Increases in Water Yield Following Clear-cut Logging in the Pacific Northwest

JACK ROTHACHER

USDA Forest *Service, Pacific Northwest Forest and Range Experimental Station*
Corvallis, Oregon 97330

Abstract. Increases in water yield following timber harvest roughly conform to the proportion of the area cleared. In high precipitation areas of the Oregon Cascades, clear-cut logging can increase annual water yield 18 inches. Approximately 80% of the increase occurs during the October to March season.

INTRODUCTION

Each year, 6 to 7 by l0° board feet of timber is harvested from about 200,000 acres of forest land in the Pacific Northwest. Much of this comes from clear-cut logging operations in the coastal mountains or Cascade Range of Oregon and Washington. There can be little doubt that the drastic change from a dense forest to a clear-cut and burned area has a pronounced effect on water yield from the logged area.

Hibbert [1967] has summarized much of the information available in 'Forest Treatment Effects on Water Yield.' He concluded that the practical upper limit of yield increases might be about 4.5 mm per year for each percent reduction in forest cover or 450 mm (17.7 inches) if an area were completely denuded. At the time of his summary, detailed water yield data for the Pacific Northwest were not available. Recent data from the H. J. Andrews Experimental Forest in western Oregon now suggest that increased yields following logging may approach or exceed this upper limit.

The natural characteristics of three small watersheds currently being studied on the H. J. Andrews Experimental Forest are covered in detail by *Rothacher et al.* [1967]. Briefly, these watersheds range from 150 to 250 acres in area, support a dense stand of old growth Douglas fir on steep, northwest facing topography, and receive approximately 90 inches of precipitation annually. Strongly influenced by the ocean 100 miles to the west, the climate is typically wet in winter and dry in summer. Most of the area within the watersheds has an elevation below 3000 feet and generally receives the major portion of the precipitation as rain. Potential evapotranspiration estimated by the Thornthwaite method [*Thornthwaite and Mather,* 19571 averages about 24 inches annually. The great precipitation excess of the colder months is succeeded by a warm season deficiency reaching a maximum of 4½ inches during July. Soils formed on colluvial material and formed from deep weathering of relatively soft tuff and breccia parent material have shallow genetic profiles but may have substantial depth that has high retention storage. These characteristics represent the upper range of wetness in the west side Douglas fir region.

Increases in water yield are directly related to reduction in evaporative loss whose components have been described by *Penman* [1963].

Evaporation from interception should be high on the H. J. Andrews Experimental Forest because of the mild climate, frequent rainstorms during the long rainy season, dense vegetation, and the generally higher degree of interception in coniferous forests as opposed to other types of forest vegetation *[Swank,* 1968]. Transpiration should also be high since summers are dry and warm, the dense vegetation has a large needle surface area, and soil moisture is completely recharged each winter. Evaporation from soil is low under a dense stand of timber but might increase considerably after logging. However, in the climate of western Oregon, typified by dry summers with infrequent wetting of surface soil and wet, humid winters, evaporation from the soil surface should remain relatively small even after clear-cutting. Evaporation from interception and transpiration would decrease to near zero, and the compensating increase in evaporation from the soil would be small, resulting in a large decrease in evaporation from all sources and a correspondingly large increase in streamflow.

THE STUDY

The data on increases in water yield are based on gaged watersheds in which a linear regression is computed between two watersheds while both are undisturbed. After one watershed was modified, measured streamflow was compared with predicted values based on a still undisturbed control watershed. All charts presented show the difference between measured and predicted streamflow expressed in inches over the watershed. Positive values are yields higher than expected. Three sets of regressions were computed : annual, seasonal, and monthly.

In the study at the H. J. Andrews Experimental Forest, one of the three watersheds (150 acres) remained undisturbed throughout the study. A 250-acre watershed with a complete road network was patch-cut logged by the high-lead cable yarding system. This watershed typifies current standard logging practices in the Pacific Northwest.

