WATER RESOURCES BULLETIN
VOL. 18, NO. 5 AMERICAN WATER RESOURCES ASSOCIATION OCTOBER 1982

FOG DRIP IN THE BULL RUN MUNICIPAL WATERSHED, OREGON[1]

R. Dennis Harr[2]

ABSTRACT: Net precipitation under old growth Douglas fir forest in the Bull Run Municipal Watershed (Portland, Oregon) totaled 1739 mm during a 40-week period, 387 mm more than in adjacent clearcut areas. Expressing data on a full water year basis and adjusting gross precipitation for losses due to rainfall interception suggest fog drip could have added 882 mm (35 in) of water to total precipitation during ayear when precipitation measured 2160 mm in a rain gage in a nearby clearing. Standard rain gages installed in open areas where fog is common may be collecting up to 30 percent less precipitation than would be collected in the forest. Long term forest management (i.e., timber harvest) in the watershed could reduce annual water yield and, more importantly, summer stream flow by reducing fog drip.
(KEY TERMS: precipitation; precipitation measurement; fog interception; water balance; stream flow; clearcut logging.)

INTRODUCTION

Analysis of stream flow data for the Fox Creek experimental watersheds, located on the Bull Run Municipal Watershed in the western Cascades about 40 km east of Portland, Oregon, indicated a small (< 20-mm) decrease in annual water yield from two 25 percent patch logged watersheds instead of the expected 100 to 150 mm increases in water yield (Harr, 1980). This is contrary to results of other studies in western Oregon in which increases in annual water yield from partially logged watersheds averaged 150-200 mm the first six years after logging (e.g., Rothacher, 1970; Harris, 1977; Harr, *et al.*, 1979). In addition, the number of low flow days, i.e., days with flow below an arbitrary base level, increased during many postlogging years at Fox Creek. This suggests summer flows have decreased following logging, a result also contrary to what has been found in the other studies in western Oregon. Usually, reduced evapotranspiration makes more water available for stream flow, both on an annual basis and during the summer low flow period.

Reduction of fog interception and drip was hypothesized as a possible cause of the lack of increase in annual yield and for the increases in number of low flow days at Fox Creek (Harr, 1980). Fog is common at the 840-1070 m elevation of the Fox Creek watersheds, and field crews have reported precipitation (fog drip) under the forest canopy in all seasons at times when no water was collected by a rain gage located in a clearing nearby. If the forest stands that were logged had contributed substantial amounts of fog drip to annual precipitation, then cutting these stands may have altered the amount of precipitation received by the watersheds, offsetting reductions in evaporative losses, thereby reducing net water yield. Because the Fox Creek watersheds are within the City of Portland's 227 km^2 Bull Run Municipal Watershed, decreases in net precipitation could impact annual and seasonal water yields and reduce municipal water supplies. This could be most important during low flow periods when a large percentage of the flow is retained in storage reservoirs.

Several studies of fog drip beneath trees along the Pacific Coast have measured fog or cloud interception and drip. In general, these studies have shown that the amount of drip is directly related to the area and density of the tree profile and to the degree of exposure of trees to windblown fog. On the Oregon coast, annual precipitation under the forest canopy was 520 mm (26 percent) greater than in the open (Isaac, 1946). During a 46-day rainless period during summer in coastal northern California, fog drip beneath 18 m tall Douglas fir trees ranged up to 425 mm (Azevedo and Morgan, 1974). In Hawaii, Ekern (1964) measured 760 mm of fog drip under a 9 m tall pine tree, a 20 percent greater annual precipitation than that measured in the open. Other fog drip measurements during rainless periods include 1524 mm and 52 mm beneath an exposed tanoak tree and a sheltered redwood tree, respectively, during the summer (Oberlander, 1956) and 57 mm per month beneath exposed knobcone pine in southern California (Vogl, 1973).

This exploratory study was done to determine if removal of forest vegetation could have decreased net precipitation (gross precipitation plug fog drip minus interception loss) at the Fox Creek watersheds and to determine if additional fog related research is warranted.

