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INCREASES IN MAXIMUM STREAM TEMPERATURES
After Logging in Old-Growth Douglas-Fir Watersheds

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Water temperature, one of the important factors of water quality, is strongly influenced by solar radiation reaching the stream and its channel. To determine the water temperature changes that occur when old-growth Douglas-fir forests are logged, maximum and minimum thermometers were installed in three streams on the H. J. Andrews Experimental Forest near Blue River, and records were maintained from 1959 through 1966.

The three small (237-, 150-, and 250-acre) northwest-sloping watersheds under study are located on the west side of the Cascade Range at an elevation of 1,500 to 3,500 feet (fig. 1). Climate is maritime with cool, dry summers and mild, wet winters. Average annual temperature is approximately 49° F., with a January average of 35° and a July average of 69° F. Snow is usually short-lived at these elevations. Topography is steep, and vegetation is predominately dense old-growth Douglas-fir with a relatively sparse understory. Each watershed contains about 10,000 feet of live stream with flow variations from 0.025 cubic foot per second during summer lows up to 60 cubic feet per second during winter storms.

THE STUDY

Weekly maximum and minimum water temperatures were recorded at the gaging stations on the three watersheds from 1959 through 1966. The period from 1959 to 1962 represents before-logging conditions. Watershed 2, which remained undisturbed through this period, served as a