The third watershed (237 acres) was completely clear-cut logged beginning in 1962 (Figure 1). Because of operational problems with a new fixed skyline system, logging was not completed until 1966. Heavy slash was broadcast burned in 1966. There were no roads in this watershed.

RESULTS

Annual Yields

In much of the Pacific Northwest, streamflow is a high proportion of the total rainfall. At the experimental forest with an average annual precipitation of 90 inches, streamflow averages approximately 57 inches on the unlogged watershed. An October 1–September 30 water year is used throughout.

The correlation of annual streamflow for the three small watersheds used in this study was good. During the 6-year calibration period for the patch-cut watershed and the uncut drainage, the predicting equation explains 97% of

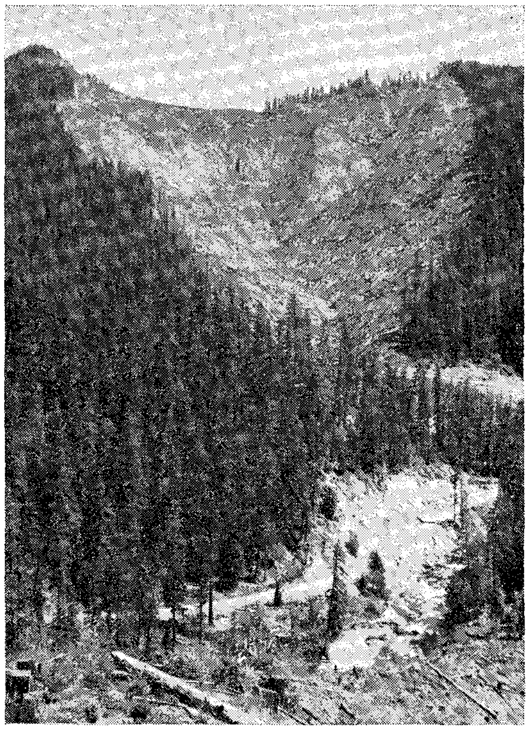

Fig. 1. Clear-cut watershed after logging and burning.

the variation with a standard error of estimate of 2.37 inches. During the 10-year calibration period for the clear-cut and unlogged watersheds, the predicting equation explains 93% of the variation with a standard error of estimate of 2.85 inches.

100% clear-cut logging. Logging began in the completely dear-cut watershed late in August 1962. All yarding was completed and the area was burned in October 1966.

Figure 2 shows the differences between predicted and measured annual water yields for the entire period of study including the 10-year calibration period. Increased yields following the start of logging are roughly proportional to the percent of the area clear-cut. The increase did not exceed the 95% confidence level $[(t_{0.95})(S_{yx})]$ of the regression equation until 1964, when over 40% of the timber had been felled. The 1965 water year increase appears higher than expected. This was a year which included two record storms, one in December 1964, the other in January 1965. In the 1966 and 1967 water years, probably the most representative

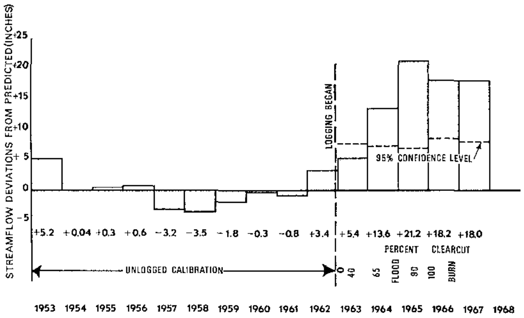

Fig. 2. Annual water yield increases following logging (clear-cut watershed).

of postlogging conditions, measured yield was 18.2 and 18.0 inches greater than expected flow. These deviations exceeded the 95% confidence interval of the prediction equation by more than 100%.