METHODS

A randomized block design with two replications was used to evaluate differences in net precipitation between forested and clearcut areas. Net precipitation was measured with a series of eight 24.4 m long collector troughs. Two troughs were randomly located in each of two logged areas (Figure 1) and

[1]Paper No. 82012 of the *Water Resources Bulletin.* Discussions are open until June 1, 1983.
[2]Principal Research Hydrologist, Forestry Sciences Laboratory, USDA Forest Service, Pacific Northwest Forest and Range Experiment Station, 3200 Jefferson Way, Corvallis, Oregon 97331.

one unlogged stand within Fox Creek watershed 1 and one unlogged stand just outside Fox Creek watershed 1. Overstory vegetation in the forested areas consisted of old growth Douglas fir (*Pseudotsuga menziesii* (Mirb.) Franco) and western hemlock (*Tsuga heterophylla* (Raf.) Sarg.), 46-55 m tall, mixed with younger Pacific silver fir (*Abies amabilis* (Dougl.) orbes). Canopy density of the forest ranges from 60 to 90 percent. The clearcut areas, which were logged in 1969, support primarily fireweed (*Epilobium angustifolium* L.), Alaska huckleberry (*Vaccinium alaskaense* How.), and numerous young Douglas fir trees, 1.0 to 2.5 m high.

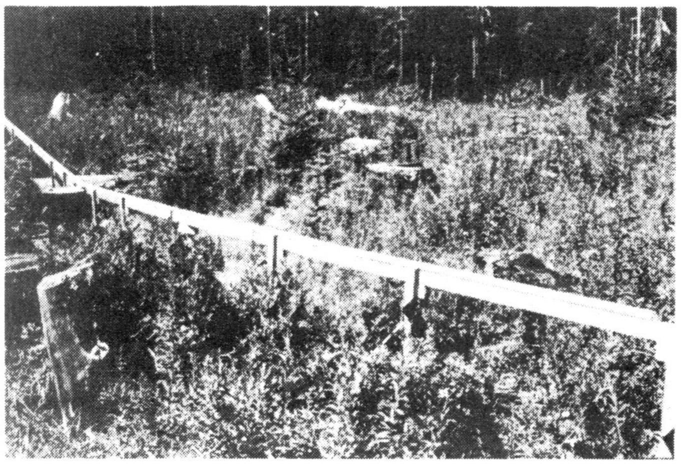

Figure 1. Precipitation Collector Trough and Storage Tank.

Collector troughs were constructed from 3.8 cm diameter polyvinyl chloride pipe with a 6 or 7 mm wide opening cut the full length of the pipe. The openings were cut off center to minimize splash out of the trough. Two 12.2 m trough sections drained (4 percent gradient) into a single, covered 200 liter tank. Total storage capacity of each tank was equal to approximately 1000 mm of net precipitation, about 25 percent more than the maximum three-week gross precipitation measured at Fox Creek in 18 years.

Net precipitation at each site was determined by measuring the distance between the tank cover and the water surface. The difference between successive measurements equaled depth of water collected since the last measurement was made. The area of opening of each collector trough was also measured. For troughs in the open, a 10 mm increment of water depth in the storage tank equaled 18 mm of net precipitation; for the forest plots, 10 mm of water depth equaled 16 mm of net precipitation. Measurements of net precipitation began in mid-September 1979 and continued until stopped by deep snow and freezing weather in mid-December. Measurements resumed in May 1980 and continued until mid-November 1980. No measurements were possible during winter and early spring because storage tanks were frozen and snow covered parts of several collector troughs.

RESULTS AND DISCUSSION

Over the 40 weeks of measurement, net precipitation under the forest totaled 1739 mm compared to 1352 mm in the clearcuts (Table 1). During the same period, 1388 mm of precipitation was measured in a standard rain gage in a clearing nearby. The greatest relative difference (44 percent) between forest and clearcut occurred in the late spring and summer. During the two fall seasons, differences between forest and clearcut were 22 and 18 percent.

