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Net Precipitation under a Douglas-Fir Forest

BY
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Abstract. Under dense stands of old-growth Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) and associated species typical of Douglas-fir forests of western Oregon and Washington, throughfall averaged 76 percent of gross summer precipitation. Throughfall varied with storm size from near 0 percent in storms under 0.05 inch to about 82 percent in storms over 3 inches. Density of old-growth stands, which ranged from 75 percent to 92 percent, had some influence on interception. However, since estimates of density are not generally available, a relationship based on storm size was determined to be more useful. A linear relation, which fits the data best, explained 96 percent of the variation in throughfall in summer months. Throughfall in winter months increased to an average of about 86.3 percent. A precise relationship with storm size was not determined, but in storms producing 8 inches or more gross precipitation, throughfall was estimated to approach 96 percent. Stemflow was relatively unimportant for nearly all species. Weighted average stemflow measured in the 1959-60 water year was only slightly more than 0.27 percent of the total precipitation.

MATURE Douglas-fir forests of the Pacific Northwest grow in a relatively high rainfall zone and produce a dense crown canopy. Interception by this vegetative cover appreciably reduces rainfall that reaches the soil surface. Using terminology suggested by Hamilton and Rowe (1949, p. 6, 7),[1] this study reports throughfall in summer and winter, determines how throughfall is influenced by storm size, and assesses the importance of stemflow as a factor in net precipitation.

Although many interception studies have been made in other areas, few studies of net precipitation in the Douglas-fir region have been reported. Simson (1931, p. 7) measured summer storms in both old growth and second growth but made no estimate of stemflow. McMinn (1957) measured interception in a series of vegetation associations as a part of his study of water relations on Douglas-fir on Vancouver Island, B.C., and Chowdappa[2] studied interception by individual trees of several species. None of these investigators has specifically studied the variation of net precipitation with storm size.

Data for the study reported here were collected on the H. J. Andrews Experimental Forest (Berntsen 1959), an area representative of the old-growth Douglas-fir forest on the west slopes of the Cascade Range in Oregon. The experimental forest, about 40 miles east of Eugene, Oregon, includes the entire drainage of Lookout Creek, a tributary of the McKenzie River. Climate is maritime; summers are dry and

[1]Net precipitation is the quantity which actually reaches the ground. It is the sum of throughfall and stemflow.

[2]Chowdappa, Papanna. A study of interception, stemflow, and litterfall in some plantations in Pack Forest. MSF thesis, Univ. of Wash., 1960.

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warm and winters wet with mild temperatures. At elevations below 3,500 feet, snow is generally short-lived with most precipitation falling as rain. Annual precipitation averages 92 inches at 1,500-foot elevation with about 14 percent normally falling between May and September.

Six study plots were randomly chosen adjacent to existing clear-cut areas at elevations from 1,600 to 3,500 feet. Precipitation was modified only slightly by elevation. Characteristics of the forest cover on these plots are shown in Table 1. Timber is predominantly old-growth Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) mixed with western hemlock (*Tsuga heterophylla* (Raf.) Sarg.), western redcedar (*Thuja plicata* Donn), and true firs (*Abies grandis* (Dougl.) Lindl., *Abies amabilis* (Dougl.) Forbes, *Abies procera* Redh.) in the overstory. In addition to young trees, the understory was primarily rhododendron (*Rhododendron macrophyllum* D. Don), vine maple (*Acer circinatum* Pursh), golden chinkapin (*Castanopsis chrysophylla* (Dougl.) A. DC.) and Pacific yew (*Taxus brevifolia* Nutt.). All except plot 5 were covered with old-growth Douglas-fir stands in which the larger trees were over 300 years old, up to 5 feet in diameter, and 200 feet in height. Plot 5 was in a younger stand of Douglas-fir with a few scattered old-growth trees, survivors of an old fire. This younger stand was approximately 100 years old and averaged 160 feet in height. Volume removed from adjacent clearcuts ranged from 42,000 to 96,000 board feet per acre. Crown density was high, averaging 75 percent or more.

