VOL. 1, NO. 1 WATER RESOURCES RESEARCH FIRST QUARTER 1965

# *Streamflow from Small Watersheds on the Western Slope of the Cascade Range of Oregon*

JACK ROTHACHER

*Pacific Northwest Forest and Range Experiment Station*
*U. S. Forest Service, Portland, Oregon*

*Abstract.* Streamflow from small watersheds on the western slopes of the Oregon Cascade Range is strongly influenced by a maritime climate (wet winters and dry summers). Although annual precipitation is high (94 inches in the study area), overland flow is almost unknown. Peak flows result largely from subsurface flow and under conditions in which both retention and detention reservoirs are almost filled during extended periods of low-intensity rainfall. Under these conditions, vegetation appears to exert a minimum influence on high streamflow. Lowest streamflow occurs from late August to mid-November and may follow a 60- to 100-day period with little or no rain. The dense vegetation of this part of the Douglas-fir region appears to exert its major influence at such times. Removal of vegetation from only 30% of a 250-acre watershed has caused a 12–28% increase in minimum streamflow. On a 237-acre watershed on which 80% of the trees were cut, the increase in low flow was 85%.

*Introduction.* Streamflow from small watersheds in the western Cascade Range of Oregon depends to a large extent upon a climate characterized by extremely heavy annual rainfall concentrated in the winter months, with little or no rain during 2 or 3 months in the summer. The characteristics of three small western Oregon watersheds in their natural state and how these characteristics are altered by timber cutting are described in this report.

Those concerned with the effects of various land treatments on the hydrology of a given area are especially aware of the need for adequate description of the set of conditions under which given results occur. This need is clearly evidenced by the common plea that the results from one area not be extrapolated to some far distant and different area.

Research into the effects of logging on streamflow, currently being conducted by the Pacific Northwest Forest and Range Experiment Station, provides an opportunity to describe the characteristics of three small watersheds with topography and climate typical of a 2000 to 3500-mi$^2$ area along the western slopes of the Cascade Range. The study area, part of the H. J. Andrews Experimental Forest [*Berntsen and Rothacher,* 1959], is located 45 miles east of Eugene, Oregon, on a tributary of the McKenzie River. Here the effects of logging-road construction and two methods of logging on streamflow and water quality are being studied. One watershed is left undisturbed as a control in the traditional manner; a second is being logged by the conventional 'high-lead' system, requiring a network of roads aggregating about 5 miles per section; the third is being logged by the 'skyline' system, which is particularly suited to steep topography but requires few or no roads. Work began here in August 1952. The period of study during which the watersheds were undisturbed (until the summer of 1959) serves as our calibration period.

This report describes streamflow characteristics of these watersheds when undisturbed and discusses what we expect and are learning about hydrologic changes due to modification of vegetation. Water quality of these watersheds has been discussed briefly by *Fredriksen* [1962] and will be covered in more detail in future publications.

*Experimental watersheds.* The three small (237–, 150–, and 250-acre) watersheds are adjacent and roughly parallel, draining from southeast to northwest (Figure 1). They rise from an elevation of about 1500 to 3500 feet MSL in