Roads plus patch-cut logging. Following the 6-year calibration period for the patch-cut watershed, road construction began in April 1959 and was completed by October 1959. Approximately 8% of the drainage was cleared. There was no further activity in this watershed until logging began in August 1962. All logging was completed by February 1963, and the three clear-cut units, which increased the cleared area on the watershed to *30%,* were burned in September of the same year. Three major storm periods occurred during the study. The first, in December 1957, resulted in no noticeable change in the watershed characteristics. The second, in December 1961, resulted in a slide from below a culvert that scoured 3000 feet of tributary and main stream channel *[Fredriksen,* 19631. The third, in December 1964 and January 1965, resulted in scouring of the major portion of the stream channels in the drainage *[Fredriksen,* 19651. The debris that moved down the main channel destroyed the gaging station and buried the concrete flume under tons of mud, rock, and woody debris. Although the gaging station was repaired and put back into temporary operation by spring, a 2-month portion of the record was lost and had to be reconstructed from records on the adjacent watersheds.

The differences between predicted and measured yields for each year of record are shown in Figure 3. Although a slight increase following clearing of 8% of the drainage in road right-of-way (years 1959–1962) would be expected, the differences are well within the range of variation during the calibration period. Linear regressions were computed for the three distinct periods: (1) during calibration, (2) after road building, and (3) after logging. A covariance analysis of relation for the periods during calibration and after road building showed no significant difference in either slopes or mean values, that is, no indicated difference between these two periods.

After 30% of the area was cleared, measured streamflow was consistenly higher than predicted streamflow. A covariance analysis of the calibration period (1953–1958) and after-logging-plus-roads (1965–1967) relationships showed no significant difference in adjusted means. If a common slope is assumed, the indicated average difference between the two periods represents an increased yield of 6.69 inches for the 1963–1967 period. For individual years, the 1965, 1966, and 1967 measured flows exceeded the 95% confidence interval of predicted flow.

The largest increase in yield would be expected the year immediately following burning (1964), when vegetation was at a minimum. That the largest increases came after 1964 is not readily explained. Because revegetation of the clear-cut units increased from a low of 15% herbaceous and shrub plus tree cover in midsummer 1964 to 62% cover in 1967, some increased transpiration on the clear-cuts and a decrease in the difference between measured and predicted would be expected rather than the increase shown. The cover in 1967 was still largely herbaceous with only 4% cover by forest tree species. The larger increases in 1965–1967 may have resulted, at least in part, from changes caused by the December 1964 and January 1965 floods which scoured all main stream channels and removed all streamside vegetation.

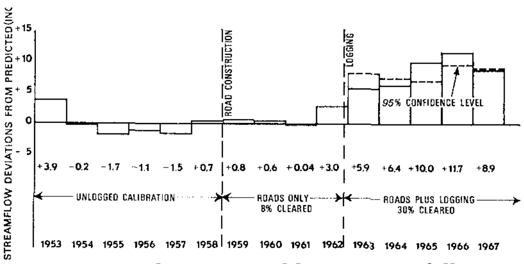

Fig. 3. Annual water yield increases following logging (patch-cut watershed).

Hibbert [1967] has presented evidence that in well watered regions streamflow response is proportional to reduction in forest cover. When the patch-cut watershed with one-third cleared area was compared with the 100% clear-cut watershed, increases were approximately proportional during 1963 and 1964 (about 6 inches) but 1½ to almost 2 times higher in 1965, 1966, and 1967 (10.0, 11.7, and 8.9 inches).

Seasonal Increases

The distribution of yield increases through the year may be of more importance than the total annual increase. This distribution is shown best by the 100% clear-cut watershed (Figure 4). Increases which exceeded the confidence interval of the prediction equation were not recorded until the April–June season of 1963 after some 40% of the timber on the watershed had been felled. From then on, all seasons have shown measured streamflow exceeding the confidence interval except the April–June season of 1966. Streamflow during April–June 1966 was the lowest for the 15 years of record for this season. A similar but less significant pattern was found on the patch-cut watershed.

By far the largest portion of the annual increase occurs during the first fall rains. Not only is interception much less on the cleared area, but also in the fall the soil moisture is much higher in the clear-cut area, where transpiration draft on the water stored in the soil has been almost eliminated. In studies elsewhere in the experimental forest, at the end of our dry season as much as 6 inches more water was found in the soil of the clear-cut than in the uncut forest.

