Rainfall Interception by Mature Coastal and Interior Forests in British Columbia

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Abstract

Interception of rainfall by forest canopies and its evaporation back to the atmosphere is an important component of the hydrological balance. We quantify the influence of six mature forests at two coastal and one southern interior locations in British Columbia on interception loss. Drainage from the canopy was measured with throughfall troughs and stemflow collars that emptied into tipping buckets monitored by data loggers. Interception loss was evaluated on an event basis and summed to monthly and seasonal totals. The throughfall coefficients increased with a decrease in canopy volume with values of 0.3 for the south coast forest, 0.5 for the north coast forests, and 0.6 for the southern interior forests. The respective saturation capacities were 2.0, 1.1, and 0.6 mm. The average evaporation rates during events varied from 0.05 to 0.3 mm h^{-1} at all sites. Consequently, for large events, interception loss was dominated by evaporation and replenishment of water in storage during the event. Increasing event size increased interception loss, which tended to plateau at large events. The coastal forests had throughfall 75±2 percent, stemflow 1±0.2 percent, and interception loss 24±2 percent of the May to November rainfall. The respective values for the interior forests were 72±3 percent, 0.05±0.05 percent, and 28±3 percent of the late May to October rainfall. The similarity between coastal and interior sites in the partitioning of the seasonal rainfall resulted from the differing distributions of event size and similar evaporation rates of intercepted water during events.

Keywords: *rainfall, throughfall, stemflow, interception loss, evaporation, mature forest*

Introduction

Rain falling on a forest canopy can fall directly through the canopy to the forest floor, drip off the canopy (throughfall), travel down tree stems (stemflow), or return to the atmosphere by evaporation (interception loss). Globally, interception loss contributes 10 to 20 percent of the total evaporation from the land surface (Wei et al., 2017; Miralles et al., 2020) and forests provide a greater contribution to this loss than short vegetation (Zinke, 1967; Calder, 1998). Page et al. (2020) suggest interception loss helps to reduce the flood risk in mountainous forests in the United Kingdom. Consequently, disturbance of forests can result in increased amounts of precipitation reaching the ground and streams with the potential for negative hydrologic consequences (Winkler et al., 2010b; Goeking & Tarboten, 2020).

Numerous studies have quantified throughfall, stemflow, and interception loss of forests. Partitioning of rainfall depends on the time of year, event size, event intensity, weather conditions prior to and during the event, and tree species, density, and age (Zinke, 1967; Pypker et al., 2005; Winkler et al., 2010a; Cisneros Vaca et al., 2018; Sadeghi et al., 2020). Increase in the forest age and leaf area tends to result in a decrease in the fraction of the seasonal rainfall as throughfall and stemflow and an increase in the fraction as interception loss. Mature forests in western North America tend to have negligible stemflow in summer with the result that 50 to 80 percent of the rainfall is throughfall and the remaining 20 to 50 percent evaporates back to the atmosphere (interception loss) (Table 1). In winter, throughfall is a greater percentage of the rainfall, there may be a small amount of stemflow, and interception loss is a lower percentage of the rainfall than in the summer. Younger forests tend to have higher throughfall than old forests; stemflow is 3 to 10 percent of the rainfall and interception loss is 12 to 20 percent (Table 1). Even though stemflow is only a minor component of the balance it can be important in transferring key nutrients and water to tree roots and sub-canopy soils (Carlyle-Moses et al., 2018).

Table 1: Throughfall (TF), stemflow (SF), and interception loss (IL) as a percentage of the rainfall for forests in western North America.

Forest	Age	Location	Period	TF %	SF %	IL %	Source
Douglas-fir/western hemlock – 5 sites	>300	Western Oregon	May–Sept Oct–Apr	70 to 82 86	0 0.3	18 to 28 14	Rothacher (1963)
Douglas-fir/western hemlock	~500	South Central Washington	Apr–Nov	76	N/A	24	Link et al. (2004)
Douglas-fir – 4 sites	>250	East Coast Vancouver I.	May–Sept Annual	43 to 70 66 to 80	N/A	30 to 57 20 to 44	McMinn (1960)
Western hemlock/Douglas-fir	>250	East Coast Vancouver I.	May–Sept	60	N/A	40	McMinn (1960)
Redcedar/western hemlock	>250	Central Coast B.C.	Mar–Dec	77	1	22	Beaudry & Sagar (1995)
Douglas-fir	>100	Western Oregon	May–Sept	78	N/A	22	Rothacher (1963)
Engelmann spruce/ lodgepole pine	>80	Southern Interior B.C.	Jul–Aug	59	0	41	Carlyle-Moses et al. (2014)
Lodgepole pine – ~85% MPB kill	>80	Central Interior B.C.	May–Aug	88	0.01	12	Spittlehouse & Foord (unpublished data)
Ponderosa pine	65	Western California	Mar–Nov	84	3.8	12.3	Rowe & Hendrix (1951)
Douglas-fir	55	East Coast Vancouver I.	Mar–Dec	75	3	22	Winkler et al. (2010a)
Douglas-fir – 2 sites	25	East Coast Vancouver I.	Mar–Dec	70, 85	9, 4	21, 11	Spittlehouse (1998) Winkler et al. (2010a)
Sitka spruce/western hemlock	20	West Coast Vancouver I.	Jan–Dec	77	9	14	Spittlehouse (1998) Winkler et al. (2010a)
Lodgepole pine	25	Southern Interior B.C.	May–Sept	71	5	24	Winkler et al. (2010a, 2021)
Douglas-fir	25	South Central Washington	Jun–Nov	79	N/A	21	Pypker et al. (2005)

Notes: IL, interception loss; SF, stemflow; TF, throughfall; MPB, mountain pine beetle

There are three phases to an individual rainfall event on a forest canopy (Rutter et al., 1971; Gash et al., 1995; Sadeghi et al., 2020). The first is a wetting phase from the onset of rainfall to the filling of the saturation capacity of the canopy. Drainage from the canopy is by throughfall and stemflow is usually negligible. The second phase is the saturation phase where drainage from the canopy (throughfall and stemflow) becomes a greater fraction of the rainfall and interception loss is by evaporation of stored water. The third phase occurs once the rain stops. Drainage from the canopy may continue for an hour or more and the water remaining on the canopy is lost by evaporation.

Older forest canopies often have extensive leaf area, numerous dead branches, thick bark, mosses, and epiphytes that increase the saturation capacity of the forest canopy (Pypker et al., 2005). However, the storage capacity of forests is relatively small (1 to 4 mm), and interception loss frequently exceeds the canopy saturation capacity because evaporation of intercepted water during the event allows the continued replenishment of the saturation capacity (Calder, 1998; Link et al., 2004; Cisneros Vaca et al., 2018; Page et al., 2020). Sensible heat advected downward from the planetary boundary layer and the low aerodynamic resistance of forests results in wet evaporation rates of 0.2 mm h^{-1} or more (Gash et al., 1999; Humphreys et al., 2003; van der Tol et al., 2003; Cisneros Vaca et al., 2018), up to 10 times that for shorter vegetation (Calder, 1998). Long-duration, low-intensity rainfall events have greater interception losses than high-intensity, short-duration events of the same rainfall amount because, during the latter, there is a shorter period for evaporation to occur, and weather conditions are less favourable (Calder, 1998). The time since the last rainfall influences the amount of drying of the canopy and the amount of storage available to be filled by the following event.

Given the interaction between weather conditions and the forest, it is important to quantify interception loss on an event basis in a range of environments in British Columbia. It is also important to understand the implications of changing forest cover on interception loss. The goal of this research was to measure event-based throughfall and stemflow to determine interception loss in mature forests in three rainfall regimes. These variables are examined at six sites that represent forests typical of their climatic zones: two north coast sites near Prince Rupert (Smith Island and Diana Lake), a south coast site on the west coast of Vancouver Island (Carnation Creek), and three sites in the southern interior (Upper Penticton Creek). Preliminary results of these studies have been published (Spittlehouse, 1998; Maloney et al., 2002; Winkler et al., 2010a). Here we provide event-based data in the context of weather conditions, event size, event intensity, and discuss similarities and differences between the three rainfall regimes and forest types.