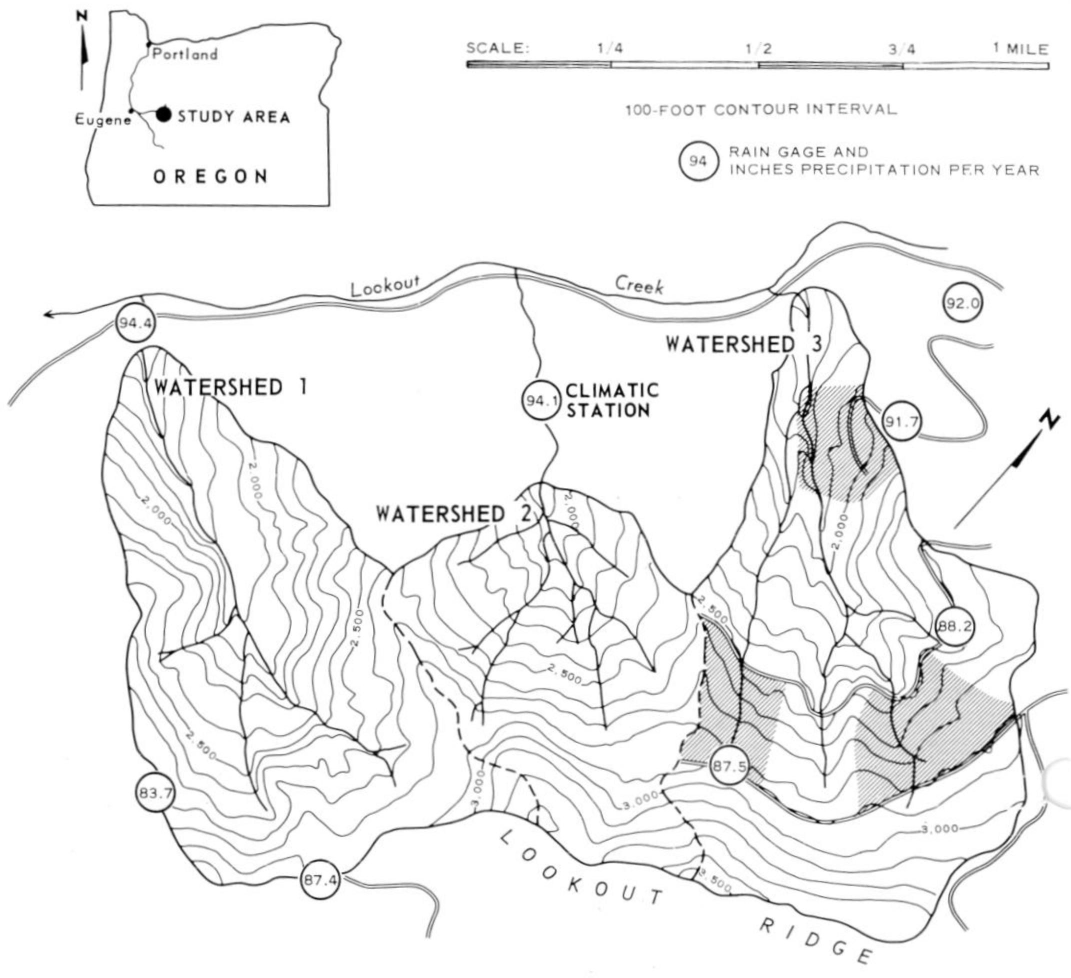


Fig. 1. Map of experimental watersheds, showing location of rain gages, and the roads and clear-cutting units in watershed 3, H. J. Andrews Experimental Forest.

approximately 1 mile. Drainage pattern is dendritic with a high density of 3.9, 7.3, and 5.1 mi/mi². Stream slope, extended to the topographic divide, is 28, 40, and 32% for watersheds 1, 2, and 3, respectively.

*Climate.* Gross precipitation, predominantly in the form of rain, has averaged 94 in./yr for the period of study. The climate is typically maritime; most precipitation falls as rain during the relatively warm (average January temperature, 35.0°F), moist winter months (Figure 2). Snow falls sporadically from mid-November to late March but seldom remains on the ground for more than a few weeks. Rainfall intensities are low, rarely exceeding ½ in./hr. Maximum 6-hour intensity has been 2.15 inches. Summers are cool (average July temperature, 69.2°F) and dry, only 7% of the annual precipitation falling during the June–September period. July and August may be entirely rain-free. Potential evapotranspiration, estimated from local temperature records and Thornthwaite's tables [*Thornthwaite and Mather*, 1957], averages 24 inches annually.

*Vegetation.* Dense stands of predominantly coniferous forests develop under these climatic conditions. Douglas-fir forests may have 90–95% crown cover and contain over 50,000 board feet of timber per acre. Under dense stands, ground-cover vegetation may be sparse, but whenever openings occur, young trees or understory vegetation fill in to make a complete vegetative cover. Due to rapid decomposition of organic matter at