Studies at Coweeta Hydrologic Laboratory [*Hewlett*, 1966; *Hewlett and Douglass*, 19681 have shown that water savings from reduced transpiration may remain stored in the soil until new rains come. In the Pacific Northwest, increases in streamflow from vegetation removal are small during the long, dry summer but increase sharply with arrival of the heavy fall rains. During the 1967 water year, almost 50% of the annual increase occurred during the season of October through December (Figure 4). Increases remained high during the rest of the rainy season so that approximately 80% of the annual increase took place during the October-March season. Although there has been a general increase in yields during the rainy season, there has been no noticeable change in peak flows from the largest flood producing storms.

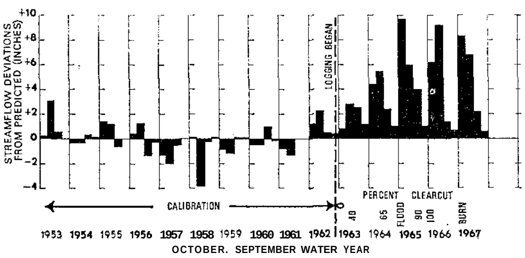

Fig. 4. Seasonal deviations from predicted streamflow for calibration, years 1953–1962, and after clear-cutting, years 1963–1967 (clear-cut watershed).

DISCUSSION

Data from the 100% clear-cut watershed show that annual water yield increases following logging in high precipitation areas of the Oregon Cascades are high, possibly exceeding the 450 mm (17.7 inches) suggested by *Hibbert* [1967]. Increases of this magnitude would not be expected in drier portions of the Pacific Northwest or where shallow soils offer limited soil storage capacity.

Approximately 80% of the increase occurs during the wet October–March season. The remaining 20% occurs during spring and summer months. In our area of high winter flows, the increased yields at this time of year are at a time of minimum demand. Small but important increases in the August–September low period may be much more significant for downstream use. For example, the September 1967 increase of 0.15 inch represents a 150% increase over predicted streamflow of 0.10 inch. This increase is equivalent to an average increase of 87,000 gallons per square mile per day during this low flow month, or enough to meet the daily needs (200 gallons/day) of 435 additional people for each square mile cleared.

The results of this study and many others cited by *Hibbert* [1967] clearly demonstrate that there is a significant increase in water yields when forests are harvested. Though the onsite increase may be large, as in areas of high precipitation and deep soils in the Pacific Northwest, the increase may be largely obscured on large watersheds harvested on a long-term sustained yield basis.

Data from the patch-cut watershed and during progressive logging from the clear-cut watershed confirm the basic principle that increases from vegetation removal are roughly proportional to the area cleared. Thus if the increased yield following complete timber removal approximates 18 inches annually, we would expect about a 6-inch increase if one third of the area was cleared for roads and logging units. In a typical large drainage in the National Forests of western Washington and Oregon that has been patch-cut on a 100-year rotation, an average of about 1% would be cleared each year. We do not yet know how long the increases resulting from timber harvest will persist in the Pacific Northwest. *Kovner* [1956], working with hardwoods at the Coweeta Hydrologic Laboratory, suggests it may be more that 30 years before increases become insignificant. *Zeimer* [1964], studying soil moisture changes following logging in the subalpine zone of California, estimated that increases in water stored in the soil would become insignificant in about 16 years. Assuming annual increases that decline logarithmically (as both Kovner and Zeimer suggest), over a 20-year period we would have an average of about 4 inches increase per year, or the equivalent of 20% of the area with a 4-inch increase. For 80 years of the 100-year rotation or on 80% of the area increases would be insignificant. This increase would be equivalent to approximately 0.8 inch increased streamflow for a large drainage under full sustained vield management. For a 50-year rotation, the increase would be 1.8 inches.

