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REGIMES OF STREAMFLOW AND THEIR MODIFICATION BY LOGGING

Jack Rothacher

Abstract

Streamflow in the Pacific Northwest is most strongly influenced by the precipitation pattern, somewhat less by evapotranspiration losses. Evaporation and transpiration are strongly influenced by logging. Logging and burning old-growth Douglas-fir forests on an experimental watershed increased annual yields of streamwater by 18 inches or more. Most of the increase occurred in fall and winter months. We can't positively attribute any great increase in major "wet mantle" flood flows to logging in west slope forests. Logging which removes transpiring vegetation increases lowest summer streamflow. Such increases may be short lived as vegetation rapidly invades the cutover areas.

In the opening papers at this Symposium, we have heard of the importance of the *fish resource* and of the *forests* of the west coast. Now we are about to embark on discussions of the effect that the use of one resource (forests) has on the other (fisheries). I will start this off with consideration of the effects of logging on the amount of water in our streams and the fluctuation in streamflow with time of year. These are especially important subjects at this Symposium since water is the medium in which fish live.

The relation of forests to streams has been the subject of many misconceptions. Sartz (1969) points out that most of the "folklore and bromide in watershed management" resulted from the assumption that research findings from one place would apply throughout the country.

Basic Hydrologic Relationships

To start at the beginning, we should look at the basic hydrologic relationships as they apply to our west coast forested areas. I am sure you are all familiar with the hydrologic cycle. The portion of the hydrologic cycle with which we are most concerned is expressed by the basic relationship:

Streamflow = precipitation minus evapotranspiration losses.

Evapotranspiration losses include (1) interception and reevaporation of precipitation at the crown canopy, (2) transpiration of water extracted from the soil by plants and given off to the air as water vapor, and (3) soil moisture changes related to incoming precipitation and outgoing drainage or evapotranspiration use. For any given period, water stored in the soil may increase or decrease. All these losses to streamflow are strongly influenced by the vegetative cover.

Precipitation and evapotranspiration

Precipitation varies greatly both throughout the region and from year to year. Losses are much more consistent. For example, in the high rainfall forest of the Bull Run watershed east of Portland, recorded precipitation may vary by 50 inches from a low of 85 inches to a high of 135, but evapotranspiration losses estimated by the Thornthwaite method (Thornthwaite and Mather 1957) may vary only by 3 or 4 inches, from 18 to 21. Thus we can see, by reference to the basic relationship, that the total amount of runoff is most strongly influenced by the precipitation pattern. Throughout the Northwest, the year-to-year variation is greater than changes that we could make in reduction of losses.

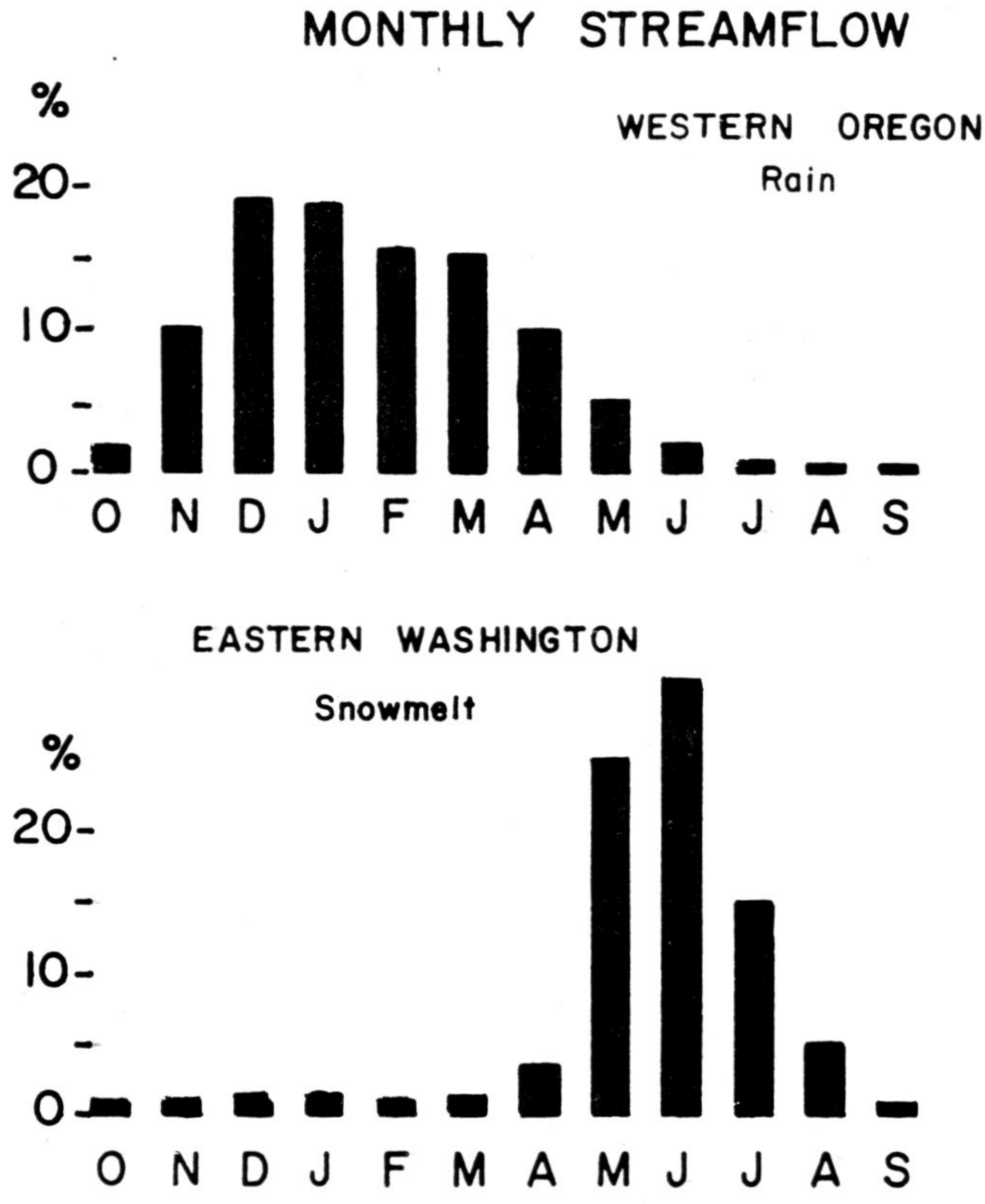

Figure 1. Monthly distribution of streamflow resulting primarily from rain in western Oregon and from snowmelt in eastern Oregon.