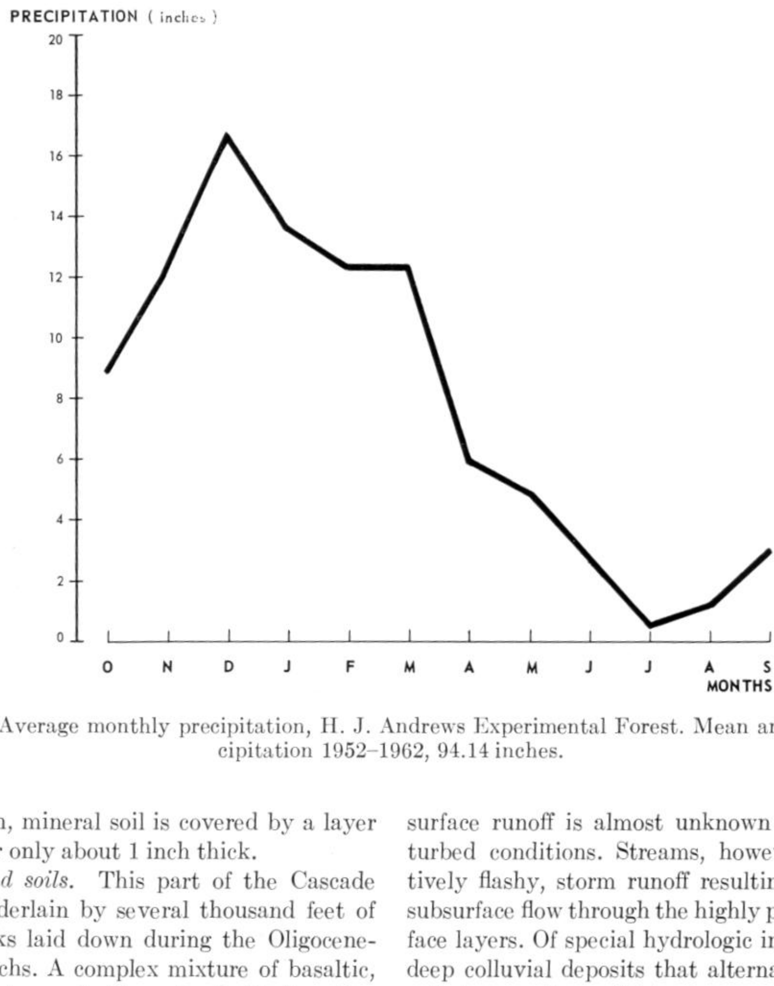


Fig. 2. Average monthly precipitation, H. J. Andrews Experimental Forest. Mean annual precipitation 1952–1962, 94.14 inches.

this elevation, mineral soil is covered by a layer of fresh litter only about 1 inch thick.

*Geology and soils.* This part of the Cascade Range is underlain by several thousand feet of volcanic rocks laid down during the Oligocene-Miocene epochs. A complex mixture of basaltic, andesitic, and pyroclastic rocks (tuffs, breccias, and other easily weathered material from volcanic ejecta) has been further complicated by a vast amount of surface mixing through colluvial action and alpine glaciation. Rock outcrops are common. Youthful streams have cut deeply into the bedrock, resulting in rough topography. Slopes over 60% are found on 49–69% of the area. Slopes of 80–100% are not uncommon.

Soils developed under these conditions of climate, vegetation, parent material, and topography are mainly clays, clay loams, and silty clay loams. In many places, shallow soil profiles are underlain by deep unconsolidated parent materials, giving a hydrologically deep soil which pedologically is considered shallow. The soils are porous and well aggregated at the surface. Density tends to increase and percolation to decrease with depth. Infiltration capacities are so high that surface runoff is almost unknown under undisturbed conditions. Streams, however, are relatively flashy, storm runoff resulting from rapid subsurface flow through the highly permeable surface layers. Of special hydrologic importance are deep colluvial deposits that alternate with thin-soiled steep slopes. Water temporarily stored in deep colluvial soils probably helps to maintain low flows. Rapid runoff from thin-soiled, steep slopes contributes to stormflow.

*Streamflow characteristics.* Streamflow from the study watersheds is measured with field-rated trapezoidal flumes equipped with continuous water-stage recorders (Figure 3). Runoff follows the precipitation pattern closely. Normally, high flow during the winter months is followed by an annual recession to low flow in late summer or early fall (Figure 4). This cyclical pattern is associated with thoroughly wetted soils throughout the winter that gradually dry to near wilting point at the surface by the end of the dry summer. The water year ending on September 30 usually coincides closely with the cycle from one low period to the next. Correlation between annual precipitation and streamflow is fair without

Fig. 3. Trapezoidal flume at gaging station 1, H. J. Andrews Experimental Forest.

adjustment for changes in soil storage (Figure 5). This relation shows that the annual runoff from watershed 2 would be expected to average 61 inches if gross annual precipitation averages 94 inches. The corresponding yield from watersheds 1 and 3 would be 54 and 53 inches, respectively. Such high yields (57–65% of total precipitation) are due in part to the fact that most precipitation occurs on wet soil during the period when evapotranspiration losses are at a minimum.

A complete explanation for differences in yield is not readily apparent. Radiation indexes for individual watersheds (watershed 1, 41.9; watershed 2, 33.2; watershed 3, 36.5) were found to be roughly inversely correlated with annual streamflow [*Lee*, 1963]. Precipitation, weighted by Thiessen polygons, accounts for an additional small percentage of the differences (watershed 1, 99.1% of watershed 2; watershed 3, 97.6% of watershed 2). Other factors, such as deep seepage and instrumental errors, may account for most of the residual differences. The close correlation among watersheds indicates that these differences are consistent over the years.

