P1.1 RAINFALL INTERCEPTION IN YOUNG AND MATURE CONIFER FORESTS IN BRITISH COLUMBIA

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1. INTRODUCTION

Numerous studies, e.g., Zinke (1967), Ford and Deans (1978), Crockford and Richardson (1990), Calder (1990), have shown that in coniferous forests up to 25% of the annual rainfall does not reach the ground. The fraction of the rain intercepted depends on storm size, intensity, duration and weather conditions. Interception loss increases with an increase in leaf area of the stand (Plamondon et al., 1984; Giles et al., 1985). Harvesting of trees results in a reduction in the interception of precipitation, fog drip and plant transpiration, and an increase in the rate of snow melt. This could result in water-logged soils, decreased slope stability, erosion of roads and streams banks, and disturbance of fish habitat and potable water supplies (Hetherington, 1987). Procedures to assess the effects of forest harvesting on a watershed assume that increasing the harvested area increases the potential and magnitude of hydrologic impacts, and that these impacts decline as the forest regrows.

Rainfall interception studies in British Columbia (BC) have measured only throughfall in mature forest on a weekly to monthly basis (Giles et al. 1985; Beaudry and Sagar 1995). The present study was initiated to obtain data on a storm by storm and within storm basis to provide information to refine procedures for assessing the impact of harvesting on watersheds. Rainfall interception as a function of storm size is presented for young and mature forests in a coastal environment, and mature forests in the interior of BC.

2. METHODS

Forests were monitored at three locations (Table 1). Each location had solar radiation, air temperature and humidity, rainfall, wind speed and wind direction measured above the canopy or in a nearby large opening. Five throughfall and five stemflow units, and air temperature and humidity sensors were below the canopy. Dataloggers (Campbell Scientific Inc. (CSI) 21X and CR10) with pulse multiplexers (CSI SDM-SW8A) monitored the weather, and the throughfall

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TABLE 1. Site characteristics. The Carnation Creek site, on the west coast of BC (48°54'N, 125°00'W), had a young Sitka spruce, western redcedar and hemlock forest at 5 m elevation, and a mature western hemlock forest at 450 m. The two young Douglas-fir forests were at the Cowichan Lake Research Station (48°50'N, 124°08'W) at 175 m. Upper Penticton Creek (49°38'N, 119°3'W) had mature lodgepole pine and mature Engelmann spruce-subalpine fir forests at 1650 m.

Forest	Height m	Density stems ha^{-1}	Cover %
Hemlock	30 to 40	480	85
Spruce	6 to 10	1500	75
D.-Fir #1	14 to 16	1050	85
D.-Fir #2	12 to 15	1090	70
Pine	22 to 26	720	40
Spruce/fir	20 to 24	1470	45

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and stemflow systems. All rain gauges (0.25 mm resolution) were calibrated on-site to ±0.005 mm/tip using a burette.

The system for measuring throughfall is similar to that described in Crockford and Richardson (1990). Throughfall was collected by stainless steel (1 mm thick) troughs, 0.1 m wide and 0.1 m deep, with 20 mm high vertical sides and a V-shaped bottom to minimize loss of water through splashing. Troughs were 5 to 8 m long depending on the forest, at an angle of 10° from the horizontal, and each emptied into a tipping bucket gauge. The collection area of a trough was calculated on a projected area basis. Resolution of each unit varied from 0.15±0.01 mm to 0.05±0.005 mm per tip.

A 50-point storage gauge network as well as the troughs was used to measure throughfall in the young Sitka spruce forest. This forest had the most variable cover with gaps of up to 5 m in diameter. The gauges (0.16 m diam.) were at 5 m intervals on a 25x50 m grid. Gauges were emptied after each storm or a number of storms depending on availability of personnel.

Stemflow was collected with a 10-mm wide collar of one and half turns of a spiral round a tree at 1.5 m. The collar drained into a tipping bucket (33 ml, calibrated to ±0.2 ml). The volume of water (average of all trees) was multiplied by stand density and divided by the area of a hectare to give stemflow in mm.
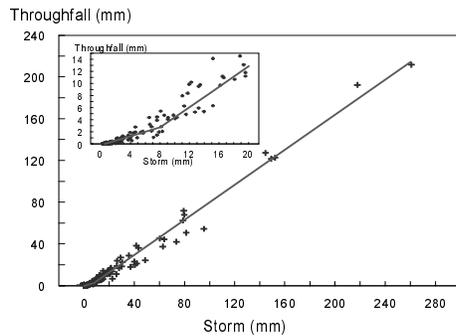

Figure 1. Throughfall as a function of storm size for the mature coastal hemlock forest. Lines were fit by regression.
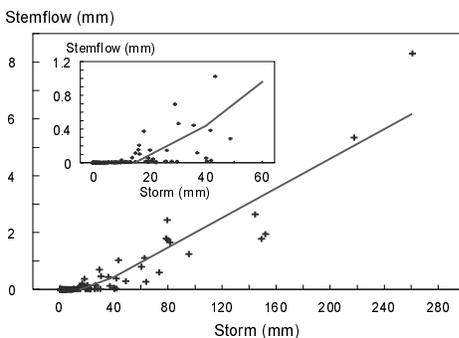

Figure 2. Stemflow as a function of storm size for the mature coastal hemlock forest. Lines were fit by regression.

