SNOWPACK DENSITY: AN INDEX OF SNOWPACK CONDITION

by

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Introduction

Snowpack density is often a useful index to the stage of "ripening" in a snowpack. In general, freshly fallen snow has a density of 0.10 gm cm^{-3}. A density of 0.35 to 0.50 gm cm^{-3} is characteristic of a snowpack undergoing metamorphosis and ripening. In most instances, additional inputs of energy will cause the snowpack to melt and runoff to occur.

To evaluate the usefulness of snowpack density as an index of snowpack condition in the forest types of Arizona, a number of studies have been conducted, as described below.

Description of the Studies

Over an eight-year period, a series of studies were conducted to obtain baseline data on the spatial and temporal variations in snowpack densities in the mixed conifer forests, the aspen forests, and the ponderosa pine forests of Arizona. Collectively, these studies were designed to:

1. describe the variations in snowpack densities;

2. relate these variations to hydrographic characteristics, where possible; and

3. determine the effects of differences in forest density, elevation, and potential solar radiation on snowpack densities.

Study Areas

The studies were carried out on several locations that were representative of the forest types of Arizona. In particular, measurements in the mixed conifer forests were obtained on experimental watersheds on the Thomas Creek drainage in east-central Arizona (Rich and Thompson 1974). Seven coniferous and two deciduous tree species (Douglas-fir, white fir, corkbark fir, Engelmann spruce, ponderosa pine, southwestern white pine, quaking aspen, and Gambel oak) were found on these watersheds. Topography varied, with the lower and middle slopes of the watersheds quite steep. Soils were derived from basaltic parent materials. Elevations varied from 8,400 to 9,200 feet. Annual precipitation averaged 28 inches, approximately one-third of which occurred during the snowfall season of November through April.

Quaking aspen does not occur as extensive, continuous forests in Arizona, rather it is found as isolated stands varying from less than 10 to over 100 acres in size. Two stands, on the lower slopes of the San Francisco Mountains near Flagstaff, comprised the study areas for measurements in the aspen forest (Timmer et al. 1984). Average slope was less than 5 percent. Soils were basaltic. Elevations ranged from 7,900 to 8,100 feet. Annual precipitation was approximately 26 inches.

Measurements in the ponderosa pine forests were collected on experimental watersheds on the Beaver Creek drainage in north-central Arizona (Brown et al. 1974). Cutover ponderosa pine comprised over 75 percent of the forest overstory on these watersheds, with Gambel oak and alligator juniper as intermingling species. Few slopes exceeded 15 percent, and the general aspect was southwest. Soils, derived from volcanics, were primarily basaltic. The elevation ranged from 6,500 to 7,800 feet. Annual precipitation averaged 24 inches, with nearly one-half occurring in the winter months.

Collection of Source Data

Estimates of snowpack density were obtained from total snow depth and corresponding water equivalent measurements taken with a federal snow sampler and scale at randomly located sample points throughout the winter periods of the year of study. Different years were measured in each of the forest types studied, although the range of conditions sampled within the forest types was similar. In general, the measurements were taken prior to peak seasonal snowpack accumulation, at the time of peak seasonal snowpack accumulation, and during the snowmelt-runoff period.

On the experimental watersheds that were studied, streamflow was measured at a water-stage gaging station. Daily streamflow values, expressed in terms of area-inches, were computed from a streamflow discharge-water stage rating curve.

Data required to develop expressions of forest density, elevation, and potential solar radiation were also obtained at the sample points. Forest density, in square feet of basal area per acre, was estimated by point sampling techniques (Avery and Burkhart 1983). The elevation of each sample point was estimated from 7 1/2-minute USGS topographic maps. Potential solar radiation, in gm calories cm^2, received on selected index dates was determined from slope and aspect measurements (Frank and Lee 1966).

Results and Discussion

Regardless of the forest type, the snowpack density values appeared to be normally distributed. Furthermore, the coefficients of variation remained statistically constant throughtout a major portion of the runoff periods. Ripening of the snowpacks was rapid, once snowpack metamorphosis was initiated. Empirical relationships between snowpack density and associated inventory-prediction variables, while statistically weak, reflected some qualitative characteristics of Arizona's snowpack as affected by these variables. Other, more specific results are described in the following paragraphs.

