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FOG DRIP, WATER YIELD, AND TIMBER HARVESTING IN THE BULL RUN MUNICIPAL WATERSHED, OREGON[1]

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ABSTRACT: Analysis of recent streamflow data from the Fox Creek Experimental Watersheds in the Bull Run Municipal Watershed, Oregon, indicates a significant recovery from the impacts on summer water yield due to a loss of fog drip upon timber harvesting. Measurable impacts and their associated recovery are notable only during the months of June and July. Recovery begins about five or six years following harvest, possibly due to renewed fog drip from prolific revegetation. Watershed positioning with respect to prevailing weather systems and the extent of burning or removal of slash and residual vegetation during logging appear to be important factors in predicting the impact of fog drip reduction associated with planned harvest. Apparently, once the temporary reduction in summer yield is offset by renewed fog drip, the expected increase in yield due to decreased evapotranspiration can be observed. Redistribution of fog drip may be a major factor in the measurements of local interception and water yield.

(KEY TERMS: fog interception; timber harvest; water yield.)

INTRODUCTION

In order to evaluate the effects of timber harvesting on the water resource in the Bull Run Watershed, the U.S. Forest Service and the City of Portland, Oregon, entered into a cooperative study in 1955. The initial objectives of the study were to determine impacts of timber harvest on 1) water yield and timing of runoff and 2) the quality of streamflow. To monitor these effects, the Pacific Northwest Forest and Range Experiment Station instrumented three small (146, 625, 175 acres) experimental watersheds on Fox Creek, in the Bull Run (Figure 1).

Between 1969 and 1971, after about 11 years of preactivity data collection, prescribed timber harvesting was conducted in two of the watersheds (WS1 and WS3). A road was constructed through WS1 and WS2 to gain access to WS3. Logging slash was burned after harvest in WS1, but not in WS3. The central and by far largest watershed (WS2) was selected to represent a control.

Analysis of summer streamflow data indicates significant decreases at WS1 following logging of clearcut patches totaling 25 percent of each watershed's area (Harr, 1980). This represents an apparent anomoly, since previous research associated with timber harvesting and water yield in the Northwest suggests increases are expected (Harr, 1979, 1983). Summer low flows are of particular importance in most municipal watersheds because of high water demand and storage depletion during the summer months.

The reduction in fog interception and drip has been hypothesized as a possible cause of the decrease in summer flows. The scenario for impact due to a reduction in fog drip is as follows. Large stands of old-growth forest intercept large quantities of moisture in the form of fog from the air. The amount of interception which then falls or flows to the ground as "precipitation" may be significant. Harvesting such a stand would eliminate a significant source of moisture, perhaps more than enough to offset the expected water yield gain from decreased evapotranspiration. A recent study conducted at Fox Creek has shown the importance of fog drip in the measurement of total precipitation (Harr, 1982). Previous studies have documented varying degrees of fog drip under different vegetative canopies along the Pacific Coast (Isaac, 1946; Azevedo and Morgan, 1974; Oberlander, 1956; Vogl, 1973).

Examination of recent data indicates that streamflow responses may be changing. The purpose of this paper is to present new analyses and explore how an extension of the fog drip hypothesis may well explain results of recent data analysis.

METHODS

To evaluate recent trends in streamflow, data from each watershed were summarized as total monthly flow in inches from mean daily records. The double mass plotting technique was used to visually examine streamflow responses for each month. Only data from months which demonstrated slope breaks in double mass plots (June and July) were further examined. Data were then condensed to represent total inches of flow at each watershed from June 1 to July 31. As a measure of hydrologic change, analysis of covariance was employed

