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THE RELEASE OF WATER FROM FOREST SNOWPACKS DURING WINTER

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ABSTRACT

In the northern Rocky Mountains, in Idaho, data collected during three winters demonstrate why there is always less snow beneath the canopy of a cedar-hemlock forest than in the adjacent small openings. The author presents as evidence the differential release of water, which originates in the canopy as throughfall-drip, thus accounting for part of the deficiency in snow water equivalent beneath the canopy by April 1. Such informative data were made possible by a new instrument designed to collect waterflow from the snowpack.

INTRODUCTION

Processes affecting the amount of snowfall that penetrates the canopy of coniferous forests and reaches the ground surface are largely unknown to snow hydrologists. Comparisons of the amounts of snow on the ground almost invariably show less snow under the crowns than in the adjacent opening; but, according to Hoover (4) this leaves unanswered the following questions:

(a) Is the deficiency of accumulated snow in the forest a result of evaporation of snow from tree crowns?

(b) Was intercepted snow blown off the tree crowns and redeposited into the opening?

(c) Or did the wind eddies caused by the surrounding tree crowns deposit excess snow in the opening and, conversely, deposit less in the forest?

Surprisingly, after one hundred years of research, there remains a deficiency of basic data to answer these questions and a lack of suitable instruments for resolving the problem (7).

We are looking at this problem from a new point of view--the base of the snowpack. At the Priest River Experimental Forest (latitude 48°21'N., longitude 116°47'W.) in the northern Rocky Mountains, in Idaho, we have asked the question: Is the deficiency of snow in the forest a result of greater release of water from the snow mantle beneath the tree crowns? As a partial answer, this report describes a new instrument designed to collect outflow from the snowpack; and it also summarizes data on the releases of water in the undisturbed forest and small openings on two slope aspects over a 3-year period. We offer as evidence the differential release of water as accounting for part of the deficiency in snow water equivalent beneath the canopy by April 1.

This investigation is part of continuing research being conducted by the USDA Forest Service to develop management systems for the mountainous forests in the West where winter snowfall provides much of the water.

STUDY METHODS

The study area lies between 4,000 and 5,000 feet elevation in the rugged, upper portion of the Priest River Experimental Forest. The area is divided into north and south aspects by a sharp-crested ridge, which extends 1,200 feet higher to the summit of the Selkirk Mountain range. The forest ecosystem is comprised predominantly of western hemlock (*Tsuga heterophylla* (Raf.) Sarq.), western white pine (*Pinus monticola* Dougl.), and western redcedar (*Thuja plicata* Donn.), undisturbed by man and mature in age (fig. 1). Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco), western larch (*Larix occidentalis* Nutt.) and Engelmann spruce (*Picea engelmannii* Parry) are intermingled but subordinate in volume on the moist north aspect. On the drier south aspect, western hemlock and western redcedar are usually missing from the mixture and Douglas-fir assumes a dominant role. The general canopy is 120 to 140 feet tall and very dense on the north aspect; it is 20 to 30 feet shorter and more open on the drier south aspect.

Influenced by the Pacific Ocean, the winters are cool and wet and the summers dry. Winter temperatures are less severe than in the higher elevations of the Rocky Mountains. Storm-bearing winds usually sweep in from the southwest. Occasionally, during the winter a continental storm will come from the east and northeast. Year-long precipitation averages over 40 inches.

Instrumentation.--During the planning stage, we were confronted with the lack of a suitable instrument to measure directly the outflow from beneath a snowpack. The problem was solved by designing a snow lysimeter based on a concept used earlier by the Corps of Engineers at the Central Sierra Snow Laboratory (9).

The snow lysimeter collects outflow in a ground-level pan (fig. 2) from an undisturbed, finite column of snow deposited in place (fig. 3). A thin layer of polyethylene encloses the column of snow and prevents lateral flow from entering the lysimeter. (The cross-sectional area of the column and pan is 2.7 sq. ft.) As the effluent drains into a catchment tank it is monitored continuously by a water level recorder. The outflow, depending upon the nature of the storm or thawing condition, represents an integrated measure of rain, throughfall-drip, and snowmelt percolate. The installation and routine operation of the lysimeter are more fully described elsewhere (2,3).

Figure 1.--Cedar-hemlock ecosystem surrounds lysimeter station 42.

In this study, six lysimeter stations are grouped in pairs as follows: station 39 adjacent to station 40 and station 45 adjacent to station 42, both pairs situated on the north aspect; and station 49 adjacent to station 47 on the south aspect. A distance no greater than 300 feet separates the stations in each pair. The three pairs were placed into operation in 1967, 1968, and 1969 in the order mentioned. In relation to forest cover, station 39 is located in the northeast quadrant of a small, manmade clearing; stations 45 and 49 are situated midway across long, 50-foot-wide clearcut strips. These stations represent the situation termed "small opening." The "forest condition" includes stations 40, 42, and 47 positioned well into the undisturbed forest. These stations lie within the drip zone of a major tree species but away from the annular zone of the tree bole. Other descriptive details of each lysimeter station appear in table 1.