Analysis of variance did not show a statistically significant difference in net precipitation between forested and clearcut areas. Still, these comparative data should be seriously considered for several reasons. First, they are supported by observations by field crews who have witnessed fog precipitation in the forest on numerous occasions when no rainfall occurred in the open. Secondly, mean net precipitation for the forest was greater than for clearcuts in 11 of 13 measurement periods. In each of the other two periods, the clearcut mean was the larger because of one exceptionally large and unexplained value that was 55 percent greater than the mean of four values in one case and 176 percent greater in the other case.

Although net precipitation measurements were not made during five months of winter and early spring, assessment of fog drip's contribution to precipitation over the entire 1980 water year has been attempted. For the 40 weeks of measurement, the difference in mean net precipitation between the forest and the clearcuts was about 30 percent (Table 1). This increase, however, results primarily from the relative differences in net precipitation between forest and clearcuts measured in late spring and summer and should not be extrapolated to an entire water year. The relative difference in net precipitation between forest and clearcuts in the winter was probably similar to those observed during the fall periods because fall and winter storms are similar. Thus, for the purposes of this analysis, net precipitation under forest in winter has been conservatively estimated at 17 percent more than in clearcuts. If net precipitation in the clearcuts is assumed to have been 963 mm or the same as that measured at the standard rain gage during the winter period, then precipitation under the forest would have been about 1130 mm (Table 2). Thus, for the 1980 water year, net precipitation under the forest and in the clearcuts would have totaled 2494 mm and 1996 mm, respectively, a difference of 498 mm or 25 percent. In other words, fog drip may have been sufficient to not only offset rainfall intercepted by the forest and evaporated but also to provide an additional 498 mm of water to the forest.

An estimate of the contribution of fog drip to gross annual precipitation can be made by applying precipitation throughfall relationships from Rothacher's (1963) study of interception by a similar old growth Douglas fir forest where fog is much less common (Table 3). For storms in the May-September period, throughfall = 0.831 x gross precipitation – 1.168 mm. During the rainy season, which corresponds to the fall and winter seasons of this study, throughfall in Rothacher's study averaged 86 percent of gross precipitation. Adjusting measured fall and spring-summer catch data and estimated winter data for the clearcuts yields 498 mm, 828 mm, and 286 mm for

TABLE 1. Measured Precipitation in Forest and Clearcuts.

Season	Measurement Date	Length of Collection Interval (days)	Net Precipitation: Forest Mean (mm)	Forest Standard Error (mm)	Clearcut Mean (mm)	Clearcut Standard Error (mm)
Fall	10-17-79	29	104	12	72	18
	11-08-79	21	202	30	222	40
	11-28-79	20	117	8	102	21
	12-18-79	20	284	27	182	59
	TOTAL	90	707		578	
Spring/Summer	06-03-80	19	273	37	154	22
	06-24-80	21	109	13	96	16
	07-16-80	22	76	22	78	47
	08-06-80	21	45	7	15	5
	08-26-80	20	25	5	10	6
	09-17-80	22	129	30	102	16
	TOTAL	125	657		455	
Fall	10-07-80	20	130	15	94	9
	10-30-80	23	47	10	45	12
	11-18-80	19	198	31	180	45
	TOTAL	62	375		319	
40-Week Total			1739		1352	

TABLE 2. Net Precipitation Under Forest and in Clearcuts for 1980 Water Year.

Season	Forest (mm)	Clearcuts (mm)
Fall 1979	707	578
Winter 1979-80	1130*	963*
Spring/Summer 1980	657	455
Water Year	2494	1996

*Estimated from standard rain gage data.

TABLE 3. Predicted and Measured Net Precipitation Under Forest for 1980 Water Year.

Season	Precipitation Under Forest: Predicted (mm)	Measured (mm)
Fall 1979	498[b]	707
Winter 1979-80	828[a,b]	1130[a]
Spring/Summer 1980	286[b]	657
Water Year	1612	2494

[a]Estimated from standard rain gage data.

