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# SNOWPACK DENSITY ON AN ARIZONA MIXED CONIFER FOREST WATERSHED

BY

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## INTRODUCTION

Snow density is one useful index of the stage of "ripening" in a snowpack. Fresh snow often has a density of 0.10 gm $cm^{-3}$ or less. As the snowpack undergoes metamorphosis and ripening, a density of 0.35 to 0.50 gm $cm^{-3}$ is attained. Arizona snowpacks are usually "ripe" in this range. Additional energy input to the snowpack will cause runoff.

## DESCRIPTION OF THE STUDY

The objective of this study was to obtain basic inventory data on the seasonal variations in snowpack density on an Arizona mixed conifer forest watershed and to relate these variations to hydrograph characteristics. Also, we attempted to determine how peak seasonal snowpack densities are affected by differences in forest density, elevation, and potential insolation.

The study was carried out on the 440-acre North Fork watershed of the Thomas Creek drainage in east-central Arizona. Seven coniferous and two deciduous overstory species are found on the watershed: Douglas-fir, white fir, corkbark fir, Engelmann spruce, blue spruce, ponderosa pine, southwestern white pine, quaking aspen, and Gambel oak. Topography varies, with the lower and middle portions of the watershed being quite steep. Soils are derived from basalt parent materials; and elevations range from 8,400 to 9,150 feet. Annual precipitation averages 27 inches, approximately one-third of which occurs during the snowfall season of November through April.

Estimates of snowpack density were obtained from total snow depth and water-equivalent measurements taken with a federal snow sampler and scale at 75 to 90 randomly located sample points throughout the winters of 1972-73, 1973-74, and 1974-75. Measurements were taken prior to peak seasonal snowpack accumulation, at the time of peak seasonal snowpack accumulation, and during the snowmelt-runoff period.

Watershed streamflow was measured at a water-stage gaging station and converted to discharge values using a rating curve.

Data required to develop expressions of forest density, elevation, and potential insolation were obtained at each sample point. Forest density was estimated by point sampling techniques (Avery 1975). The number of trees tallied with an angle gage corresponding to a basal area factor of 25 were determined at each sample point. This measurement represents an index of the amount of crown closure over the sample points.[2/] The elevation of each sample point was estimated from 7 1/2-minute USGS topographic maps with 20-foot contours. Potential insolation (gram calories $cm^{-2}$) received on an index date was obtained from slope and aspect measurements (Frank and Lee 1966).

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2. An unpublished study conducted on the North Fork of Thomas Creek showed percent of overhead crown closure estimated from canopy photographs (Brown 1962) to be correlated with basal area estimated by point sampling techniques.

## RESULTS AND DISCUSSION

The source data for this study were obtained from a relatively large number of sample points located on the watershed studied. Therefore, the sampled population was considered to be the entire basin snowpack, not just localized snowpacks in the immediate vicinity of snow courses. In this respect, the study differs from most of the other investigations which have been less concerned with statistical characterization of the spatial variation in snow densities on entire watersheds.

An average snow density of between 0.35 and 0.40 gm $cm^{-3}$ apparently represented ripe conditions for the North Fork of Thomas Creek, as the snowpack generally remained in this density range for most of the runoff period in each of the years of study (Figures 1, 2, and 3). Snow density did not drastically change in this period, although water-equivalents decreased. Occasionally, densities exceeded this range near the end of runoff, when only residual patches of snow remained on the watershed.