Weather stations provide precipitation and temperature data to complement the lysimeter information. Each weather station is mounted on an elevated platform (fig. 4), situated near the lysimeter. In the forest, the weather station is located underneath a tree with a canopy configuration similar to that over the lysimeter; in the small opening, the station is nearly the same distance from the bordering trees as is the lysimeter.

The precipitation instruments are incapable of separating rain from snow; therefore, observed rainfall (in the small opening) is determined indirectly by comparing the catch of precipitation with ambient air temperature recorded in a standard (ventilated) shelter. It is assumed that rain occurs if the temperature is greater than 33° F. There are exceptions when snow falls during a storm, although the temperature indicates rain or vice versa.

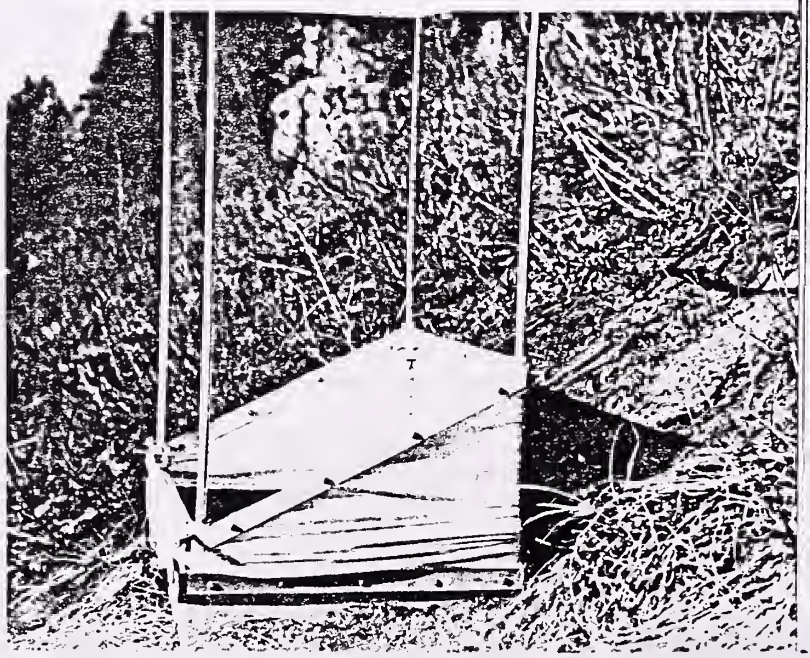

Figure 2.--Typical lysimeter pan with rod-frame, sliding collar, and polyethylene bag attached. Inclination of collar is parallel to angle of ground surface.

Figure 3.--Lysimeter station 42 shows a snow column depth of approximately 43 inches (measured March 31, 1971). Completely hidden is the thin layer of polyethylene which separates the snow column from the surrounding snowpack.

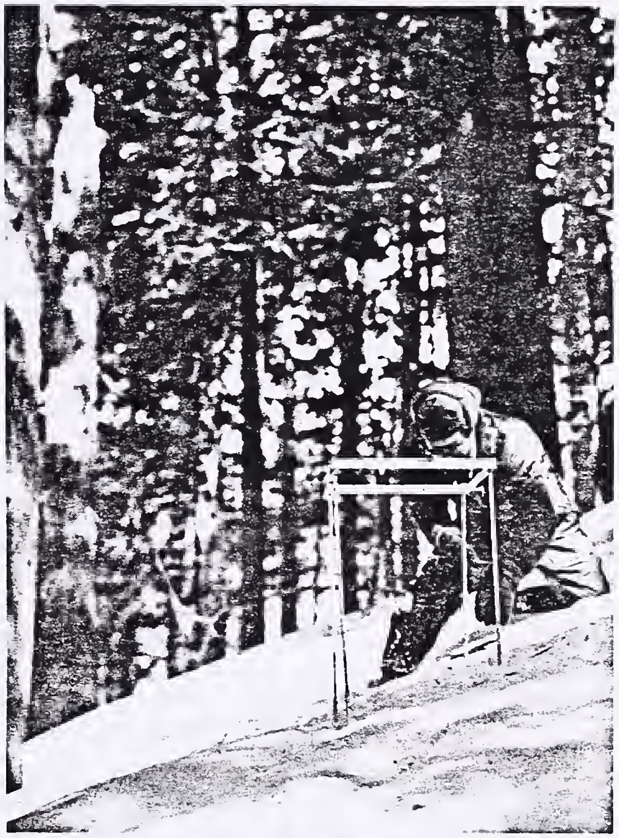

Figure 4.--Weather station 45, shown mounted to a culvert pipe which provides entry to the catchment tank of lysimeter station 45.