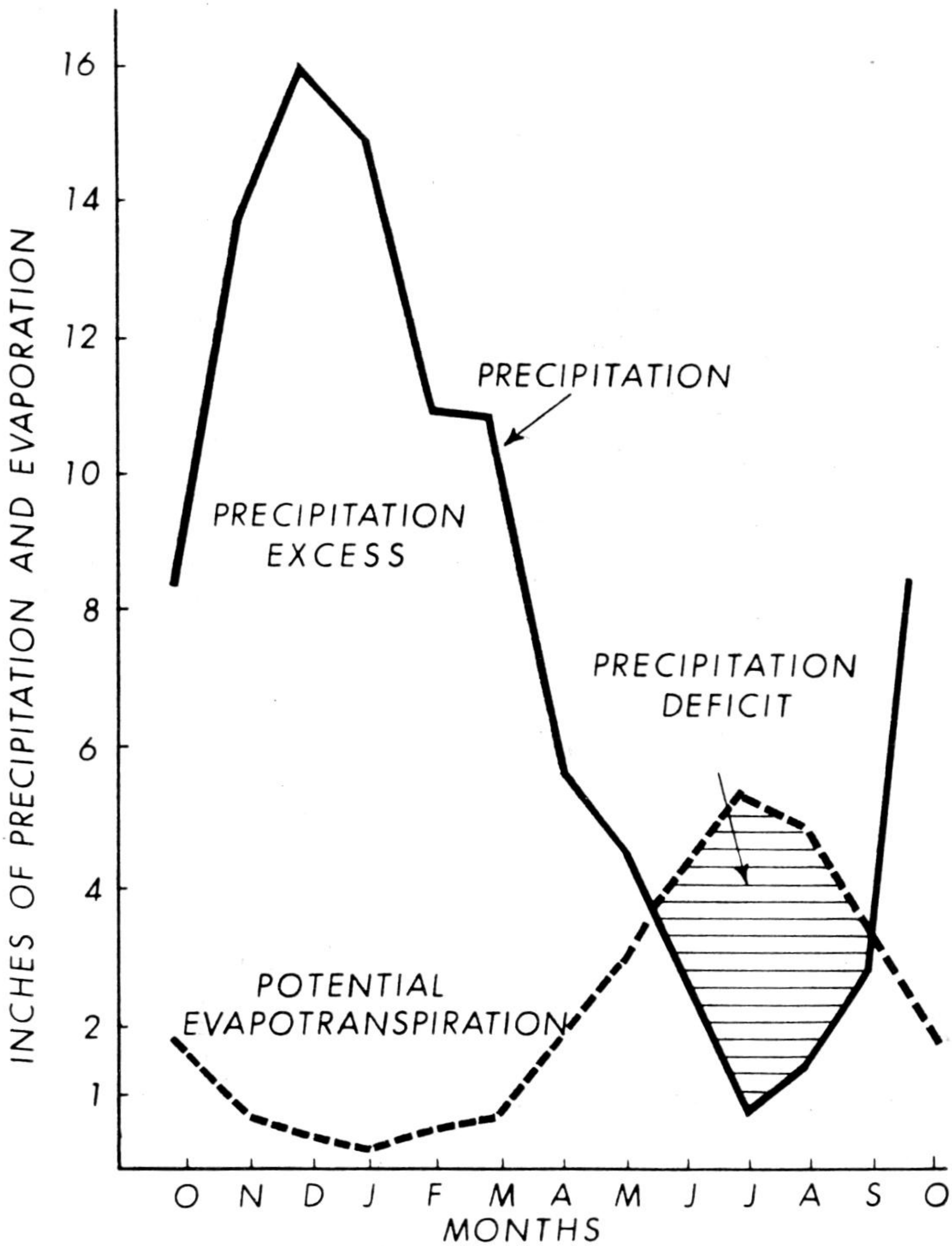

Figure 2. Mean monthly precipitation and evapotranspiration (from H. J. Andrews Experimental Forest).

The form of precipitation also influences the seasonal distribution of runoff. At lower elevations where rain or rain plus snow is the usual form of precipitation, streamflow is greatest during the early winter period (Fig. 1a). In the higher elevations with colder climates, snow that accumulates during late fall and winter melts in the spring causing greater streamflow at that time (Fig. 1b). In middle elevations we may get two periods of high streamflow, one in the fall when the rainy season starts and before cold weather changes the precipitation to snow and a second peak when the snow melts.

You will notice in these patterns that low flows generally occur at the end of the summer season. This is, of course, true in almost all climates but especially here on the west coast where our streamflow is so strongly influenced by dry summers during which we often have one or more months with no precipitation. During the summer, precipitation is considerably less than evapotranspiration (Fig. 2). As a result of this pattern of low rainfall and relatively high evapotranspiration stresses, vegetation has an important influence on streamflow in our area and perhaps also on living space available for the fish that live in the streams.

Soil moisture

In most of the area west of the crest of the Cascades there is adequate precipitation during the winter months to recharge the soil to what we generally call field capacity (Fig. 3). In general terms, this is the total amount of water that the soil can hold against the forces of gravity. Beginning in early summer evapotranspiration begins to exceed precipitation. This requires withdrawal of water from that stored in the soil. By the end of the summer dry season, water stored in the top 4 feet of soil may have been reduced by 6 to 8 inches. When transpiring vegetation is removed, the reduction in soil water is much less and is limited to the top foot or less.

Changes in Annual Streamflow from Clearcutting

What then if we remove the forest–the transpiring vegetation? In harvesting west coast forests, the most complete removal of vegetation results from clearcutting and burning. If there is no limit in water available to the forest, we would expect clearcutting and burning to cause an increase in water available for streamflow approximately equal to transpiration.

Removal of forest vegetation also makes more water available for streamflow by reducing interception losses. Evaporative losses are less from the ground surface than when trees intercept water and it evaporates from the foliage. This is, in part, due to greater exposure of the intercepted water to wind and sun and also because leaf surface may exceed ground surface by four to eight times. On the other hand, because the soil is exposed to more direct solar insolation, we would expect greater evaporative losses from the soil in clearcut areas than under the shade of a forest cover. Such evaporative losses from the soil are, however, limited to the top foot or less.