Because of variations due to total precipitation and its distribution, as well as variations due to other causes (measurements, climatic cycles), it might be difficult to measure a change in annual yield of this magnitude. An excellent streamflow record by U. S. Geological Survey standards should have an error as low as ±5%. But 5% of an annual flow of 40 inches is ±2.0 inches. Since many of the headwater drainages yield 40 inches and over, it may be difficult to detect the downstream increases that result from standard patch-cut logging even though there is little doubt that the increases do occur. Even if the initial increase from cutting in an originally undisturbed watershed could be detected, no further increases would be noted as a sustained yield rate of cutting continued because after the initial period the regrowth would be using enough more water each year to compensate for the increased yield from each year's clear-cut area. This explains, at least in part, why some earlier reports showed no effect on water yield following logging in large west coast watersheds *[Martin and Tinney*, 19621. Additional vegetation removal through thinning might result in small additional increases. A large-scale fire or exceptionally heavy clearing over a short period could make a noticeable increase in yields.

Information gathered in this study is also related to changes in peak (flood) flows, minimum summer streamflows, and changes in water quality. Prelimiiiary changes recorded on these watersheds were reported by *Rothacher* [1965]. More complete results will be reported as they become available.

REFERENCES

Fredriksen, R. L., A case history of a, mud and rock slide on an experimental watershed, 4 pp., *U. S. Dep. Agr., Forest Serv., Pac. Northwest Forest Range Exp. Sta. Res. Note PNW–I*, 1963.

Fredriksen, *R*. L., Christmas storm damage on the H. J. Andrews Experimental Forest, 11 pp., *U. S. Dep. Agr., Forest Serv., Pac. Northwest Forest Range Exp. Sta. Res.* Note *PNW–29*, 1965.

Hewlett, John D., Will water demand dominate forest management in the East?, SOC. *Amer. Forest. Proc.*, 154159, 1966.

Hewlett, John D., and Douglass, James E., BIending forest USES, 15 pp., *U. S. Dep. Agr., Forest Serv., Southeast Forest Exp. Sta. Res. Pap.* SE-37, 1968.

Hibbert, A. R., Forest treatment effects on water yield, in W. E. Sopper and H. W. Lull, *International Symposium on Forest Hydrology*, pp. 527-543, Pergamon Press, New York, 1967.

Kovner, J. L., Evapotranspiration and water yields following forest cutting and natural regrowth, *Soe. Amer. Forest. Proc.*, 106-110, 1956.

Martin, Iury L., and E. Roy Tinney, Logging in west coast watershed shows no effect on area's water yield, *The Timberman*, 43(5), 46-48, 1962.

Penman. H. L., Vegetation and hydrology, 124 pp., *Commonwealth Agr. Bur. (Gt. Brit.), Bur.* Soils *Tech. Commun.* 53, 1963.

Rothacher, Jack, Streamflow from small watersheds on the western slope of the Cascade Range of Oregon, *Water Resour. Res.*, 1(1). 125-134, 1965.

Rothacher, Jack, C. T. Dymess, and Richard L. Fredriksen, Hydrologic and related characteristics of three small watersheds in the Oregon Cascades, 54 pp., U.S. *Dep. Agr., Forest Serv.*, *Pac. Northwest Forest Range Exp. Sta. Misc. Publ.,* 1967.

Swank, W. T., The influence of rainfall interception on streamflow, *Proc. Conf. Hydrol. Water Resour. Manage.,* Water Resources Research Institute, Clemson University, Clemson, South Carolina, 101–112, March, 1968.

Thornthwaite, C. W., and J. R. Mather, Instructions and tables for computing potential evapotranspiration and the water balance, Drexel *Inst. Tech. Pub. Climatol., 10,* 185–311, 1957.

Zeimer, Robert R., Summer evapotranspiration trends as related to time after logging of forests in Sierra Nevada, *J. Geophys. Res., 69(4),* 615-*620,* 1964.

(Manuscript received August 13, 1969; revised September 29, 1969.)