Methods

Study sites

Six forest stands were monitored in three climatic regimes in British Columbia and their differing forests ecosystems (Figure 1). The two central coastal sites and the south coast site are in the Coastal Western Hemlock Biogeoclimatic Zone and the three interior sites are in the Engelmann Spruce Sub-Alpine Fir Biogeoclimatic Zone (Meidinger & Pojar, 1991).

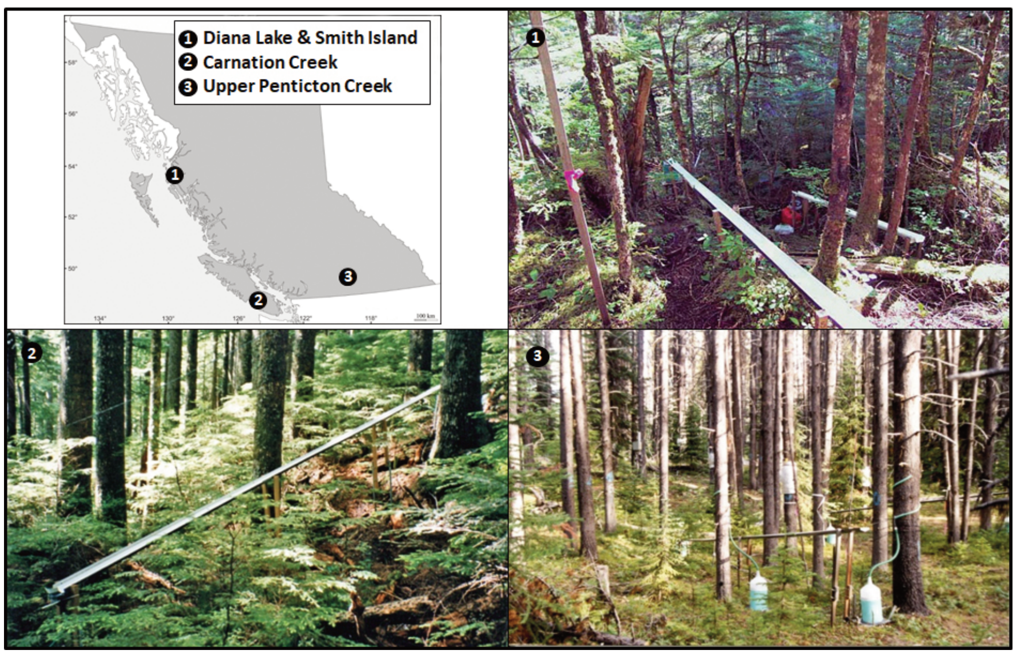

Figure 1: Site location in British Columbia and forest vegetation, throughfall troughs and stemflow collectors.

Notes: The upper right panel shows the Smith Island site; lower right panel UPC_P7; lower left Carnation Creek

Central Coast: Smith Island and Diana Lake

Smith Island and Diana Lake are in the Coastal Western Hemlock very wet hypermaritime subzone (CWHvh2) (Banner et al., 1993). The Smith Island site (54°11'N, 130°13'N) was 20 km southeast of Prince Rupert Airport at 52 m above sea level (asl) on a 15 percent northeast aspect slope. The Diana Lake site (54°14'N, 130°10'N) was 20 km east of Prince Rupert Airport at 72 m asl on a 10 percent northeast aspect slope. The forests are dominated by western hemlock (*Tsuga heterophylla* [Raf.] Sarg.) and western redcedar (*Thuja plicata* Donn, ex D. Don). Stand density was determined from cruise plots and canopy cover measured using hemispherical photography and a canopy densitometer (Table 2).

Table 2: Forest characteristics and study period for each site. Stand density is for live and dead trees >3 m in height.

Location	Elev. m asl	Dominant species	Age y	Height m	Stems ha^{-1} Live, dead*	Canopy cover† %	Period months, years
Diana Lake	52	Western hemlock, western redcedar	>250	7–20	3432, 1067	86	May–Nov 1999–2001
Smith Island	72	Western hemlock, western redcedar	>250	6–27	1984, 629	77	May–Nov 1999–2001
Carnation Creek	350	Western hemlock	>120	30–40	480, 2	85	Jan–Dec 1995–1999
UPC_P6	1800	Engelmann spruce, sub-alpine fir	>125	20–24	1470, 170	45	May–Oct 1997–1998
UPC_P7	1650	Lodgepole pine	>125	22–26	848, 8	43	May–Oct 1997–2001, 2003–2008
UPC_PG	1650	Lodgepole pine	>125	22–26	1000, NA	45	May–Oct 2004–2006

Note: Canopy cover is based on hemispherical photography.

Mean annual precipitation (1981 to 2010) at the Prince Rupert airport (34 m asl) is 2619 mm, of which 97 percent falls as rain (Environment and Climate Change Canada, 2021). Average monthly rainfall varies from a minimum of 109 mm in June to a maximum of 373 mm in October, and there are 236 days per year with rainfall >0.2 mm. The research sites have greater rainfall than the airport due to the orographic influence of the surrounding mountains (Maloney et al., 1999). Mean daily air temperature ranges from 2.4°C in January to 13.8°C in August (Environment and Climate Change Canada, 2021).

South Coast: Carnation Creek

The Carnation Creek site (Tschaplinski & Pike, 2017) was on the west coast of Vancouver Island (48° 55' 20.19" N, 124° 56' 43.84" W) about 500 km south of Prince Rupert (Figure 1) in the Coastal Western Hemlock very wet maritime subzone (CWHvm1). The forest was on a 30° southeast-facing slope at 450 m asl and consisted of >120-year-old western hemlock plus a few >300-year-old Douglas-fir (*Pseudotsuga menzeisii* [Mirb.] Franco). Stand density and canopy cover (Table 2) were based on hemispherical photographs at 20 grid points in a 50 x 50 m plot.

Mean annual precipitation (1981 to 2010) at Carnation Creek (26 m asl) is 2995 mm, almost all of which falls as rain. Average monthly rainfall varies from 55 mm in July and August to 470 mm in November, December, and January, and there are 190 days per year with rainfall >0.2 mm. Mean daily air temperature ranges from 4.6°C in December to 15.2°C in August. As with the Prince Rupert sites, orographic effects result in approximately 20 percent higher precipitation at the interception site compared with the main weather station, and there is more precipitation as snow. Carnation Creek is drier than the Prince Rupert sites in the summer.

Southern Interior: Upper Penticton Creek

The Upper Penticton Creek (UPC) Watershed Study is on B.C.'s southern interior plateau 26 km northeast of Penticton (Winkler et al., 2017, 2021) (Figure 1). The three research stands were on 0 to 5 percent sloping terrain in the Engelmann spruce-subalpine fir dry cold subzone (Lloyd et al., 1990). Two sites, P7 (49° 39' 21.18"N, 119° 23' 59.74"W, 1637 m) and PG (49° 39' 33.78"N, 119° 23' 38.47"W, 1668 m), were in mature lodgepole pine (*Pinus contorta* Dougl.) stands. The third site, P6 (49° 37' 29.56", 119° 22' 35.17", 1810 m), was in a mature stand of Engelmann spruce (*Picea engelmanni* Parry) and subalpine fir (*Abies lasiocarpa* [Hook] Nutt.) (Winkler et al., 2021). Stand density and canopy cover (hemispherical photographs at 20 grid points) were determined for 50 x 50 m plots (Table 2).

On average 327 mm (45%) of the annual precipitation falls as rain and 431 mm as snow (Winkler et al., 2017, 2021). Rainfall occurs from May to late October, with a monthly average ranging from 38 mm in August to 90 mm in June, and there are 65 days with rainfall >0.2 mm. Mean daily temperature ranges from -11°C in December to 19.2°C in July. Upper Penticton Creek has less than half the total rainfall of Prince Rupert and Carnation Creek in May to October.

Meteorological measurements

Weather stations were in large openings near the forests. Solar radiation (Licor 200SA silicon pyranometer), air temperature and humidity (Vaisala HMP35C), rainfall (Jarek Manufacturing model 4025 and Sierra Misco model 2502), and wind speed and wind direction (Met-One 014A and RMYoung Wind Monitor) were monitored with data loggers (Campbell Scientific Inc. 21X and CR10X). Throughfall and stemflow are reported for the snow-free period, which varies by site and by year (Table 2). Data gaps resulted from blockage of the tipping buckets by needles and lichens, and damage to troughs and stemflow units by falling trees, bears, and cattle.

