected to return to pre-logging levels by about 1998.

Winter Peak Flow

Logging-induced changes in the South Fork's peak streamflow were greatest for the first storms following lengthy dry periods. There was no significant change in the largest peak flows caused by selective logging in the South Fork (Wright et al., 1990). Preliminary analysis of peak streamflows following clearcut logging in the North Fork produced similar results—that is, logging caused no significant changes in large peak flows.

Annual Runoff

Annual runoff in the South Fork increased between 9% and 30% for the first 5 years after selective logging. This is equivalent to an average increase in water yield of 900 m^3ha^{-1}. The increased annual water yield slowly returned to prelogging levels over the following 15 years. After clearcut logging in the North Fork, annual water yield increase varied from 9% to 58% in the first 5 years. The average increase during these 5 years was 840 m^3ha^{-1}, similar to that observed following the removal of about the same volume of trees from the South Fork.

Sediment Discharge

Annual suspended sediment loads were estimated by multiplying the volume of flow in about 20 discharge classes by the mean concentration from samples collected in each of those classes and summing the products. Calibration relations were established by regression between the two watersheds for undisturbed periods. Suspended loads in the South Fork increased by almost 400% (130 m^3km^{-2}) relative to the predicted load in the winter following road building and between 100% (30 m^3km^{-2}) and 500% (460 m^3km^{-2}) greater than the predicted load in the five winters after logging commenced. Sediment loads appeared to have returned to pre-logging levels in the sixth or seventh winter after logging was completed in the South Fork. To date, the effect of logging in the North Fork has been much smaller than that following logging in the South Fork. The greatest increase in suspended loads in the North Fork in the six winters since clearcutting was resumed in 1989 has been 56 m^3km^{-2}. However, a large landslide (more than 5000 m^3) that occurred in the winter of 1995 will probably delay recovery to pre-logging suspended sediment levels. That landslide is delivering sediment directly into a tributary of the North Fork from the area that was clearcut in 1986.

About one-third of the total sediment load at the North Fork gauging station consists of bedload. Bedload has been estimated annually by surveying sediment deposited in debris basins immediately upstream of the North and South Fork gauging stations. These deposits typically include about 40% of the suspended load as well as the bedload. No changes in debris basin deposits were detected after road building or logging in either watershed.

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