Throughfall was measured in the six plots, all of which were identical in arrangement and size (5 acres). Four standard rain gages were randomly located in each plot. These were moved after each storm in accordance with the system of roving gages suggested by Wilm (1943). "Storms" are described as periods of precipitation separated by intervals during which the foliage dries. A total of 40 locations was sampled on each of the 6 plots during the study period.

Gross precipitation was measured in clearcuts as near as possible to each of the six throughfall plots. Gages in the open and under the timber were all read at the same time and as soon as practicable after a storm to prevent evaporation loss.

Storms were relatively easily defined during the summer months (May through September). A statistical relationship of throughfall by storm size was established only for this period, which coincided essentially with the time deciduous vegetation was in leaf. Although the overstory was predominantly evergreen coniferous species, deciduous vegetation, principally vine maple, made up a considerable portion of the understory vegetation.

During winter rains, intervals between storms when foliage dried completely were infrequent and difficult to determine. Because of limited access to many areas, only plot 1 was operated throughout the winter. Data for the winter season (October through April) are based only on this plot.

Stemflow was also measured in plot 1. Aluminum collars were fitted around 10 trees ranging in diameter from 11 to 46 inches. Voigt (1960) pointed out that stemflow dripped from rough bark and fell in a diffuse pattern around the base of the tree. A narrow stemflow collar caught less of this drip than a wide one. In our study a narrow collar, less than 1 inch wide, was used to limit the catch to water flowing down the stem. Drip from the rough bark was proportionately sampled by the roving gages as a part of throughfall.

Stemflow is Negligible

Early in our study, observations indicated that stemflow from rough-barked old-growth Douglas-fir and hemlock was relatively minor. This is in contrast to some studies in which stemflow appreciably increased net precipitation.

All stemflow data were converted to their equivalent in inches depth on the

TABLE 1. *Characteristics of throughfall plots, H. J. Andrews Experimental Forest.*

Plot	Aspect	Elevation	Precipitation Total for 23 summers storms	Average crown density and range	Volume[1] per acre	Diameter range by species	Trees over 2 inches dbh (per acre) Basal area	Trees over 2 inches dbh (per acre) stems	Remarks
		Feet	*Inches*	*Percent*	*M bd. ft.*	*Inches*	*Sq. ft.*	*Number*	
1	NW	1,600	17.35	89.4 (72-100)	91	Douglas-fir, 20-60 Western hemlock, 2-42	361	224	Old-growth Douglas-fir with hemlock understory; open ground cover.
2	SE	2,100	17.39	92.3 (59-100)	42	Douglas-fir, 2-56 Western hemlock, 2-24 Western redcedar, 2-22	288	338	Decadent stand; much young timber and underbrush.
3	SW	2,700	18.58	81.4 (51-100)	96	Douglas-fir, 20-62 Western hemlock, 2-40	508	178	Old-growth Douglas-fir with scattered hemlock understory; open ground cover.
4	W	2,900	19.76	75.2 (53-88)	70	Douglas-fir, 26-62 Western hemlock, 2-36 Western redcedar, 2-68	409	169	Decadent stand; dense understory; open ground cover.
5	S	3,500	18.00	86.1 (58-100)	57	Douglas-fir, 2-60 Western hemlock, 2-8	341	364	Young stand with few old-growth Douglas-fir; vine maple understory.
6	S	3,300	19.20	91.0 (65-100)	50	Douglas-fir, 12-72 Western hemlock, 2-40 Western redcedar and others, 2-34	395	486	Decadent, scattered, large Douglas-fir with dense reproduction and underbrush.

[1]Estimate based on net volume removed from adjacent clearcut.

TABLE 2. Stemflow for period October 1, 1959, to September 30, 1960.