Table 1.--*Characteristics of lysimeter stations, Priest River Experimental Forest, Idaho*

Lysimeter station	Aspect	Elevation	Slope inclination	Description of station site: Small opening	Description of station site: Undisturbed forest	Horizontal distance to nearest tree crown
		Feet	*Percent*			*Feet*
40	N	4,000	27		Range of dominant tree heights, 120-140 feet; crown closure, 90-100%	0
39	N	4,000	30	Circular-shaped clearing, diameter averages 100 feet		14
42	N	4,300	48		Range of dominant tree heights, 120-140 feet; crown closure, 90-100%	0
45	N	4,300	38	Clearcut-strip, 50 by 600 feet, long-axis oriented N-S		25
47	S	4,600	44		Range of dominant tree heights, 90-100 feet; crown closure, 20-30%	0
49	S	4,600	51	Clearcut-strip, 50 by 650 feet, long-axis oriented N-S		25

During a snowstorm the loading of snow in the canopy is determined by comparing the rate of snow catch in the precipitation gage in the forest with the rate measured in the small opening. A rapid rate of catch in the small opening occurring simultaneously with a substantial reduced rate of catch in the forest indicates that the trees are loading. If little or no snow slides off the canopy into the precipitation gage between storms, it is assumed the canopy is retaining its snow load. This documental evidence is partially confirmed by weekly visits to the sites.

The lysimeter and weather stations are operated continuously through the accretion (winter) and ablation (spring) periods. This paper will deal only with the winter period; November-March, inclusive, on the north aspect and November-January, inclusive, on the south aspect. In 1970, the spring season on the south aspect began in February.

Data analysis.--Computation of the total volume of outflow for the lysimeter represents a straightforward summation of instantaneous hourly flow rates converted to area-inches.

A more complex analysis involves the partitioning of outflow into its components of origin--*rain percolate* (in the small opening), *throughfall-drip percolate* (in the forest), and *snowmelt percolate* from the snowpack proper. This analysis is based primarily upon a number of generalized assumptions dealing with the disposition of rainfall, throughfall, and drip that occur during and after storms. The entire scheme is undergoing refinement; the approach presented in this paper is an earlier version and has certain limitations that will be discussed subsequently.

The partitioning of outflow in the small opening depends upon the amount of observed rainfall. If outflow is equal to or less than observed rainfall, it is defined as rain percolate. Excess outflow, or that which exceeds the observed rainfall, is called snowmelt percolate. In a sheltered opening, such as found on the north aspect, the gage rainfall catch represents a realistic estimate of the amount of rain that actually infiltrates the snowpack. In a windblown opening, on the south aspect, the gage rainfall catch measured less than that which actually reaches the snow surface. Thus, the snowmelt percolate portion of the outflow is very likely an overestimation.

The separation of outflow in the forest hinges first on two basic assumptions: (a) That the amount of rainfall observed in the opening is the same amount as the rainfall incident on the canopy; and (b) that a small portion of rainfall (about 20 percent) is intercepted by the canopy and lost for the duration of the storm. The larger portion of rainfall that is not intercepted is defined as throughfall.

Throughfall-drip percolate includes the following: (a) Throughfall from a canopy bare of snow which in turn percolates through the snowpack into the lysimeter; (b) drip from melting snow held in the canopy during a storm-free period which in turn percolates through the snowpack; or (c) combined throughfall and drip during rain on canopy-held snow. Drip in this experiment refers to drops of melt water falling from canopy-held snow; it does not include small releases of snow. Throughfall-drip percolate may include some melt from the snowpack during hours when the percolate is passing through the snowpack. During warm, storm-free periods and in the absence of snow in the canopy, all outflow in the forest originates as snowmelt percolate.

Recession flow, which drains slowly from the snowpack, is assigned to the previous outflow event on a prorated basis either as rain, throughfall-drip, or snowmelt percolate. Recession flow near the end of depletion may be a few thousandths of an inch per day; therefore, it may require days to accumulate to 0.01 inch in the catchment tank.

An example of the daily separation of water released from the snowpack at stations 42 and 45 for February 6-12, 1970, is presented in table 2.

Table 2.--*Example of the daily separation of water released from snowpack in the lysimeter for stations 42 and 45, February 6-12, 1970*

February 1970	Maximum air temperature	Precipitation	Presence of snow in canopy	Throughfall-drip percolate	Snowmelt	Total outflow
	°F	*Inch*		*Inch*	*Inch*	*Inch*
FOREST [STATION 42]						
6	30	0.00	Canopy covered	[1]0.01		0.01
7	33	[2].46	do			.00
8	35	[2].41	do	.05		.05
9	39	[2].08	Canopy partially bare	.13		.13
10	40	.00	Canopy bare (observed)	[1].03	.05	.08
11	41	.00	Canopy bare		.05	.05
12	37	.00	do		.07	.07
Total		.95		.22	.17	.39
SMALL OPENING [STATION 45]						
				Rain percolate	Snowmelt	
6	31	.08	--			.00
7	35	.00	--			.00
8	37	.00	--			.00
9	42	.00	--			.00
10	42	.00	--	[1].01		.01
11	42	.00	--			.00
12	39	.02	--	.02	.02	.04
Total		.10		.03	.02	.05

[1]Accumulated recession flow, previous event.
[2]Released as sliding snow and drip from canopy.

