Rainfall Interception in Young and Mature Coastal Conifer Forests

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Abstract

Interception of rain by a forest canopy and the subsequent evaporation of the water is a significant term in the water balance of coastal forests. Thus, the removal of forests through harvesting and the subsequent regrowth of the forest can result in significant changes in the amount of water reaching the soil. Measurements in one mature and three young coastal forest stands show that the fraction of rain intercepted and lost (rainfall minus [throughfall plus stemflow]) decreases as the size of the storm increases. Maximum interception loss for storms greater than 100 mm was 14±3 mm for the young forest and 25±10 mm for the mature forest. The mature stand had a lower interception loss during the winter than in the spring for long duration storms.

Résumé

L'interception des précipitations par le couvert forestier et l'évaporation subséquente de l'eau est un terme de grande importance dans l'équilibre hydrique des forêts côtières. Par conséquent, la suppression des forêts par la coupe du bois ainsi que la repousse subséquente de la forêt peuvent modifier considérablement la quantité d'eau qui atteindra le sol. Les données recueillies dans un peuplement forestier mature et dans trois jeunes peuplements démontrent que la fraction de pluie interceptée et perdue (quantité d'eau tombée moins [précipitations au sol + écoulement sur écorce]) diminue lorsque l'ampleur de la tempête augmente. La perte d'interception maximale lors de tempêtes de plus de 100 mm était de 14±3 mm pour les peuplements jeunes et de 25±10 mm pour le peuplement mature. Le peuplement mature subit une perte d'interception moindre en hiver qu'au printemps lors des tempêtes de longue durée.

Introduction

The reduction in vegetation biomass and height due to 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. Consequently, the soil may be wetter and drainage from the site greater than in the unlogged situation. This has the potential to 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. The work presented here on rainfall interception in coastal forests is part of a larger study to provide information to refine assessment procedures. Rainfall interception as a function of storm size will be presented for young and mature forests at the Carnation Creek Experimental Watershed and at the Cowichan Lake Research Station on Vancouver Island.

Review

Rain either falls directly to the forest floor through gaps between trees and within the foliage (throughfall), or hits foliage, branches and stems. Rain that hits the trees may bounce off and fall to the forest floor (throughfall), run down branches and stems to the forest floor (stemflow), remain on the surface of the foliage and branches and evaporate after the storm (interception loss), or be absorbed by bark, lichens and moss in the canopy and evaporate after the storm (interception loss). The maximum amount that can be absorbed or reside in the canopy at any one time is the saturation capacity of the canopy. Fog drip can be a significant component of the water balance in some ecosystems (Hetherington 1987). Fog droplets collide with, and adhere to, the foliage and branches. Individual drops coalesce, drip from the canopy or flow down the branches and stem to the ground.

Rainfall interception studies in coastal BC have measured throughfall in mature Douglas-fir, western redcedar and western hemlock (Giles et al. 1985; Beaudry and Sagar 1995) and young Douglas-fir (Spittlehouse and Black 1981). These and numerous other studies (e.g., Zinke 1967; Ford and Deans 1978; Calder 1990; Crockford and Richardson 1990) have shown that up to 30% of the annual rainfall does not reach the ground in coniferous forests. The fraction of the rain intercepted depends on storm size, intensity, duration and weather conditions. The saturation capacity of many forest canopies is between 0.5 and 2 mm (Shuttleworth 1989). However, evaporation of intercepted water by advective energy and the efficient mixing of the air often occurs during storms, and the saturation capacity is constantly being replenished (Calder 1990). Interception loss increases with an increase in leaf area of the stand (Plamondon et al. 1984; Giles et al. 1985). Consequently, hydrologic recovery is expected to vary with stand age and structure.

Methods

Site Description

The Carnation Creek watershed is on the west coast of Vancouver Island (48°54'N, 125°0'W) in the very wet

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maritime Coast Western Hemlock subzone. The young forest is in the flood plain at an elevation of 5 m. The overstory is dominated by 6 to 10 m tall, 20-year-old Sitka spruce. There are some small western hemlock and alder trees in the lower canopy. Stand density is 1500 stems ha^{-1}. There are openings of 3 to 5 m in diameter and the average canopy cover is 70%. The understory is dominated by salmonberry, salal and sword fern. The mature forest is on a 30° south-east facing slope, 450 m elevation, about 2 km east of the young forest. This stand consists of mixture of 100-year old western hemlock plus a number of veterans remaining from the last disturbance (probably blowdown) and there is negligible understory vegetation. Stand density is 480 stems ha^{-1}, trees are 40 to 30 m tall, and canopy cover is 85%.