The combined effect is less water used by transpiration and by interception but some compensation in more soil water loss to evaporation because of exposure of the site. We are not too sure of all the details, but experimental watersheds throughout the country show a pronounced increase in annual streamflow after clearcutting (Hibbert 1967). The height of the bars in Figure 4 represents the amount of streamflow greater or less than we would have predicted. Our predictions are based on the relationship of two watersheds before any cutting. You will notice that during this calibration period before the old-growth Douglas-fir forests were cut there were some years in which annual yield was greater than predicted and some less. These balance to zero for the calibration period. Then logging began in 1963, and we see a series of years in which yield was considerably greater than predicted. The maximum increase is over 21 inches. Under conditions in the Pacific Northwest where soils are relatively deep, precipitation is high and recharges the soil each year; and when evapotranspiration rates are fairly high, we could expect about an 18-inch increase in streamflow following clearcutting and burning. These figures were from the H. J. Andrews Experimental Forest on the west slope of the Cascades (Rothacher 1970).

A similar watershed study in the Alsea drainage of the Coast Range suggests increased yields may be as

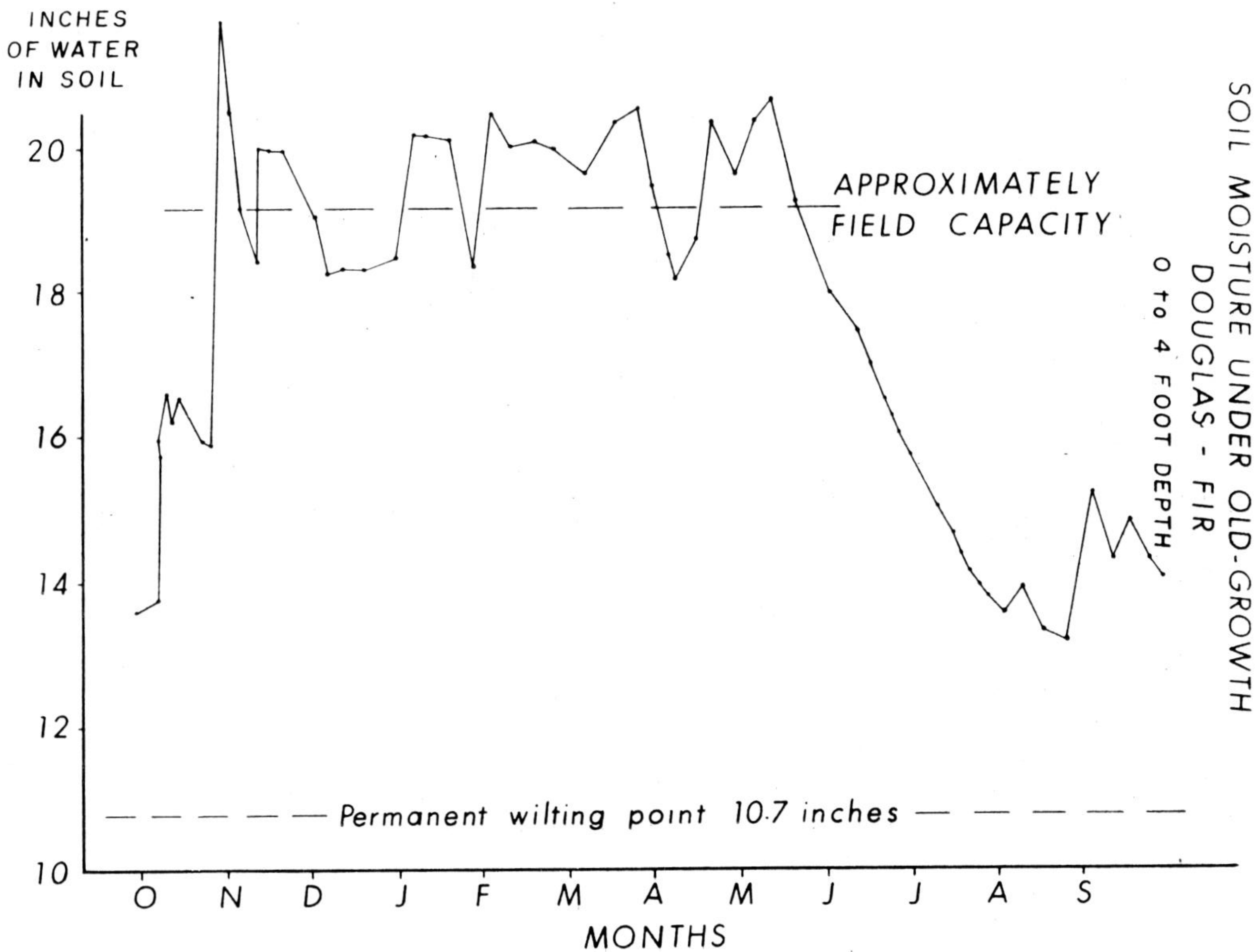

Figure 3. Annual soil moisture changes in the 0- to 4-foot depth under old-growth Douglas-fir (from H. J. Andrews Experimental Forest).

