SOME TERRAIN AND FOREST EFFECTS ON MAXIMUM SNOW ACCUMULATION IN A WESTERN WHITE PINE FOREST

By

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INTRODUCTION

Results of a snowpack accumulation study reported in this paper show that the maximum amount of water stored as snow in a western white pine forest is influenced by the degree to which timber cutting opens the forest canopy. They also show that the extent of influence can be predicted rather closely. Understanding of how the forest and its treatment affects the accumulation characteristics of snow is requisite to development of forest management methods that allow continued use of the timber resource without intensifying snowmelt floods and sediment production.

How white pine forests can be managed to prevent aggravation of snowmelt floods is a high priority watershed management objective in the northern Rocky Mountain region. Hydrologic conditions leading to snowmelt floods from white pine forests are frequently in critical balance. More specifically, snowpacks usually occur on a soil mantle already fully recharged by fall rains.[2] They melt rapidly between April and June, a period of heavy seasonal rainfall.

This combination of snowmelt and rainwater frequently exceeds the storage capacity of the soil mantle even on undisturbed forest sites, resulting in high streamflow discharges. Floods of this nature from white pine forests are normal (2). Their magnitude depends upon the amount of water accumulated in the snowpack, the rate of snowmelt, the amount and rate of rainfall during melting, and the capacity of the soil to absorb and store water. Whether the number and size of floods is aggravated by forest management activities depends upon the manner in which these activities influence the accumulation and melting characteristics of the snowpack and the storage characteristics of the soil mantle.

This paper presents results of a study to determine the variability of maximum snow water content at different elevations, on various aspects, and under forest canopy conditions reflecting different forest management treatments. Snow accumulation data in natural and clear-cut forest openings and in forest stands of various densities in the Priest River Experimental Forest in northern Idaho were available for study.

METHODS

Snowpack water content was measured at weekly to 10-day intervals from the beginning of its accumulation in early winter until its disappearance in the spring. These measurements were made at 273 stations in 1949, 408 in 1950, 370 in 1951, and 191 in 1952; they provided a total of 1,242 station years of record.

Snow water measurements.--Maximum snow water equivalents ranged from less than 3 to more than 60 inches. The maximum snow water values in inches were used as the dependent variable in this analysis regardless of the dates on which they occurred. They provide an index of flood potential in terms of the amounts of water the soil mantle is required to handle.

Years.--During the 4 years of study, winter precipitation varied from 15 percent below to 49 percent above the 44-year winter average at Priest River Experimental Forest Headquarters. This variation in snowfall from year to year was eliminated in the study by using as an independent variable the mean maximum snowpack water content at 10 stations where measurements had been obtained in each of the 4 years of study. All of these stations were located at the same elevation, on level terrain, and in large openings. It was assumed that the differences in snow water content at these stations from year to year were attributable primarily to annual snowfall differences.

Elevation.--Priest River Experimental Forest ranges in elevation from 2,660 feet to 5,510 feet. The snow sampling stations varied in elevation from 2,700 to 5,500 feet and had a mean elevation of 3,657 feet. Approximately 70 percent of the stations were below the median elevation of 3,900 feet.

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2/ Unpublished soil moisture data in files of Intermountain Forest and Range Experiment Station.

Aspect.—The experimental forest slopes generally from east to west and has aspects lying only between azimuths 160 and 50 degrees measured clockwise around the azimuth circle from the north. Mean aspect of the sampling stations was 250 degrees. About half of the stations were equally divided between north- and south-facing slopes. The other half sampled northeast, northwest, west, and southwest slopes.

Forest canopy density.—Several different kinds of forest cuttings have been made in the experimental forest for research purposes during the past 45 years. These have included clear cuttings, partial cuttings, and thinnings. As a result, the forest has a wide variety of forest canopy conditions, ranging from large openings with no canopy to dense, completely closed forest stands. Density of the forest canopy was measured at each sampling station with the "ceptometer," a type of spherical densiometer described by Ingebo (1). Mean canopy density of the sampling stations was 45 percent and about half of the stations had densities greater than this amount.

Each of the elevations, aspects, and forest canopy densities selected for study was not sampled uniformly. Also, variation in the number of stations from year to year contributed to nonuniformity in the sampling of these variables. The treatment of the data by variance analysis techniques was thus complicated unduly, and curvilinear multiple regression was adopted to evaluate the separate effects of the independent variables on snow water accumulation.

ANALYSIS

Snow water content increased with elevation and the relation was curvilinear. The degree of curvature was not clear from inspection of the plotted raw data. Consequently, the first four power functions of the elevation variable were selected for use in a curvilinear multiple regression.