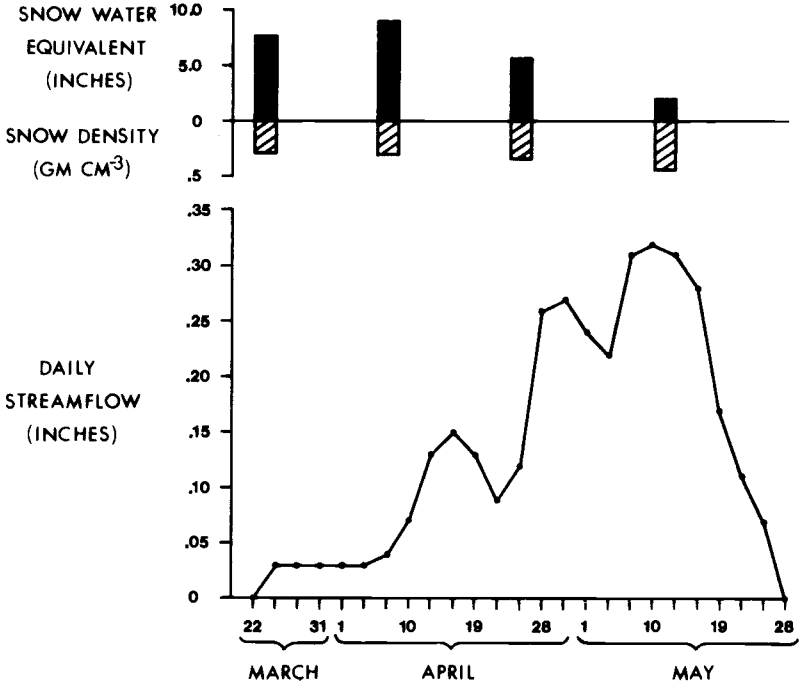


Fig. 1. Snowpack density, water equivalent, and daily streamflow for 1972-73.

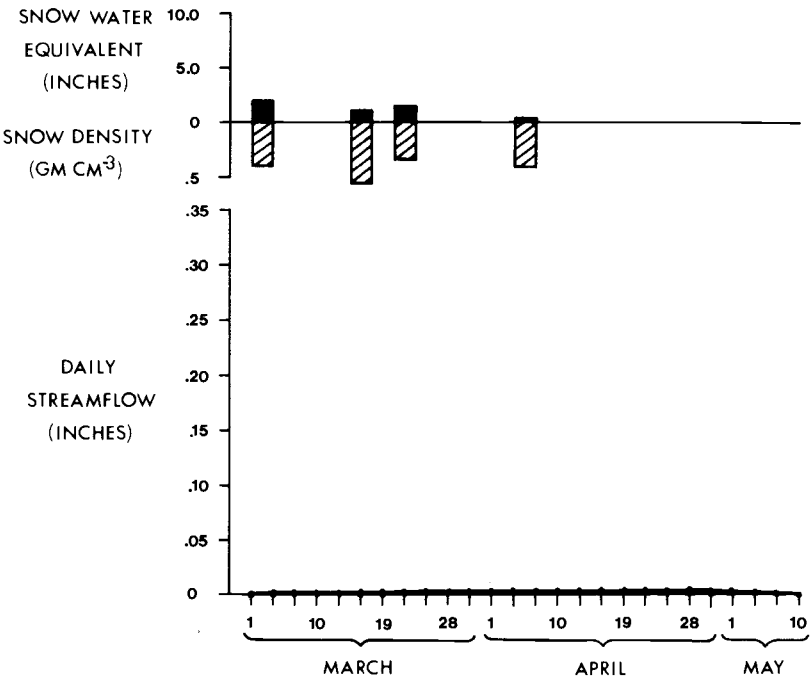


Fig. 2. Snowpack density, water equivalent, and daily streamflow for 1973-74.