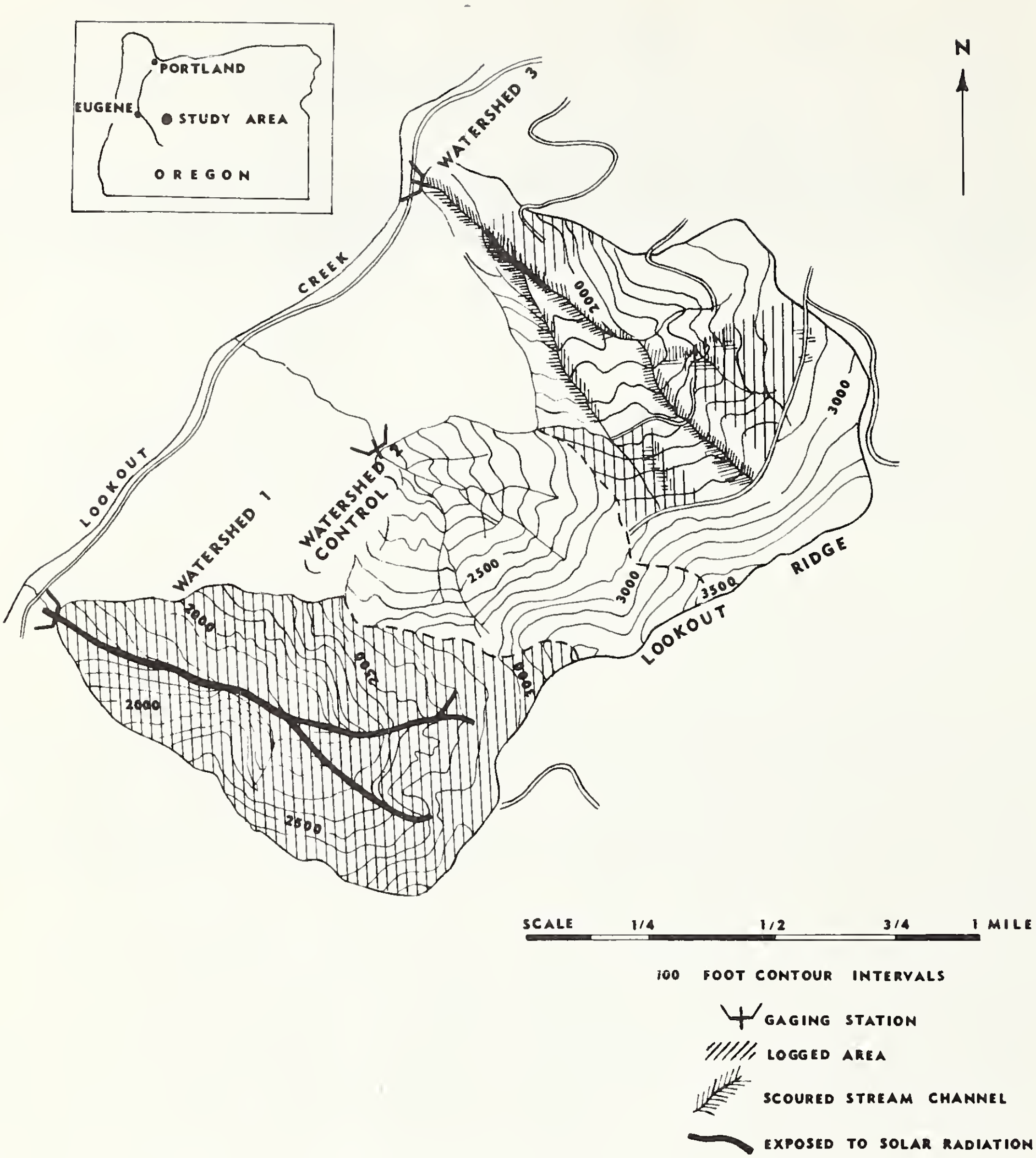

Figure 1.--Experimental watersheds, H. J. Andrews Experimental Forest.

control in statistical comparisons. Stream channels, characteristic of undisturbed areas, contain an accumulation of natural debris and are heavily shaded by streamside vegetation (fig. 2).

Figure 2.--The streams under old-growth Douglas-fir forests receive only diffuse radiation through the forest and streamside vegetation.

Beginning in 1962, the following changes took place on the other two experimental watersheds:

1. One hundred percent clearcut. The entire 237-acre drainage of watershed 1 was logged by the skyline system during the 4-year period from August 1962 to July 1966. This report was completed before the creek had been cleaned and the slash burned (fig. 3).

Figure 3.--Watershed 1 stream channel after logging was completed (period 5). Logging debris partially shades the creek from heating by the sun.

2. Twenty-five percent clearcut. Logging in watershed 3 was typical of the patch cutting system of timber harvesting in the Douglas-fir region. In 1959, right-of-way for 1.65 miles of road cleared 8 percent of the drainage. High-lead logging of three clearcut units during the winter of 1962-63 cleared another 25 percent of the drainage. In conjunction with logging, cull logs were cleared from approximately 1,300 feet of the stream channel which flows through the lower unit. The stream was shaded by smaller debris, and some vegetation remained in and adjacent to the channel. Slash burning followed in September 1963.

3. Stream scour after clearcutting. During the 1964 flood,[1] most of the main stream channels in watershed 3 were scoured to bedrock (fig. 1). The 1,300 feet of stream in the lower unit was directly exposed to the sun's radiation (fig. 4).

Figure 4.--Scoured section of stream channel in the lower clearcut unit of watershed 3. This section of stream channel is exposed to direct radiation from the sun (periods 3 and 4).

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[1] Fredriksen, R. L. Christmas storm damage on the H. J. Andrews Experimental Forest. Pacific Northwest Forest & Range Exp. Sta. U.S. Forest Serv. Res. Note PNW-29, 11 pp., illus. 1965.

Water temperature was measured with "U" tube maximum-minimum thermometers,[2] submerged in the stream near the gaging station on each watershed. The thermometers were checked with a standard mercury thermometer at the time of each weekly reading. Although the registering thermometers are graduated in 2° increments, all temperatures were interpolated to the nearest degree.