The relation of water content to aspect also appeared to be curvilinear and indicated a maximum and minimum water content value within the range of aspects studied. This suggested the use of at least the first three power functions of aspect as variables.

Water content of the snowpack decreased as density of the forest canopy increased. Whether the relation was linear or slightly curvilinear in one direction was questionable. Therefore, both a linear and a second power function of canopy density were selected for further investigation.

At this stage we asked several questions about the manner in which one variable might influence the effects of another on the snow water content. Do differences in snowfall from year to year affect the relations between snowpack water content and elevation, aspect, and forest canopy? Do aspect and forest canopy affect the snowpack differently at different elevations? Does the forest canopy affect the snowpack differently from aspect to aspect? Consideration of these questions led to the selection of six additional variables expressing interaction effects of the snowpack year, elevation, aspect, and forest canopy on snowpack water content. Thus, a total of 16 independent variables was provided for investigation.

The analyses required the solving of 60 separate regression problems of which four were of utmost importance. Solutions for these four problems are summarized in Table 1, showing the variables used, the changes in snowpack water content attributable to a change in each variable over its total range, the variances explained, and the standard errors of estimates.

The first regression problem was designed to determine which of the 10 primary variables explained significant portions of the variance in snow water content. Its solution revealed that all of the variables except the fourth power of elevation and the second power of forest canopy density contributed significantly to an accounting of the variance, explaining 89.2 percent of it with a standard error of 3.2 inches.

In the second regression problem we discarded the fourth power of elevation and second power of forest canopy and considered only the eight variables that were significantly related to snow water content. Its solution did not reduce the amount of explained variance from that obtained in the first problem; this indicated that a linear, quadratic, and cubic function of elevation and a linear function of forest canopy provided the best power series fit for those variables.

The eight variables used in problem 2 and all six of the interaction variables were considered in problem 3. Its solution showed that only two of the interaction variables contributed additional significant explanation of the variance in snow water content. These were the years-elevation and aspect-elevation interactions which, together with the eight primary variables, explained 91.6 percent of the variance.

The next 56 problems considered the effects on snowpack water content of the eight significant primary variables, together with all possible combinations of the six interactions taken two, three, four, and five at a time. In all of these problems the only interactions that showed a significant relation to the amount of water in the snow were those of years with elevation and aspect with elevation. The effect on the snowpack of snowfall differences from year to year was shown to occur totally in the years-elevation interaction. Years, therefore, was omitted as a primary variable and the other seven primary variables and two interactions were retained for consideration in problem 60.

Solution of problem 60 showed that the first three power functions of elevation and aspect, a linear function of forest canopy, and the two interactions (years-elevation and aspect-elevation) explained as much of the snowpack variance (91.6 percent) with as small a standard error of estimate (2.8 inches) as did all of the variables combined. This analysis, therefore, was examined further to determine the specific effect of each variable on the snowpack water content throughout its entire range of variation.

RESULTS

Effect of elevation.—Changes in elevation had the greatest effect on the accumulation of snowpack water. The average increase in amount of water, as elevation increased from 2,700 to 5,500 feet, was 30.1 inches. The snowpack increased at a decreasing rate up to an elevation of about 3,550 feet and then continued to increase, but at an accelerated rate, to the top of the watershed.

Effect of aspect.—The next greatest effect on snow water accumulation was its increase with a change of aspect from 165 degrees clockwise around the azimuth circle to 11 degrees. The amount of increase differed greatly between elevations. At 2,700 feet it was 4.4 inches; at mean elevation of 3,657 feet it was 9.2 inches, and at 5,500 feet it had increased to 18.8 inches. Thus, the effect of a change in aspect on snow water content was about four times greater at the upper end than at the lower end of the experimental forest. This suggests that the magnitude of differential melting between south and north slopes during the winter accumulation period is greater at higher than at lower elevations.

Effects of years.—The increase in amount of snowpack water due to an increase in the amount of snowfall from the low year, 1951, to the high year, 1952, varied considerably between elevations. It was 5.9 inches at an elevation of 2,700 feet, 8.0 inches at 3,657 feet, and 12.1 inches at 5,500 feet. Thus, excluding the effect of differences in elevation, the variation in showpack water due to snowfall differences between years was about twice as large at 5,500 feet as at 2,700 feet.

