TIME-SPACE EFFECTS OF OPENINGS IN ARIZONA FORESTS ON SNOWPACKS

by

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Introduction

Forest openings affect a snowpack during both accumulation and melt phases. At any point in time, a snowpack is the integrated result of all accumulation, redistribution, and melt processes that have taken place before the time of measurement. Since snowpacks do not always have distinct accumulation and melt phases, it is difficult to determine the effect that an opening will have on a snowpack regime.

This paper describes an analysis of the effects of openings in Arizona ponderosa pine forests on snowpacks in and adjacent to the openings, using readily available input variables.

Methods

Seven study areas were established in ponderosa pine forests to simulate an array of openings (Table 1). Three sites were located 40 miles south of Flagstaff, while the other four were established in the White Mountains. Many of the sites were transmission line rights-of-way. In all cases, the openings were oriented with their long axes up and down the slope.

Two parallel transects, each extending 5H (H = average height of surrounding trees) into the forest on both sides of the openings, were established 50 feet apart on the study areas. All sampling points were located along each transect at an interval of 1/4H.

During a year of record snowfall in Arizona, 1972-73, data were collected on 10 sampling dates approximately two weeks apart. Total snow depth and snowpack water equivalent were measured at each sample point with a Federal snow tube and scale.

To evaluate the effects of an opening on the snowpack for a sampling date, the assumption was made that the influence of the opening is confined somewhere within the boundaries of the measurement transect. This assumption is supported by earlier studies which demonstrated that the effect of an opening is essentially nonexistent by the 2 to 3H distance within the forest (Anderson, 1963; Rothacher, 1965; Hansen and Ffolliott, 1968; and others).

Table 1. Range of Conditions on Study Areas.

Variable	Units	Range of Conditions		
		Minimum	Mean	Maximum
Timber Density	Square feet of basal area per acre	76	103	155
Opening Width[1]	H (average height of timber surrounding opening)	1.0	1.6	2.0
Slope-Aspect	Langleys (average potential input per day between December 1 and May 31)	599	658	709
Elevation	Feet (above sea level)	6600	7450	8100

[1]Dimension perpendicular to forest edge.

It was further assumed that the effect that an opening has on snowpack conditions becomes less as one proceeds away from the opening. It was felt, and subsequently verified, that the zones between 3 and 5H on both sides of an opening would be most representative of an undisturbed forested condition. However, it may also be possible that the entire influence of an opening at some point in time is confined within the opening itself. If this is the case, the average of all sample points within a forest would be most representative of the undisturbed forested condition.

Since a strict delineation of the extent of influence exerted by an opening into a forest at a point in time is difficult, a weighted average of all sample points within the forested condition was selected at the appropriate method to determine the average snowpack water equivalent of the undisturbed forested condition. As the 3 to 5H zone was most representative of an undisturbed forested condition at all points in time, sample points within this zone were given the heaviest weight. Zones closer to the opening were given less weight due to the likelihood that sometimes these zones would be more affected by the opening. Therefore, sample points from 3 to 5H were given a weight of 4; from 2 to 2-3/4H, a weight of 3; from 1 to 1-3/4H, a weight of 2; and from 0 to 3/4H, a weight of 1.

Once the average snowpack water equivalent of an undisturbed forested condition has been determined, the net effect of the opening was obtained by computing the signed deviation between that of the observed water equivalent of every sample point in the snowpack profile and the average snowpack water equivalent of the undisturbed forested condition. The summation of these deviations indicated the net effect of the opening for the point in time being analyzed.

The net effect of the opening calculated at the end of each time period for the different sites over the snow season was then regressed against readily available input variables that change with time and with location.

Variables that varied with time were:

1. Temperature. The total number of degree-days occurring between each time interval was calculated for each site from temperature records.

2. Potential insolation. Daily potential insolation values were obtained from curves developed for each site from December 1 through May 31, using appropriate values (Frank and Lee, 1966). The variable was expressed as the total number of potential langleys occurring between measurement dates at each site.

3. Precipitation. The amount of precipitation, expressed as inches of water equivalent, that fell at each site was recorded for the intervals between measurement dates.

4. Albedo. The daily snowpack albedo was calculated for each site by determining the number of days between precipitation events from weather records, and then changes in albedo with time relations (U.S. Army Corps of Engineers, 1956). The average daily albedo was computed for each time interval at each of the sites.

Variables that changed with location, but were independent of time, included:

1. Opening width. This variable was expressed in terms of the average height (H) of the surrounding forest.

2. Forest density. Average forest density along the measurement transects on either side of the opening, expressed as square feet of basal area per acre, was estimated by point sampling techniques (Avery, 1975).

3. Elevation. Elevation, expressed in feet, was obtained from USDI Geological Survey 7-1/2-minute quadrangle maps.

4. Tree height. Average tree height of the forest surrounding the opening was expressed in feet.

5. Slope-aspect. Using data previously obtained to determine potential insolation, the average number of langleys received from December 1 through May 31 was computed for each site; this is a way of numerically expressing slope-aspect combinations for different sites and, therefore, does not change with time once computed for a given site. (In comparison, the potential insolation variable listed under "time dependent variables" was used to evaluate potential insolation inputs over a given time period at a particular site.)

The dependent variable, the actual value of the net effect of an opening at the end of each time period, was regressed on the nine independent variables, using multiple regression techniques. To empirically evaluate their relative significance, the independent variables were expressed in linear form, squared form, and in cross-products. Data compilations from all study areas over all time periods were included in the analysis.