Linear regressions based on weekly maximum and minimum water temperatures were calculated to express the relationship of watershed 1 (skyline logging) to watershed 2 (undisturbed) during five periods representing a range in cover conditions on watershed 1 from none to 100 percent logged:

Period:	Watershed 1	Stream exposure to solar radiation
1	Before logging; old-growth Douglas-fir with crown density of over 90 percent	All 7,000 feet of main stream channels shaded by timber
2	0 to 40 percent of timber felled; 0 to 30 percent logged[1]	Timber felled along 3,000 feet; logged along 1,000 feet, south side only; logged along 300 feet, both sides
3	40 to 65 percent of timber felled; 30 to 55 percent logged	Timber felled along 7,000 feet; logged along 3,700 feet, south side only; logged along 1,300 feet, both sides
4	65 to 100 percent of timber felled; 55 to 90 percent logged	Timber felled along 7,000 feet; logged along 1,000 feet, south side only; logged along 6,000 feet, both sides
5	90 to 100 percent logged	Logged along 7,000 feet, both sides

[1] *Timber was felled considerably in advance of logging. In general, felled timber provided more shade to soil and water surfaces before logging than after logs had been yarded.*

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[2] Taylor No. 5458.

Similar regressions were calculated for watersheds 3 and 2, representing four periods of stream exposure on watershed 3:

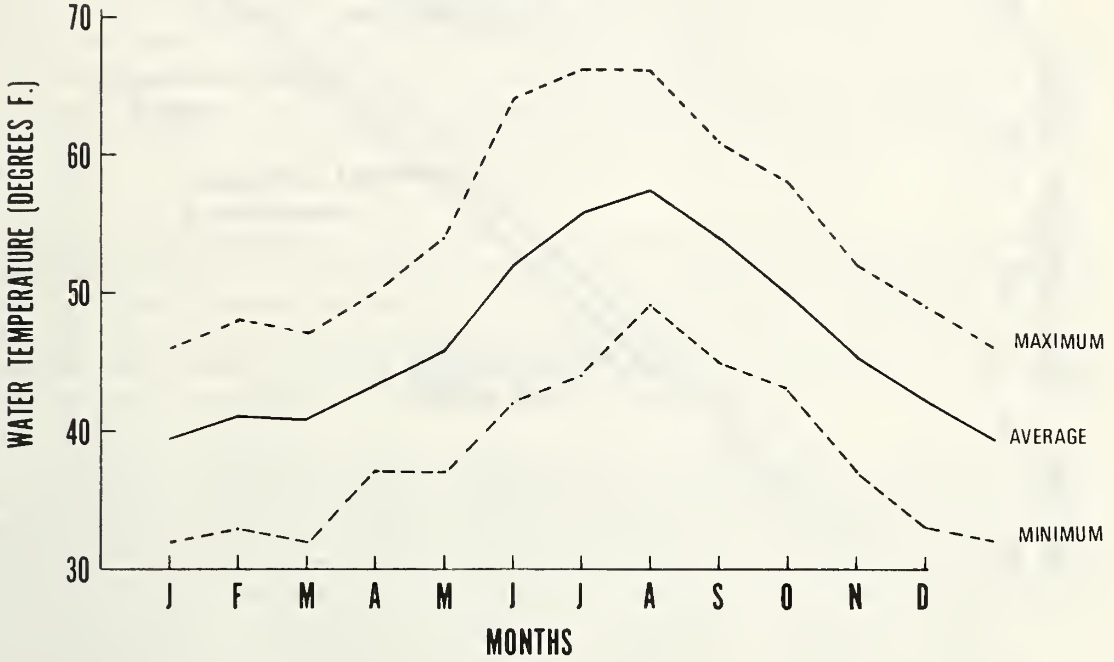
Period:	Watershed 3	Stream exposure to solar radiation
1	Before logging; road crosses stream channel in two places	Direct exposure negligible
2	25 percent logged (2,600 feet logged and burned out of a total stream channel of 9,000 feet)	Partial (29 percent of channel)
3	25 percent logged; stream scoured by 1964 flood	1st year after scouring, 1,300 feet (14 percent) of main stream directly exposed; 1,300 feet partially exposed
4	25 percent logged	2d year after scouring; same exposure as for period 3

RESULTS

Direct solar radiation and convection are the principal processes influencing water temperatures. Under a dense forest cover, sunlight reaching the stream channel is largely diffuse and intermittent, and changes in water temperature vary primarily with air temperature by convection. When the forest cover is removed, direct solar radiation provides a large part of the energy required to raise water temperature.