Effect of forest canopy.—Snow water content was affected least by the forest canopy; it increased 4.2 inches as the density of the forest canopy was reduced from 100 percent in densely stocked timber stands to zero in large openings. This relation occurred rather uniformly regardless of differences in year, elevation, or aspect. Because of the uniformity of the effect, it is inferred to be due primarily to interception losses rather than differential melting during the snow accumulation period.

DISCUSSION

This study answers questions asked earlier in the paper. For instance, the years-elevation and aspect-elevation interactions were the only ones that explained significant amounts of the variance in snowpack water content. From this we infer that differences in the amount of snowfall from year to year in no way conditioned the influence of aspect and of the forest canopy on snowpack water. We also infer that differences in density of the forest canopy did not affect either the aspect or elevational influences on snow water content.

The maximum snow water content increased in direct proportion to the amount by which openings were created or enlarged in the forest canopy. It is, therefore, reasonable to conclude that progressively more drastic silvicultural methods, ranging from thinnings through various intensities of partial cuts to clear cuttings, will produce correspondingly greater accumulations of snowpack water. On the other hand, however, the direct relation of snowpack water content to degree of forest canopy opening suggests that we cannot expect to affect the snowpack very differently from site to site by any single silvicultural method.

The largest amount of increase in snow water content is inferred to occur where a dense forest stand is clear cut. Under average conditions of elevation and aspect and average snowpack conditions occurring in Priest River Experimental Forest during the 4 years of study, such a cutting would result in an increase of about 4.2 inches in the maximum amount of snowpack water. This represents an average water gain of 32 percent on the areas cut. Whether the addition of as much as 4 more inches of water to the snowpack is sufficient to aggravate an existing flood-producing condition or create one requires knowledge of the melting behavior of the snowpack under various terrain and forest conditions and of the soil profile characteristics. These considerations are beyond the intended scope of this paper.

LITERATURE CITED

(1) Ingebo, P. A. 1955. An instrument for measurement of the density of plant cover over snow course points. 23rd Annual Western Snow Conference Proc., pp. 26-28.

(2) U. S. Forest Service. 1950. How forest conditions affected the 1948 Columbia flood. AIB 10, 17 pp.

Table 1. Summary of 4 curvilinear multiple regression problems showing the mean effect of each variable on the maximum snowpack water content

Independent variables	Units	Range: Limits			Effect on snowpack water content1/ (inches)			
		Lower	Upper	Total	Problem 1	Problem 2	Problem 3	Problem 60
Primary								
Years	Inches	6.50	11.30	4.80	7.9	7.9	-2.6	(3/) → 8.0
Elevation	100 feet	27.00	55.00	28.00				
Elevation^2	100 feet^2							
Elevation^3	100 feet^3				32.2	31.6	-2.4	0.3 → 30.1
Elevation^4	100 feet^4				(2/)	(3/)	(3/)	(3/)
Aspect	100 degrees	1.65	.11	2.06				
Aspect^2	100 degrees^2				8.9	8.9	-10.7	-9.7 → 9.2
Aspect^3	100 degrees^3							
Canopy density	0.01 percent	.00	1.00	1.00	-4.2	-4.2	-3.1	-4.2 → -4.2
Canopy density^2	0.01 percent^2				(2/)	(3/)	(3/)	(3/)
Interaction								
Years x elevation	100 inch-feet				(3/)	(3/)	24.5	20.2
Years		237.68	413.20	175.52			10.6	8.0
Elevation		256.50	522.50	266.00			13.9	12.2
Aspect x elevation	10,000 degree-feet				(3/)	(3/)	36.6	36.5
Elevation		67.46	137.42	69.96			17.7	17.6
Aspect		60.34	135.66	75.32			18.9	18.9
Canopy x elevation	percent-feet	.00	55.00	55.00	(3/)	(3/)	2/ 1.8	(3/)
Years x aspect	100 inch-degrees	10.70	41.90	31.20	(3/)	(3/)	2/ 1.8	(3/)
Canopy x aspect	percent-degrees	.00	3.71	3.71	(3/)	(3/)	2/ .8	(3/)
Canopy x years	0.01 percent-inches	.00	11.30	11.30	(3/)	(3/)	2/ .8	(3/)
Regression equation constant . . . . (inches)					-94.5	-101.1	-57.0	-56.8
Standard error of estimate . . . . (inches)					3.2	3.2	2.8	2.8
Explained variance . . . . (percent) . . .					89.2	89.2	91.6	91.6

1/ Effect is a change in snowpack water due to a change in each independent variable over its total range holding other variables constant at their mean values

2/ Variable not significant at 1-percent level

3/ Variable not included in analysis