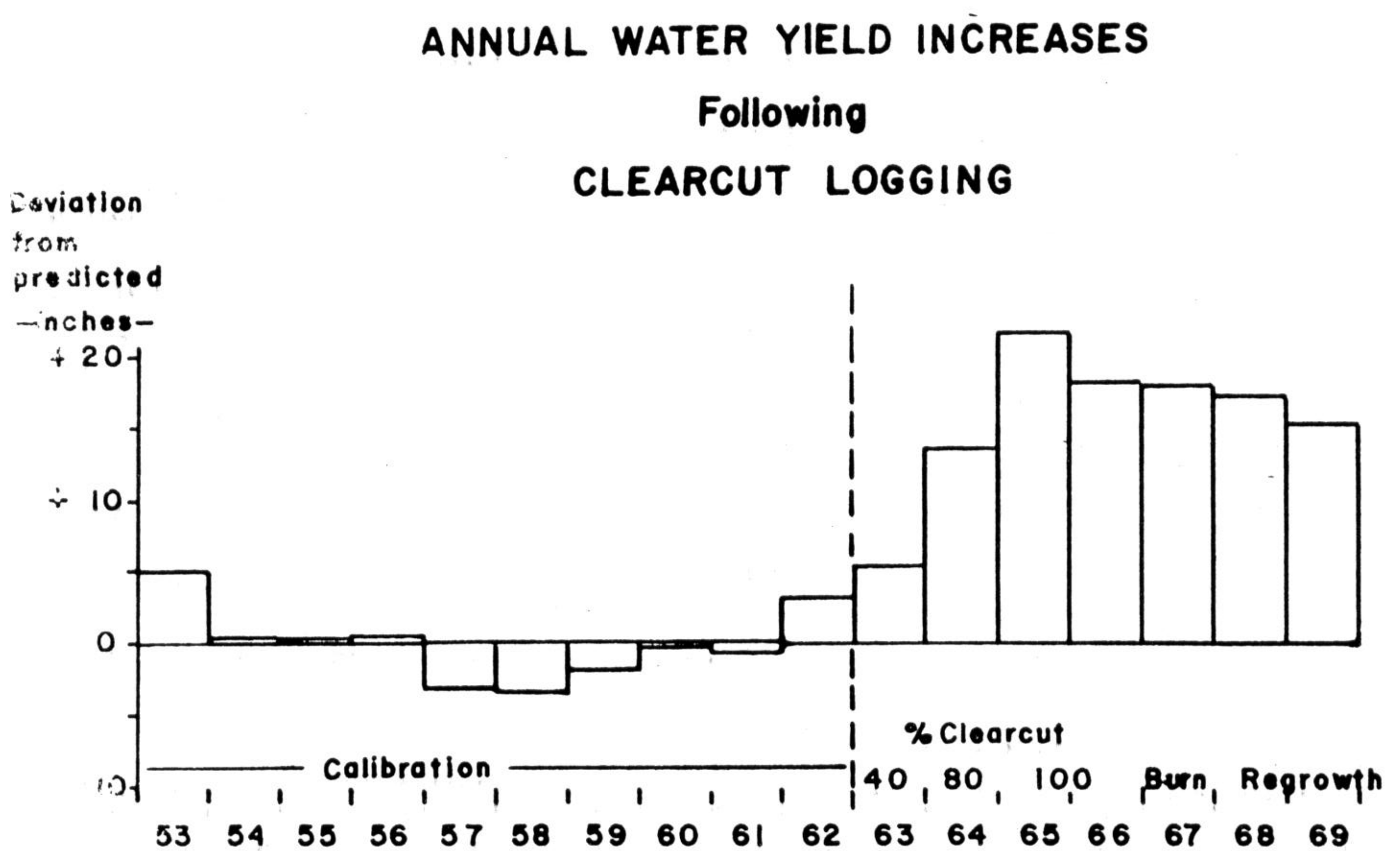

Figure 4. Deviation of annual water yield from predicted, before and after clearcut logging (from H. J. Andrews Experimental Forest).

high or even higher there.[1] However, revegetation is fairly rapid in these areas. Although the record is short, you will notice that in Figure 4 there is a downward trend in excess yields with years since the area was burned (1967). We don't know how long it will take for the evapotranspiration use to return to precut conditions and excess yield to drop to zero, but other studies suggest it might be as long as 15-30 years (Kovner 1956). This pattern of change should be typical of much of the wetter Douglas-fir region west of the crest of the Cascades. Because less water is available for plant growth and vegetation is less dense in much of the area east of the Cascades, we would expect much less change in annual yields after clearcutting. In a recent study, the Forest Service Pacific Northwest Region (n.d., Circ. 1969) estimates that potential average annual water yield increases after complete vegetation removal could be 0.3 inch in the juniper type; ponderosa pine type, 3.8 inches; associated species type, 6.3 inches; and lodgepole pine type, 7.1 inches.

Using the same type of analysis as in Figure 4, let us look at a 30-percent patch-cut watershed (Fig. 5). This would be representative of the common practice of harvesting old-growth Douglas-fir forests in much of the Pacific Northwest. We see essentially the same pattern but smaller increases in annual yields following cutting. As a general rule, we expect the increase to be roughly proportional to the percent of the drainage clearcut. Though the onsite increase may be large, this increase may be largely obscured on large watersheds harvested on a long-term, sustained-yield basis. Rothacher (1970) estimates that an 18-inch onsite increase would be equivalent to about an 0.8-inch increase in an area patch cut on a 100-year rotation.

Seasonal Changes in Streamflow

Seasonal streamflow is often more important than annual flow. You will notice in Figure 6, which shows monthly changes after clearcutting, that the largest increases were in the fall and winter months. One of the significant points is the large increase in flow in the early fall months, especially November. This is primarily because, at this time of year, soils under forest cover are much drier than those in a clearcut. In a soil moisture study on an adjacent watershed, we found that the soil under an old-growth forest stand contained 6 to 8 inches less water at the end of the growing season than that in a clearcut area.[2] More of the fall rains must go to recharge storage available in the soil under the forest cover with less surplus for runoff.

Flood flows

This leads us directly into the next important point to consider—peak or flood flows. There has been much study and controversy about how forests influence floods, and more often than not the logger has been "damned" for causing floods. It may surprise some of you to hear me say that under normal conditions, logging—and I'm including clearcutting—does not significantly increase major floods in the Douglas-fir area west of the crest of the Cascades. By "normal conditions" I am including the usual light disturbance caused by logging which is not sufficient to decrease infiltration capacity of the soil below the rate of precipitation. That is, there is no large-scale change from subsurface flow to surface flow. This is a reasonable statement because most of our soils have extremely high infiltration rates and precipitation rates are relatively low. I don't mean to convey the idea that we can't disturb the soil structure and severely reduce infiltration by logging, but studies show that, except in some tractor logging operations, serious compaction occurs only on limited areas in the Douglas-fir region (Dyrness 1965). There are exceptions, naturally.

I have used Figure 7 to illustrate this point that flood flows are not greatly changed because it includes the record floods of 1964-65. Each dot represents a distinct storm represented by a rise in streamflow to over 10 cubic feet per second per square mile. As in earlier figures, the distance that the dots are above or below the line is how much greater or less that storm was from predicted. Note the first dot in November. The flow from the clearcut watershed was over 150 percent greater than expected. This is explained by reference to our discussion of soil moisture at the end of the summer. With less use of water in the clearcut, more water remained in storage in the soil. Less of the precipitation of the first storm was needed to fill the storage

[1] Unpublished data from the Alsea Watershed Study, OSU, Corvallis.

[2] Unpublished data from the H. J. Andrews Experimental Forest, Blue River, Oregon.