Throughfall

Throughfall was measured using a system similar to that of Crockford and Richardson (1990) and Grunicke et al. (2020). Each unit consisted of a stainless-steel trough (6- or 9-m long, 0.1-m wide, 0.1-m deep, at an angle of 10° from the horizontal) that drained into a tipping bucket (Jarek Manufacturing model 4025 and Sierra Misco 2502, nominally 33 mml/tip) covered with a mesh screen to catch debris. Troughs were 9-m long, and each unit had resolution of 0.04 mm/tip at Carnation. At Smith Island, Diana Lake, and UPC, troughs were 6-m long, and each unit had a resolution of 0.05 mm/tip. Five units were randomly located in each site at least 200 m from the stand edge. Cumulative half-hourly or hourly throughfall was recorded using Campbell Scientific data loggers (21X and CR10) with an eight-channel multiplexer (Campbell Scientific SDM-SW8A).

Stemflow

Stemflow was measured using collars directing water into tipping buckets (~33 ml/tip) monitored by the data loggers or into standpipes. The tree bark was smoothed in a 150 mm band over one- and one-half turns of a spiral around the stem of each tree at 1 m above the ground. Garden hose (20 mm id) 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 the collection unit. At the Prince Rupert sites, collars were installed on 15 to 17 trees and snags of various diameters, heights, and species that drained into standpipes that were read manually. This approach missed individual events, but the data provided monthly and annual totals. At the Carnation Creek and UPC sites, five stemflow collars and tipping buckets were installed on live trees selected randomly based on stem diameter. Tipping buckets were calibrated to ±0.1 ml with a burette and monitored with the data loggers.

Measurement uncertainty

Rainfall

The tipping bucket rain gauges were calibrated to ±1 percent or ±0.254 mm (gauge resolution), whichever was larger. However, gauge exposure and wetting error can result in an underestimation of the event (Rhodda, 1967; Mulder, 1985). These errors were accounted for by assuming a total uncertainty of 2 percent or ±0.3 mm, whichever was larger. Consequently, for 5-, 20-, and 100-mm events, the rainfall measurements had a ±0.3, ±0.4, and ±2 mm uncertainty, respectively. The rain gauges were located 250 to 700 m from the throughfall and stemflow measurements. Consequently, depending on the type and direction of storm, they may not fully represent the amount of rain that fell above the forest measurements. It is assumed that this error is random and tends to cancel out for monthly and seasonal totals. The coastal sites are subject to low cloud or fog impacting and depositing water on the canopy, which then falls to the ground (Harr, 1982). This would increase throughfall and possibly stemflow but would not be measured by the open site rain gauge.

Throughfall

The throughfall troughs were calibrated to ±1 percent or 0.05 mm, whichever was the larger, and wetting error was approximately 0.05 mm. Consequently, for 5-, 20-, and 100-mm events, the uncertainty in the throughfall measurements was ±0.05, ±0.2, and ±2 mm, respectively. There can be substantial spatial variability in throughfall (Zimmermann & Zimmermann, 2014, Carlyle-Moses et al., 2014). The 6- and 9-m long troughs are expected to integrate much of this variability. The standard error on the mean throughfall was determined for individual events with the bootstrap procedure using the nptest package in R (Helwig, 2021; R Core Team, 2021). Possible bias in the measurements was not estimated. The five troughs at Smith Island were relocated in June 2000 to evaluate the sampling protocol. Linear regression between troughs was used to estimate throughfall for damaged troughs to aid calculating seasonal totals.

Stemflow

The stemflow collectors were calibrated to ±0.5 percent (33.0±0.1 ml). Linear regression equations between trees were used to estimate stemflow for damaged units. At the Prince Rupert sites, measurements were weighted by diameter class to create a stand average, whereas the mean of the five trees was used at Carnation Creek and the UPC sites.

Interception Loss

The uncertainty in rainfall, throughfall, and stemflow were assumed to be independent. Thus, uncertainty in interception loss for an event was calculated as the sum in quadrature of these three uncertainties. The contribution of the spatial variability in rainfall to the uncertainty of individual events was not known but it was assumed to average out for monthly and seasonal totals.

Analysis of individual events

Rutter et al. (1971) present a predictive model of interception loss that describes the relationship of cumulative rainfall with canopy drainage and evaporation of intercepted water. As noted in the Introduction, there is a wetting phase, a saturation phase, and a drying phase. Gash et al. (1995) and Valente et al. (1997) modify the Rutter model to separate storage and evaporation into canopy and trunk components and for estimating evaporation of intercepted water from a sparse canopy. As will be shown in the results, storage capacity of and evaporation from the trunks were low and were neglected. Thus, drainage from the canopy was assumed to equal throughfall. A throughfall coefficient (*p*, dimensionless) is the fraction of the cumulative rainfall (P, mm) that is throughfall during the wetting phase (Valente et al., 1997; Link et al., 2004). The transition point between the phases (P' mm) occurs when the saturation capacity of the canopy (S = [1 - *p*] P', mm) is filled. The saturation phase is assumed to have a mean evaporation rate (E, mm h^{-1}) and a mean rainfall rate (R, mm h^{-1}) where (1 - E/R) is the slope of the relation between cumulative rainfall and drainage. Saturation capacity of and evaporation from stems was determined from a plot of cumulative stemflow and rainfall. Breakpoint analysis with the segmented package (Muggeo, 2017) in R (R Core Team, 2021) was used to identify P'. The linear regression coefficients, P', and event rainfall and duration were used to calculate the other values. The evaporation rate from a wet canopy was calculated with the Penman-Monteith equation (Gash et al., 1999) assuming that the ground-based weather station data approximated that at the top of the forest canopy (Pearce et al., 1980; Mulder, 1985).

Analysis of events

The throughfall–rainfall relationship for events is similar to the individual event model described above with P equal to the total rainfall in an event (Leyton et al., 1967; Pypker et al., 2005). As before, the value of *p* is the slope of the relationship between throughfall and rainfall for the first phase ($0 < P \leq P'$), S is calculated from *p* and P', and E/R is determined from the regression line for the second phase. Stemflow was included with throughfall to give canopy drainage. Analysis for the wetting phase was based on events that fell on a dry canopy, i.e., at least 24 hours since the end of the previous event. Analysis of the saturation phase was based on events with precipitation less than 20 mm. Breakpoint analysis with the segmented package was unable to reliably identify the transition point between the phases due to the lack of a sharp transition and the curvilinear nature of the relationship (see later). Consequently, P' was estimated based on linear regressions fit to the wetting and saturation phases (Leyton et al., 1967; Klaassen et al., 1998; Grunicke et al., 2020). The resulting estimate of S was evaluated assuming that the upper bound of the saturation phase represents events that have minimum evaporation. A line through these points with a slope of 1 has a value of S where it intersects the x-axis (Leyton et al., 1967; Pypker et al., 2005). The analysis was applied to individual years but used a single value for P' based on all years for a site.

Results

Meteorology

The rate of rainfall varied during an event and rain might stop for an hour or more during the event while throughfall and stemflow continued. The authors assumed, similar to Grunicke et al. (2020), that individual events terminated after at least two hours without rain, by which time drainage from the canopy as throughfall and stemflow was negligible. The exception was low intensity drizzle over 6 to 12 hours where there could be up to three hours between activation of the tipping buckets.

Most events at the interior site were in smaller event categories than the coastal sites (Table 3) and the interior site did not have large events that last for a number of days. Events <1 mm made up a high proportion of total events at all sites, and all sites had the greatest proportion of events in the 1.0–19.9 mm range. These events accounted for 25 percent of the precipitation on the coast compared with 77 percent at the interior. The frequency of occurrence of events of different sizes changed throughout the year, with a greater percentage of the smaller events in mid-summer months. The distribution of event size is consistent with climatology of the sites (Moore et al., 2010).

Table 3: Frequency of events (%) by size at each site is in columns 2 to 7.