EXPERIMENTAL RESULTS

Precipitation and snowpack.--In the upper reaches of the Experimental Forest, wind reduces the efficiency of precipitation (shielded) gages. This effect results in reduced totals, especially in the openings on the south (windward) aspect. Therefore, it is assumed that the catch in the small openings on the north (leeward) aspect come nearer to representing the "true" precipitation. At these sites, seasonal precipitation ranges from 20 to 26 inches (table 3). The amounts were above average at this elevation during the 1968-1969 season and near average during the 1967-1968 and 1969-1970 seasons.

The gages at the forest and small opening sites may register different phases and amounts of precipitation during and after individual storms for reasons not related to the wind factor. For instance, if the trees at the beginning of a storm are bare or nearly bare of snow and the storm is comprised of snow, the gage in the small opening will indicate a much greater catch by a wide margin than the gage in the forest because the overhead canopies are loading and temporarily detaining the snowfall. On the other hand, if it rains when the canopies are snow-loaded from a previous storm, the gage in the forest will invariably show a greater catch than the gage in the small opening because of the addition of sliding snow and drip from the canopy. Occasionally, during storm-free periods, sliding snow and drip will be measured in the gage beneath the canopy; of course, nothing will register in the gage in the small opening (see the precipitation column for February 7-9 in table 2).

Rainfall is interspersed with snowfall during early November which is the period of transition. By December the annual snowpack begins to accumulate, although rainstorms occur infrequently after that time. At the end of the winter season, total rainfall may amount to several inches (table 3). On the north aspect, the snowpack usually attains maximum depth in late March. On the south aspect, the start of the ablation period may occur 40 to 55 days earlier. As expected, the greatest depth of snow (table 3) is in the small openings.

Table 3.--*Seasonal precipitation, maximum snow depth, amount of rain, total outflow, and components of outflow (rain percolate, throughfall-drip percolate, and snowmelt percolate) in inches*

Forest stations				Small open stations		
40	42	47		39	45	49
			1967-68			
			Total precipitation	20.26		
24			Maximum snow depth	44		
			Amount of rain	5.10		
18.24			Total outflow	12.79		
			Rain percolate	3.92		
8.34			Throughfall-drip percolate			
9.90			Snowmelt percolate	8.87		
			1968-69			
21.17	22.53		Total precipitation	26.34	23.93	
50	70		Maximum snow depth	78	82	
			Amount of rain	4.55	6.27	
9.44	9.91		Total outflow	7.70	8.56	
			Rain percolate	4.04	5.21	
5.65	6.61		Throughfall-drip percolate			
3.79	3.30		Snowmelt percolate	3.66	3.35	
			1969-70			
17.64	19.67	[1]14.71	Total precipitation	21.58	20.83	[1]10.96
39	45	49	Maximum snow depth	72	71	68
			Amount of rain	2.84	4.18	[2]1.36
6.69	6.23	6.91	Total outflow	4.06	3.97	3.32
			Rain percolate	2.71	3.08	1.36
5.82	5.38	5.45	Throughfall-drip percolate			
.87	.85	1.46	Snowmelt percolate	1.35	.89	1.96

[1]November-March, inclusive.
[2]November-January, inclusive.

During 1967-1968 the forest accumulated a very shallow snowpack (24 inches) which did not persist over the usual period because of unseasonable melting in late February and early March. By early March, the lysimeter in the forest became bare several weeks before the lysimeter in the small opening. Actually, the ablation season in 1968 began well before April 1; yet the data are of interest and are included in the report because of the unusual magnitude of melt in midwinter.

Gross release of water from snowpack.--Lysimeter outflow occurred in each of 56 station-months included in the study. Except for brief periods during each November and in March (1968), the outflow drained from an established snowpack. The monthly values range as low as 0.02 inch and as high as 6.72 inches; they also display a diverse range in values among months in each station-year. In contrast, seasonal totals among stations show a fairly consistent relationship from year to year. All-station outflow was roughly the highest during 1967-1968, intermediate during 1968-1969, and lowest during 1969-1970. A complete tabulation of seasonal outflows is presented for each year, by study, in table 3.

By comparing the lysimeter outflow with precipitation observed during all 3 years at station 39, we find that 63 percent of the precipitation observed during 1967-1968 had drained from the snowpack by April 1; during 1968-1969 the release by April 1 was 29 percent; and during 1969-1970 the release was only 19 percent prior to the spring season.

Sources of water released from snowpack.--Except for a few of the months of study, throughfall-drip percolate in the forest exceeded rain percolate in the small opening. Throughfall-drip percolate reached significant proportions during brief periods of general thaw from December through March. Four weather events in the interval of December 1969 to January 1970 are cited as typical examples of water being released at moderately high rates in the forest and small openings. The individual events plot as rather sharp inflections on the six accumulation curves in figure 5. The extended rises on the three curves for the forested stations include additional water that apparently resulted from melting snow suspended in the trees. (The suspended snow had accumulated in the canopies prior to each general thaw.) All four events in this example are associated with rainfall and a warming trend. In fact, much of the throughfall-drip percolate originates as rain filtering through suspended snow melting in the canopy. At the end of two of the four events, the canopies were completely bare of snow.