[b]Obtained by adjusting clearcut catch data for rainfall interception loss (Rothacher, 1963).

those respective seasons – a total of 1612 mm. In other words, in the absence of fog drip, the troughs under the forest canopy would have collected throughfall totaling 1612 mm. The difference between 1612 mm and 2494 mm described in the preceding paragraph most likely would be fog drip. That is, fog drip would have accounted for 882 mm of precipitation under the forest canopy during the entire October 1-September 30 water year.

Explanation of Stream Flow Anomalies

Results of the fog drip study appear to explain several anomalous results of the Fox Creek stream flow study described earlier (Harr, 1980). At the rain gage in a clearing near the outlet of watershed 1, annual precipitation averaged 2880 mm during an 11-year prelogging period, during which time annual water yield averaged 94 percent of annual precipitation. This percentage is much higher than those observed elsewhere within the same general climatic and vegetation zones as the Fox Creek watersheds and allows only about 150 mm for annual evapotranspiration. This is approximately only a sixth of estimated evapotranspiration and interception at Fox Creek (Luchin, 1973). In the Douglas fir region of western Oregon, average annual water yield has ranged from 51 to 78 percent of average annual precipitation (Rothacher, *et al.*, 1967; Fredriksen, 1972; Harris, 1977; Harr, *et al.*, 1979). If the figure for average annual precipitation at Fox Creek of 2880 mm is supplemented by the estimate of fog drip's contribution to precipitation described here, then annual precipitation would have averaged 3762 mm during the 11 prelogging years. Water yield would have averaged 72 percent of annual precipitation, a percentage more in line with those of other studies.

A second apparent anomaly in the Fox Creek stream flow study can be explained by results of this fog drip study. Harr (1980) reported slight decreases in annual water yield from small watersheds after logging in clearcut patches totaling 25 percent of watershed area instead of the expected 100 to 150 mm increases suggested by results from other similar studies in western Oregon (Rothacher, 1970; Harris, 1977; Harr, *et al.*, 1979; Harr, *et al.*, 1981). If the logged watersheds had received 3770 mm of precipitation from rain, snow, and fog drip instead of the 2880 mm of rain and snow measured in the rain gage in a clearing, precipitation amounts could have been altered by logging. After logging, average annual precipitation would have been (3762 x 0.75) + (2880 x 0.25) = 3542 mm, a reduction of 220 mm. Thus, the expected increase in annual water yield that should have been derived from reduced evapotranspiration on logged areas could have been more than offset by reduced fog interception and drip.

A similar argument can be made to explain the decrease in summer stream flow indicated by increased number of low flow days after logging (Harr, 1980). Fog drip accounted for about a third of all precipitation received during the May-September period (Table 1). Eliminating this third of precipitation could have more than offset any increases in summer stream flow that would have resulted from sharply reduced transpiration in clearcut areas.

Results of this fog drip study can also help explain a discrepancy in an analysis of water yield from the Bull Run Watershed. Using a water balance approach, Luchin (1973) found that annual water yield was 460 mm greater than predicted by his water balance analysis. This discrepancy was finally attributed to computational errors and to the seepage of ground water into the Bull Run MWatershed from adjacent basins. If 882 mm of fog drip on only half of the Bull Run Watershed at elevations above those of the Fox Creek watersheds is included in Luchin's water balance, Luchin's 460-mm discrepancy in annual water yield disappears.

Forest Management and Fog Drip

Results of this fog drip study, when used to explain results of the Fox Creek stream flow, indicate that timber harvest conducted as part of the long term management of the Bull Run Municipal Watershed could reduce the quantity of stream flow, particularly during the summer. A preliminary analysis, based on results of this study and on management still being planned (Glenn McDonald, Columbia Gorge District, Mt. Hood National Forest, personal communication, March 5, 1981), suggests a maximum reduction in annual water yield of 220 mm or about 9 percent if comparable fog drip occurs over the entire Bull Run Watershed.