Frequency of rainfall events (%)							% of total rainfall	
Event (mm)	Smith Island	Diana Lake	Carnation Creek	UPC _P6	UPC _P7	UPC _PG	Carnation Creek	UPC _P7
<1.0	30.1	37.1	26.9	38.4	35.2	28.5	0.9	3.5
1–4.9	17.1	19.8	26.2	33.7	36.3	40.9	4.5	19.4
5–9.9	14.6	9.1	12.3	15.1	14.8	18.3	5.7	23.2
10–19.9	15.4	13.8	14.3	8.1	9.9	9.1	13.4	30.8
20–49.9	9.8	13.2	13.0	4.7	3.6	3.2	26.5	21.0
50–99.9	8.9	5.7	4.6	0.0	0.2	0.0	22.7	2.1
100–300	4.1	1.3	2.6	0.0	0.0	0.0	26.2	0
Events	412	379	584	86	576	186	584	576
Months	21	21	44	8	54	16	44	54

Note: The contribution (%) of events by size to the total rainfall at Carnation Creek and UPC_P7 is in columns 8 and 9.

Events tended to last longer at the coastal site (Table 4) with rainfall intensity varying widely through the duration of the event. This is to be expected because the interior rainfall regime is dominated by convective storms as opposed to frontal systems on the coast in fall and winter (Moore et al., 2010). However, the distribution of maximum rainfall intensity during events was similar between the coastal and interior locations with 75 percent of events at ≤1 mm in 30 minutes and under 2 percent in the 5 to 10 mm in 30 minutes range. There were a few periods each year at Carnation Creek when there was a small amount of throughfall due to fog drip with no measurable rain. In these cases, throughfall was less than 0.2 mm and represented a negligible component of the seasonal total.

Table 4: Distribution (%) of the length of the period of rainfall (hours) during an event at Carnation Creek (January-December 1998) and UPC (May-October 1997 and 1998).

Hours	≤2	2.5–4	4.5–8	8.5–12	12.5–24	24.5–48	48.5–96	>96
Carnation %	38.6	13.7	13.7	9.4	7.7	7.7	3.9	0.4
UPC %	57.6	18.4	17.7	6.3	0	–	–	–

Note: UPC, Upper Penticton Creek

Measurement uncertainty

Throughfall

Ranking of troughs by throughfall amounts was consistent between events and linear regressions between troughs had adjusted R^2 of >0.98. The standard deviation for the five troughs varied from <1 mm for small events to 4 mm for the largest events at Carnation Creek and to 2 mm for the largest events at UPC_P7. The throughfall bootstrap standard error was ±0.25, ±0.6, and ±3 mm for 10-, 20-, and 100-mm events. The random component of measurement error is included in the bootstrap standard error and only the bootstrap error was applied in calculating the uncertainty in interception loss. The fraction of rainfall as throughfall before and after relocation at Smith Island was essentially the same, indicating the sampling protocol was robust, particularly considering that this site was more open than the other coastal sites (Table 1).

Stemflow

Stemflow showed greater variability between individual trees than occurred between individual troughs. The standard deviation of stemflow varied from ±100 ml for small events to ±60,000 ml for largest events at Carnation Creek and to ±4000 ml at UPC_P7. Some of this variability may be related to the size and species of trees. As with throughfall, bootstrap values for the standard error on the site mean of stemflow were calculated for individual events and they varied between ±0.001, ±0.03, and ±0.25 mm for events of 5, 20, and 100 mm, respectively. The variability in stemflow between stems was about 50 times greater than the calibration uncertainty.

Interception loss

The above-mentioned uncertainty in rainfall, throughfall, and stemflow contributed approximately 55 percent, 42 percent, and <3 percent, respectively, to the error in interception. Consequently, the uncertainty in interception loss was ±0.4, ± 0.6, and ±2.4 mm for 5-, 20-, and 100-mm events, respectively.

The anatomy of an event

At Carnation Creek the dense canopy means that there was 0.5 mm or more of rainfall before throughfall began. The transition between the first two phases occurred during the first 2 to 3 mm of the event (Figure 2). Stemflow began after 3 to 5 mm of rainfall, though it was low, and it took 10 to 20 mm of rain for larger flows to occur. The result was that interception loss increased rapidly up to a cumulative rainfall of about 5 mm, then more slowly during the second phase, and sometimes decreased as water continued to drain from the canopy after the rain had stopped.

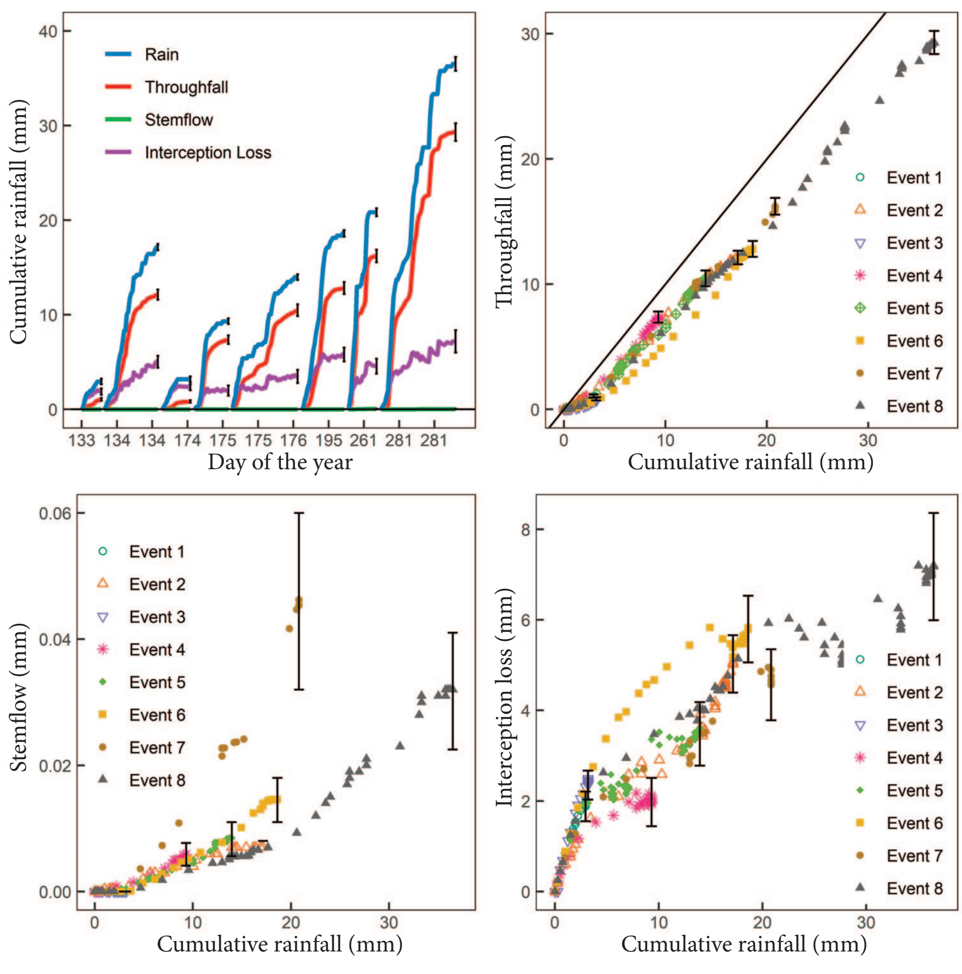

Figure 2: Cumulative rainfall, throughfall, stemflow, and interception loss (mm) for eight events in 1998 at Carnation Creek.

Notes: The upper left panel shows a time series of the half-hourly accumulation of the four components of the canopy water balance during each event. The accumulation of throughfall, stemflow, or interception loss as a function of the rainfall during each event is shown with error bars on the totals of each event and the 1:1 line (throughfall graph).

The events in Figure 2 ranged from 8 to 26 hours in length and 2.9 to 36.5 mm of rain. Weather conditions were similar between events with air temperature 5 to 14°C, relative humidity >90 percent, wind speed 0 to 3 m s^{-1} and total solar radiation 0 to 6 MJ m^{-2}. Events that occurred shortly after a previous event, e.g., events 2, 5, and 6 in Figure 2, tended to have greater throughfall and stemflow and slightly lower interception loss. Event 7 has stemflow that is greater than other events for the same rainfall. The short, intense nature of the event means that some of the rainfall may not have the opportunity to enter storage or evaporate and instead drained from the canopy. Longer events included periods of low and high rainfall intensity as well as no rainfall, resulting in substantial evaporation of intercepted water. The UPC sites have a similar pattern (not shown) to Carnation Creek; however, the transition between the two phases occurred between 1 to 2 mm of rainfall, because of a smaller storage capacity of the canopy. Stemflow was a much smaller fraction of an event than at Carnation Creek.