3.   RESULTS

The data discussed here are for periods without snow, i.e., February through December for the coastal forests and May to early October for the interior forests (Upper Penticton Creek). Throughfall and stemflow data are analyzed separately and then combined to estimate interception loss on a storm-by-storm basis. Interception loss equals [Rainfall - (Throughfall + Stemflow)]. A storm is a period of rain separated by at least two rain-free hours from the next rain event. Data lost due to blocked buckets or disturbance by animals were estimated from other units using linear regressions.

3.1   *Throughfall*

The five throughfall measurements had a coefficient of variation of about 0.2 in each forest. Throughfall from the troughs agreed well with that from the adjacent 50-point network of storage gauges in the Sitka spruce forest. An analysis where grid points were picked at random, found that 25 gauges were sufficient to measure throughfall to within 5% of the average of the 50 points. Similar results were noted by Lloyd and Marques (1988). The 5 troughs have 6 to 8 times the sampling area of 25 gauges.

Throughfall showed a strong linear relationship with storm size. The mature coastal hemlock stand has a change in slope of the line at about 8 mm (Figure 1). This break occurs at a lower storm size for the younger forests (e.g., 3 mm for the Sitka spruce (Spittlehouse 1998)), and the mature interior forests. The hemlock forest had less throughfall than these forests for any storm size. Throughfall was highest in the mature interior forests with the low canopy cover (Table 1). In all cases, throughfall began soon after the rain started. There was no evidence of a significant contribution of fog drip to throughfall during non-storm periods.

3.2   *Stemflow*

Stemflow did not begin until rainfall exceeds a certain amount: 15 mm for the coastal hemlock forest (Figure 2), and about 2 mm for the young forests. Stemflow was a much smaller fraction of a storm in both the coastal and interior mature forests than in the young forests. Canopy geometry and a low canopy water storage capacity are probably responsible for the large amount of stemflow that occurs in the young forests. Antecedent conditions affected stemflow. When a storm followed within a few hours of another, stemflow began at a lower cumulative amount of rain. This accounts for much of the scatter in Figure 2.

3.3   *Interception Loss*

The hemlock forest had the greatest interception loss with the maximum amount reaching 25±10 mm for storms greater than 100 mm (Figure 3). Weather conditions during a storm, particularly long duration storms, had a greater influence on interception than for the young forests. The flagged points in Figure 3 indicate storms of 2 to 4 days in length with variable rain intensity and weather conditions. The upper two points are for spring storms which had warmer conditions than the lower three which represent winter storms. The affect of antecedent conditions is also seen in the interior forests (Figure 4). The low

canopy density in these forests results in a maximum interception loss 4±0.5 mm. Maximum interception loss for the young coastal forests is 10 to 15 mm (Figure 5).
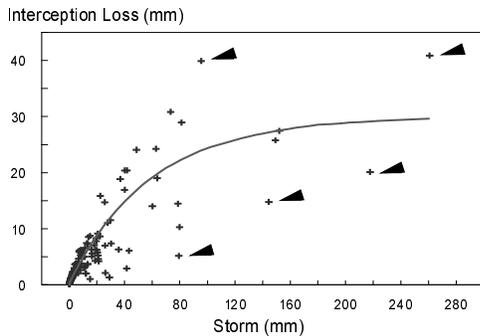
Interception Loss (mm)

Figure 3. Interception loss as a function of storm size for the mature coastal hemlock forest. Line was fit by eye. The arrows indicate winter (lower three) and spring (upper two) storms of two to three day duration.
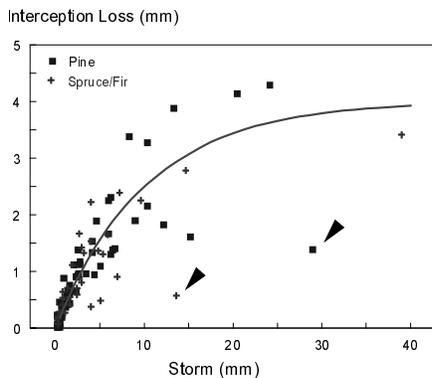
Interception Loss (mm)

Figure 4. Interception loss from storms for the lodgepole pine (•) and Engelmann spruce-subalpine fir (+) forests at Upper Penticton Creek. The arrows indicate interception for storms that occurred when the canopy was wet from a preceding storm. The line was fit by eye.