Number and species of sample tree		Diameter (inches)	Percent of basal area sampled	Stemflow in percent of throughfall[1]		
				Annual	Winter	Summer
1	Douglas-fir	41	21.3	56.5	64.1	24.5
2	Western hemlock	15	3.0	103.3	109.0	77.1
3	Yew	11	1.5	362.0	381.9	270.9
4	Western hemlock	12	1.7	109.5	124.8	39.0
5	Douglas-fir	46	26.6	13.9	15.7	5.9
6	Western hemlock	36	16.7	8.6	10.0	2.3
7	Western hemlock	23	6.7	65.9	77.6	12.0
8	Douglas-fir	27	9.4	52.8	61.1	14.9
9	Western hemlock	15	2.7	125.9	146.2	32.6
10	Western hemlock	28	10.4	23.3	26.8	7.1
	Weighted average	—	—	42.8	48.3	18.0

[1] Volume of water caught by stemflow gages divided by volume of water that would have been caught by a rain gage with diameter equal to that of the sample tree.

basal area of the tree measured, since the collar gage would, in effect, be a rain gage with a diameter equal to that of the tree. This conversion permits direct comparison of water measured as stemflow with that measured as throughfall.

Stemflow data for the water year from October 1, 1959, to September 30, 1960, are summarized in Table 2. Total precipitation during this period was 83.9 inches. Of this, 65.6 inches were measured as throughfall. Average stemflow accumulated from the 10 sample trees equaled only 42 percent of the annual throughfall that would have been received on the area occupied by the tree stem. In winter, stemflow was equivalent to 48.3 percent of 53.9 inches of throughfall; in summer, it was 18.0 percent of 11.7 inches.

As found by Voigt, stemflow varied greatly by tree species. During the summer, stemflow from all species started after about 0.4 inch of rain; during the winter, after 0.25 inch. On the Douglas-fir and large hemlock sample trees, maximum winter stemflow was 120 to 150 percent of throughfall, and on small hemlock it reached 270 percent. In summer, maximum stemflow on small hemlock sample trees was 150 percent, but never exceeded 50 percent on the Douglas-fir.

Among the trees sampled, only yew, a minor stand component, and small hemlock consistently yielded more stemflow than would have been caught in a rain gage equal to the stem diameter. The one 11-inch yew tree sampled (number 3) showed the influence of smooth bark pointed out by Voigt. The equivalent depth of stemflow for this tree averaged 360 percent of throughfall for the 1959-60 water year, with maximum ranging from 450 percent in summer to 535 percent in winter. In contrast, stemflow on a 36-inch hemlock (number 6) with a pronounced lean was only about 9 percent of the annual throughfall. Undersides of leaning trees have been observed to remain dry even after long periods of rain.

On an annual basis, only the four smallest trees, representing 8.9 percent of the basal area sampled, produced stemflow that exceeded throughfall (100 percent) on an equivalent area (Table 2).

Average stemflow per square foot of basal area weighted by stem area of the individual sampled trees was 28.14 inches compared to 65.64 inches of throughfall for the period October 1, 1959, to September 30, 1960. Basal area of trees over 2 inches d.b.h. in the area sampled totaled 361 square feet, or 0.83 percent of an acre. Stemflow on this portion of an acre is equivalent to 0.23-inch depth or 0.27 percent of gross precipitation over an entire acre. Throughfall measured on the re-

TABLE 3. Average throughfall for summer months, by plots.[1]

Plot	1957-58		1959		Total precipitation measurements	Average throughfall	Range of throughfall
	Precipitation measurements[2]	Throughfall	Precipitation measurements	Throughfall			
	Number	*Percent*	*Number*	*Percent*	*Number*	*Percent*	*Percent*
1	29	75.9	21	65.7	50	70.8	0-106.9
2	26	65.9	21	73.3	47	69.6	0- 96.1
3	28	85.5	21	78.5	49	82.0	0- 99.7
4	25	69.0	21	87.8	46	78.4	0-123.4
5	21	70.9	21	84.2	42	77.6	0-112.6
6	20	74.3	21	80.4	41	77.4	0-106.6
Average	—	73.6	—	78.3	—	76.0	—