In spite of low intensities, precipitation frequently continues over long periods, filling a large part of the detention reservoir and resulting in relatively high peaks. Peak flow rates may approach 80% of the maximum 6-hour precipitation rate that precedes the storm (Figure 6). In 10 years there have been five occasions when maximum flows have exceeded 100 $ft^3/sec/mi^2$ (cfsm). This decade, however, has been a period of excess rainfall exceeding the estimated long-term average by about 6 in./yr.

*Barnett* [1963] intensively studied six storms ranging from 2.4 to 7.7 inches of precipitation on these watersheds. He found that subsurface storage and *subsurface* rather than overland flow were characteristics that had a strong influence on storm runoff. Comparisons showed that watershed 1 peaked first and had the highest peaks and the steepest recession. Watersheds 2 and 3 were imilar to one another in these characteristics. Variations seem to be attributable primarily to differences in soil moisture storage capacity, watershed 2 having the greatest and watershed 1 the least as indicated in a survey of soils.

Analysis of the recession limb of the hydrograph did not indicate a fixed storage-discharge relationship for subsurface stormflow. *Barnett* [1963] believed that differences in antecedent

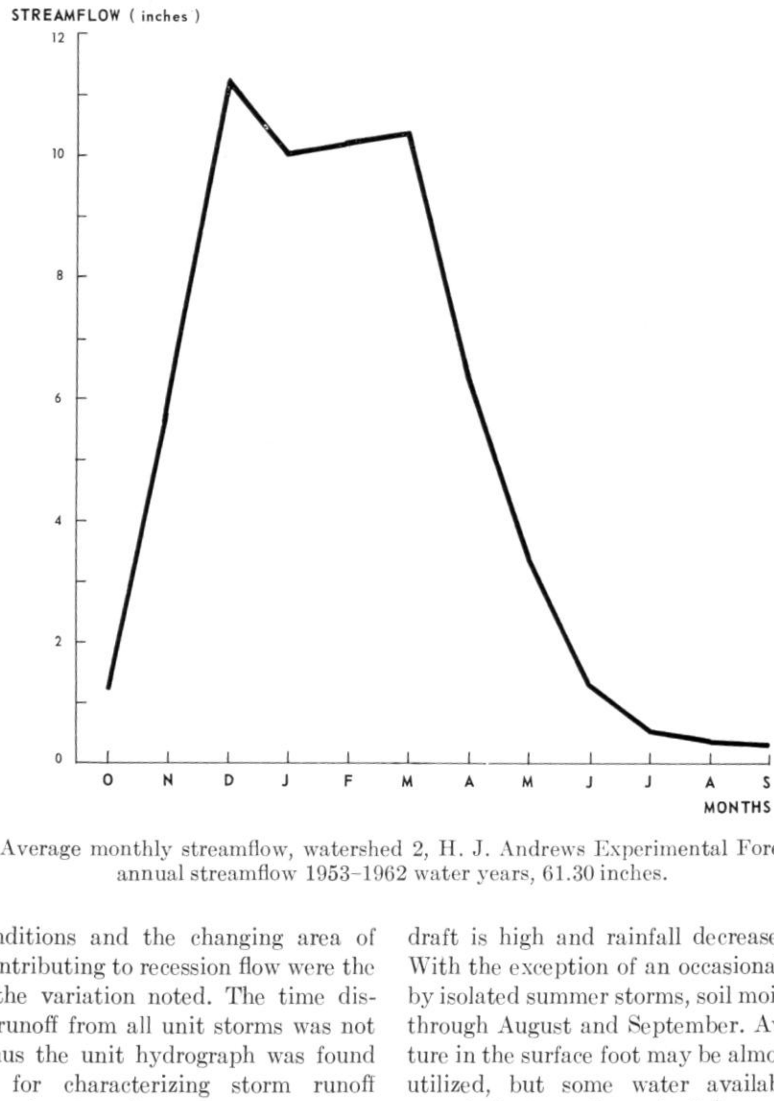


Fig. 4. Average monthly streamflow, watershed 2, H. J. Andrews Experimental Forest. Mean annual streamflow 1953–1962 water years, 61.30 inches.

moisture conditions and the changing area of watershed contributing to recession flow were the reasons for the variation noted. The time distribution of runoff from all unit storms was not identical. Thus the unit hydrograph was found inapplicable for characterizing storm runoff derived from subsurface flow.

Lag time was found to be relatively constant for each watershed. However, watershed characteristics commonly related to lag time of *surface* runoff and used for prediction purposes (length of main stream, distance from outlet to centroid of basin, and stream slope) could not be related to lag time for *subsurface* runoff.