Figure 6 illustrates the influence of antecedent conditions on interception loss. The first storm of 6.2 mm occurred in the late afternoon, two days after the last rain, and had a 2.3 mm interception loss. A second storm began just after midnight. Thus there was little time for the canopy to dry out with the result that there was a 1.4 mm interception loss for a 29 mm storm.

Measurement errors in interception loss vary from ±0.3 mm for storms of less than 10 mm to ± 2.5 mm for storms great than 100 mm of rain, i.e. about 20% of the interception loss. Errors due to inadequate sampling of throughfall or stemflow are not known. However, the good agreement between the trough and storage gauge measurements of throughfall suggest sampling is adequate. Assuming that the tree with the largest stemflow represents all trees in a stand had only a minor effect on the calculated interception for all forests.
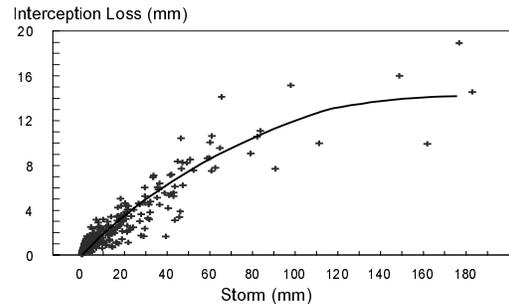
Interception Loss (mm)

Figure 5. Interception loss as a function of storm size for the young coastal Sitka spruce forest. The line was fit by eye. Similar relationships were obtained for the young Douglas-fir forests.
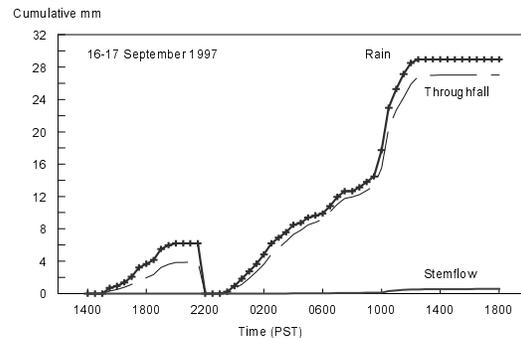
Cumulative mm

Figure 6. Cumulative half hourly rainfall (+), throughfall (dashed line) and stemflow (solid line) for two storms at the lodgepole pine forest. The first storm had 6.2 mm of rain, 2.9 mm of throughfall and no stemflow. The second storm had 29.0 mm of rain, 27.0 mm of throughfall and 0.6 mm of stemflow.

4. DISCUSSION AND CONCLUSIONS

Relationships between storm size and throughfall and stemflow for each forest were used with an annual record of storms to calculate annual interception loss. The influence of weather conditions during the storm or storm intensity is not considered. The coastal forests are under similar weather regimes and their balance is calculated for the same storm record. A different storm record is used to represent the weather regime for Upper Penticton Creek. Interception loss data in Table 2 are consistent with other published data.

TABLE 2. Calculated stemflow (Stem), throughfall (Thru) and interception loss (Intc) as a fraction of the annual rainfall. The four coastal forests are for the same storm record from March 1995 to February 1996, calculated with relationships such as those in Figures 1, and 2. The annual rainfall total was 3316 mm. The lodgepole pine and Engelmann spruce-subalpine fir forests data are based on a May to October storm record for Upper Penticton Creek totaling 454 mm.

	% of Rainfall		
Forest	Stem	Thru	Intc
Hemlock	1	69	30
D.-Fir #1	9	70	21
Sitka Spruce	9	77	14
D.-Fir #2	4	85	11
Pine/spruce/fir	<0.5	76	24

Table 2 indicates that interception loss increases with canopy cover but that canopy cover may not always be a good index of interception loss. The mature hemlock forest has the same canopy cover as young Douglas-fir forest #1, but has a greater water storage capacity in lichens, mosses, and bark, than the young forest. The Upper Penticton Creek weather regime has a greater fraction of the rain in small storms; thus, there is a greater fraction of the rainfall lost to interception than the canopy cover might lead one to expect. A 12% interception loss is calculated for this site using the coastal storm record.

Evaporation is occurring during the storms, but it is low due to relative humidity being at or close to saturation and to low net radiation. Evaporation rates were estimated using the Penman-Monteith equation (Calder, 1990) and measured net radiation and weather data. The estimates are sensitive to the value of humidity which is difficult to accurately measure close to saturation. Evaporation rates during winter storms varied from 0 to 0.3 mm h^{-1}, while those during summer varied for 0 to 0.5 mm h^{-1}. Evaporation rates were lower after storms during the winter than during the rest of the year. In winter, there is insufficient time for all of the storage to dry out between storms. This is most noticeable in the mature hemlock forest with a large storage capacity. Furthermore, this canopy probably scavenges cloud water droplets when low cloud moves through the upper part of the canopy. The influence of antecedent and within-storm conditions indicates that further analysis requires use of detailed interception models, e.g., Lankreijer et al. (1993).

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