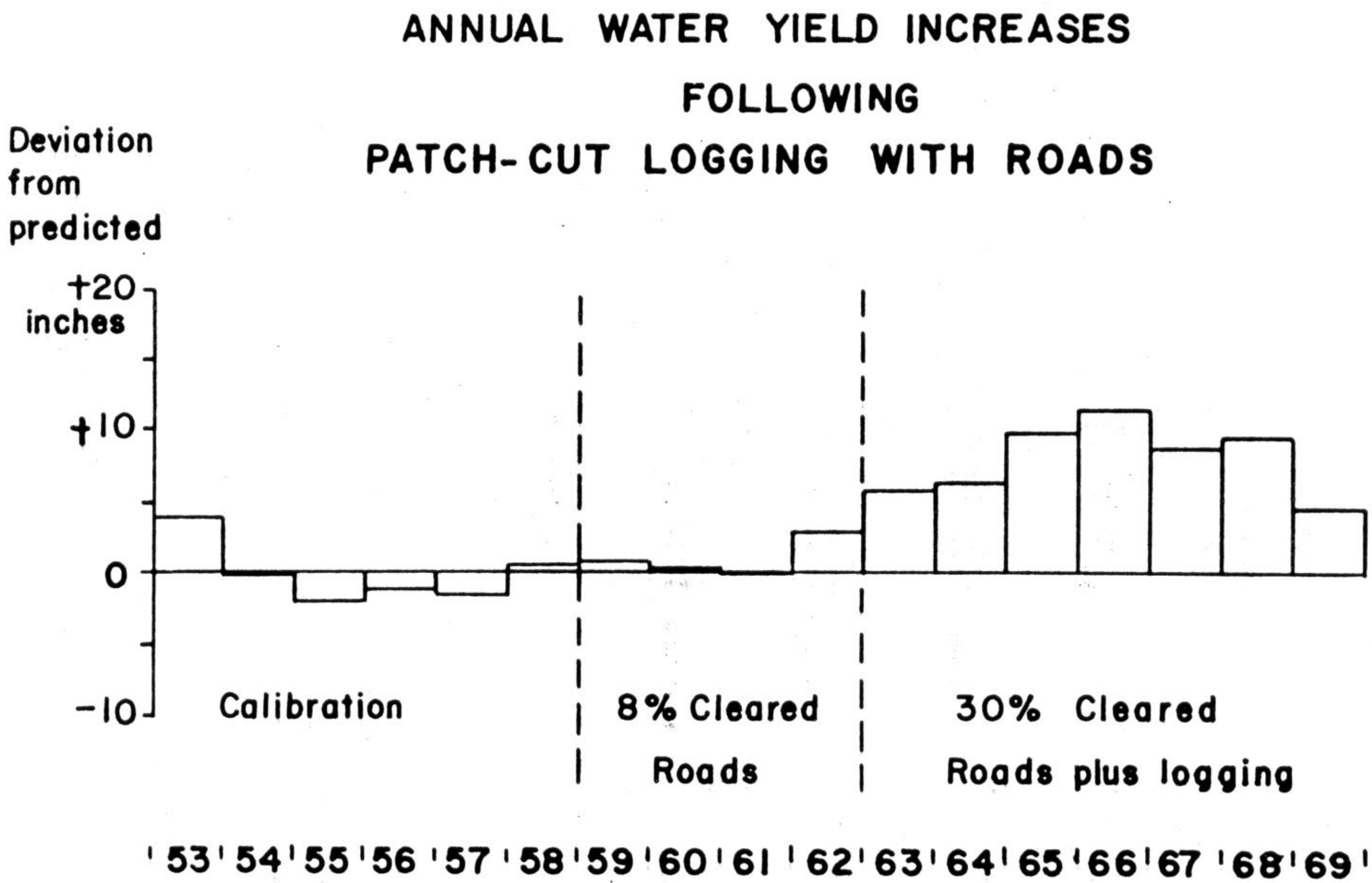

Figure 5. Deviation of annual water yield from predicted, before and after patch-cut logging with roads (from H. J. Andrews Experimental Forest).