Monitoring and Data Analysis

Meteorological Measurements: The young forest had a 13-m tall tower at the edge of a 5-m-diameter opening for monitoring above-canopy solar radiation, air temperature and humidity, wind speed and wind direction. A rain gauge was mounted on the tower at 5 m above the ground with a sky view angle of about 45° from the vertical. A second rain gauge was located at 1 m above the ground in the opening. Five throughfall and four stemflow units (described below) were installed below the canopy and above the understory. Measurements at 1.5 m above the ground in a clear-cut adjacent to the mature forest were assumed to represent meteorological conditions just above the canopy. Five throughfall and five stemflow units, and air temperature and humidity were measured 300 m in from the edge of the forest. Dataloggers scanned the sensors every 10 seconds and produced 30-minute and 24-hour summaries (averages, totals, maximums and minimums). All rain gauges (nominally 0.25 mm resolution) were calibrated on-site to ±0.005 mm/tip using a burette. Equipment was serviced every two to four weeks.

Throughfall Monitoring: The system for measuring throughfall is similar to that described in Crockford and Richardson (1990). Throughfall was collected by stainless steel (1 mm thickness) 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 6 m long (young forest), 8 m long (mature forest), at an angle of 10° from the horizontal, each emptying into a tipping bucket gauge through a mesh to catch needles. The collection area of a trough was calculated on a projected area basis. The gauges had either buckets of about 90 ml (calibrated to ±0.5 ml), or about 33 ml (calibrated to ±0.2 ml). Resolution of each unit in the young forest was 0.15±0.01 mm for the larger volume buckets and 0.05±0.005 mm for the small buckets. Values for the mature stand were 0.1 and 0.04 mm for the large and small buckets, respectively.

Stemflow Monitoring: The bark was smoothed in a 150 mm band over one and one half turns of a spiral round the stem of each tree at 1 m above the ground. Garden hose (20 mm o.d.) was nailed to the tree along the spiral and sealed to the tree using silicone caulking to create a 10-mm wide trough that drained into a rain gauge (33 ml buckets, 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.

Data Analysis: The data discussed here are for the period March 1995 to December 1996 (young forest), August 1995 to December 1996 (mature forest). Periods with snow are excluded from the analysis. Throughfall and stemflow data are analyzed separately and then combined to estimate interception loss on a storm-by-storm basis. A storm is defined by the period of rain with at least two hours without rain either side of the storm. Data lost due to blocked buckets or disturbance by animals were estimated from other units using linear regressions based on data for the whole analysis period.

Results

Young Forest: The five throughfall measurements had a coefficient of variation of about 0.2, and they averaged out the heterogeneous nature of the canopy cover. Throughfall from the troughs agreed well with average throughfall from an adjacent 50-point network of storage gauges (Spittlehouse, unpublished data). Throughfall shows a strong linear relationship with storm size (Figure 1). The slope of the line has a larger value for storms greater than 3 mm. This probably represents the point at which much of the storage capacity of the canopy has been filled. Figure 2 illustrates the time course (30 minute time steps) of throughfall during a storm. Throughfall begins almost as soon as the rain begins and the fraction of the rain as throughfall increases as the storm continues and almost equals the rainfall near the end of this storm. Throughfall is not corrected for the amount that is intercepted by the understory. This is probably within the measurement error of the techniques used. Stemflow does not begin until rainfall exceeds 2 mm (Figures 3). The coefficient of variation for stemflow is about 0.2. There was no evidence of a significant contribution of fog drip to throughfall during non-storm periods.

The fraction of a storm intercepted decreases as the storm increases. Interception loss reaches a maximum of 14±3 mm for storms greater than 100 mm (Figure 4). Variation in weather conditions during storms and measurement errors account for the scatter. Measure-

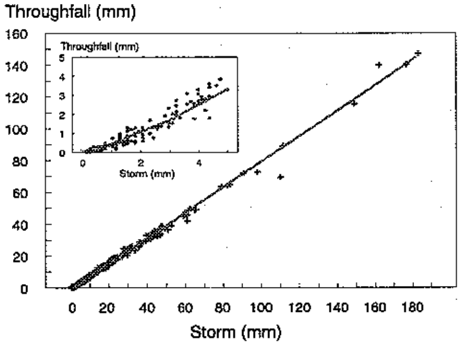

Figure 1. Throughfall as a function of storm size for the young forest. Lines were fit by regression.