A selection of events at Carnation Creek and UPC were used to determine values for p, P', S, E/R, and E for the wetting and saturation phases (Table 5, Figure 3). Time series data for individual events were not available for Diana Lake and Smith Island. The variability in the coefficients is consistent with other studies (Link et al., 2004; Pypker et al., 2005; Grunicke et al., 2020) and indicates the influence of variability in the weather during an event and the assumptions of the methodology. The values of the throughfall coefficient and the saturation coefficient reflect the differences in canopy cover (Table 2) between Carnation Creek (p = 0.30±0.04, S = 2.0±0.2 mm) and the UPC sites (p = 0.61±0.03, S = 0.6±0.1 mm). The saturation capacity of the stems was estimated to be <0.02 mm for Carnation Creek and <0.002 mm for UPC_P7.

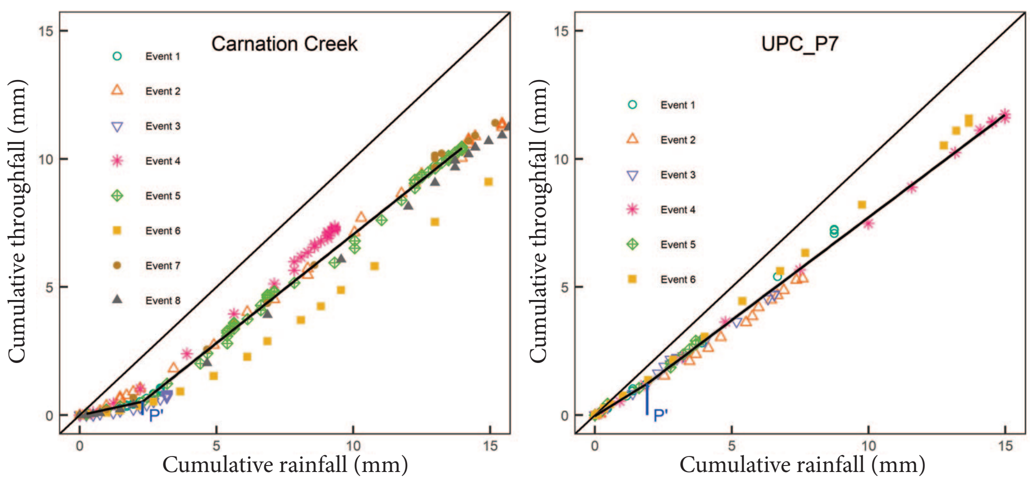

Figure 3: Cumulative throughfall and rainfall for the eight events shown in Figure 2 for Carnation Creek (left panel) and six events at UPC_P7 (right panel).

Notes: The vertical blue line indicates the location of P' at the intersection of the two regression lines. The relationship illustrated for Carnation Creek is for event 5: p = 0.23, P' = 2.3 mm, S = 1.8 mm and E/R = 0.15 mm mm^{-1}. For UPC_P7 it is for event 4: p = 0.66, P' = 1.9 mm, S = 0.7 mm and E/R = 0.2 mm mm^{-1}. The 95% confidence limits on the regression lines (shaded) and the 1:1 line are shown.

Table 5: Coefficients describing cumulative throughfall and rainfall based on individual events at Carnation Creek, UPC_P6, UPC_P7 and UPC_PG.

Location	*n*	*p* Avg. (SE)	P' mm Avg. (SE)	S mm Avg. (SE)	E/R Avg. (SE)	E mm h^{-1} Avg. (SE)
Carnation Creek	8	0.30 (0.04)	2.7 (0.2)	2.0 (0.2)	0.24 (0.04)	0.23 (0.03)
UPC_P6	6	0.65 (0.06)	1.4 (0.5)	0.5 (0.1)	0.17 (0.05)	0.16 (0.07)
UPC_P7	5	0.62 (0.04)	1.9 (0.4)	0.6 (0.1)	0.13 (0.02)	0.17 (0.03)
UPC_PG	5	0.54 (0.06)	1.3 (0.3)	0.6 (0.1)	0.26 (0.02)	0.14 (0.02)
UPC average	16	0.61 (0.03)	1.5 (0.2)	0.6 (0.1)	0.19 (0.02)	0.16 (0.03)

Notes: The average and standard error for *n* individual events are shown. See text for explanation of the symbols.

Evaporation per unit of rainfall (E/R) was similar between Carnation Creek (0.24±0.04) and UPC (0.19±0.02) with individual event evaporation rates varying from 0.05 to 0.4 mm h^{-1}. Long duration events of 50 to 100 mm in the winter at Carnation Creek had similar values for *p* and S and an average evaporation rate of 0.05 mm h^{-1}. Similar evaporation rates were calculated using the Penman-Monteith equation (Gash et al., 1999) and weather data measured at 2 m agl in nearby openings of 2 to 10 hectares.

Event-based analysis

Throughfall by event

The fraction of rainfall as throughfall increased as the size of the event increased (Figure 4). A second order polynomial provided a good fit to this relationship at all sites and the regressions for the three coastal sites were not different statistically at the 95 percent level. The relationships for UPC_P7 and UPC_PG were the same while UPC_P6 had slightly greater throughfall for all events.

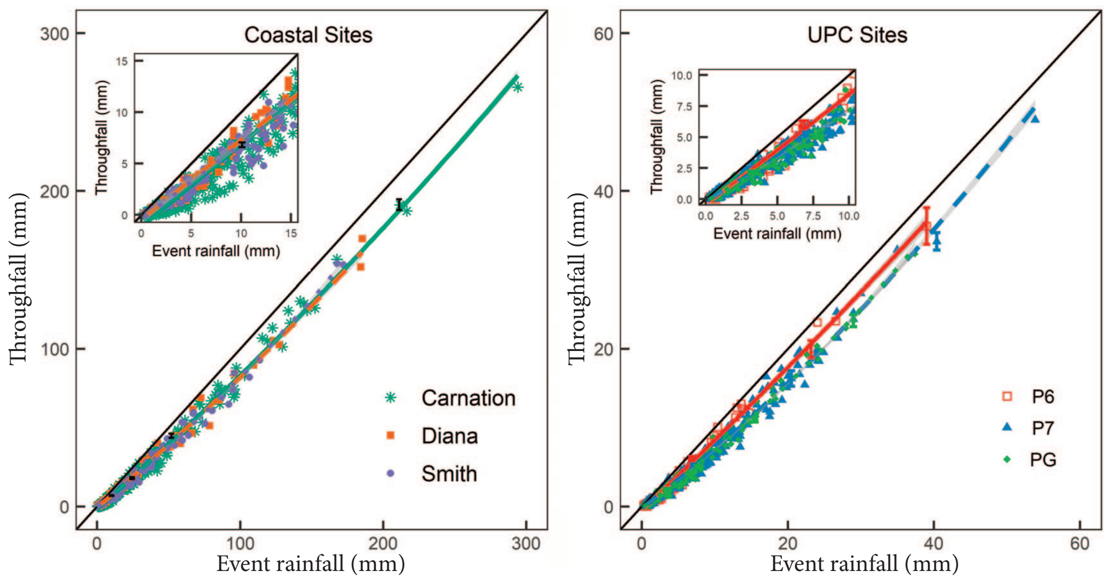

Figure 4: Throughfall and event size for coastal (left panel) and the interior (right panel) sites for all years at each site.

Notes: The inserts show throughfall for the low volume events. Second order polynomial regressions with 95 percent confidence intervals are shown. The black line is the 1:1 line. Examples of the bootstrap standard error for various event sizes are shown. Note the difference in scale between the two panels. The regressions are: Carnation Creek = -1.16 + 0.804*Event + 0004*Event^2 mm, R^2 =0.992, *se* = 2.3 mm, *n* = 567; Diana Lake = -0.47 + 0.769*Event + 0005*Event^2 mm, R^2 =0.992, *se* = 2.6 mm, *n* = 122; Smith Island = -0.45 + 0.720*Event + 0011*Event^2 mm, R^2 =0.993, *se* = 1.7 mm, *n* = 316; UPC_P6 = -0.02 + 0.682*Event + 005*Event^2 mm, R^2 =0.991, *se* = 0.5 mm, *n* = 185; UPC_P7 = -0.2 + 0.704*Event + 0045*Event^2 mm, R^2 =0.988, *se* = 0.6 mm, *n* = 575; UPC_PG = -0.2 + 0.682*Event + 005*Event^2 mm, R^2 =0.991, *se* = 0.5 mm, *n* = 186.