Mixed Conifer Forests

The snowpack densities observed on Thomas Creek ranged from less than 0.25 to over 0.55 gm cm^{-3}. An average snowpack density of between 0.35 and 0.40 gm cm^{-3} represented ripe conditions, as the snowpacks generally remained in this density range for most of the runoff periods. Similar results were obtained from an earlier study in the mixed conifer forest (Ffolliott and Thompson 1977). Occasionally, snowpack densities exceeded this range near the end of runoff, when only residual patches of snow remained on the experimental watersheds.

Comparable snowpack densities have been reported in mixed conifer forests elsewhere in the western United States. Work (1948) presented data for Crater Lake, Oregon, which indicated that snowpack melting does not occur until a density between 0.40 and 0.50 gm cm^{-3} is attained. According to Kittredge (1953), snowpack densities between 0.40 and 0.50 gm cm^{-3} are required before water will drain from snowpacks under ponderosa-sugar pine-fir forests in California. Gary and Coltharp (1967) reported maximum snowpack densities of 0.35 to 0.40 gm cm^{-3} in Douglas-fir, aspen, and grass cover types in New Mexico.

Forest density, elevation, and potential solar radiation were subjected to correlation analyses to determine the magnitude of their individual associations with snowpack densities at peak seasonal accumulation. In general, higher snowpack densities were observed under sparsely stocked, rather than densely stocked, mixed conifer stands. Quite possibly, this pattern was the result of a greater proportion of "old" snow in the samples taken on sites with low forest density; more snow accumulates on these sites, therefore, the snow persists longer.

No significant correlations existed between snowpack densities and elevation, nor between snowpack densities and potential solar radiation, possibly due to the relatively limited range of values for these inventory-prediction variables on Thomas Creek.

Aspen Forests

Snowpack density values in the aspen forests were similar to those observed in the mixed conifer forests, ranging from nearly 0.20 to over 0.45 gm cm^{-3}. This finding was not surprising, however, as aspen stands in Arizona are often found intermingled with the mixed conifer forests. Snowpack densities between 0.35 and 0.45 gm cm^{-3} apparently represented ripe conditions. Once this range was attained, snowpack density values did not drastically change, although water equivalents decreased as the snowpacks melted.

Empirical relationships describing snowpack densities as functions of forest density, elevation, and solar radiation were either statistically nonsignificant or, if significant, of little predictive value. Again, the relatively narrow range of values for the inventory-prediction variables within the aspen stands on the study areas undoubtedly contributed to these weak relationships.

Ponderosa Pine Forests

The snowpack densities in the ponderosa pine forests on Beaver Creek ranged, for the most part, between 0.20 and 0.50 gm cm^{-3}. In general, these values are comparable to an earlier, exploratory study (Ffolliott and Thorud 1969). An average snowpack density between 0.35 and 0.40 gm cm^{-3} represented ripe conditions, because the snowpacks remained in this density range for most of the runoff periods. Only residual snow patches with densities of about 0.50 gm cm^{-3} remained on the watersheds at the end of runoff. Lejcher (1969) observed that a snowpack in a ponderosa pine stand near Flagstaff was ripe and had begun to yield melt water at a similar density level.

Higher snowpack densities were found under relatively sparsely stocked ponderosa pine stands at peak seasonal accumulation. Also, higher snowpack densities were observed at higher, rather than lower, elevations. The occurrence of these high snowpack densities was probably the result of a greater proportion of "old" snow in the integrated samples obtained on these sites at peak seasonal accumulation.

No significant correlations existed between snowpack densities and potential solar radiation due, it was believed, to the relatively limited range of potential solar radiation values.

Conclusions

From the above studies of snowpack densities in the forest types of Arizona, the following conclusions can be made:

1. snowpack densities are normally distributed;

2. coefficients of variation for snowpack density remain relatively constant throughout a major portion of the runoff period;

3. an average snowpack density of between 0.35 and 0.40 gm cm^{-3} represents ripe snowpack conditions;

4. higher snowpack densities occur under relatively sparsely stocked mixed conifer stands and ponderosa pine stands; and

5. other relationships between snowpack densities and inventory-prediction variables are either statistically nonsignificant or, if significant, of little predictive value.

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