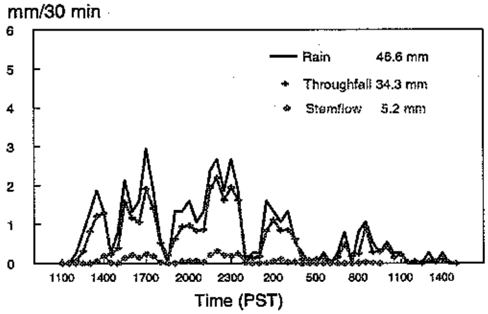

Figure 2. Rain, throughfall and stemflow for the young forest 17-18 May 1996.

ment errors 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 throughfall systems suggest throughfall sampling errors are small. Assuming that the largest stemflow represents all trees has only a minor effect on the calculated interception.

Mature Forest: Variation in throughfall between troughs is less than that for the young forest, probably because the longer length of the troughs and the more uniform forest canopy. Throughfall is a smaller fraction of the storm than for the young forest. The break in the relationship between throughfall and storm size occurs at 8 mm (Figure 5). Figure 6 shows a typical course of throughfall for the same storm shown in Figure 2 for the young forest. Stemflow (Figure 7) is a much smaller fraction of the storm than in the young forest, and does not begin until after 15 mm of rain, and there is an increase in the slope of the relationship for storms greater than 40 mm (Figure 6). There was no evidence of a significant contribution of fog drip to throughfall during non-storm periods.

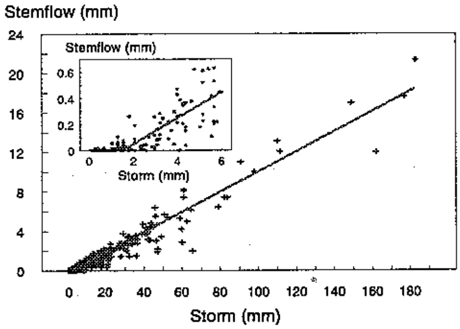

Figure 3. Stemflow as a function of storm size for the young forest. Lines were fit by regression.

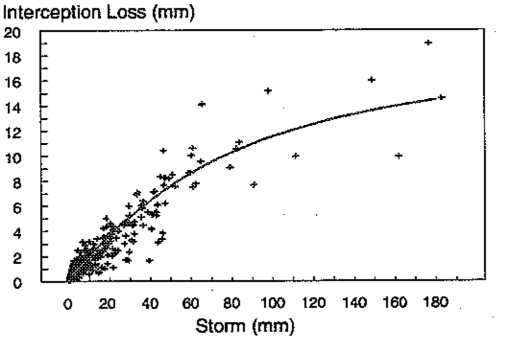

Figure 4. Interception as a function of storm size for the young forest. The line was fit by eye.

Interception loss is much greater and variable than for the young forest with the maximum amount of interception reaching 25±10 mm for storms greater than 100 mm (Figure 8). Weather conditions during a storm, particularly long duration storms, had a greater influence interception than for the young forest. The flagged points in Figure 8 indicate storms of 2 to 4 days in length with variations in 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.

Discussion and Conclusions

A much greater fraction of a rainstorm is lost as interception by the mature forest than by the young forest. This is due to a greater amount of intercepting biomass (mosses, lichens, bark, branches and foliage) and its ability to absorb water. The majority of the interception loss represents filling the canopy saturation capacity. Evaporation is occurring during these storms, but it is low due to relative humidity being at or close to saturation and to low solar irradience. 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 humid-

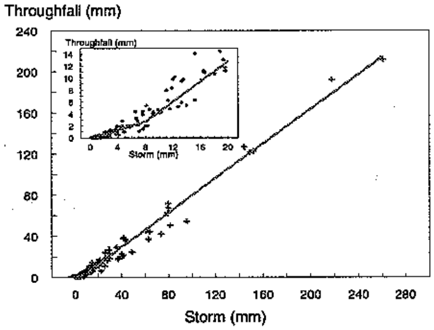

Figure 5. Throughfall as a function of storm size for the mature forest. Lines were fit by regression.