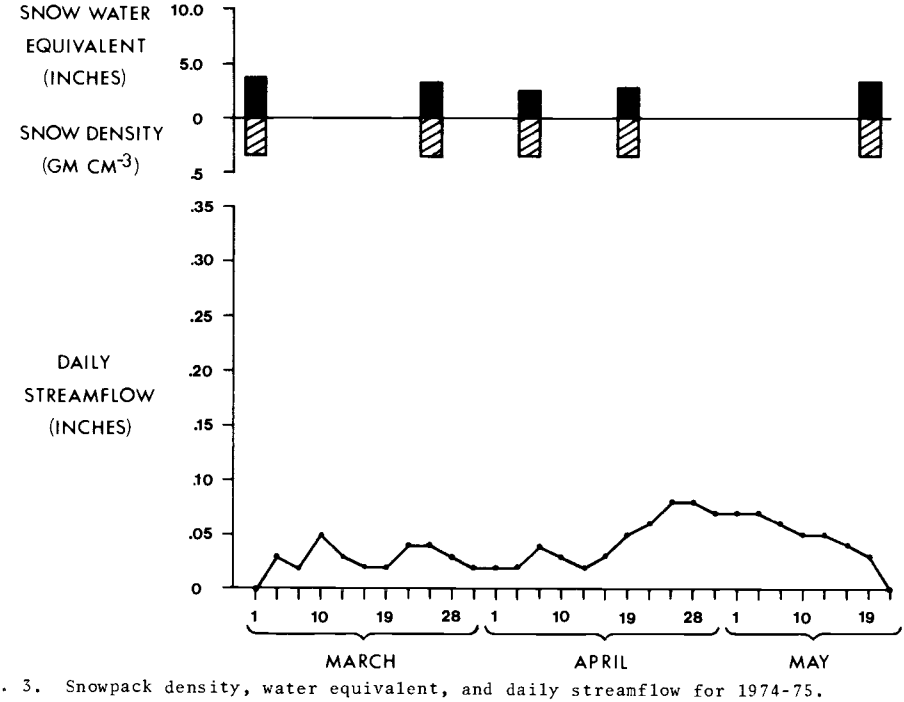


Fig. 3. Snowpack density, water equivalent, and daily streamflow for 1974-75.

The snow densities observed on the North Fork of Thomas Creek (Tables 1, 2, and 3) are comparable to those characterizing many snowpacks elsewhere in the West. For example, Ffolliott and Thorud (1969) found that an average density of 0.37 gm $cm^{-3}$ represented ripe snow conditions on a small watershed in the ponderosa pine forests of north-central Arizona. Lejcher (1969) observed that the snowpack under a ponderosa pine stand in northern Arizona was ripe and had begun to yield melt water at a density between 0.36 and 0.38 gm $cm^{-3}$. Gary and Coltharp (1967) reported maximum snow densities of 0.35 to 0.40 gm $cm^{-3}$ for aspen, grass, and Douglas-fir cover types in New Mexico. According to Kittredge (1953), snow densities between 0.40 and 0.50 gm $cm^{-3}$ are necessary before water will drain from snowpacks under ponderosa-sugar pine and fir cover types in California. Work (1948) presented data for Crater Lake, Oregon, which indicated that the snowpack did not melt significantly until it had attained a density between 0.40 and 0.50 gm $cm^{-3}$.

Table 1. Average snowpack density, confidence interval[a/], and coefficient of variation, 1972-1973.

| Date | Density (gm $cm^{-3}$) | Coefficient of Variation |
|---|---|---|
| February 24 | 0.24 ± .01 | 0.08 |
| March 10 | .25 ± .02 | .27 |
| March 24 | .30 ± .02 | .20 |
| April 7 | .32 ± .01 | .16 |
| April 28 | .34 ± .02 | .17 |
| May 12 | .43 ± .03 | .15 |

[a/] $\alpha = .05$

Table 2. Average snowpack density, confidence interval[a/], and coefficient of variation, 1973-1974.

| Date | Density (gm $cm^{-3}$) | Coefficient of Variation |
|---|---|---|
| January 6 | 0.14 ± .01 | 0.34 |
| January 12 | .19 ± .01 | .20 |
| February 16 | .35 ± .02 | .23 |
| March 2 | .40 ± .03 | .33 |
| March 16 | .55 ± .06 | .34 |
| March 22 | .33 ± .03 | .39 |
| April 6 | .42 ± .03 | .20 |

[a/] $\alpha = .05$

Table 3. Average snowpack density, confidence interval[a/], and coefficient of variation, 1974-1975.

| Date | Density (gm cm$^{-3}$) | Coefficient of Variation |
|---|---|---|
| February 16 | 0.21 ± .03 | 0.49 |
| March 1 | .33 ± .02 | .26 |
| March 25 | .34 ± .03 | .31 |
| April 6 | .32 ± .03 | .31 |
| April 19 | .34 ± .05 | .51 |
| May 19 | .34 ± .03 | .29 |

a/ $\alpha = .05$

The constancy of the coefficient of variation for snow density during the major portion of the runoff period in each of the study years indicates that the relative variation was homogeneous. Thus, a given sample size would have equal precision in estimating the average for this period. However, since sample size decreased throughout the period, the precision of the estimated average also decreased.[3/]

Snow density values appeared to be normally distributed on the North Fork for the years of study (Figures 4, 5, and 6). Strong linear trends of cumulative frequency diagrams plotted on arithmetic probability paper indicated normality. Exceptions to normality occurred on sampling dates toward the end of runoff, when too few observations were available to characterize the distribution of high snow density levels.

