A TECHNIQUE TO EVALUATE SNOWPACK PROFILES IN AND ADJACENT TO FOREST OPENINGS

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INTRODUCTION

One option available to land managers attempting to increase potential snowpack water yield is to create openings of different shapes and orientations in forest overstories. However, while clearing overstories has been shown to affect snowfall distribution patterns, it is not always known whether an increase in snowpack water equivalent (WE) occurred on a watershed as a whole.

This paper outlines the first approximation of a technique for (a) evaluating snowpack profiles in and adjacent to individual forest openings in terms of whether an estimated increase (or decrease) in WE has occurred at a point in time, and (b) defining trade-offs between the estimated increase (or decrease) in snowpack WE and the forest resource removed in creating the opening.

BACKGROUND

Profiles of snowpack build-up in openings in forest overstories have been widely observed. Often, more snow is found in openings than under adjacent forest overstories [Hansen and Ffolliott, 1968; Hoover and Leaf, 1967; Rotacher, 1965; Weitzman and Bay, 1959]. However, processes causing variations in snowpack profiles have only been qualitatively explained [Meiman, 1968]. General processes that have causal relationship to observed variations include deposition and redistribution of snow during and after precipitation events, and ablation (i.e., melting and vaporization).

Deposition and redistribution processes involve at least three factors. First, more snow may accumulate in openings than under forest overstories during precipitation events due to wind eddies in the openings [Goodell, 1966]. Second, the snowpack in openings may be augmented during and after

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storms by snow blown or dumped from surrounding forest canopies [Goodell, 1966; Hoover and Leaf, 1967]. Third, snowfall may be greater in openings than under forest overstories due to the absence of a canopy which intercepts snow [Goodell, 1966], although some reports minimize interception losses [Hoover and Leaf, 1967; Satterlund and Haupt, 1970]. Deposition and redistribution processes may cause a trough in the snow profile under forest canopies near the windward side of openings [Hansen and Ffolliott, 1968]. Possibly, this trough is due to trapping of snow in the opening combined with back eddies that cause increased deposition under the forest windward to the trough [Anderson, 1963].

Ablation factors affecting snowpack profiles involve spatial variations in solar and long-wave radiation fluxes to the snowpack in and adjacent to forest openings. Shaded sides of openings do not receive as much direct beam solar radiation as exposed sides. Field observations suggest higher rates of ablation in the open along the north side of east-west clearcut strips than along the south side [Rothacher, 1965; Weitzman and Bay, 1959]. Also, more direct beam solar radiation may impinge on a snowpack under a forest to the north of an opening than under a forest to the south of an opening [Sartz and Trimble, 1956].

Rates of ablation are also influenced by spatial variations in long-wave radiation emission from trees in and adjacent to openings. Trees that are exposed to direct beam solar radiation are warmed and, consequently, emit more long-wave radiation than trees not warmed by solar radiation. A snowpack absorbs almost all of the long-wave radiation impinging upon it [Reifsnyder and Lull, 1965]. Consequently, snow on the side of a forest opening exposed to direct beam solar radiation is also likely to be exposed to more long-wave radiation, emitted from adjacent heated trees, than snow on a shaded side [Anderson, 1963; Rothacher, 1965]. Thus, a combination of direct beam solar and long wave radiation causes, at least in part, the relatively high rates of ablation observed along exposed sides of forest openings.

It is difficult to isolate the effects that all deposition, redistribution, and ablation processes may have on snowpack profiles extending through openings and into adjacent forests. These profiles reflect a build-up which is the integrated result of all deposition, redistribution, and ablation processes operative prior to the time of measurement. However, even if individual effects of the determinant processes cannot be isolated, a quantitative characterization of the snowpack profile in an analytical framework may lead to empirical guidlines for land managers interested in improving water yields from snowpacks.

THE TECHNIQUE - AN ILLUSTRATION

To illustrate development and interpretation, a snowpack profile in and adjacent to a demonstration cutting in a ponderosa pine (*Pinus ponderosa*) stand in north-central Arizona has been evaluated within the framework of the proposed technique. The cutting is a clearcut strip 67 feet in width, equal to one and one-half the height (1-1/2H) of the adjacent overstory. The strip is located on an east aspect of 15 percent slope and is oriented with the long-axis up-down slope.

Snowpack WE was measured with a snowtube and scale at sample points established at 11 1/4-foot (1/4H) intervals along two parallel transects across the strip and extending 135 feet (3H) into the adjacent overstory on both sides. Measurements were made at peak seasonal accumulation, a time index assumed indicative of potential water yield from a snowpack, during the winter of 1970-71. Source data illustrated were the average of measurements obtained from each pair of sample points established along the transects.

After graphically describing the snowpack profile, a "zone of influence" was delineated (Figure 1). This "zone" is defined as the area bounded by sample points to the windward and leeward of an opening (the clearcut strip) which have measurable differences in snowpack WE as compared to sample points further from the opening [Hansen and Ffolliott, 1968]. With the above-mentioned sample design, a rule of thumb for snowpack conditions in ponderosa pine forests of Arizona allows differences of 15 percent in WE to be attributed to spatial variations in overstories and to measurement errors; differences exceeding this value are considered due to the influence of the openings.