These streams were found to reach a minimum flow in late summer, just before the start of fall rains. Minimum flows occur from the last of August to November 10 and follow a period of 60–100 or more days with little or no rain. Soil moisture in the deeper soils on moderate slopes remains high until early June, when transpiration draft is high and rainfall decreases (Figure 7). With the exception of an occasional interruption by isolated summer storms, soil moisture declines through August and September. Available moisture in the surface foot may be almost completely utilized, but some water available for plant growth (at least theoretically) remains at the 2-foot depth and below. By late summer, plants survive on water held at high tensions that would contribute little if any to streamflow. Late summer rains may raise soil moisture but appear to have minor influence on sustained streamflow.

These characteristics are of one set of 'benchmark' watersheds representative of *undisturbed* areas of the Douglas-fir region on the western slopes of the Oregon Cascades.

*Results of logging disturbance.* After almost 7 years of calibration on undisturbed watersheds, roads were constructed into watershed 3 in the summer and fall of 1959. About 8% of the drainage area was cleared in the process. The effect of

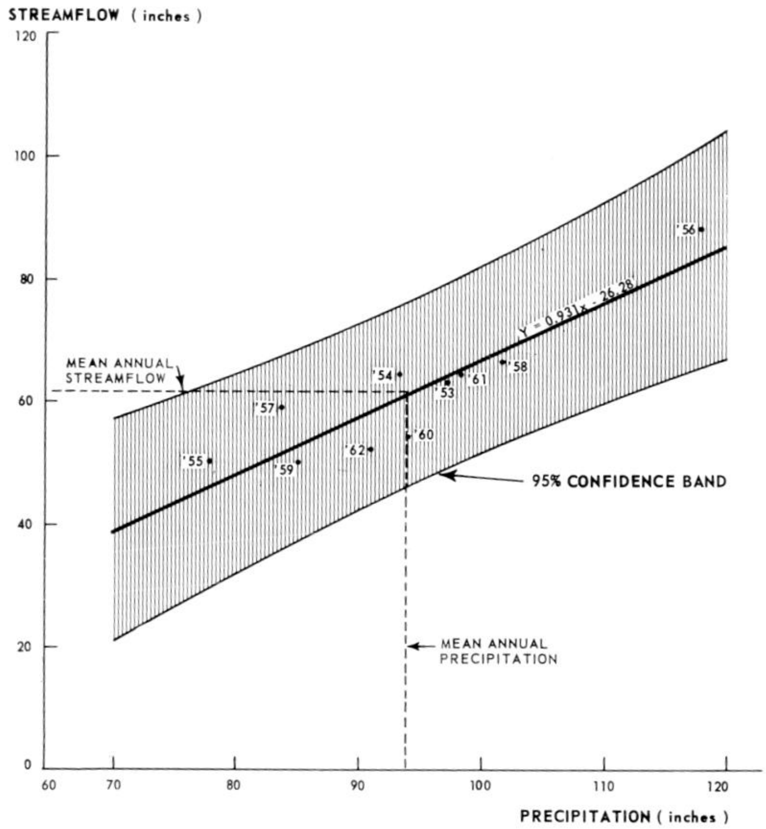


Fig. 5. Linear regression showing relationship of precipitation to streamflow on watershed 2, H. J. Andrews Experimental Forest. Mean annual precipitation of 94 inches yields a mean annual streamflow of 61 inches.

this disturbance was studied for 3 years (water years 1960, 1961, 1962), after which another 25% of the watershed was clear-cut and logged. A year after logging (winter 1963), the clear-cut area was broadcast-burned. With road and clear-cut units combined, over 30% of the watershed was, for all practical purposes, temporarily devoid of vegetation.

*Effect of logging on peak flows.* Peak streamflow from these watersheds is primarily the result of long-duration, low-intensity rainstorms, or a series of storms, that fill much of the retention and detention reservoirs. The maximum storm of record totaled 12.5 inches of rain in 3 days, with over 6 inches in one 24-hour period. Rainfall intensity reached a rate of 0.4 in./hr for only 1 hour during the storm; at all other times intensity was 0.3 in./hr or less. When such conditions prevail, interception becomes less effective [*Rothacher*, 1963], and antecedent moisture conditions become decreasingly important in determining maximum flows as the duration of the storm lengthens. Peak flows from watershed 3 were not measurably increased during the 3 years after 8% of the area was cleared and roads were constructed (Figure 8). Also, this watershed, when compared with an undisturbed watershed, showed no increase in maximum flow during 1 year (water year 1963) after an additional 25% of the drainage was clear-cut. No exceptionally large storms occurred during this period, although maximum flow approached 100 cfsm in two storms.