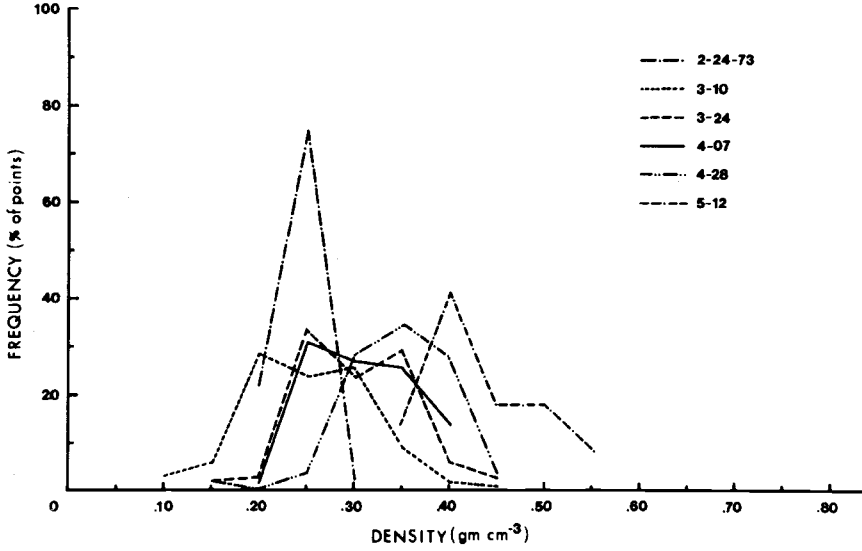


Fig. 4. Frequency distribution for snowpack density, 1972-73.

3. All statistical characterizations of density are based on sample points that had measurable snow. As the snowpack disappears, the number of sample points with measurable snow decreases.

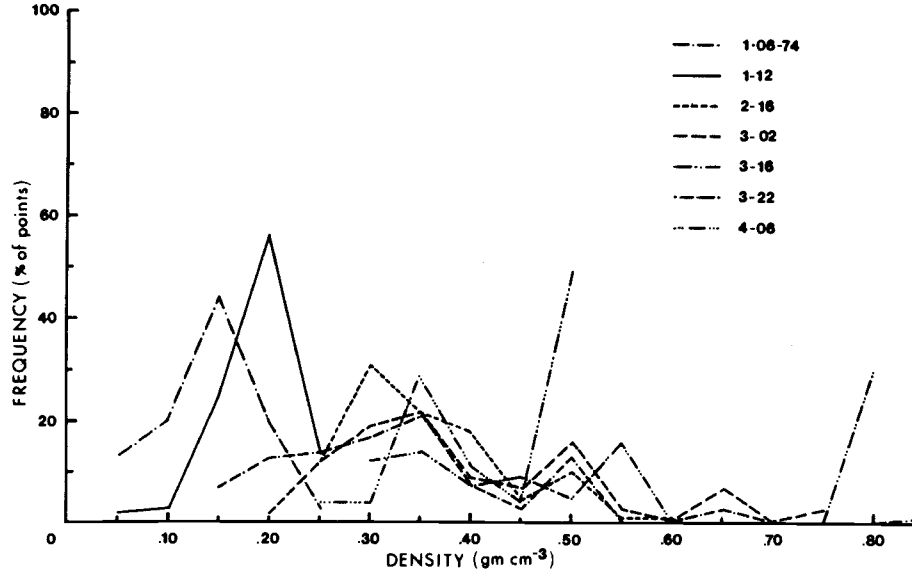


Fig. 5. Frequency distribution for snowpack density, 1973-74.