Next, a Cartesian coordinate system was imposed on the snowpack profile, with the Y-axis the left-hand boundary of the "zone of influence" and the X-axis a reference line representing the "average" snowpack WE without the effect of the clearcut strip (Figure 2). A numerical scale with snowpack WE (in inches) on the Y-axis and distance (in feet) on the X-axis was constructed, and data points corresponding to the snowpack WE measurements in the "zone of influence" were assigned X, Y coordinates.

A mathematical expression was empirically selected to describe the snowpack WE data points. In this illustration, a 4-degree polynomial was the "best" statistical fit of the data points (Figure 2). This expression defined the snowpack profile in terms of the deposition, redistribution, and ablation characteristics discussed above.

The 4-degree polynomial was integrated to determine the respective areas above and below the X-axis (Figure 2). The result of this integration formed the basis for evaluating a ratio between the two areas. With this ratio

$$r = \frac{\text{area above}}{\text{area below}}$$

values exceeding 1 indicate an increase, values less than 1 a decrease and a value equal to 1 represents no change. In this illustration, a ratio exceeding 1 was obtained, indicating an increase in snowpack WE due to effects of the clear-cut strip.

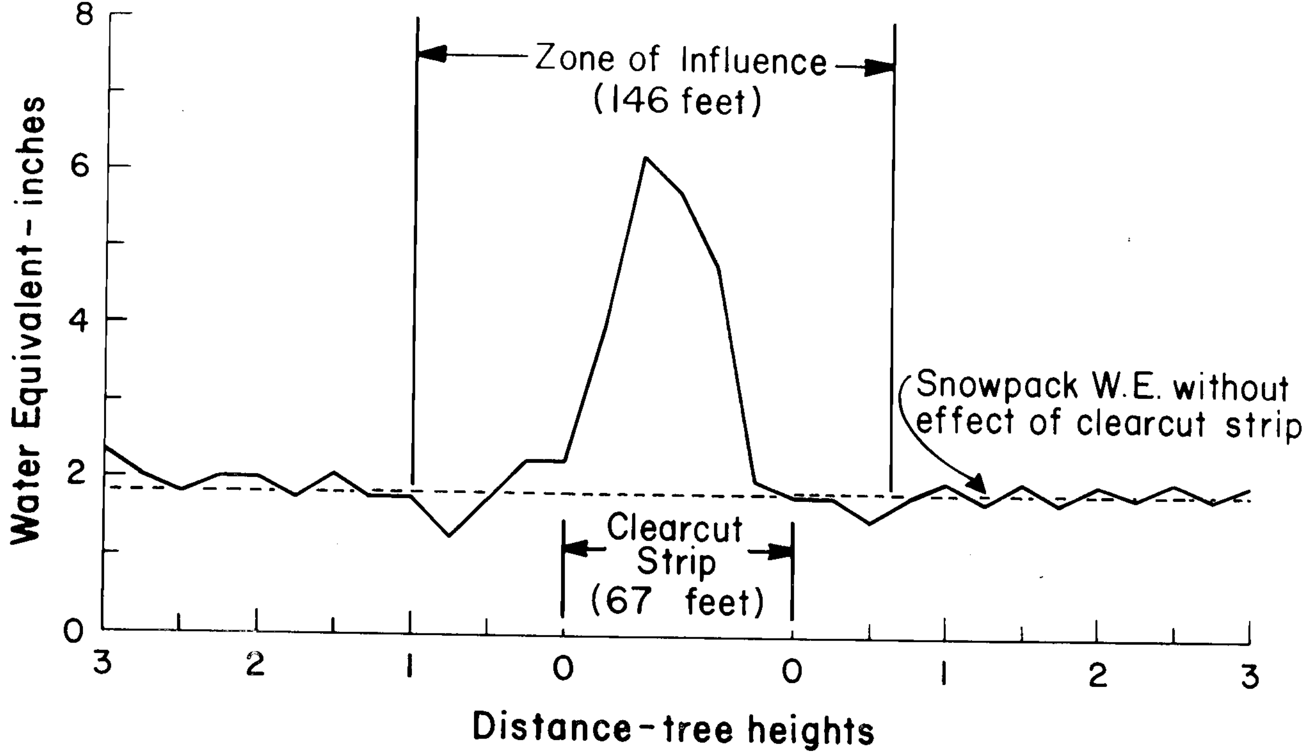

Fig. 1. Snowpack profile at peak seasonal accumulation, with the "zone of influence" delineated.