Determining coefficients for the wetting and saturation phases of event-based throughfall data for Carnation Creek and UPC_P7 is illustrated in Figure 5. As with the individual event analysis, the coastal sites had a higher storage capacity and lower throughfall coefficient than the UPC sites (Table 6). This is to be expected because the coastal sites had denser canopies (Table 2) and thus greater ability to intercept and store water. The Prince Rupert sites were intermediate between Carnation Creek and UPC. The average value of E/R for large events tended to be less than that for small events.

Table 6: Coefficients describing event-based throughfall and rainfall calculated for events starting with a dry canopy (at least 24 hours since the last event ended) at Carnation Creek, Diana Lake, Smith Island, UPC_P6, UPC_P7 and UPC_PG.

Location	*n*	*p* Avg. (SE)	P' mm Avg. (SE)	S mm Avg. (SE)	E/R Avg. (SE)
Carnation Creek	5	0.27 (0.08)	2.45	1.9 (0.2)	0.12 (0.03)
Diana Lake	2	0.51 (0.13)	2.0	1.1 (0.2)	0.15 (0.01)
Smith Island	3	0.39 (0.05)	1.7	1.1 (0.1)	0.18 (0.05)

Table 6 (continued)

Location	*n*	*p* Avg. (SE)	P' mm Avg. (SE)	S mm Avg. (SE)	E/R Avg. (SE)
UPC_P6	2	0.58 (0.05)	1.8	0.8 (0.05)	0.06 (0.02)
UPC_P7	10	0.57 (0.09)	1.75	0.8 (0.13)	0.16 (0.06)
UPC_PG	3	0.56 (0.03)	1.9	0.9 (0.05)	0.19 (0.06)

Notes: The average and standard deviation of the coefficients and number of years in the average (*n*) are shown. P' was assumed constant for each year at a site. See text for explanation of the symbols.

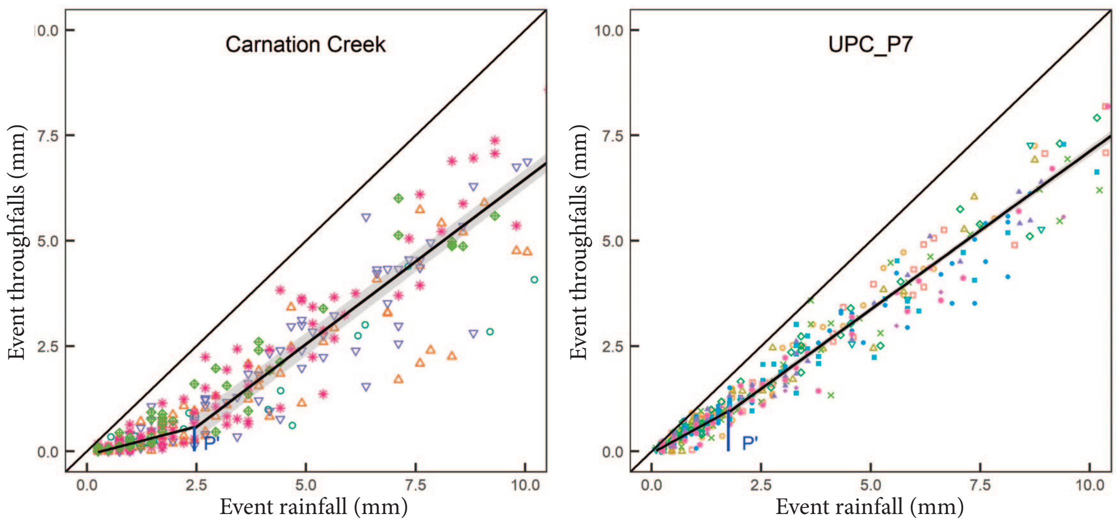

Figure 5: Event throughfall and rainfall at Carnation Creek (left panel) and UPC_P7 (right panel) for all years (coloured symbols).

Notes: The vertical blue line indicates the location of P' at the intersection of the two regression lines based on all of the data. For Carnation Creek: $p = 0.27$, P' = 2.24 mm, S = 1.9 mm and E/R = 0.22 mm mm^{-1}. For UPC_P7: $p = 0.57$, P' = 1.75 mm, S = 0.8 mm and E/R = 0.24 mm mm^{-1}. The 95% confidence limits on the regression lines (shaded) and the 1:1 line are shown. The figure is based on the data in the inserts of Figure 4.

As noted earlier, the variability around the regression lines depends on the weather conditions during the event, event intensity, and event duration. For example, for Diana Lake and Smith Island, average throughfall increased with an increase in event duration and event intensity and was greatest for high-intensity/long-duration events regardless of antecedent moisture conditions (Table 7). The difference in average throughfall between short and long events was greater for low-intensity events than for high-intensity events. Short, low-intensity events had slightly more throughfall under wet canopy conditions. Diana Lake had an overall higher fraction of the rainfall as throughfall than Smith Island as a result of its event size distribution (Table 3). However, as Figure 4 shows, the relationships between throughfall and event size for each site were similar.

Stemflow by event

As with throughfall, stemflow by event size showed a non-linear relationship and large variability (Figure 6). UPC_P7 had greater stemflow than UPC_P6 and UPC_PG. Stemflow required 3 to 10 mm of rain on a dry canopy to be initiated and then it increased with event size. However, if the canopy was wet from a previous event, stemflow started at lower event sizes. Differences in stemflow between trees at Smith Island and Diana Lake were related to tree size and whether trees were alive or dead (Table 8), with snags showing substantially less stem flow than live trees. An old Douglas-fir tree had the lowest stemflow at Carnation Creek. There was also a difference between species at UPC with Engelmann-spruce and subalpine fir trees showing less stemflow than the lodgepole pine trees.

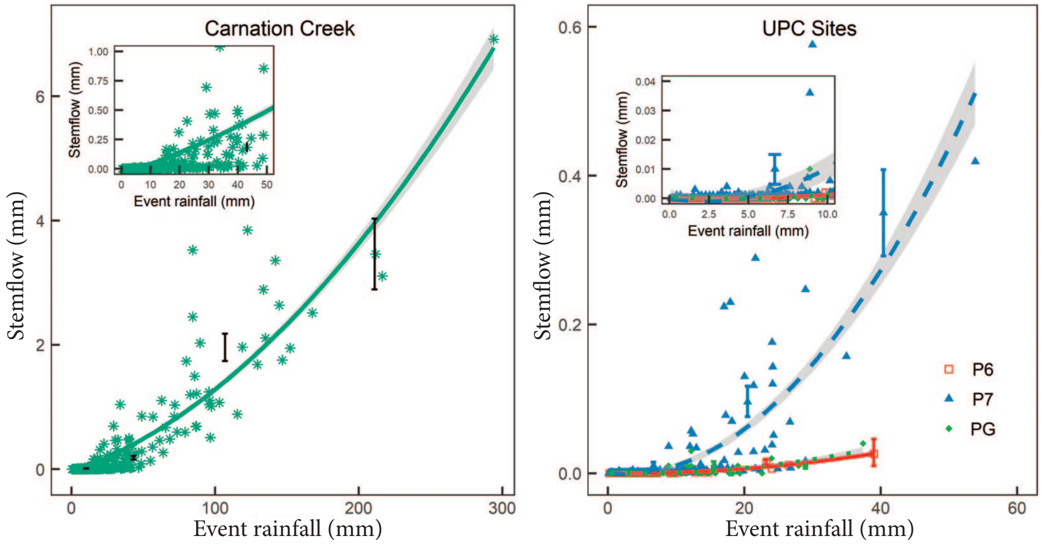

Figure 6: Stemflow and event size for Carnation Creek (left panel) and the UPC sites (right panel) for all years at each site.