Water temperature fluctuations at the lower end of these small watersheds reflect climatic events during the year (fig. 5). Minimum temperatures drop as low as 32° F. during extended cold spells in midwinter but may rise rapidly during rainstorms associated with warm fronts from the Pacific Ocean. Maximum water temperatures occur during the months of July and August when air temperature is high, solar radiation is intense, streamflow is low, and water movement is slowed considerably. The slowly moving stream with numerous shallow pools has more time to absorb heat by convection under timber cover and by direct radiation from the sun where the cover has been removed. Maximum water temperature recorded at the gaging station on the undisturbed watershed during the years of study was 66° F. Water temperature records of springs near the headwaters of both watersheds 2 and 3 show that ground water varied only from 43° to 45° F. throughout each of several years. Direct sunlight reaches the stream in only a few areas under undisturbed forests, indicating that surface water may warm up 20° F. or more, primarily by convection.

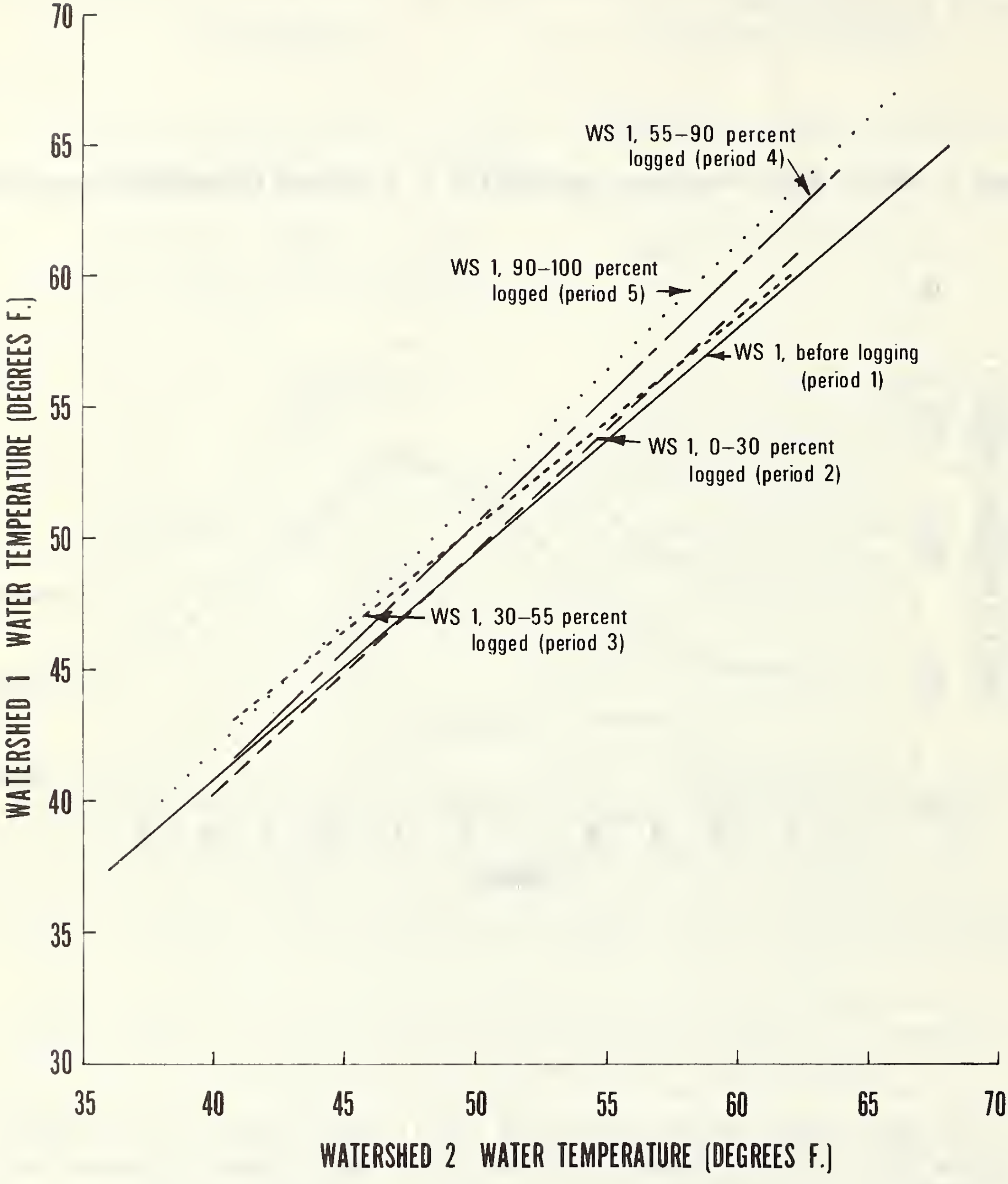
Figure 5.--Monthly water temperature, watershed 2; H. J. Andrews Experimental Forest, 1959-66.