[1]May through September. [2]Includes some rainy periods which were not isolated storms, but two or three closely spaced rains with partial drying between.

maining 99.17 percent of the acre equals 65.10 inches when adjusted to an acre basis. The combined total of 65.33 inches is slightly less than that indicated by throughfall gages alone. From these results, stemflow appears to have a negligible influence on net precipitation and is not considered further in the following discussion of throughfall.

Summer Throughfall

Throughfall for all recorded summer precipitation in 1957-58[3] and 1959 is shown by plots in Table 3. Average throughfall for plots and years varied considerably, but an analysis of variance showed that the variations among plots and between years was not significantly greater than that attributed to chance. Combining all data for the summer period, average throughfall was 76.0 percent. This figure, however, is of only general utility since it is subject to extreme variation associated with point sampling and to variation in distribution of storm sizes. As shown in Table 3, percent throughfall for all plots, ranged from 0 in small storms to over 100 percent in larger storms when gages, located by chance under drip from branches, caught more than gross precipitation.

Two factors were found to be associated with variations in summer throughfall shown in Table 3. These were crown density and storm size. Since rainfall in this area is typically gentle with rates over 0.3 inch per hour the exception, the relation of throughfall to storm intensity was not analyzed.

Crown Density is Related to Throughfall

Several criteria of crown density were investigated in an effort to arrive at a readily available measure. Volume and basal area poorly describe intercepting crown cover in old-growth defective stands because canopy development tends to remain static after trees reach maturity. These were abandoned in favor of direct estimates.[4]

To investigate the influence of density, 23 summer storms were chosen which were easily identified as single storms and for which we had complete data for all six plots. Density, estimated at each rain gage location, ranged from 50 to 100 percent. Because there was considerable overlap of canopy measured above gage locations, all density measurements were averaged by plots. Table 1 shows a range from 75 to 92 percent for the six plots. A linear regression relating average throughfall to average density for the six plots has a cor-

[3]Since 1957 was only a partial season, data from both 1957 and 1958 were combined.

[4]Density measured with a spherical densiometer (Lemmon 1956) was adjusted to photograph closure measured with a pinhole camera, using curves developed by R. Madison at Cascade Head Experimental Forest (unpublished data).

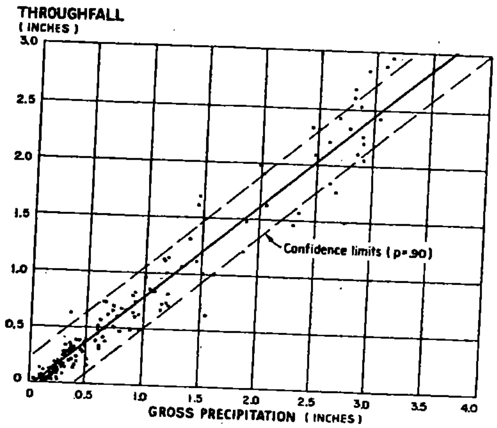

FIGURE 1. *Relation of throughfall to storm size. Summer season, May-September.*

relation coefficient of 0.87. Kittredge (1948, p. 109) has suggested that this relationship may not be linear. While there is some indication of a curvilinear function, six points with a limited range in density do not provide sufficient data to warrant assumptions of a curvilinear relationship for this study.

Storm Size Highly Correlated with Throughfall

Storms occurred at an average rate of 21 per summer season and produced gross precipitation in amounts ranging from a trace to almost 3 inches. Not all precipitation measured in the six plots during the summer season could be segregated into individual storms. The total number of single storms measured varied from 24 to 32 for individual plots.