Notes: The inserts show stemflow for the low volume storms. Examples of the error for various event sizes are shown for Carnation Creek, P6, P7 and PG. Note the difference in scale between the two panels. The regressions are: Carnation Creek = -0.005 + 0.0084*Event + 00005*Event^2 mm, R^2 =0.846, se = 0.22 mm; UPC_P7 = 0.0009*Event + 0002*Event^2 mm, R^2 =0.567, se = 0.03 mm; UPC_P6 and UPC_PG = 0.0004*Event + 00003*Event^2 mm, R^2 =0.528, se = 0.003 mm. The 95% confidence limits on the regression lines (shaded) are shown.

Table 7: Average throughfall as a percentage of event rainfall grouped into low and high average event intensity and three events lengths (hours) for Smith Island and Diana Lake.

Intensity	Low (≤1 mm h^{-1})			High (>1 mm h^{-1})		
Event length (h)	<5	5 to 24	>24	<5	5 to 24	>24
Smith Island	34	58	69	72	74	79
Diana Lake	30	69	77	67	80	81

Table 8: Stemflow as a percentage of total stemflow for trees less than and greater than 17.5 cm DBH and snags at Smith Island and Diana Lake.

	Smith Island – 1.2% of total rainfall			Diana Lake – 0.8% of total rainfall		
DBH (cm)	Samples	% trees	% stemflow	Samples	% trees	% stemflow
<17.5	5	63	53	7	68	68
>17.5	8	13	30	5	9	20
Dead	4	24	17	3	23	12

Note: Data are based on measurements from May through November in 1999 to 2001.

Stemflow was a small fraction of an event at all the sites. The maximum stemflow at Carnation Creek was 7 mm for a 300 mm event (approximately 2% of the event). Stemflow for UPC_P7 had a maximum of 2 percent of the rainfall for a 30-mm event, while stemflow at UPC_P6 and UPC_PG was only 0.1 percent of a similar sized event.

Interception loss by event

Interception loss varied substantially with event size (Figure 7) as a result of weather conditions during the event and how well the rain gauge measurement represented the amount of rain falling on the forests. The coastal and interior sites showed similar patterns of interception loss and event size with the fraction of an event lost decreasing as the event size increased. The interior sites had a lower maximum amount of interception loss. The low volume of stemflow means that it had negligible impact on the interception loss at all sites.

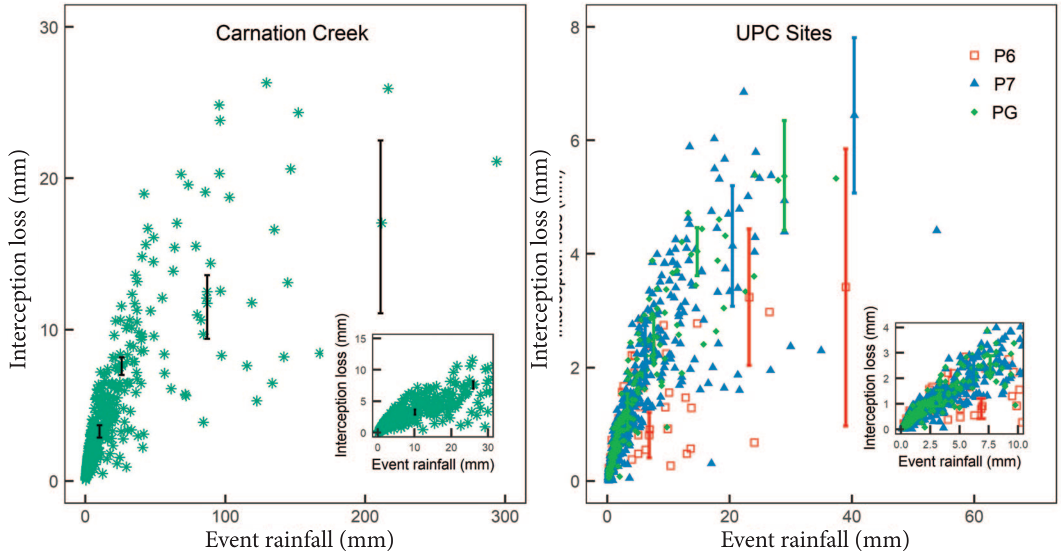

Figure 7: Interception loss and event size for Carnation Creek (left panel) and UPC (right panel) for all years at each site.

Notes: Examples of the standard error for various event sizes are shown. Note the difference in scale between the two panels.

Uncertainty in calculated interception loss is relatively large (Figure 7). At Carnation Creek, it varies from approximately 10 percent for events up to 50 mm, rising to over 20 percent for events greater than 100 mm. At UPC_P7, uncertainty is 20 to 25 percent of the interception loss for events from 5 to 40 mm. The rainfall and throughfall measurements contribute approximately 55 percent and 43 percent of the uncertainty. The increase in uncertainty for large events results because the rate of increase in interception loss decreases as event size and event uncertainty increase.

Seasonal throughfall, stemflow, and interception loss

There was substantial variation between months in the fraction of rainfall as throughfall, stemflow, and interception loss (Table 9). This was a result of the month-to-month variation in the distribution in event size and event duration and the weather conditions. For example, the smaller size of events in the summer resulted in a greater percentage loss to interception than in the other seasons. UPC_P7 and UPC_PG had similar throughfall and interception loss relationships while UPC_P6 had slightly greater throughfall and less interception loss. Although there is a difference in stemflow between UPC_P7 and UPC_PG, it had negligible influence on interception loss of the two stands.

Table 9: Monthly average rainfall (mm) and average percentage (%) of the rainfall as throughfall (TF), stemflow (SF) and interception loss (IL) at Carnation Creek (1995-1999) and UPC_P7 (1997-2008).

	Carnation Creek				UPC_P7			
Month	Rain mm	TF %	SF %	IL %	Rain mm	TF %	SF %	IL %
Jan	441.3*	84.6	1.6	13.8	NA	NA	NA	NA
Feb	189.3*	76.3	0.7	23.0	NA	NA	NA	NA
Mar	246.5	70.1	0.5	29.4	NA	NA	NA	NA
Apr	222.5	66.0	0.3	33.7	NA	NA	NA	NA
May	149.4	71.4	0.2	28.4	34.8*	68.8	0.1	31.1
Jun	149.0	69.5	0.1	30.5	70.5	73.0	0.1	26.9
Jul	69.0	59.7	0.2	40.2	48.5	67.5	0.1	32.4
Aug	70.2	55.2	0.1	44.7	38.0	66.8	0.02	33.2
Sep	147.3	68.3	0.2	31.5	54.1	70.9	0.2	28.9

Table 9: (continued)

	Carnation Creek				UPC_P7			
Month	Rain mm	TF %	SF %	IL %	Rain mm	TF %	SF %	IL %
Oct	284.7	74.7	0.6	24.7	27.0*	72.2	0.1	27.7
Nov	545.7*	83.9	1.6	14.5	NA	NA	NA	NA
Dec	317.6*	81.4	1.4	17.2	NA	NA	NA	NA

Notes: Asterisk indicates months that precipitation as snow is not included in the totals. NA indicates no monthly data at UPC_P7 due to snow.

Despite the large differences between the coastal and interior sites in the distribution of event size and in the amount of forest canopy, there was a similarity between the percentages of the annual rainfall as throughfall, stemflow, and interception loss (Table 10). Differences between coastal sites were related to their measurements occurring during different periods of the year and the distribution of event size (Table 3) as well as differences in interception characteristics.

Table 10: Averages for the measurement periods of rainfall (mm) and percentage (%) of the rainfall as throughfall (TF), stemflow (SF) and interception loss (IL).

Site	Years	Period	Rain (mm)	TF (%)	SF (%)	IL (%)
Carnation Creek	1995–1999	Jan–Dec	1771	76.1 (1.9)	1.0 (0.3)	22.9 (1.8)
Carnation Creek	1995–1999	May–Nov	923	73.8 (5.0)	0.7 (0.6)	25.5 (5.5)
Smith Island	1999–2001	May–Nov	1862	73.8 (5.6)	1.2 (0.1)	25.0 (5.8)
Diana Lake	1999–2001	May–Nov	1943	78.1 (1.2)	0.8 (0.1)	21.1 (1.2)
UPC_P6	1997–1998	May–Oct	154	77.4 (6.3)	0.01 (0.02)	22.6 (6.3)
UPC_P7	1997–2008	May–Oct	232	71.7 (3.5)	0.1 (0.1)	28.2 (3.5)
UPC_P7	2004–2006	May–Oct	297	69.9 (3.9)	0.1 (0.1)	30.0 (3.2)
UPC_PG	2004–2006	May–Oct	289	69.8 (2.5)	0.03 (0.02)	30.1 (2.4)

Notes: Data with standard deviations are shown for Carnation Creek, Smith Island, Diana Lake, UPC P6, UPC P7 and UPC PG. Periods where precipitation occurred as snow are not included.