Accurate assessment of the effects of timber harvest on annual and seasonal water yields will depend not only on the long term management plan finally implemented but also on the nature of fog drip itself. Additional information is needed to determine (1) the areal distribution of fog drip throughout the Bull Run Watershed, (2) whether reduced fog drip in a clearcut is at least partially offset by increased fog drip in an adjacent stand downwind, (3) at what age a newly established forest begins to intercept substantial amounts of fog once again, and (4) if there is a reliable relationship between annual precipitation and annual fog drip.

SUMMARY

(1) Net precipitation under forest totaled 1739 m during a 40-week period, 387 mm more than in adjacent clearcut areas.

(2) Expressing data on a full water year basis and adjusting precipitation data for losses caused by rainfall interception suggest fog drip added 882 mm of water to gross precipitation when rain gage catch in a clearing nearby totaled 2160 mm.

(3) Fog drip eliminated by removal of trees during logging appears to explain why expected increases in postlogging annual water yield were not observed and why summer stream flow decreased after logging.

(4) Additional information about fog drip is needed before the effects of long term forest management on water yields can be accurately assessed.

ACKNOWLEDGMENTS

The assistance of Al Levno, George Lienkaemper, Roswell Mersereau, and Don Henshaw in this study is gratefully acknowledged.

LITERATURE CITED

Azevedo, J. and D. L. Morgan, 1974. Fog Precipitation in Coastal California Forests. Ecology 55:1135-1141.

Ekern, Paul C., 1964. Direct Interception of Cloud Water on Lanaihale, Hawaii. Soil Science Society of America Proceedings 28(3):419-421.

Fredriksen, R. L., 1972. Nutrient Budget of a Douglas-Fir Forest on an Experimental Watershed in Western Oregon. *In:* Proceedings, Research on Coniferous Forest Ecosystems – A Symposium, Jerry F. Franklin, L. J. Dempster, and Richard H. Waring (Editors). USDA Forest Service, Pacific Northwest Forest and Range Experiment Station, Portland, Oregon, pp. 115-131.

Harr, R. Dennis, 1980. Streamflow After Patch Logging in Small Drainages Within the Bull Run Municipal Watershed, Oregon. USDA Forest Service Research Paper PNW-268, 16 pp., illus. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

Harr, R. Dennis, Richard L. Fredriksen, and Jack Rothacher, 1979. Changes in Streamflow Following Timber Harvest in Southwestern Oregon. USDA Forest Service Research Paper PNW-249, 22 pp. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

Harr, R. Dennis, Alfred Levno, and Roswell Mersereau, 1982. Changes in Streamflow After Logging 130-Year-Old Douglas-Fir in Two Small Watersheds in Western Oregon. Water Resources Research 18(3): 637-644.

Harris, D. D., 1977. Hydrologic Changes After Logging in Two Small Oregon Coastal Watersheds. U.S. Department of Interior Geological Survey Water Supply Paper 2037, 31 pp.

Isaac, Leo A., 1946. Fog Drip and Rain Interception in Coastal Forests. USDA Forest Service Research Note No. 34, pp. 15-16. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

Luchin, Luciano V., 1973. High Yield From the Bull Run Watershed. Journal of American Water Works Association 65:183-186.

Oberlander, G. T., 1956. Summer Fog Precipitation on the San Francisco Peninsula. Ecology 37:851-852.

Rothacher, Jack, 1963. Net Precipitation Under a Douglas-Fir Forest. Forest Science 9(4):423-429.

Rothacher, Jack, 1970. Increases in Water Yield Following Clear-Cut Logging in the Pacific Northwest. Water Resources Research 6(2): 653-658.

Rothacher, J., C. T. Dyrness, and R. L. Fredriksen, 1967. Hydrologic and Related Characteristics of Three Small Watersheds in the Oregon Cascades. USDA Forest Service, Pacific Northwest Forest and Range Experiment Station, Portland, Oregon, 54 pp.

Vogl, R. L., 1973. Ecology of Knobcone Pine in the Santa Ana Mountains, California. Ecological Monographs 43:125-143.