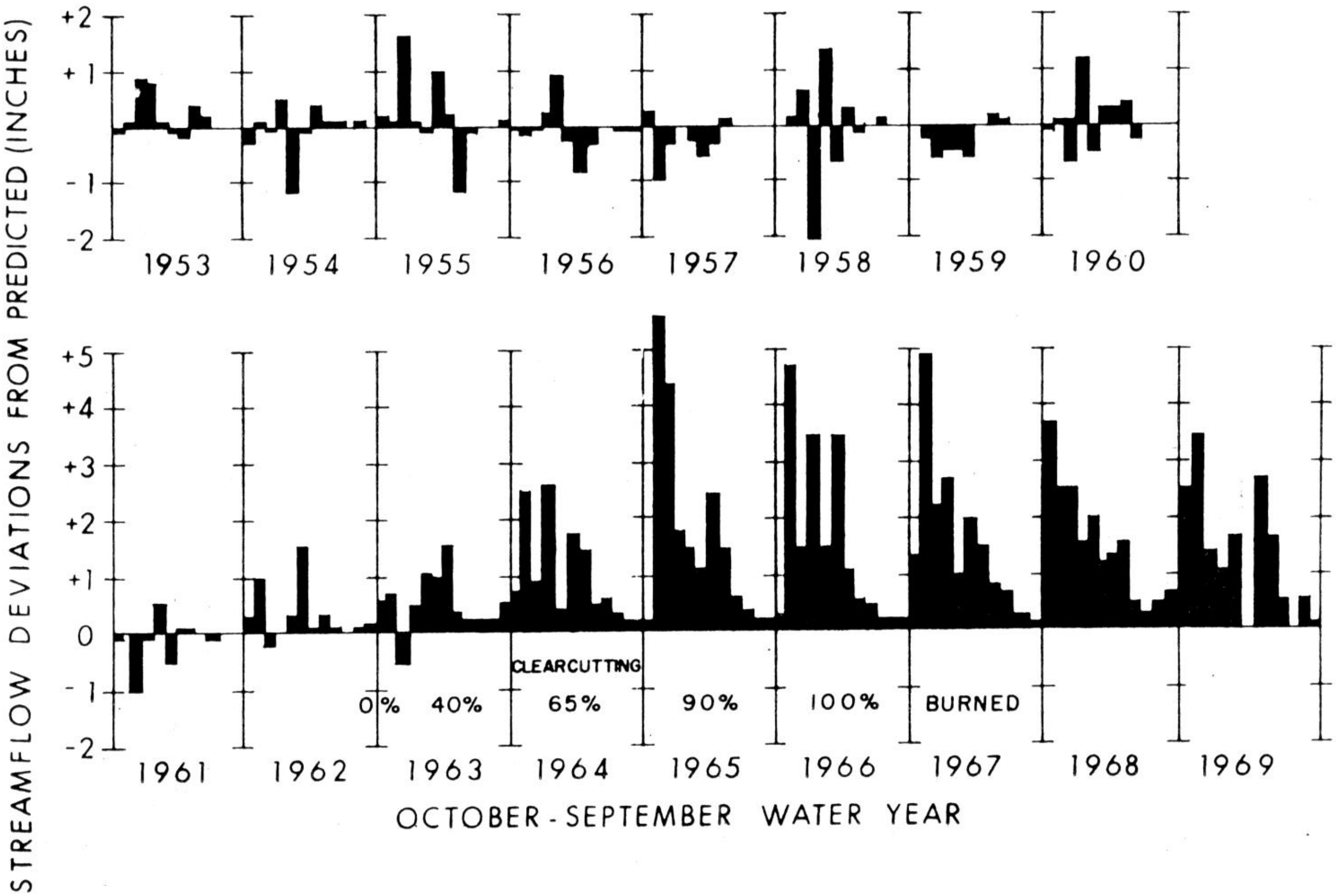

Figure 6. Deviation of monthly water yield from predicted, before and after clearcut logging (from H. J. Andrews Experimental Forest).

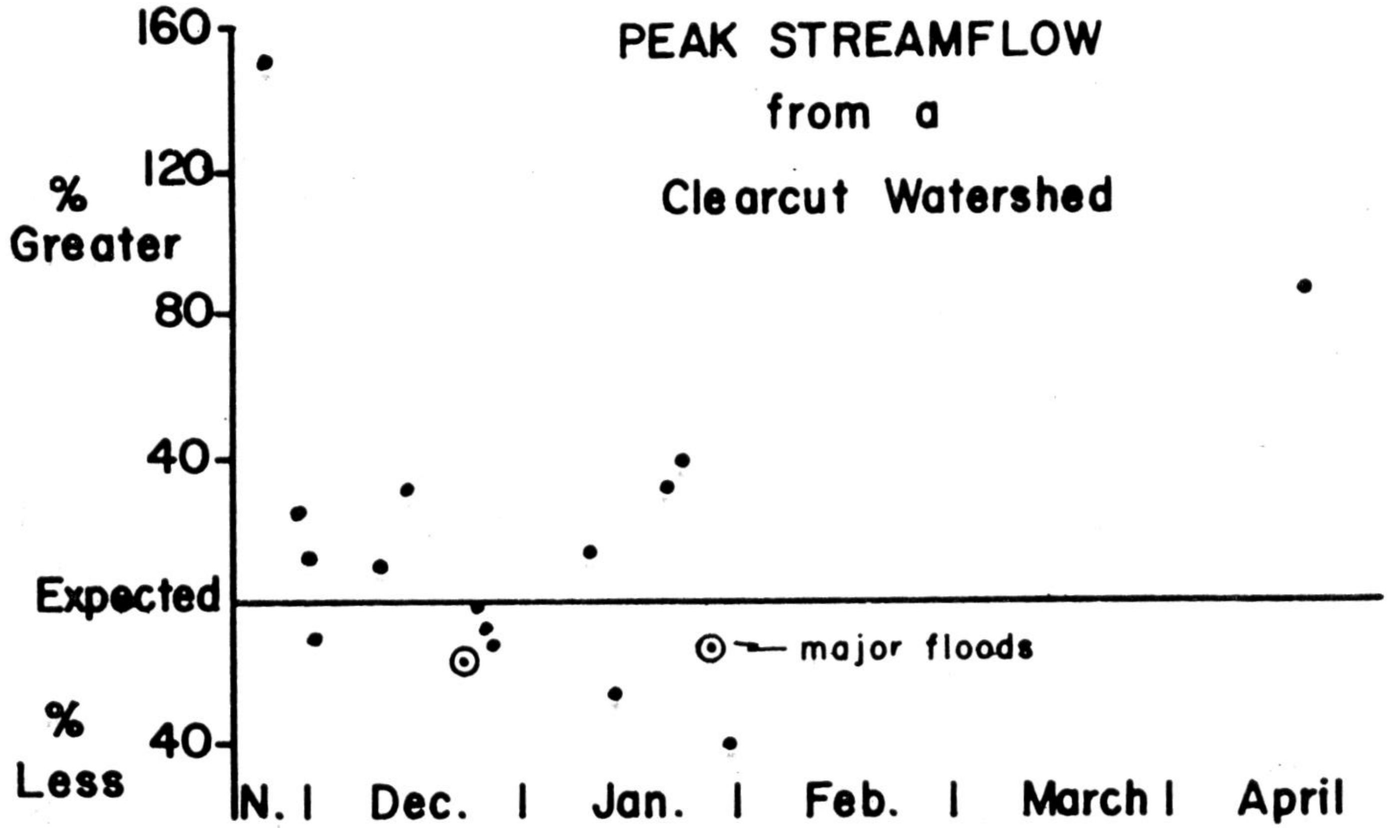

Figure 7. Percentage deviation of peak streamflow from predicted after clearcut logging (from H. J. Andrews Experimental Forest).