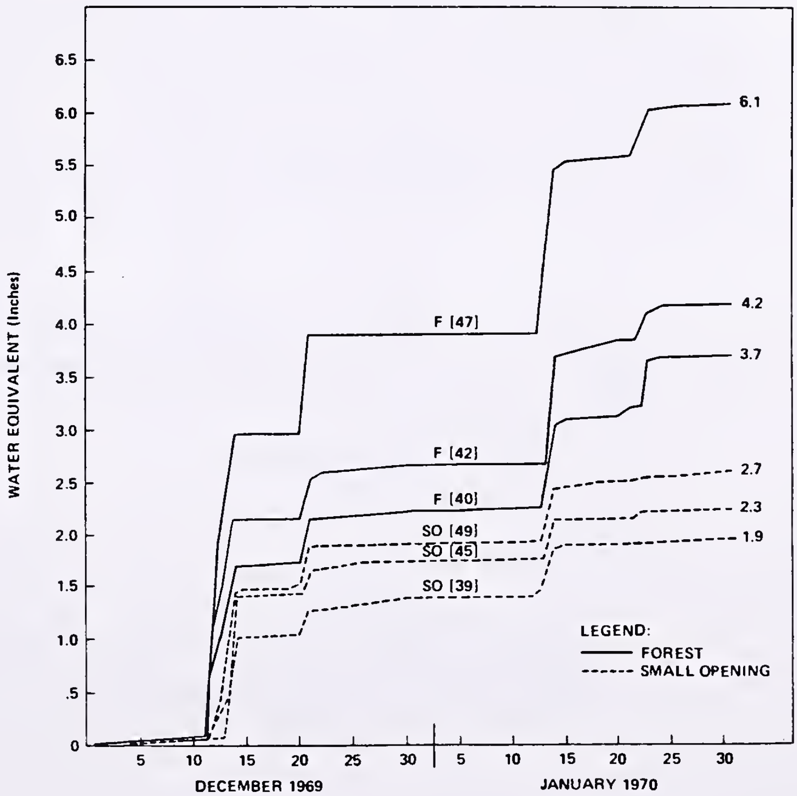

Figure 5.--Accumulated release of water from snowpack for representative period, December 1969-January 1970, at small opening stations SO[39], SO[45], and SO[49], and forest stations F[40], F[42], and F[47]. Number at end of curve represents total release of water in inches for 2-month period.

Table 4.--*Sources of outflow at small opening station 39 and forest station 40 in midwinter, 1968*

Date	Small opening station 39	Sources of outflow	Forest station 40	Sources of outflow	Presence of snow in canopy
	Inch		*Inch*		
February					
11			0.11	M	CB
12			.07	M	CB
13			.05	M	CB (observed)
14					CB
15					CB
16					CB
17					CC[1]
18	0.13	R	.79	T-D	CC[1]
19	.47	R,M	.76	T-D,M	CC-B
20	.42	R,M	.38	T-D,M	CB (observed)
21	.58	R,M	.63	T-D,M	CB
22	.24	R,M	.18	T-D,M	CB
23	.69	R,M	.70	T-D,M	CB
24	.19	M	.18	M	CB
25	.11	M	.20	M	CB
26	.18	M	.27	M	CB
27	.15	M	.35	M	CB (observed)
28	.19	M	.38	M	CB
29	.29	M	.56	M	CB
March					
1	.40	M	.73	M	CB
2	.50	M	.74	M	CB
3	.85	M	[2].83	M	CB
4	.96	M	[2].67	M	CB
5	.73	R,M	[2].39	T-D,M	CB (observed)
6	.13	M	[2].04		CB
7	.04	M	([3])		CB
8	.01	M	([3])		CB
9	.01	M	[3].01	M	CB

LEGEND

R--Rain percolate
T-D--Throughfall-drip percolate
M--Snowmelt percolate
CB--Canopy bare
CC--Canopy covered
CC-B--Canopy partially covered

[1]Storm on February 17-18 precipitated 0.93 inch snow (W.E.) and 0.16 inch rain (sta. 39).
[2]Lysimeter pan partially bare of snow.
[3]Lysimeter pan contained trace of snow.

Of special interest is the amount of throughfall-drip percolate that occurred at station 47 on the south aspect. Water contributed by throughfall and drip at this station is large in comparison with stations on the north aspect (table 3). The contribution for the 2 months exceeded that of station 40 and station 42 by 1.71 inches and 1.31 inches, respectively.

Snowmelt as defined in this study did not occur in every month of the experiment. For instance, during November 1967 melt did not occur because precipitation fell as rain early in the month and drained promptly from the lysimeter pan to catchment tank. By the end of November, snow fell and remained frozen.