In this study, no statistically significant change in the normal fluctuations of water temperature was found until drastic changes had been made in the vegetative cover along the stream channels.

The relationships of maximum weekly water temperatures recorded on watersheds 1 and 2 are shown in figure 6. Each line represents one of the five periods from none to 100 percent logged on watershed 1. Watershed 2 remained undisturbed through all periods. The standard error of the regressions was less than 2° F. in all periods.

Figure 6.--Maximum weekly water temperature, watersheds 1 and 2.



The relationships for periods 1, 2, and 3 are not statistically different; i.e., there was no statistical evidence for a difference in maximum temperatures when less than 55 percent of the drainage was logged. Both periods 4 and 5 were statistically different from period 1 (before logging), indicating that when a major portion of watershed 1 was cleared there was a measurable increase in maximum water temperatures. After 100 percent of the drainage had been logged (period 5), but before burning and stream cleaning, the average of July and August weekly maximums measured on watershed 1 was 62° F. This was 4° higher than the predicted average of 58° F. had the area remained unlogged and the relationship of period 1 remained unchanged.

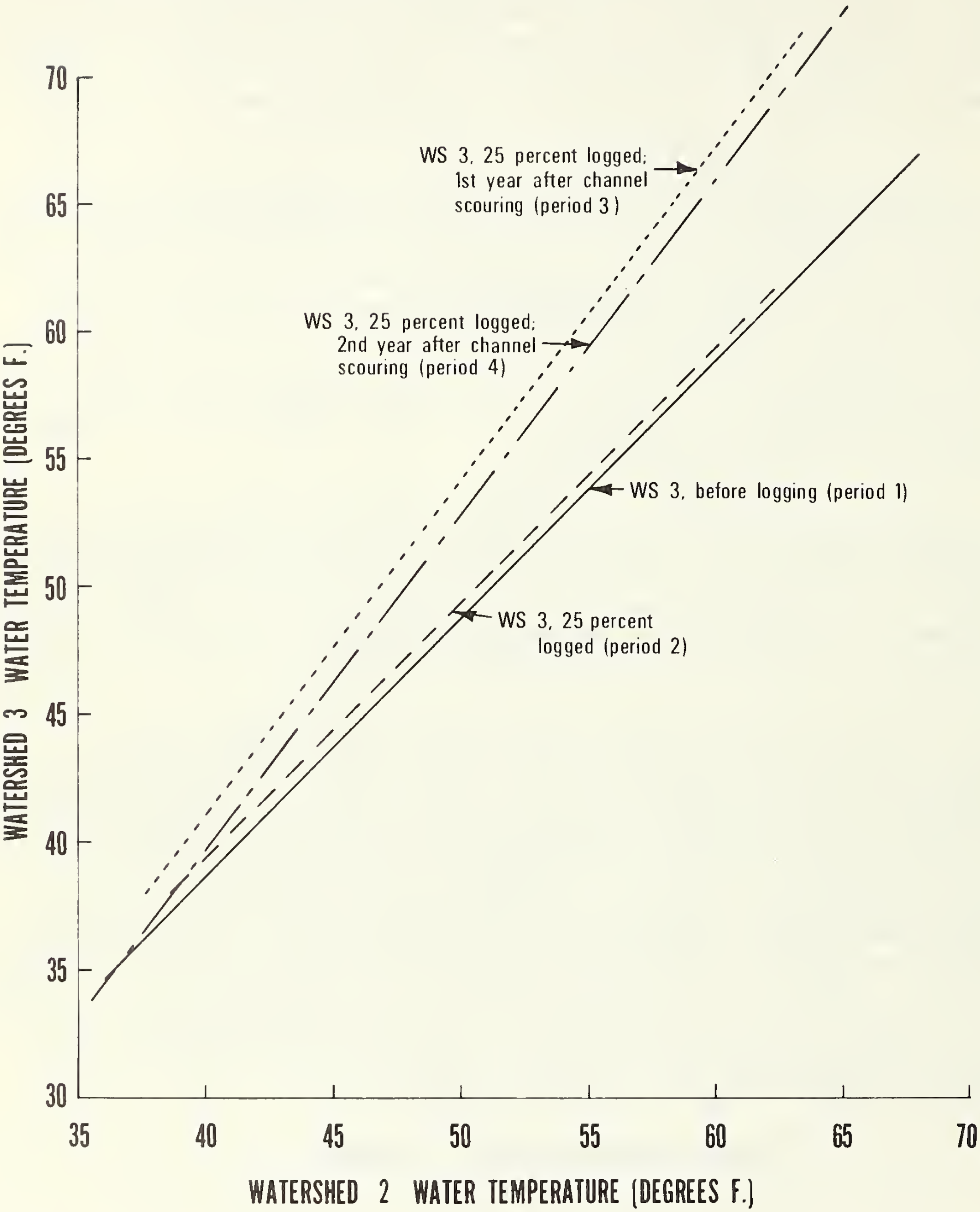
As expected from results in watershed 1, logging and burning of 25 percent of the area in watershed 3, plus removal of cull logs from the stream channel, showed no statistical evidence of a change in maximum water temperatures (fig. 7, periods 1 and 2). However, highly significant increases in maximums were recorded the year after the stream had been scoured by the 1964 flood (period 3). Since little cover developed in the scoured streambed during the first year, it was not surprising to find that maximums recorded during the second year after the storm (period 4) still showed highly significant increases over the prelogged and logged years.

Maximum temperatures were not only higher in the scoured channel, but water temperature responded much more rapidly to changing climatic factors. The standard error of the regression was less than 2° F. until after stream scouring when it rose to 3.5° F. The added variation may be principally due to the difference in the manner of heating--convection in watershed 2; radiation in watershed 3.

At the scoured section of the streams in the lower unit of watershed 3, Brown, working with energy budget techniques to predict water temperature,[3/] found increases of as much as 16° F. from the time the stream entered the clearcut at the upper edge of the unit until it left the area at the lower end, a distance of 1,300 feet exposed to direct solar radiation. On June 14, 1966, he recorded a maximum of 77° F. Further downstream, after the stream had passed through 700 feet of undisturbed canopy, maximum water temperature at the stream gaging station was 69° F., indicating considerable cooling in the forest-shaded stretch. Although a continuous record is not available for the lower end of the scoured stream section, a maximum water temperature of 71° F. at the gaging station would suggest that the instantaneous maximum might have approached 80° F. in the clearcut.