Discussion

The results of this study are consistent with other mature coastal and interior forests in western North America (Table 1). At the Carnation Creek and Prince Rupert sites, the May to November throughfall averaged 74 percent to 78 percent, stemflow averaged 1 percent, and interception loss averaged 21 to 25 percent of the rainfall (Table 9). However, interception loss can be over 40 percent of the rainfall in the driest months. The difference in canopy cover at the three coastal sites does not result in a large difference in the partitioning of the rainfall. This may be because, as discussed later, interception loss appears to be dominated by evaporation during large events rather than the storage capacity of the canopy. Annually, interception of rainfall and its evaporation back to the atmosphere means that 20 to 30 percent of the rainfall never penetrates below the canopy (Table 10). This is greater than the fraction of precipitation as snow that is intercepted and sublimates back to the air (Rowe & Hendricks, 1951; Winkler et al., 2017, 2021).

The drier environment at UPC has similar average throughfall and interception loss fractions for the May to October period as the coastal sites. The interior sites do not generally experience winter rain and the average May to October monthly rainfall does not have a high variability. Consequently, interception loss generally does not show a large month-to-month variation except for months when the rainfall is substantially higher or lower than the average (Table 9). Although the UPC forest canopies are more open than the coastal sites (Table 2), they show a similar average percentage of the annual rainfall as throughfall and interception loss. This is partially a result of the distribution of events at UPC being dominated by smaller events, which have a greater fraction of the rainfall lost as interception than larger, long-lasting events such as occur at the coastal sites (Table 3). Coastal and interior sites have similar rainfall intensities and summer evaporation rates (Table 5).

The dryness of the canopy at the start of an event mainly influences the partitioning between throughfall and interception loss in the wetting phase, e.g., events of up to 3 mm for Carnation Creek. During the saturation phase the trajectory is similar for all events, and weather conditions during this phase of the event are the driver of interception loss. There seems to be some influence of canopy wetness prior to an event on stemflow in that flows are initiated earlier for wet canopies.

The canopy water storage capacity of the Carnation Creek forest (1.9 mm) is larger than that for the Prince Rupert forests (1.1 mm) and UPC forests (0.6 mm) (Tables 5 and 6). This likely reflects the difference in size of the canopies and canopy cover (Table 2). Consequently, the water storage capacity of these forests is small compared with the interception loss of large events (Figure 7). Canopy cover also influences the throughfall coefficient (p), which is smallest at Carnation Creek (0.3), followed by Prince Rupert (0.4 to 0.5) and UPC (0.6). These values of p and S are consistent with other studies (Zinke, 1967; Klaassen et al., 1998; Link et al., 2004).

Values of 0.07 to 0.26 for E/R for this study compare well with other studies (Klaassen et al., 1998; Link et al., 2004; Pypker et al., 2005). Average evaporation rates of 0.05 to 0.3 mm h^{-1} (Table 4) agree with direct measurement of evaporation from wet canopies (Humphreys et al., 2003; van der Tol et al., 2003; Cisneros Vaca et al., 2018). Consequently, during an event the evaporation from and replenishment of water in canopy storage result in large interception loss from coastal events that occur over two to three days.

Winkler et al. (2021) note that May to October transpiration at UPC ranges from 175 to 270 mm, which means that interception loss (Table 9) is 25 to 30 percent of total evaporation. This is similar to the global land surface average (Wei et al., 2017; Miralles et al., 2020). Temperate conifer forests in Canada have annual dry canopy evaporation (transpiration and soil surface evaporation) of 250–350 mm (Brümmer et al., 2012). Annual interception loss of rain from the Carnation Creek and Prince Rupert sites (Table 9) is greater than 400 mm, indicating a much greater contribution to total forest evaporation than for the UPC site. This is a result of the greater amount of rainfall and therefore interception loss at these sites. An estimate of annual evaporation of 700 mm or more from these coastal sites is consistent with data for other high rainfall regions (Baldocchi & Ryu, 2011).

As with any study, there are a number of caveats to the results. Uncertainty in calculated interception loss is relatively large, varying from 10 to 25 percent depending on event size. There is an approximately 60:40 split between the contribution of the error in the rainfall and throughfall measurements to this uncertainty. The small amount of stemflow relative to throughfall and interception loss means that stemflow contributes minimally to the uncertainty. Increased sampling would only marginally reduce throughfall uncertainty and higher rain gauge resolution would only be a benefit for small events. Another uncertainty is that the rainfall on the canopy may be different from that measured at the open area station 200 to 600 m from the forest. For example, the weather stations for UPC_P7 and UPC_PG are about 1 km apart and although they have similar totals for the May–October period, the difference between individual events varied from the gauge resolution (0.254 mm) to 10 percent of the rainfall in a large event. This is consistent with Nkemdirim and Meller (1982), who report a standard error of the mean of 10 to 45 percent for individual events of <10 mm for a similar gauge separation.

Stemflow sampling at Carnation Creek and UPC did not fully capture the variability between trees. The similarity between the annual stemflow for Carnation Creek and the larger number of trees sampled at Smith Island and Diana Lake is encouraging. However, because stemflow is such a small component of the canopy water balance, error due to the limited sampling of stemflow is within the uncertainty in the rainfall and throughfall measurements.

Saplings, shrubs, and forbs below the canopy will intercept some of the rain that penetrates below the canopy. However, their saturation capacity will be less than that of the forest and evaporation rates will be much lower than from the forest canopy. Consequently, depending on their density, their interception loss is likely within the uncertainty of the forest canopy interception loss.

This study confirms that interception loss in mature forests substantially reduces the amount of water reaching the ground. Removal of forest cover can produce measurable changes in streamflow (Winkler et al., 2010b). For example, Oda et al. (2021) note that the initial increase in streamflow after clearcutting a small forested watershed in Japan was similar to the decrease in interception loss. However, material left after tree removal intercepts rainfall. For example, Kelliher et al. (1992) found that debris left after a thinning operation in a Douglas-fir stand intercepted 11 percent of the rainfall. Plamondon et al. (1984) measured interception loss of 32 percent of the summer rainfall by debris and shrubs in a well vegetated clearcut. Young forests with low canopy volume have lower interception loss than that of mature forests (Table 1). Consequently, depending on the rate of regrowth after disturbance, it may take decades for rainfall interception loss to approximate that of mature forests.

Conclusions

Rainfall interception loss was assessed for six forest stands in three climate regimes in the coastal and southern interior regions of British Columbia. Interception loss varied with the size, length, and intensity of the rainfall event and the evaporation rate of intercepted water during the event. Water storage capacities of the forest canopies were relatively small (0.6 to 2 mm), thus for events greater than 20 mm interception loss was dominated by the evaporation and replenishment of intercepted water in storage during the event.

Despite large differences in size of the forest canopies there was a strong similarity in the partitioning of the seasonal rainfall into throughfall, stemflow, and interception loss between the coastal and interior stands. This is related to the compensating effects of the different distribution of event size between the coastal and interior climate regimes and the evaporation of intercepted water during the event. On an annual basis interception loss averaged 21 to 30 percent of the annual rainfall depending on the climate regime and forest cover.

Uncertainty in measured interception loss is relatively large, varying from 10 to 25 percent depending on event size. Increased sampling would only marginally reduce throughfall uncertainty and higher rain gauge resolution would only be a benefit for small events. There would be negligible gain in accuracy from an increased number of stemflow measurements in this study; however, the greater stemflow of young trees requires a larger sample size for accurate measurement.

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Data availability

Data for the Upper Penticton sites can be found at https://zenodo.org/record/5519654 (Moore et al., 2021). Data for the Carnation Creek and Prince Rupert sites are available from the authors.

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