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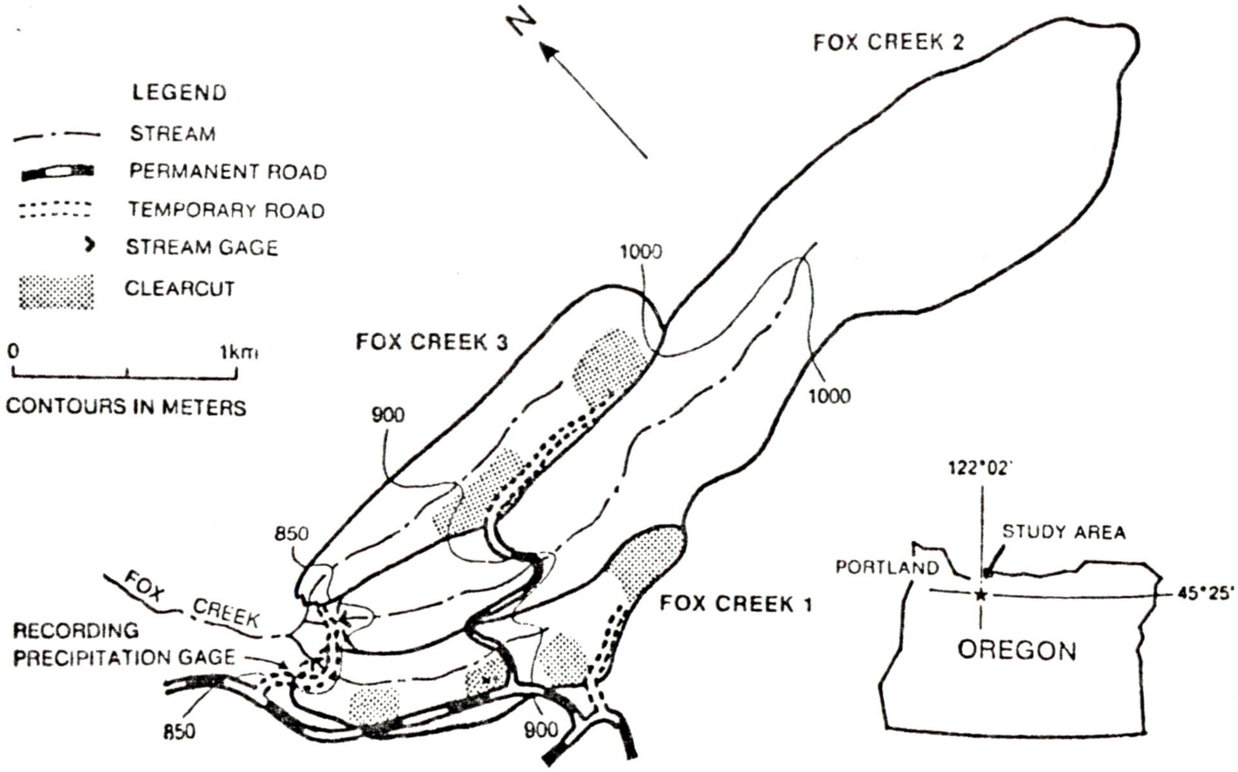

Figure 1. Fox Creek Experimental Watersheds, Oregon (after Harr, 1980).

to test for significance of differences between regression coefficients of different periods in paired basin relationships between the treated (WS1 and WS3) and control (WS2) watersheds.

RESULTS

Results indicate the response of decreasing streamflows after timber harvesting is detectable only in June and July. Also, it appears recovery begins after about five or six years. Examination of Figure 2 reveals that following harvest in 1969-1970, total June and July flows appear to have decreased for about five years at the treated watersheds. From about 1976 on, however, the total flow pattern appears to be similar to the pre-1970 pattern.

It is difficult to induce accurate results from the time series in Figure 2 due to the pronounced year-to-year variation. Examination of Figure 3, double mass curves of cumulative total June and July flows for WS1 and WS3, reveals a slope break in 1970 at WS1. This corresponds to decreases reported by Harr (1980). Of particular interest here, however, is the slope change beginning in 1975-1976. A small, seemingly temporary, shift is also seen in 1963. All responses at WS1 appear to be more dramatic than those observed at WS3, although both treated watersheds do exhibit the same general responses when compared against the control watershed.

Three periods are suggested by the double mass curves and are classified for the sake of discussion as pre-harvest (1958-1969), post-harvest (1970-1975), and recovery (1976-1983). Three sets of tests were performed to compare the periods: 1) pre-harvest was compared to the post-harvest period, 2) post-harvest was compared to the recovery period, and 3) the pre-harvest period was compared to the recovery period. To demonstrate the lack of response observed later in the summer, a plot of total flow at WS1 versus that observed at WS2 between August 1 and September 30, separated by the periods defined above, is presented in Figure 4. Plots representing total flow observed between June 1 and July 31 are shown in Figures 5 and 6 (WS1 vs. WS2, WS3 vs. WS2, respectively), and results of corresponding analyses of covariance are given in Table 1.

At both harvested watersheds, the regression coefficients with the control watershed were significantly different between the post-harvest and recovery periods. In both cases, water yield during the June-July period appears to be increasing.

Regression coefficients between the pre-harvest and post-harvest periods are significantly different (in the direction of decreasing flow) only at WS1. This, combined with the fact that no significant difference can yet be found between pre-harvest and recovery periods at WS1, suggests that the recovery period at WS1 has thus far merely offset impacts experienced during the post-harvest period.