*Effect of logging on minimum summer flows.* Low flows, following the long dry summers, are sustained by base flow alone. Recent studies in the southeast and elsewhere have demonstrated that slow drainage of water from unsaturated soils may contribute materially to base flow [*Hewlett*, 1961]. Removal of vegetation with the attendant decreased transpiration would be ex-

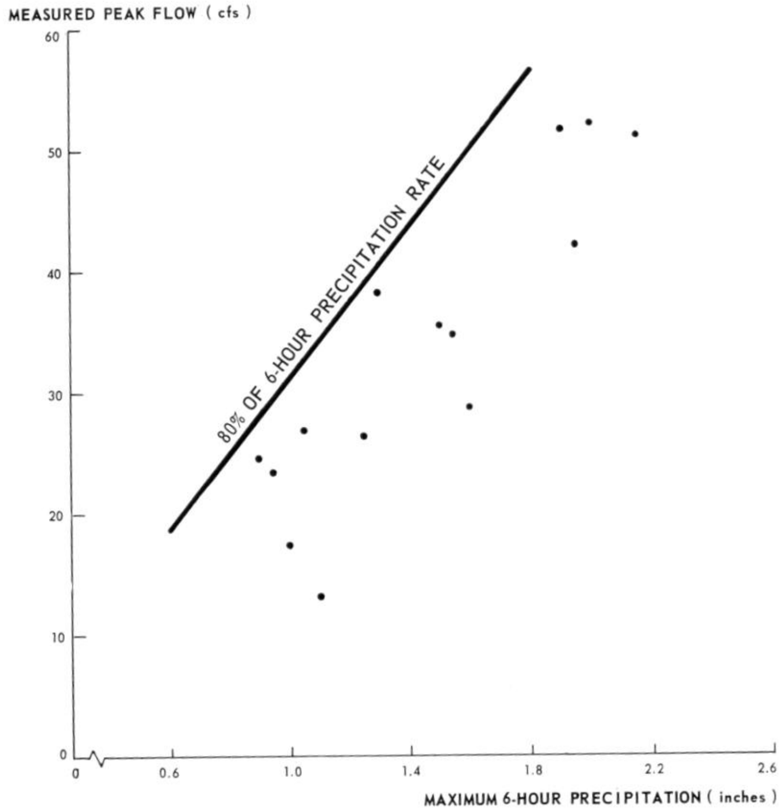


Fig. 6. Peak streamflow following maximum 6-hour precipitation during a storm, watershed 1, H. J. Andrews Experimental Forest.

pected to result in higher soil moisture levels. Records of soil moisture after cutting have confirmed this expectation in our studies and in studies conducted by *Bethlahmy* [1962]. Only late in summer does soil moisture in recently clear-cut areas begin to decline, and even then the decline is limited to the surface layers, where evaporation is most effective. In one area, water removed from the soil by evapotranspiration after logging decreased by about 80%, and soils remained close to field capacity almost all summer. Slow drainage from these areas of higher soil moisture could increase minimum flows.

Six years of record (one low flow each calendar year 1959–1964) following road construction and logging on one watershed showed a 12–28% increase in minimum streamflow (Figure 9). Although the first-year record after both road construction and logging (1963) indicated a 22% larger flow than that predicted for undisturbed conditions, this increase was no greater than that which occurred during the fourth year after road construction but before logging (1962). At the time of the 1963 low flow, logging slash, small trees, and brush remained on the clear-cut areas. Slash was burned in late September 1963 after the first heavy rains. By late summer 1964, regrowth of brush and herbaceous vegetation covered about 16% of the burned area. Low flow for this year was slightly higher than for previous years (28% greater than predicted). On the other watershed on which logging has been in progress continuously since late 1962, low flows increased 45% in the fall of 1963, when trees had been cut on about 40% of the watershed, and 85% in the fall of 1964, when trees had been cut on 80% of the watershed. This general increase in low flows as more vegetation was cut from the watershed is consistent with data reported by *Reinhart, Eschner, and Trimble* [1963]. They show an increase in low flow roughly proportional to extent of logging; i.e., small increase for intensive selec-