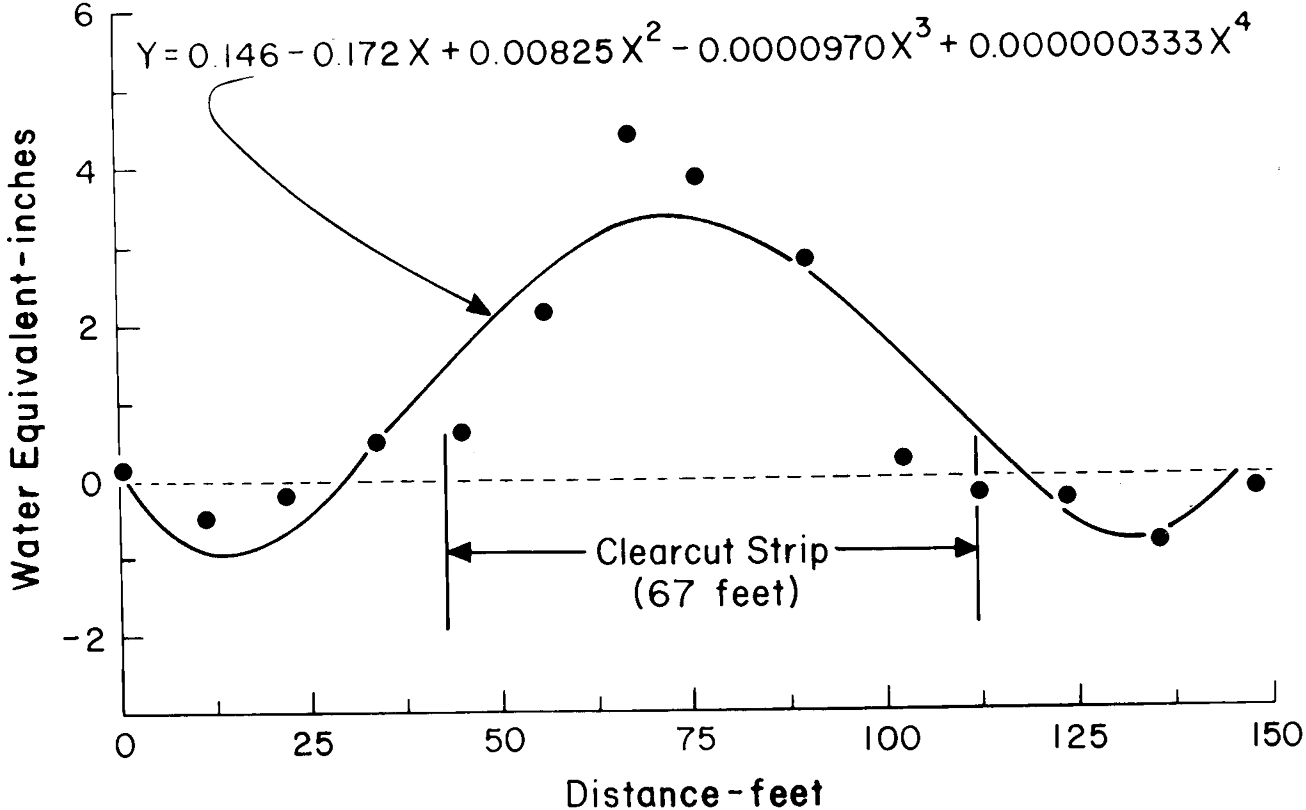

Fig. 2. Graphical representation of mathematical expression illustrating

To define the trade-off between the indicated increase in snowpack WE and the forest resource removed in creating the clearcut strip, the net change in the snowpack profile (the difference between the areas above and below the X-axis) was determined. Here, the net change was 170 inch-feet, which must be "distributed" over the area delineated by the "zone of influence" to obtain an average increase in snowpack WE. As the "zone" extends 146 feet (Figure 1), the average increase in snowpack WE approximated 1.2 (170 inch-feet/146 feet) inches, which represented an increase of 60 percent when compared to the "average" snowpack WE without the effect of the clearcut strip.

The forest resource removed in creating the clearcut strip was quantified by determining the clearcut proportion of the "zone of influence." In this illustration, 46 percent of the "zone" was clearcut (Figure 1). Assuming homogeneous forest density conditions existed within the "zone" prior to cutting, the forest resource removed approximates 821 (46 percent of the original 1,785) cubic feet of wood per acre. Therefore, an increase of 1.2 inches (60 percent in snowpack WE was realized by removing 821 cubic feet (46 percent) of ponderosa pine per acre, with the cutting in the form of the above-mentioned clearcut strip.

SUMMARY

Although the above illustration represents only one study site at one time of measurement, comparable analyses over an array of study sites and several measurement periods have provided quantitative information regarding the effects of creating opening in forest overstories to increase potential snowpack water yield over entire watersheds. If an increase in snowpack WE did occur, the magnitude of the increase was equated with the amount of forest resource removed in creating the openings. Presumably, defined can then be contrasted with trade-offs representing other land management options (i.e., alternative shape, orientation, and arrangement of openings, and different intensities of forest density reduction) to prescribe "optimum" land management systems.

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FIGURE LEGEND

Fig. 1. Snowpack profile at peak seasonal accumulation, with the "zone of influence" delineated.

Fig. 2. Graphical representation of mathematical expression illustrating snowpack profile within "zone of influence."