An important result is that regression coefficients are significantly different between pre-harvest and recovery periods in the direction of increasing flow at WS3. Thus, the expected increase in water yield to harvesting of timber apparently is being realized at WS3.

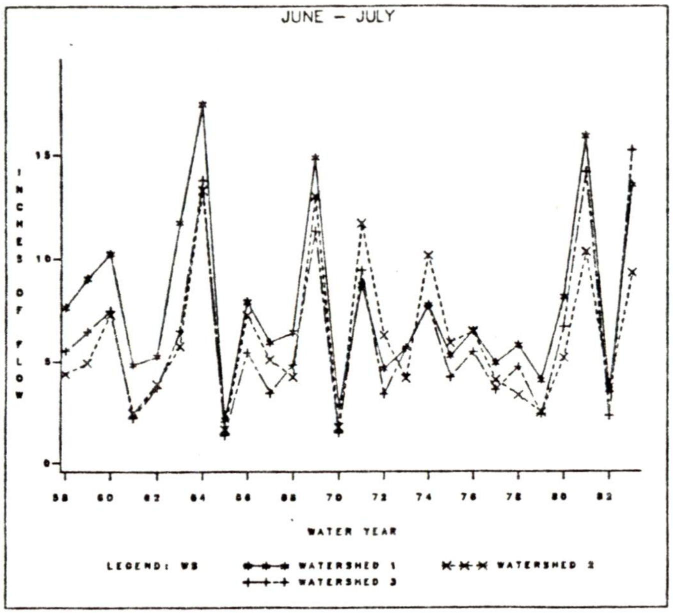

Figure 2. Total June 1-July 31 Flow at the Fox Creek Watersheds, 1958-1983.

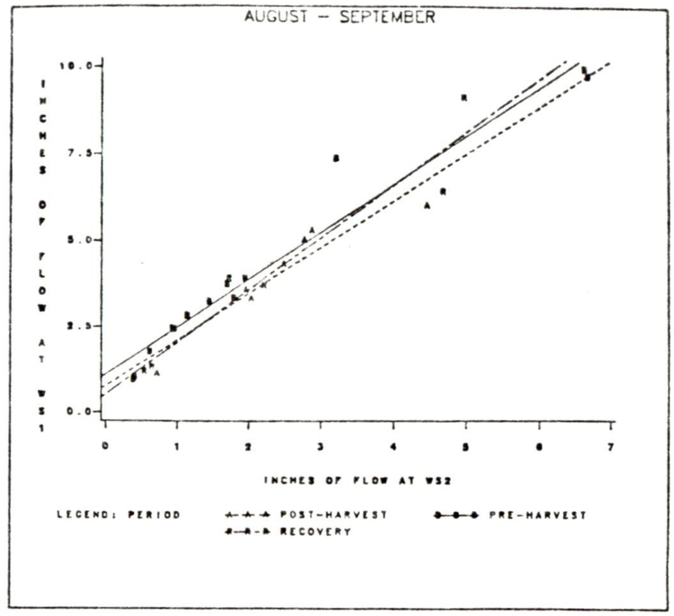

Figure 4. Relationship Between Total August 1-September 30 Flow at WS1 and WS2 for Each Harvest-Related Period.

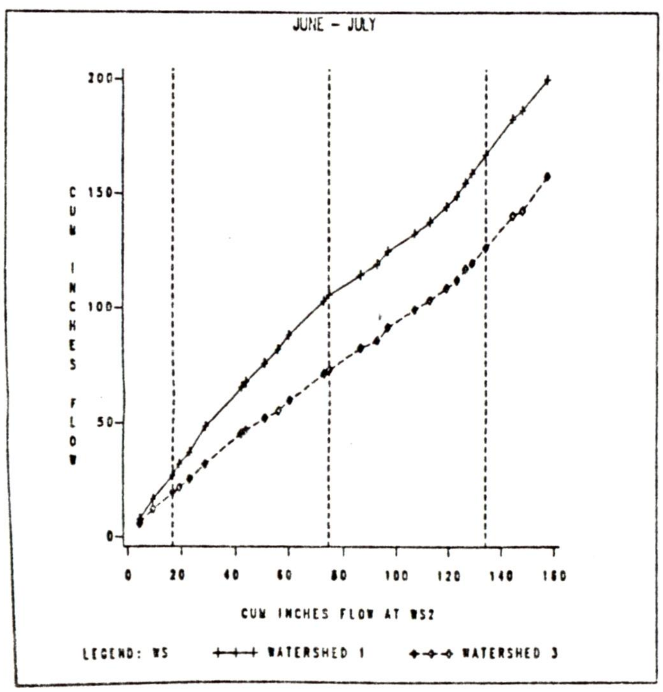

Figure 3. Cumulative June1-July 31 Flow at WS1 and WS3 versus WS2. Vertical dashed lines from left to right represent 1960, 1970, and 1980.