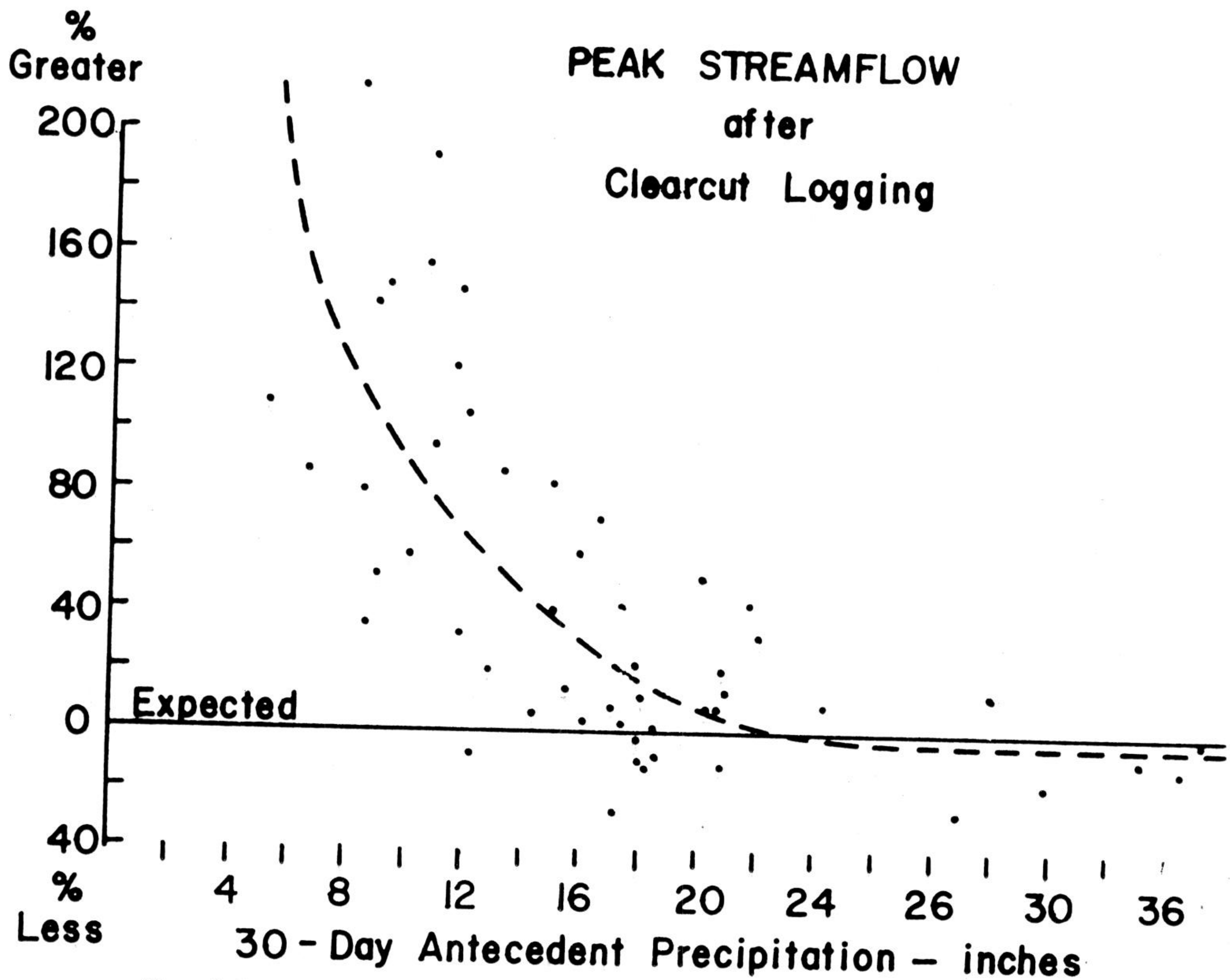

Figure 8. Relationship of 30-day antecedent precipitation to percentage deviation of peak streamflow from predicted, after logging.

capacity of the soil in the clearcut—thus more runoff. We should note that west of the crest of the Cascades our really big floods do not occur until after soils are thoroughly wet. These are known to hydrologists as "wet mantle" floods. After soils are thoroughly wet both under the forest and in the clearcut, the peaks are much nearer the predicted, although the average may show some increase. The variation around the predicted line probably results from a number of unmeasured factors, one of which is snow cover. A significant point is that these dots include the two record floods, December 22, 1964, and January 27, 1965. Actually, both fall below the predicted line, but they are well within normal variation.

Chow (1964) and others have pointed out that on small watersheds the magnitude of peak discharge is closely related to moisture conditions on the watershed for all but the largest storms. In a detailed analysis of records from the Coweeta Hydrologic Laboratory, Hewlett and Helvey (1970) show the effect of clearcutting on the production of flood waters. Although the peak flows increased slightly at the mean peak flow, there was no conclusive evidence that clearcutting resulted in an increase in record high peak flows. The authors, however, point out that there was a significant increase in total volume of water throughout the stormflow period and speculate that such increases could contribute significantly to downstream flooding.

Figure 8 further emphasizes the decreased effect of vegetation as antecedent moisture conditions of the watershed become wetter. Under relatively dry conditions vegetation has considerable influence; under very wet conditions, much less. Black (1970), working with models of watersheds, came to the conclusion that when "surficial storage is saturated, output (runoff) is solely a function of input (precipitation)."

At this point, I must admit that although the evidence and discussion of peak flows that I have presented are theoretically sound, there is other evidence that, under some conditions, roadbuilding and logging may increase peak flows more than I have indicated, especially on small drainages. Gilleran (1968), Harper (1969), and Hsieh (1970) have intensively analyzed data from the Alsea watersheds. They found significant changes in some factors of the hydrographs of storm peaks. In general, they found that roadbuilding which altered 3 to 4 percent of the drainage had little influence on peak flows. When over 12 percent of the drainage was in roads, there was a significant increase in peak flows which was increased still further when 72 percent of the drainage was logged. Clearcut drainages also showed marked increases in peak flows, in some cases as much as one-third higher in the winter. I am not sure that these results conflict with those I have presented. In most cases larger increases were noted in the fall than later in the winter for reasons we have already discussed. Also the period of study included only limited samples of the extreme events that cause our major floods.

As you can see, the debate over the influence of cutting on flood flows is still not definitely settled. The evidence available indicates that we can't positively attribute any great change in major flood flows to logging on the west slopes.

The east slopes may be different, especially where high intensity summer storms result in "gully-washers" which scour the streambeds. These storms occur under relatively dry antecedent conditions and under precipitation and soil conditions conducive to surface runoff. Forest vegetation may greatly reduce flood flows under these conditions. The annual peak flows east of the mountains generally originate from spring snowmelt (Fig. 1b). In general, logging results in greater snow accumulation in the forest openings; but forests have been observed to delay snowmelt longer into the spring. If the watershed is partially cleared of forest, spring streamflow peaks may be reduced in magnitude when rapid melt in the clearcut areas is not synchronized with slower melt from forested parts of the drainage. However, the opposite may occur if synchronization of melt rates is enhanced. Goodell (1959) has suggested that forest management practices can reduce the occurrence of spring flood flows by aiding the desynchronization of snowmelt.