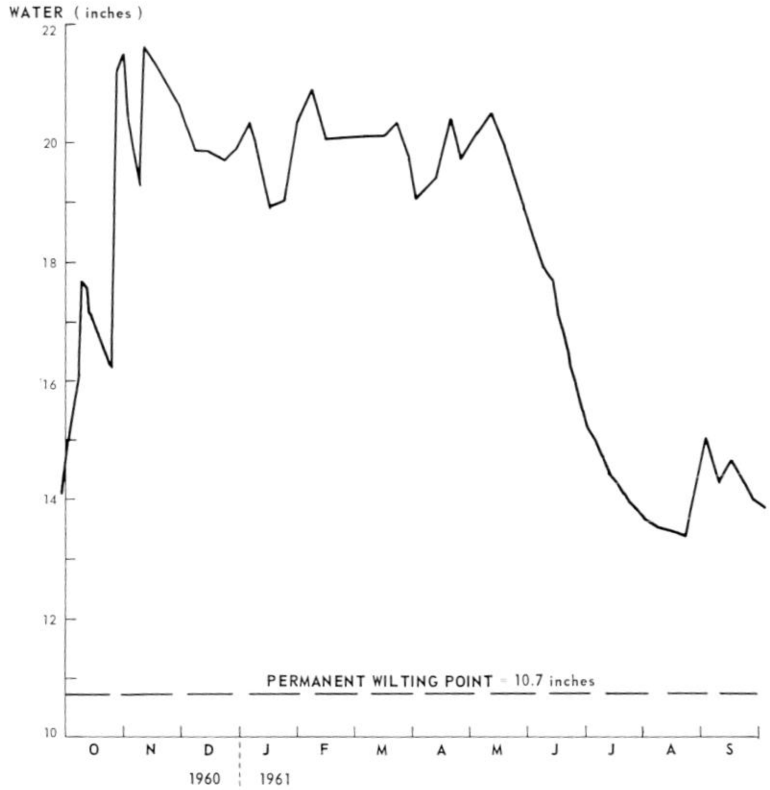


Fig. 7. Annual fluctuation in soil moisture under an old-growth Douglas-fir forest, 0- to 4-ft depth, H. J. Andrews Experimental Forest.

tion cut becoming greater through extensive selection and diameter limit cuts to a maximum increase after a commercial clear-cut.

The increases in low flow from the logged watersheds are not large volumes of water. Owing to extremely low flows late in the summer, increases range only from 25 to 100 gal/acre/day (0.001 to 0.004 in./day).

*Discussion.* Some caution is needed in interpreting these results; i.e., timber cutting and roadbuilding cause little or no increase in peak flows but a modest increase in low flows. The data were obtained from only one pair of watersheds with no replication and are based on only a few years of record. Removal of vegetation has been accomplished for the most part with no great change in soil conditions, except on 2% or less of the drainage which is compacted road surface. Over most of the area, stable aggregates still permit rapid infiltration, and runoff is still predominantly subsurface. Results on these watersheds may differ widely from results on watersheds where vegetation removal leads to increased overland flow or on watersheds that differ widely in climate, topography, geology, or other features.

We expect rapid regrowth of vegetation on the logged areas. This study will be continued over a period of years to determine how rapidly the changes noted are offset by revegetation.

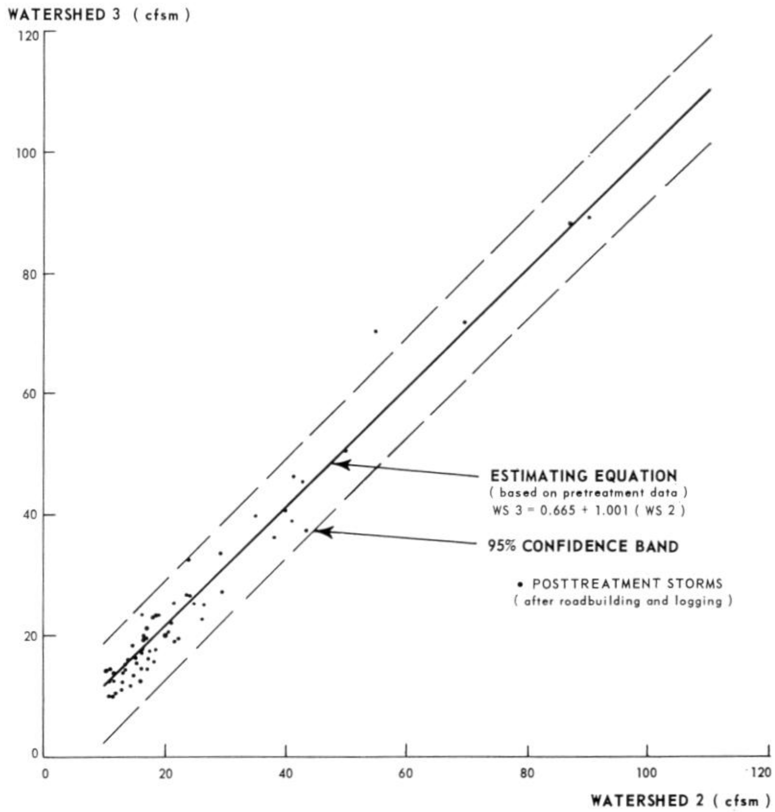


Fig. 8. Linear regression relating maximum streamflow from watershed 2 and watershed 3 when both were undisturbed. Plotted points show maximum streamflow during 3 years, after 8% of watershed 3 was cleared for roadbuilding, and during 1 year, after an additional 25% of watershed 3 had been clear-cut. H. J. Andrews Experimental Forest.