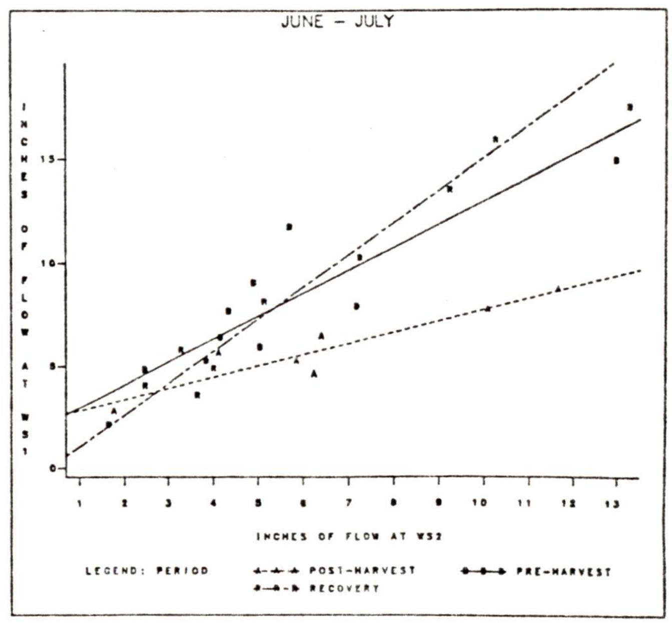

Figure 5. Relationship Between Total June 1-July 31 Flow at WS1 and WS2 for Each Harvest-Related Period.

DISCUSSION

Results from the analyses presented above raise three main questions:

1. If loss of fog drip upon harvesting caused a flow reduction (or no increase at WS3) during the post-harvest period, then what is causing a recovery after five or six years?

2. Why does data from only early summer indicate timber harvesting effects on low-flow?

3. Why does WS1 always appear to respond more dramatically than WS3?

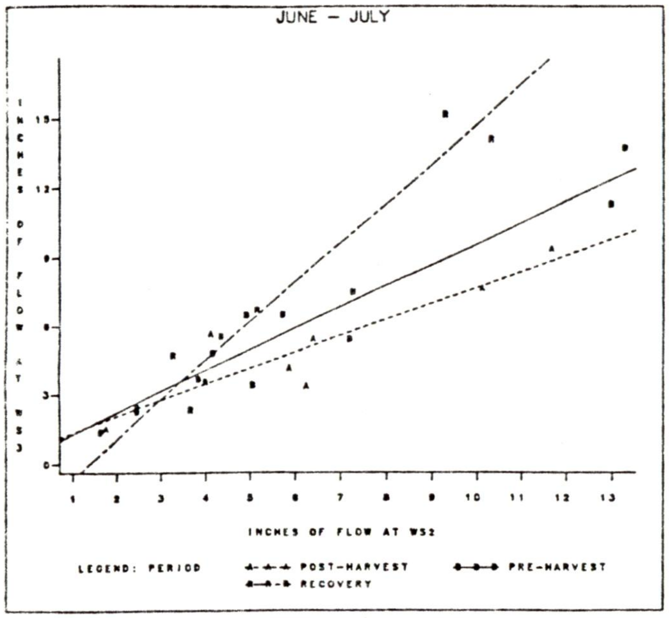

Figure 6. Relationship Between Total June 1-July 31 Flow at WS3 and WS2 for Each Harvest-Related Period.

TABLE 1. Results of Analysis of Covariance Between Different Periods of Paired Basin Relationships.

	+/–/0	Regression Slope	F	Probability of >F
		WATERSHED 1 VS. 2		
Pre-Harvest Post-Harvest	(–)	1.11 0.54	7.11	0.018
Post-Harvest Recovery	(+)	0.54 1.55	35.82	<0.001
Pre-Harvest Recovery	(0)	1.11 1.55	3.53	0.080
		WATERSHED 3 VS. 2		
Pre-Harvest Post-Harvest	(0)	0.93 0.71	1.64	0.220
Post-Harvest Recovery	(+)	0.71 1.72	17.95	0.002
Pre-Harvest Recovery	(+)	0.93 1.72	17.17	0.001

NOTE: Symbols for direction of change:
(–) Significant negative change relative to control.
(+) Significant positive change relative to control.
(0) No significant change.