Minimum streamflow

At the other extreme, we have the summer low flow period. The "old wives' tale" that cutting the forest dries up the springs and streams has been consistently disproved by research but is still a common misconception. Most evidence indicates that removal of vegetation increases late summer streamflow (Hibbert 1967). The only exception might be under conditions in which surface soil is so seriously compacted that infiltration is restricted and causes excess surface flow without replenishing soil water storage. This does not occur in coast areas of Washington and Oregon.

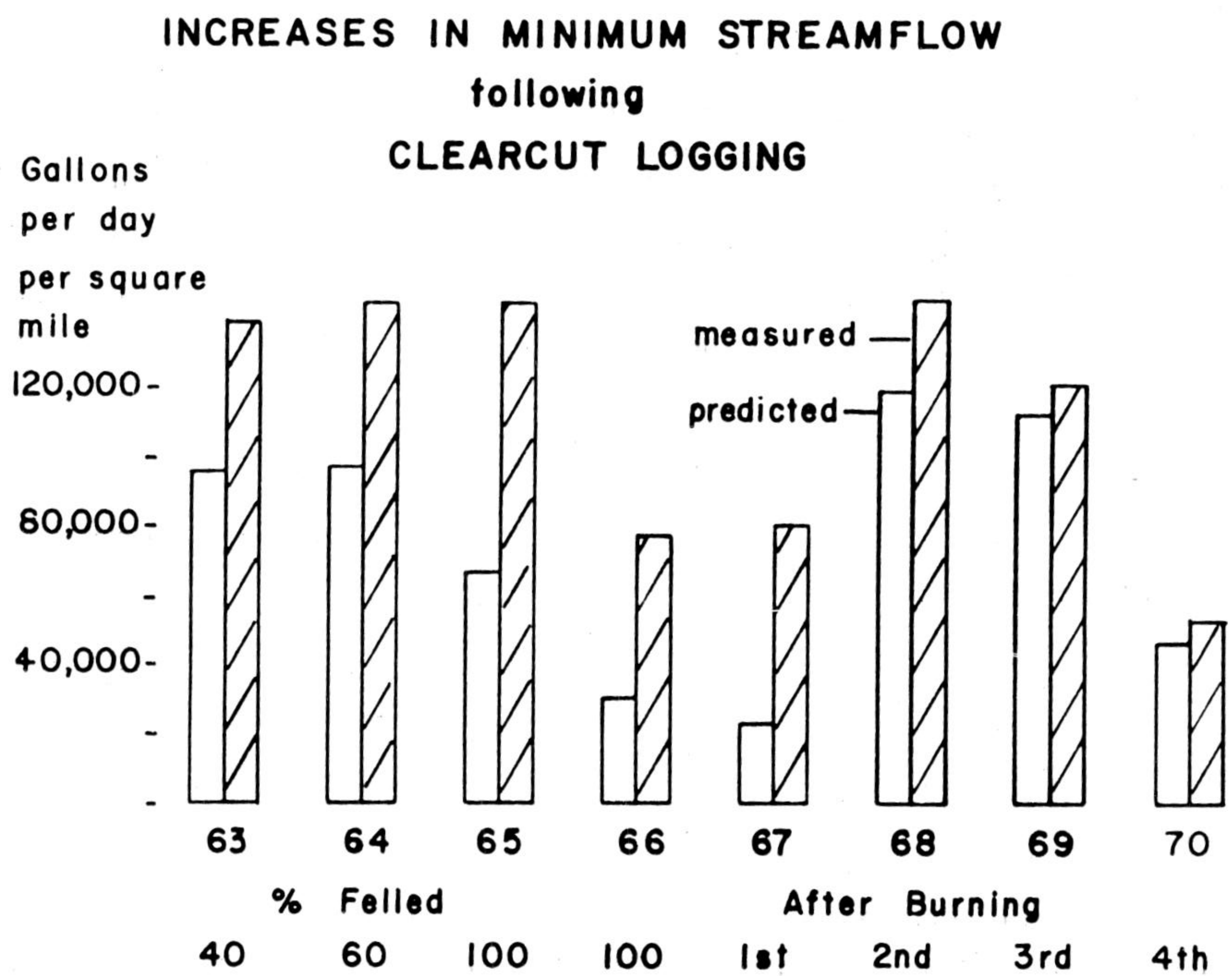

Figure 9. Comparison of measured and predicted minimum streamflow showing increases after clearcut logging (from H. J. Andrews Experimental Forest).

Concrete evidence of the increases in streamflow after logging in the Pacific Northwest is scarce, but we do have the results of one study in the Cascades. Using the week of lowest flow during the summer as an index, we can see in Figure 9 that measured streamflow was much greater than predicted streamflow after clearcutting an experimental watershed. There appears to be a larger percentage increase as more of the trees on the watershed were felled. Because of our long, dry summers, minimum streamflow is an extremely small volume of water. Even a small increase may double or triple the expected flow. This is especially true during dry years such as 1966 and 1967. In wetter years, such as 1968 and 1969, increases may be less obvious. In this study there was considerable regrowth of vegetation during the second and third years after burning. A vegetation survey on these watersheds showed an increase in plant cover from 29 percent in 1967 to 76 percent in 1968.

Again, we do not know how long these increases in low flow will last, but there is some evidence in Figure 9 that the increases may be short lived where regrowth of vegetation is rapid. Also, on the Alsea logging-aquatic study area, 4 years after burning, the riparian alder is already well established and causing a pronounced diurnal fluctuation due to heavy water use during the day. Because of the extremely small volumes of water, the increases and subsequent decreases of flow must be of considerable importance to the stream environment as these changes influence available living space, dissolved oxygen, water temperature, and other factors. We will hear more about these later.

Changes in Streamflow After Partial Cutting

Up to this point our discussion has been based on complete removal of forest vegetation for a portion (patch cut) or all of a drainage. Partial cutting which does not remove all of the forest at any one time would be expected to have a much reduced influence on the streamflow regime. It is doubtful if removal of 20 percent or less of the forest cover would result in a detectable change in streamflow. Rapid expansion of root systems and crowns of trees left after partial cutting or thinning would be expected to quickly reduce any changes in streamflow that did result from this type of logging.

Summary

We conclude that although timber harvest may influence the stream environment in a number of ways, evidence to date suggests that any modification in streamflow regime is probably generally beneficial to the fishery, at least on the west slope. More water flows in the streams all year long; major flood flows are apparently not markedly increased; minimum streamflow during dry summers is materially increased. In the majority of cases, changes in streamflow resulting from vegetation manipulation will probably be much less than the normal climatic variation.

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