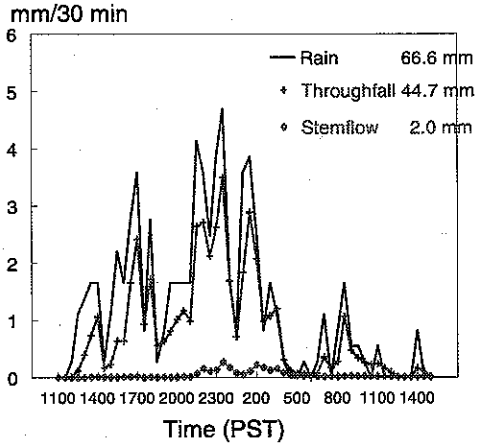

Figure 6. Rain, throughfall and stem flow for the mature forest 17-18 May 1996.

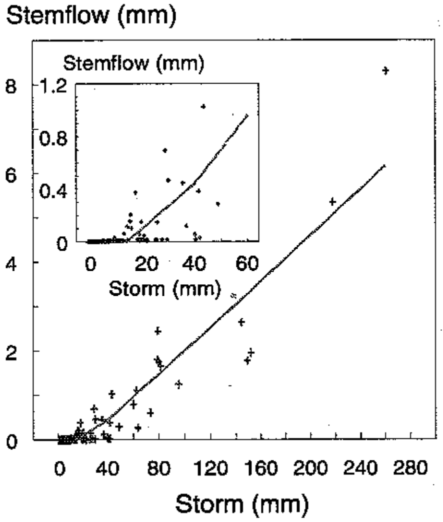

Figure 7. Stemflow as a function of storm size for the mature forest. Lines were fit by regression.

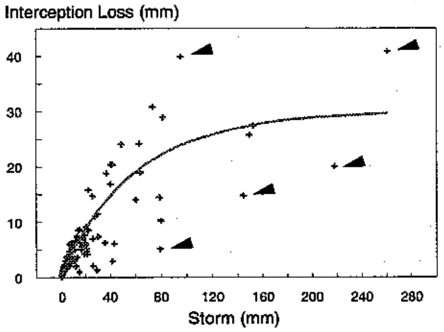

Figure 8. Interception as a function of storm size for the mature stand. Line was fit by eye. The arrows indicate winter (lower three) and spring (upper two) storms of two to three day duration.

ity which is difficult to accurately measure close to saturation. Typical evaporation rates during winter storms vary from 0 to 0.3 mm h^{-1}, while those during summer vary for 0 to 0.5 mm h^{-1}. This reflects the slightly lower humidity and greater net radiation during the latter period. Evaporation rates are higher after storms during the spring, summer and fall than in winter. Thus, it is likely that during winter conditions there is insufficient time for all of the storage to dry out between storms, and this is most noticable in the mature forest with a large storage capacity. Also this canopy is probably scavenging cloud water droplets when low cloud moves through the upper part of the canopy.

Similar relationships to those in Figures 1, 3, 5 and 7 were obtained for two young Douglas-fir stands at the Cowichan Lake Research Station, 50 km east of Carnation Creek at 175 m (48°50'N, 124°8'W) (Spittlehouse, unpublished data). These relationships were used with an annual storm record for Carnation Creek to compare interception between forests. The influence of weather conditions during the storm or storm intensity is not considered. This requires models such as those presented in Lankreijer et al. (1993) and is the subject of future work on this project. Table 1 indicates that interception loss increases with canopy cover but that canopy cover may not a good measure of interception loss. The mature forest has a much greater storage capacity of lichens, mosses, and bark, than the young forests and canopy cover measurements do not capture this. Values for the fraction of rainfall as throughfall are consistent with data for mature Douglas-fir (Giles et al. 1982) and old-growth western redcedar (Beaudry and Sagar 1995), and young Douglas-fir (Spittlehouse and Black 1981). The neglect of stemflow in these studies means that they overestimated interception loss.

Table 1. Calculated stemflow, throughfall and interception loss for the same storms from March 1995 to February 1996 for four forests. The annual rainfall total was 3316. Calculations are based on the relationships in Figures 1, 3, 5 and 7 for the Carnation Creek (CC) young and mature forests and similar ones (Spittlehouse, unpublished data) for two young stands at Cowichan Lake (CL).

		% of rainfall		
Forest	% Cover	Stemflow	Throughfall	Interception loss
Young - CL	70	4	85	11
Young - CC	75	9	77	14
Young - CL	85	9	70	21
Mature - CC	85	1	69	30

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