In attempting to answer the first question concerning recovery, I offer the following scenario: during a pre-harvest condition, windblown fog passes across the tops of old-growth forest stands and a substantial amount is probably intercepted by only the top 10-20 percent of the trees. Throughfall of the intercepted water is subject to interception loss, but certainly (verified by frequent observation) some portion reaches the forest floor. Immediately after harvest, this source of "additional" precipitation is lost and results in a decrease in yield. Once the clearcut openings are created, however, windblown fog passes near or next to the ground in these openings, unlike in the previous forest. After five or six years of recovery, prolific vegetation reinhabits the clearcut and is usually made up of species with high foliar surface area. When fog encounters these trees, shrubs and herbaceous cover, they probably intercept significant amounts of water. Also, throughfall from this interception is not subject to reinterception loss and likely reaches the ground surface. Therefore, after five or six years in normal cases, the deficit created by a loss of fog drip is eliminated, and one would expect to see a slow increase due to the smaller amount of water which is consumed by the vegetation in clearcuts than that used by the former old-growth forest.

It is important to note that precipitation gages positioned above the shrub and young tree canopy in clearcut areas would not measure the fog drip which may be contributed by this vegetation. Since collection troughs were elevated to avoid deep winter snowpacks, this may have been a factor in Harr's (1982) measurements of precipitation in clearcut areas during 1980. He reported 41 mm less precipitation in clearcuts than in forests between June 3 and August 6. Standing alone, this would suggest continued loss of fog drip, but results presented here show 1980 to be well within the water yield recovery period.

In answer to the second question, that of early versus late summer response, an expansion of the above scenario follows. Any fog drip occurring during the winter and spring is probably hidden within the high precipitation and runoff variance of this period. During early summer, when flows begin to decrease consistently, precipitation keeps pace with evapotranspiration and most forest sites do not yet have a deficit in soil moisture storage. Any fog drip which occurs in early summer is more likely to become effective yield and be observed as streamflow. Also, the loss of such streamflow can be observed. As the summer progresses, however, a storage deficit likely develops, during which time any fog drip would contribute more to relieving the on-site deficit and less to streamflow. Ironically, after removing the old-growth stand, the point in time when a clearcut area reaches a deficit soil moisture storage condition may be delayed considerably each year. Therefore, after recovery begins, any renewed fog drip which occurs in the clearcut may contribute to yield, while that under the adjacent stand or previous forest with high evapotranspirational losses and deeper zones of unsaturated soil moisture would not.

The answer to the third question concerning differences between the treated watersheds is likely twofold. First, the

Clearcut areas in WS1 are on a ridge top adjacent a large area which was harvested in the 1960's. This makes the clearcuts in WS1 very open to windblown fog from the southwest (most systems approach the Cascades from the south and west). Unlike the clearcuts in WS1, those in WS3 are surrounded by old-growth stands, making them (and the original stand for that matter) much less accessible to windblown fog. Second, clearcut slash and considerably amounts of residual vegetation were not burned in WS3 and such material could generate fog drip from what fog encounters it immediately after harvesting.

A potentially complicating factor should be mentioned at this point, that of fog drip redistribution. It is possible that condensation not realized in WS1 due to clearcut harvesting is passed downwind to WS2, the control. This phenomenon would accentuate the apparent decrease at the treatment watershed WS1. It is also remotely possible that some portion of this moisture passes across WS2 into WS3, thereby reducing the apparent fog drip reductions in that treated watershed. Redistribution of fog drip from harvested areas southwest of WS1 may have been a factor causing inflections (apparent increases at WS1) in the double mass curve shown in Figure 3, particularly in about 1963. Five clearcut units totaling nearly 150 acres were harvested adjacent Fox Creek WS1 in 1962 and 1963.

In summary, one would expect streamflows in early summer to begin increasing at Fox Creek WS1, as have been observed at WS3. It stands to reason that in large basins, only small, insignificant increases can be noted; namely, hydrologic responses of clearcut areas offset one another initially with a five-to-six-year lag time, but eventually recover from a fog drip deficit and begin to exhibit the expected increase in yield. If fog drip redistribution plays an important role in a large watershed, then on-site decreases caused by loss of fog drip may be offset by increased fog drip downwind.

Based on recent analyses, it appears that further research is necessary at Fox Creek. Although the process-related explanations forwarded are speculative, they may provide a basis for future hypothesis testing.

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