Melt rates from February 24 through March 2, 1968, were abnormally high at the forest station. Prior to February 24, a storm precipitated snow on the 17th; by the next day it turned to rain, continuing to produce rain intermittently through February 23. After clearing (unlike poststorm trends in other winters), the weather remained very mild and clear until after March 2. Snowmelt percolate in the forest for the 8 consecutive days was 70 percent greater than in the small opening (table 4). Throughout the period of clear weather, the canopies were bare of snow; therefore, they did not contribute drip to the snowpack.

From the ablation season (March 26, 1969, until March 31--all clear days), rates of melt were consistently greater in the forest (stations 40 and 42) than in the small openings (stations 39 and 45). There were other isolated periods during winter when rates of melt in the forest were greater (tables 2 and 4). However, the relationship was not consistent; melt in times of cloudy weather generally proved to be slightly greater in the small openings.

Differential release of water from snowpack.--Differential release of outflow is evident between the forest and small openings and between north and south aspects. Mention has already been made of how drip and snowmelt apparently account for most of the variation. A plotting of individual monthly differences as well as the algebraic sum of monthly differences shows the overwhelming effect of the forest in speeding up the release of water (figs. 6 and 7). With exception of four out of six comparisons in November, all remaining comparisons for December, January, February, and March show a difference in favor of the forest condition. Numerically the forest differences for the season range from 1.35 inches in the lowest year to 5.45 inches in the highest year (table 3).

Topographic exposure apparently has an additional effect on seasonal outflow. Based on the months of November, December, and January, outflow from all stations on the south aspect averaged 5.12 inches compared with 3.88 inches on the north aspect. This comparison pertains only to the 1 year (1969-1970) when data were taken on the south aspect.

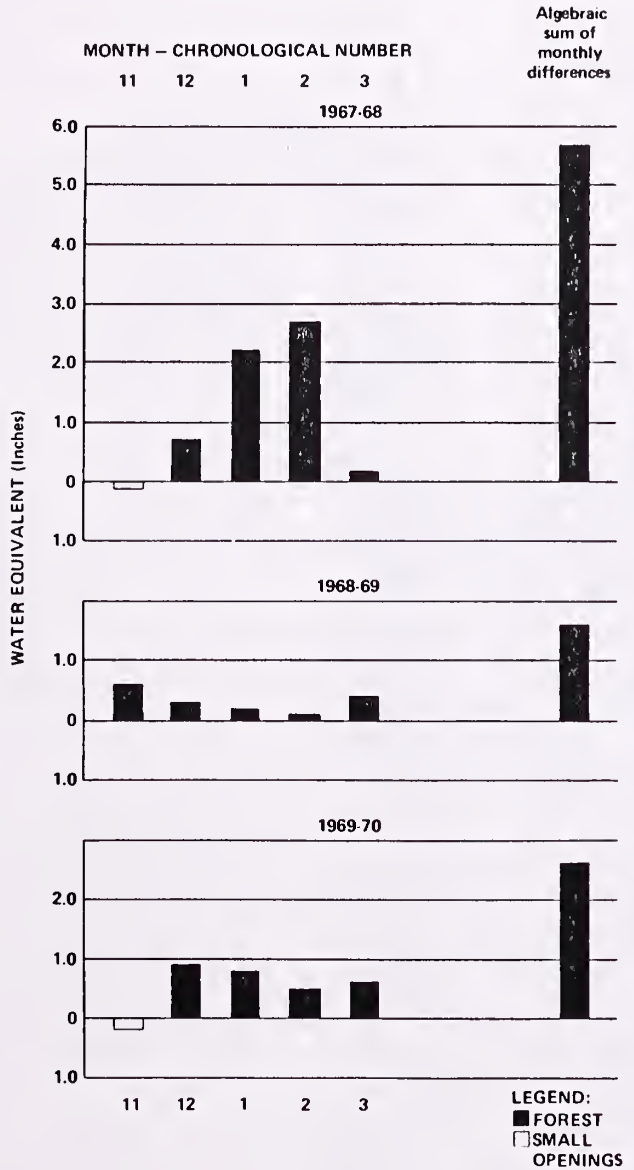

Figure 6.--Monthly and seasonal differences in release of water from north aspect snowpack at forest station 40 and small opening station 39.