Results and Discussion

While there were several significant regressions at the five percent level of significance, an equation including precipitation, slope-aspect, and a joint variable of forest density-opening width suggested potential use in practice. This regression, which accounts for nearly 60 percent of the variation in the net effect of an opening, is:

$$Y = 117 + 0.471\ (X_1^2) - 0.119\ (X_2) - 0.226\ (X_3X_4)$$

where Y = the net effect of the opening expressed as inches of snowpack water equivalent

X_1 = the precipitation variable

X_2 = the slope-aspect variable

X_3X_4 = the forest density-opening width joint variable

Information contained in the above equation is two-fold. First, if a watershed manager wanted to maximize the net effect of an opening, he would select a site where X_3X_4 (forest density x opening width) and X_2 (slope-aspect) were low. Second, having selected the site, if the watershed manager wanted to predict the net effect of such an opening at any point in time, he could evaluate the amount of precipitation that had occurred within a specified time period, and then substitute this value for X_1 (precipitation) in the equation, along with the appropriate values for the site variables. For the range of conditions studied, an optimum net effect is obtained when a 1H opening is cut in a forest density of approximately 75 square feet of basal area per acre on a site receiving an average of nearly 600 langleys per day from December 1 through May 31 and "high" amounts of precipitation.

Opening width is of primary importance during snowpack accumulation stages. Narrow opening widths have been shown as early as the 1900's to be most effective as snow traps (Church, 1912). The amount of precipitation received affects the magnitude of this trapping effect; the greater the amount of precipitation, the greater the trapping effect. This general relationship holds so long as snow storage in the opening is less than its capacity.

It is important to realize that in determining the net effect of an opening, one is comparing the average water equivalent of the snowpack lying within the "sphere of influence" with that of the undisturbed forested condition. At a point in time immediately following a heavy precipitation event, this net effect may be relatively large. However, if melt processes are more active in the opening than in the forested condition, the net effect will diminish during the melt phases. Also, the time distribution and sequence of precipitation events is important in determining the magnitude of the net effect of an opening at a given time. (Ten storms of one-inch water equivalent may differ in magnitude from one event yielding 10 inches of water equivalent.)

Forest density also has a large effect on the melt characteristics at a given site. Trees on the site affect several processes simultaneously (Anderson, 1967). The density of the forest determines the amount of short-wave radiation directly impinging on the snowpack. Forest density also determines the amount of short-wave radiation that is absorbed and reradiated as long-wave radiation (Reifsnyder and Lull, 1965). Wind movement through a forest and, consequently, the amount of evaporation is affected by the same trees. If the trees surrounding an opening are dense, the undisturbed forested condition is shaded, resulting in less impingement of direct solar radiation; and snow in openings is subjected to comparatively large amounts of long-wave radiation from the dense forest surrounding the opening, resulting in accelerated melting along the forest edges.

Openings cut in dense forested areas result in comparatively large differential melting between the undisturbed forested condition and the "sphere of influence" of the opening. Therefore, previous gains in the net effect of the opening made during accumulation phases may be rapidly offset during active melting. In contrast, rates of melt in the undisturbed forested condition progressively approach those of the opening as the forest density is reduced because: the undisturbed forest condition becomes increasingly open to both incoming solar radiation and wind movement, resulting in higher rates of ablation; and there are fewer trees around the edge of the opening, resulting in comparatively lower magnitudes of "back radiation."

It is well documented that sites having low potential insolation inputs have less intense melt characteristics than do those with high inputs (Anderson, 1967; Ffolliott and Hansen, 1968; and others). Therefore, the potential insolation variable is important when determining the net effect of an opening. Since melt is not as intense on "cool" sites, an opening is not subjected to the same amount of ablation as openings associated with "warm" sites. Consequently, the differential melting between the opening's "sphere of influence" and that of the undisturbed forested condition is less on "cool" sites, resulting in a maximization of the net effect of the opening.

Conclusions

The analysis of the net effect of forest openings on a snowpack regime may be useful in designing cutting practices to affect snow melt. However, additional data sets representing other sites and additional years are needed to verify the results presented herein. Use of the results of this study in other locations in the Southwest and for other years should be predicated on discerning acceptable values for "confidence limits" to be used for prediction purposes, and on validating the manipulation of site variables in determining locations of proposed forest cuts.

Finally, a question that remains unanswered is what proportion of a watershed should be occupied by openings to insure optimum snow melt increases. In other words, the relative spacing between openings and forested areas required to achieve desired water yield increases derived from snow melt must be determined.

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References Cited

Anderson, Henry W. 1963. Managing California's snow zone lands for water. USDA Forest Service, Research Paper PSW-6, 28 p.

Anderson, Henry W. 1967. Snow accumulations as related to meteorological, topographic, and forest variables in central Sierra Nevada, California. International Association of Sciences, Hydrology Publication 78:215-224.

Avery, Thomas Eugene. 1975. Natural Resources Measurements. McGraw-Hill Book Company, New York, 339 p.

Church, J. E. 1912. The conservation of snow. Scientific American 74:152-154.

Ffolliott, Peter F., and Edward A. Hansen. 1968. Observations of snowpack accumulation, melt, and runoff on a small Arizona watershed. USDA Forest Service, Research Note RM-124, 7 p.

Frank, Ernest C., and Richard Lee. 1966. Potential solar beam irradiation on slopes. USDA Forest Service, Research Paper RM-18, 116 p.

Hansen, Edward A., and Peter F. Ffolliott. 1968. Observations of snow accumulation and melt in demonstration cutting of ponderosa pine in central Arizona. USDA Forest Service, Research Note RM-111, 12 p.

Reifsnyder, William E., and Howard W. Lull. 1965. Radiant energy in relation to forests. USDA Technical Bulletin No. 1344, 111 p.

Rothacher, Jack. 1965. Snow accumulation and melt in strip cuttings on the west slopes of the Oregon Cascades. USDA Forest Service, Research Note PNW-23, 7 p.

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