Storm size was found to be one of the most important factors influencing the variation in throughfall shown in Table 2. For each of the six plots, a linear regression analysis was made, relating gross precipitation and throughfall and using all available plot data for isolated storms. In all cases, regression coefficients were highly significant, but slopes varied from 0.7442 to 0.9050, differences which proved significant when tested in covariance analysis.

One of the study objectives was to find a relationship between throughfall and storm size that could be readily applied to local precipitation data. Since throughfall for individual plots was significantly correlated with storm size, the common regression—weighted average regression line for all six plots—was chosen as the most useful predicting equation.

$$\text{Throughfall} = 0.8311 \text{ (gross precip.)} - 0.0460$$

The correlation coefficient of 0.98 for this equation indicates that storm size accounts for 96 percent of the variation in throughfall. The estimating equation is depicted graphically in Figure 1, which also shows the 90-percent confidence limits.

Throughfall is plotted as a percent of gross precipitation in Figure 2. This curve illustrates that practically no precipitation penetrates the crown until approximately 0.05 inch of rain has fallen. The tail of the curve shows that during the heaviest summer rains about 82 percent of total precipitation reaches the soil surface.

Winter Throughfall Approaches Gross Precipitation

During winter (October through April), many storms occur as continuous rainy periods of several weeks' duration and result in substantially increased throughfall. Exceptions to this general pattern can occur, however, when storms are separated

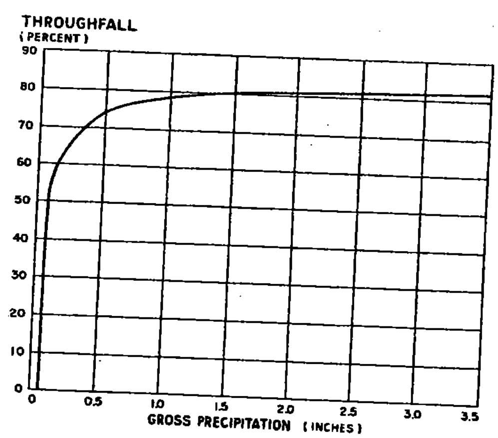

FIGURE 2. *Percent throughfall by storm size.*

by drying periods, causing a reduction in throughfall to proportions generally found during summer periods.

Winter throughfall data were limited to three seasons on plot 1. An average of 86.3 percent of total winter precipitation was throughfall, 10 percent more than the average in summer.

During winter rains, interstorm periods sufficiently long to allow complete drying of foliage were infrequent and difficult to determine. Because most winter storms could not be distinctly separated, it was not possible to develop a precise relation between throughfall and storm size as was done with summer storms. Periods of heavy precipitation which could be identified were grouped by precipitation classes. The resulting relation between gross precipitation and throughfall proved quite variable, a fact which can be attributed to the characteristics of typical winter storms. Precipitation during identifiable storm periods was not in all cases continuous, but was interspersed at times with short intervals during which there was some partial drying. Since the length and number of these drying periods is unknown, throughfall is not as well correlated with winter storm sizes as it is with neatly isolated summer storms.

Following is a tabulation of throughfall by 2-inch precipitation classes during the November-through-March period when high rainfall and runoff are expected:

Precipitation class (*Inches*)	*Storms* (*Number*)	*Average throughfall* (*Percent*)
2 - 4	5	88.4
4 - 6	4	92.9
6 - 8	6	88.4
8 and over	4	95.7

In three out of the four storms which exceeded 8 inches, precipitation under the timber nearly equaled or exceeded amounts received in the open, resulting in a relatively large catch of throughfall averaging 95.7 percent. No correction has been made for stemflow. Although winter average stemflow was less than that of throughfall, it is probable that, were data available for these individual storms, we would find stemflow increasing net precipitation slightly. In the dormant winter season, normal diversion of water to satisfy evaporation, transpiration, and soil storage is at a low ebb. Water moves quickly through the soil mantle and into the streams so that volumes of water discharged from forested watersheds during heavy winter storms can very nearly equal gross precipitation.

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