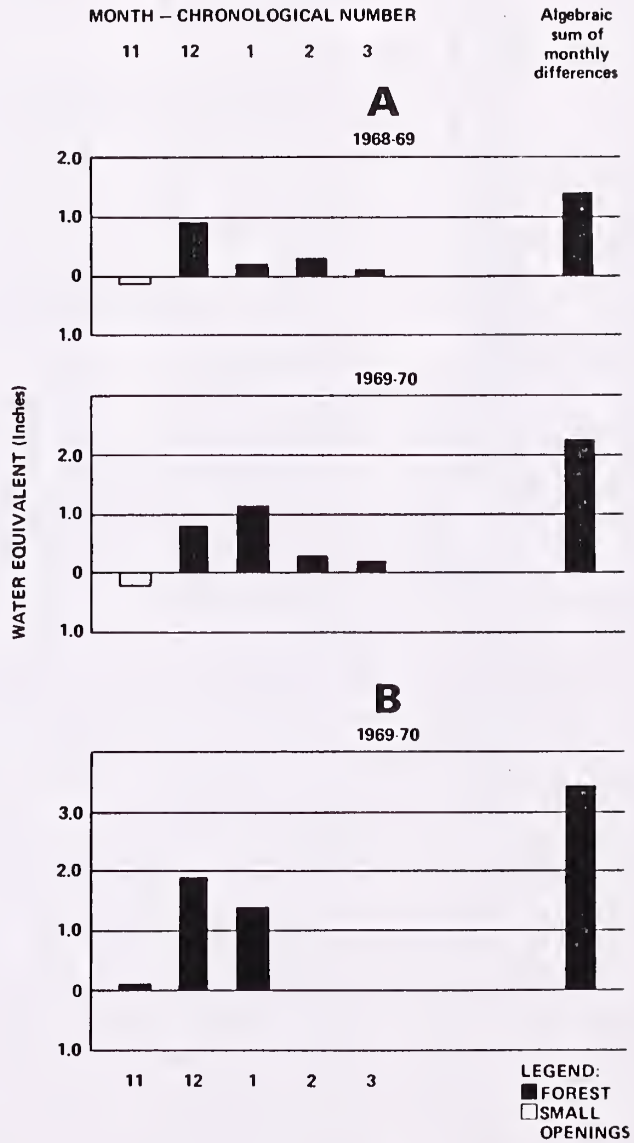

Figure 7.--Monthly and seasonal differences in release of water from snowpack in (A) forest station 42 and small opening station 45 and (B) forest station 47 and small opening station 49 on the south aspect.

DISCUSSION

Results of the study show that mature forest cover and topographic exposure greatly influence the release of snow water to the soil mantle. Rainfall prevails at the beginning of winter (early November), and more water is usually available to recharge the soil mantle in small openings than in the forest. Less rainfall reaches the soil in the forest because of canopy interception and retention. With the advent of snowfall (late November) and for the remainder of winter, the situation is reversed; water is released from the snowpack and recharges the soil mantle faster in the forest than in the small openings. Although the results are preliminary, there is some indication that the forest influence is stronger on south than on north aspects.

Throughfall-drip, originating in the canopy, is the major contribution to the greater release of water in the forest. This source of water in turn is strongly dependent upon the detention of snow in the canopy. In the Priest River climate, the deep, thick crowns of mature trees catch and temporarily hold large quantities of snow. This detention capability may relate initially to a favorable air temperature during a snowstorm. The temperature, which seldom goes below 20° F. and generally exceeds 25° F., may ensure high snow density and strong adhesion of snowflakes to the foliage. Rime formation may also contribute to the cohesiveness of snow particles to a minor degree, but we have not assessed this possibility; however, Berndt and Fowler (1) reported that rime formed concomitantly with snowfall. Their work was conducted west of Priest River Experimental Forest at an elevation of 6,100 feet in eastern Washington.

Although the temperature during a storm may contribute to detention of snow, tree-branching characteristics very likely play an important role. In observing sapling trees at a lower elevation (2,500 feet), we have found that the bulk of the snow readily slides off the narrow, limber branches in a matter of hours after each storm (8). The stiffer branches and wider foliage of mature trees at a higher elevation (4,300 feet) provide a more sturdy "platform" for holding snow loads.

Comparison of precipitation records in the forest and small openings as well as close observations on weekly trips to the study site indicate that snow tends to persist on the mature trees--sometimes for several weeks. Unlike the climatic conditions in Colorado (5), very little snow blows off the canopy and redeposits in the small openings. When snow does dislodge, usually it falls to the forest floor as massive wet clumps.

This lengthy persistence of snow in the canopy enhances the opportunity that the snow will be acted upon either by subsequent storms or by clear weather conducive to evaporation or melting. It is not uncommon for a new storm following in the wake of an old storm to be accompanied by above-freezing temperatures and thus produce rain. The rainy, thawing condition rapidly changes the physical properties of canopy-held snow and drip begins to fall within a short time. Snow clumps heavy with water slide out of the trees, but much of the intercepted snow holds fast to branches and foliage until dissipated by melting. (Our field crews often experience considerable discomfort when working under the canopy on a "heavy-drip" day.)

Noteworthy information derived from the study has been the high intensity and volume of outflow (primarily throughfall-drip percolate) recorded in the forest usually on the beginning day of a rainy, thawing condition. This volume of outflow often exceeds the outflow (primarily rain percolate) in the small openings by a wide margin. By inference, the excess outflow is attributed to drip from snow held over in the canopy from a previous snowstorm.

This poses the question as to whether the entire contribution of excess outflow has its origin as drip from snow in the canopy. There are two other possible sources--differential input by rainfall and differential melt in the snowpack. There is no scientific evidence to show that rainfall incident on the canopy is substantially greater than that which falls in the small openings. Most investigators claim that the input to the forest canopy may in fact be less than in the openings (7). Indeed, if this is the case, then by our analysis technique the outflow assigned to drip is a conservative estimate.