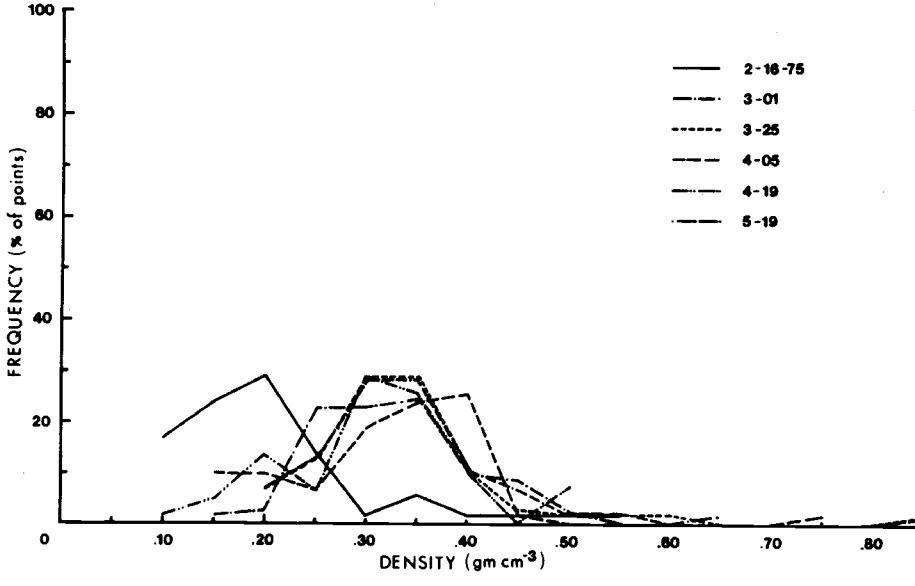


Fig. 6. Frequency distribution for snowpack density, 1974-75.

Similar frequency distributions of snow density have been observed on a small watershed supporting ponderosa pine forests in Arizona (Ffolliott and Thorud 1969).

Forest density, elevation, and potential insolation were subjected to linear correlation analysis to determine their individual associations with snow density at peak seasonal accumulation. In general, higher snow densities were observed under sparsely stocked than dense mixed conifer stands, although this correlation was not consistent in all years. 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 snow density and elevation, nor between snow density and potential insolation, possibly due to the relatively limited range of values for these variables on the North Fork of Thomas Creek.

## CONCLUSIONS AND SUMMARY

(1) An average snow density of between 0.35 and 0.40 gm $cm^{-3}$ apparently represented ripe snowpack conditions on the North Fork of Thomas Creek, a mixed conifer forest watershed in east-central Arizona.

(2) The coefficient of variation for snow density remained relatively constant for a major portion of the runoff periods evaluated.

(3) Snow density appeared to be normally distributed on the 440-acre study area.

(4) Correlations between snow density and forest density were weak and inconsistent; no correlations were found between snow density and elevation and potential insolation.

## REFERENCES CITED


Avery, T. E. 1975. Natural resources measurements. McGraw-Hill Book Co., New York, 399 p.

Brown, H. E. 1962. The canopy camera. U.S. Dep. Agric. For. Serv. Rocky Mt. For. and Range Exp. Stn. Pap. 72, 22 p.

Ffolliott, P. F., and D. B. Thorud. 1969. Snowpack density, water content and runoff on a small Arizona watershed. Western Snow Conf. 37:12-18.

Frank, E. C., and R. Lee. 1966. Potential solar beam irradiation on slopes: tables for 30° to 50° latitude. USDA For. Serv. Res. Pap. RM-18, 116 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.

Gary, H. L., and G. B. Colthorp. 1967. Snow accumulation and disappearance by aspect and vegetation type in the Santa Fe Basin, New Mexico. USDA For. Serv. Res. Note RM-93, 11 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.

Kittredge, J. 1953. Influences of forests on snow in the ponderosa-sugar pine-fir zone of the Central Sierrra Nevada. Hilgardia 22(1):1-96.

Lejcher, T. R. 1969. Snow accumulation and melt under various densities of ponderosa pine in Arizona. Unpublished Master's Thesis, Univer. of Ariz., 70 p.

Work, R. A. 1948. Snow-layer density changes. Amer. Geophys. Union Trans. 29:525-545.