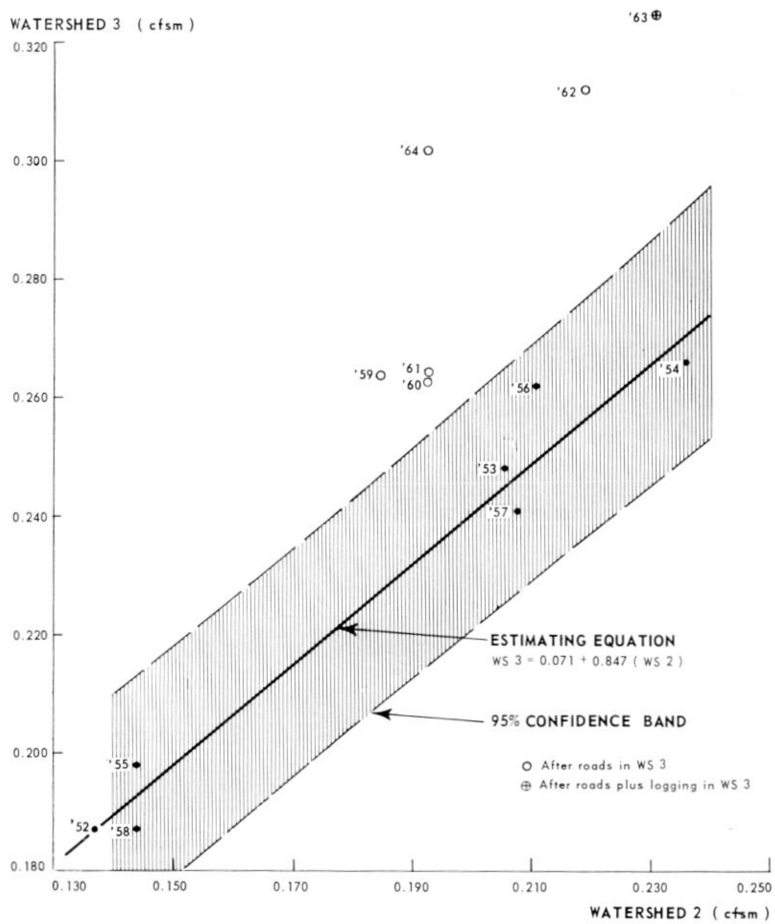


Fig. 9. Linear regression relating minimum streamflow from watershed 2 and watershed 3. H. J. Andrews Experimental Forest. Plotted points '53 to '58 represent undisturbed conditions on both watersheds. Plotted points '59 to '62 show the increase in minimum flow after 8% of watershed 3 was cleared for road construction. The '63 and '64 points were obtained from measurements after an additional 25% of watershed 3 had been clear-cut.

REFERENCES

Barnett, Loyd O., Jr., Storm runoff characteristics of three small watersheds in western Oregon, M.S. thesis, Colorado State University, Fort Collins, 1963.

Bethlahmy, Nedavia, First year effects of timber removal on soil moisture, *Bull. Intern. Assoc. Sci. Hydrol.*, *7*(2), 34–38, 1962.

Berntsen, Carl M., and Jack Rothacher, *A Guide to the H. J. Andrews Experimental Forest*, 21 pp., U. S. Forest Service, Pacific Northwest Forest and Range Experiment Station, Portland, Ore., 1959.

Fredriksen, R. L., Sedimentation following logging road construction in a small western Oregon watershed, *Proc. Federal Interagency Sedimentation Conf., Jackson, Miss.*, in press, 1962.

Hewlett, J. D., Soil moisture as a source of base flow from steep mountain watersheds, *U.S. Forest Serv., Southeastern Forest Expt. Sta. Paper 132*, 11 pp., 1961.

Lee, Richard, Evaluation of solar beam irradiation as a climatic parameter of mountain watersheds, *Colorado State Univ. Hydrol. Paper 2*, 50 pp., 1963.

Reinhart, K. G., A. R. Eschner, and G. R. Trimble, Jr., Effect on streamflow of four forest practices in the mountains of West Virginia, *U.S. Forest Serv. Res. Paper NE-1*, 79 pp., Northeastern Forest Experiment Station, Upper Darby, Pa., 1963.

Rothacher, Jack, Net precipitation under a Douglas-fir forest, *Forest Sci.*, *9*, 423–429, 1963.

Thornthwaite, C. W., and J. R. Mather, Instructions and tables for computing potential evapotranspiration and the water balance, *Climatology 10*, 1–311, 1957.

(Manuscript received August 20, 1964.)