There is the theoretical chance that more heat energy from the warm air masses is absorbed by the crowns and transmitted to the snowpack by convection and radiation. We discount this possibility because, during periods when canopies are bare of snow and warm air masses are passing in absence of rain (i.e., warm winds or Chinook conditions), the lysimeter charts in the forest exhibit no sudden surge of snowmelt percolate. In actuality, when these conditions prevail the sky is usually heavily overcast and the melt rate is comparable or slightly faster in the small openings.

The first-day outflow of throughfall-drip in the forest often percolates down through the snowpack at a rapid rate. Possibly there are extended periods during winter when the snowpack in the forest maintains an isothermal condition concomitant with complete or near-complete recharge of liquid water. As a consequence, the snowpack responds rapidly to the smallest input of throughfall-drip or heat energy. This is substantiated by the brief lag time before outflow appears in the lysimeter.

In the deeper snowpack in the small openings, conditions are different. The initial lag time is usually greater, especially after an extended period of clear, cold weather and, therefore, responses to rain and heat energy are correspondingly slower--probably because of the freezing of rain or refreezing of surface melt deeper in the pack.

Unusually warm, sunny weather, such as occurred in midwinter 1968, causes the snowpack on the north aspect to melt faster in the forest than in the small openings. This is attributed to a difference in the net energy balance between the forest and small openings. The fact that the winter sun traverses a low arc on the southern horizon apparently is not a disadvantage to a dense forest stand on a north slope. The tall, projecting crowns, which expose a dark green mass with some surfaces actually perpendicular to the sun's rays, readily absorb solar radiation and in turn reradiate considerable amounts of thermal energy to the snowpack. In contrast, the snowpack in the small openings presents a highly reflective surface which slopes to the north and away from the sun's rays, thus reducing the amount of absorbed radiation. This explanation, although conjectural, seems plausible in light of radiation measurements taken by Hornbeck (6) in an eastern forest. He reports that on clear days in February a forest (hardwood) site absorbed 2.6 times more downward solar radiation than a clearcut site. He goes on to state:

> ...That on clearer days sensible heating of the snow cover and subsequent melting may be more rapid for the forest site, provided little or no slash protrudes above the snow at the clearcut site. The above conditions could delay the advance in snowmelt runoff often associated with clearcutting... .

The lysimeter results at Priest River support Hornbeck's speculation as it applies to small openings on the north slope of a western coniferous forest.

Conclusions

The release of water from the snowpack in winter is a very important geophysical process, the ramifications of which could apply to any forest conditions and climates similar to those in Priest River. The significant happening in this process is that the volume of outflow beneath the canopy exceeds that in small openings, resulting in less snow water equivalent in the forest by April 1. During a typical winter the evidence suggests that most of the difference in outflow originates in the canopy where intercepted snow is converted to drip which in turn percolates through the snowpack and hence becomes a net loss to snow storage.

LITERATURE CITED

1. Berndt, H. W., and W. B. Fowler
   1969. Rime and hoarfrost in upper-slope forests of eastern Washington. J. Forest. 67(2): 92-95.

2. Haupt, H. F.
   1969. A simple snowmelt lysimeter. Water Resources Res. 5(3): 714-718.

3. ________
   1969. A 2-year evaluation of the snowmelt lysimeter. West. Snow Conf. Proc. 1969: 97-101.

4. Hoover, M. D.
   1962. Water action and water movement in the forest. P. 31-80, 282-289, in: Forest influences. Food and Agr. Org. United Nations, Forest and Forest Prod. Stud. 15.

5. ________, and C. F. Leaf
   1967. Process and significance of interception in Colorado subalpine forest. P. 213-224, in: W. E. Sopper and H. W. Lull, (Eds.) Int. Symp. on Forest Hydrol. Pergamon Press, New York.

6. Hornbeck, J. W.
   1970. The radiant energy budget of clearcut and forested sites in West Virginia. Forest Sci. 16(2): 139-145.

7. Miller, D. H.
   1966. Transport of intercepted snow from trees during snow storms. U.S. Forest Serv. Res. Pap. PSW-33, 30 p.

8. Satterlund, D. R., and H. F. Haupt
   1970. The disposition of snow caught by conifer crowns. Water Resources Res. 6(2): 649-652.

9. U.S. Army, Corps of Engineers
   1956. Snow hydrology. Northern Pacific Division, Corps of Engineers, Portland, Oregon. 437 p.

HAUPT, HAROLD F.

1972. The release of water from forest snowpacks during winter, USDA Forest Serv. Res. Pap. INT-114, 17 p., illus.

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Headquarters for the Intermountain Forest and Range Experiment Station are in Ogden, Utah. Field Research Work Units are maintained in:

Boise, Idaho
Bozeman, Montana (in cooperation with Montana State University)
Logan, Utah (in cooperation with Utah State University)
Missoula, Montana (in cooperation with University of Montana)
Moscow, Idaho (in cooperation with the University of Idaho)
Provo, Utah (in cooperation with Brigham Young University)