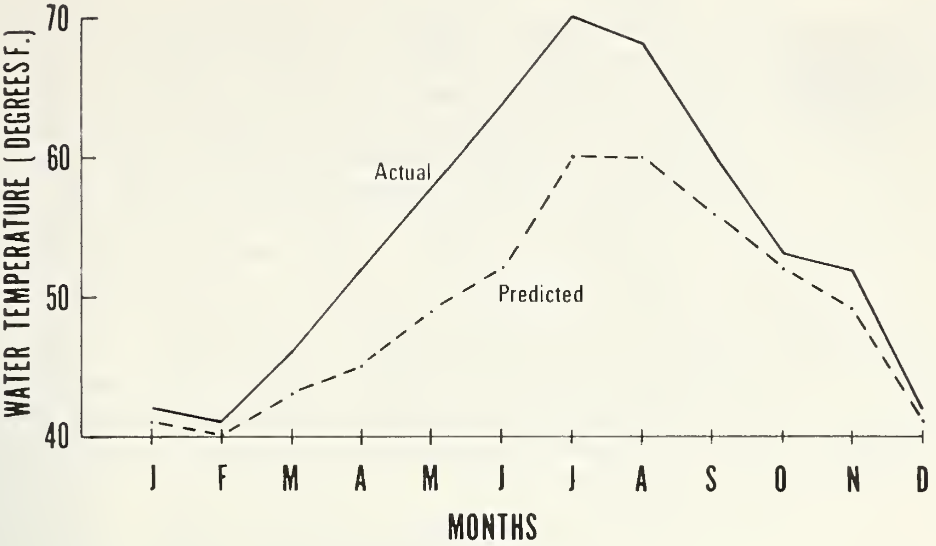
[3/] Brown, George Wallace III. Temperature prediction using energy budget techniques on small mountain streams. 1967. (Unpublished Ph. D. thesis on file at Oreg. State Univ., Corvallis.)

Figure 7.--Maximum weekly water temperature, watersheds 3 and 2.



The influence of season of the year on the increase in maximum water temperature is illustrated in figure 8, which compares measured temperatures from watershed 3 after exposure of the streambed by

Figure 8.--Estimated and measured mean monthly maximum water temperatures, watershed 3, 1965.



scouring with the predicted temperature had the watershed remained undisturbed and the relationship of period 1 remained unchanged. After stream scouring, mean monthly maximum temperatures at the gaging station reached 70° F. in July 1965 compared with an estimated maximum of 60° F. with a timber cover. Increases of 7° to 12° F. persisted from April through August.

As can be seen in figure 8, changes in winter maximum water temperatures are small. This is also shown by the convergence of the regression lines at lower temperatures in figures 6 and 7. Regressions of weekly minimum temperatures (not presented) showed no consistent relationship with progress of logging or the change in exposure following scouring of the channel by slide debris. There are apparently several interacting climatic factors, not recorded, which influence minimum temperatures whereas solar insolation is the predominant factor influencing maximum water temperatures.

SUMMARY

Under the pattern of patch clearcuts commonly used in the Douglas-fir region, little or no increase in maximum stream temperatures would be expected unless a large proportion of the streambed was directly exposed to solar radiation. Protection of any streamside vegetation which provides some shade to the stream will apparently help prevent excessive increases in maximum water temperatures.

On a northwest-facing slope, extensive logging on a forested watershed increased maximum water temperature only after 55 percent of the drainage was logged and timber had been felled along all the major stream channels. On south-facing slopes, an increase might be noted with a smaller percentage of cutting. Maximum water temperatures may also increase as a result of drastic exposure of a section of streambed, such as occurs following scouring by flood waters, burning, channel changes, excessive stream cleaning, etc. Some cooling also takes place when the stream again passes through a forest-shaded stretch. In this study, mean monthly temperature increases of 7° to 12° F. persisted from April through August, following direct exposure of the stream channel by scouring during the 1964 flood. Recent developments in techniques for temperature prediction using an energy budget approach may soon permit us to estimate the effects of several factors of stream exposure on maximum water temperature.

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