SNOW ACCUMULATION UNDER VARIOUS FOREST STAND DENSITIES AT TENDERFOOT CREEK EXPERIMENTAL FOREST, MONTANA, USA

by

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ABSTRACT

Snow accumulation in forested watersheds is controlled by climate, elevation, topographic factors and vegetation structure. Conifers affect snow accumulation principally by intercepting snow with the canopy which may later be sublimated. Various tree, stand, species and canopy densities of a subalpine fir habitat (ALBA/VASC) in central Montana were studied to determine if there was a response of snow accumulation to vegetation. Tree canopy cover, basal area, age since stand initiation, and species composition were measured at several sites with minimal topographic differences. Peak snow water equivalent was measured at 270 sample points within 8 stands divided between 3 study areas and at three corresponding open meadows. The study took place during the winter of 1995-1996 on the Tenderfoot Creek Experimental Forest in the Little Belt Mountains near Great Falls, Montana. It is administered by the USDA Rocky Mountain Research Station.

Variation in peak accumulation (SWE) on the forest floor was impacted the greatest by the percent of canopy cover measured by the 30° view angle of a photocanopyometer. Half of the variation in snow accumulation can be attributed to variation in canopy cover. A 6.4 percent decrease in peak snow water equivalent was observed per 10 percent increase in canopy density. Snow samples under subalpine fir and Engelmann spruce canopies showed a closer correlation between canopy and peak snow water equivalent than did lodgepole pine canopies. Basal area was found to be a poor predictor of snow accumulation.

INTRODUCTION

Early studies in forested watersheds noted the variability in snowpack over the landscape, with snow water equivalent (SWE) varying with climate, elevation, topography, and vegetation (eg. Connaughton 1935; Wilm and Dunford 1948; Gary 1979). Peak snow accumulation measured by SWE is a critical measurement from a watershed perspective, providing an approximate measure of the amount of water that may be added to a basin's precipitation budget from winter snowfall. Research focused on vegetation cover changes because it is the most easily manipulated of the many controlling variables. The majority of studies found that decreased canopy cover resulted in an increase in snow water equivalent of snowpack (eg. Wilm and Dunford 1948; Gary and Troendle 1982; Meiman 1987; Farnes and Hartman 1989; Hardy and Hansen-Bristow 1990, Skidmore et al. 1994), with a marginal increase in runoff (Hoover and Leaf 1966; Troendle and Leaf 1981; Troendle and King 1985; Farnes 1993), or higher soil moisture (Potts 1984).

Previous studies have outlined the factors that affect snow water equivalent of snowpack beneath forested canopies. Principle among these is the influence of the canopy density upon snow interception. Canopy density is thought to be proportional to interception potential. Conifers catch the falling snow in branches and needles where it may later be sublimated and lost from the snowpack. Of the snow that is captured by the canopy, part is sublimated back to the atmosphere and the remainder is eventually added to the snowpack below (e.g. Kolesov 1985; Meiman 1987; Schmidt and Pomeroy 1990; Troendle et al. 1993). The process of interception and subsequent loss is still under scrutiny and the magnitude of canopy effect on snow interception varies widely. Clear-cuts, with distinctly open canopies, have been shown to have 26 to 32 percent greater SWE than surrounding forests (McCaughey, unpub data). These substantial gains in SWE (Troendle and King 1985) must be balanced with losses in forested areas due to wind redistribution (Gary 1979). Previous studies in Montana, demonstrated 9 to 25 percent increases in SWE when clear-cuts are compared to surrounding forest stands (Hardy and Hansen-

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Bristow 1990; Skidmore et al. 1994). Species composition, stand age, and density, climate, storm character, and topographic setting are all likely to affect the magnitude of this influence (eg. Meiman 1970; Schmidt and Pomeroy 1990; Troendle et al. 1993; Lundberg and Halldin 1994).

Most previous studies have quantified differences in snowpack under starkly different vegetation types. The role of the more gradual growth and seral stage landscape variation upon snow accumulation has not been fully addressed in snow studies. The first investigation to study a range of forest densities on snow accumulation on the forest floor (Wilm and Dunford 1948) found that less dense canopies produced more snow than thicker mature canopies. The effect of thinning was again examined (Gary and Troendle 1982; Gary and Watkins 1985) and it was found that the canopy–snow relationship held for thinned forests in the central Rockies, although the SWE gains were not as impressive due to the minimal reduction in canopy cover. Hardy and Hansen-Bristow (1990) studied the impact of forest growth upon snow accumulation. That study found a significant inverse relationship between stand age and snow accumulation during one season, but not the following season. This study extended the research Hardy and Hansen-Bristow began to include a wider range of ages and canopy densities.

The sampling design for this study was intended to minimize area effects (e.g. one stand receiving more snow than another) and wind redistribution effects. Thus, observed differences in SWE between stands could be attributed to forest age, canopy cover, structure, or species composition. The study site, Tenderfoot Creek Experimental Forest, serves to supplement watershed knowledge because of its lodgepole pine (*Pinus contorta var. latifolia*) composition as well as its representativeness of the Northern Rockies.

STUDY AREA

This study was conducted at the Tenderfoot Creek Experimental Forest, in the Little Belt Mountains, 65 km south-southeast of Great Falls, Montana. The Tenderfoot Creek Experimental Forest (TCEF) is administered by the Rocky Mountain Research Station's Forestry Sciences Laboratory in Bozeman, Montana, and located within the Lewis and Clark National Forest.

Tenderfoot Creek drains from the plateau-like crest of the Little Belt Range toward the west–northwest. A steep incised canyon occupies the center of the TCEF, while the tributaries and eight study plots lie on a gentle terrain of 5 percent to 15 percent slope. The experimental watershed encompasses the headwaters of Tenderfoot Creek, with elevations ranging from 1800 m (6000') to 2350 m (7800'). The 3,693 ha. (9,125 acre) watershed is instrumented with precipitation gauges, stream flow gauges, weather stations and snow pillows (Farnes et al. 1995).

The Little Belt Mountains are an island range of the Great Plains. Snow density is intermediate, lying between the slightly drier snows of the Wasatch and Front Ranges of Utah and Colorado, and the moister conditions found in northern Idaho and northwest Montana (Kosnik 1995). The watershed is characterized by its lodgepole pine-dominated forests, with a mosaic of different age stands and intermixed with a few natural meadows. TCEF has had no commercial harvesting. The fire history reveals numerous burns that have occurred periodically throughout the previous four centuries, with few fires in the last 100 years (Farnes et al. 1995). The average stand age in the watershed is higher than it was 100 years ago prior to fire suppression, and species composition has presumedly shifted slightly toward the more shade tolerant species of subalpine fir (*Abies lasiocarpus*) and Engelmann spruce (*Picea engelmannii*)

METHODS

Eight plots were distributed in three areas of the watershed and represented five different age classes (Table 1). The stands included a range of ages, as well as stands of similar age but of different species composition. All stands had similar elevation, westerly aspect, gentle slopes ranging from 3° to 13°, and were positioned downslope of the windy rim of the watershed. The habitat type is *Abies lasiocarpa/Vaccinium scoparium* (ALBA/VASC), or subalpine fir/grouse whortleberry phase (Pfister et al. 1977). Measurements were made at each sampling point to capture the range of variation and a representative mean for each plot. Canopy density and basal area were measured for each stand to find the underlying cause behind the variation snow water equivalent.

Table 1. Description of the eight stands within the three study sites on the Tenderfoot Creek Experimental Forest. Descriptions include stand age, species category, community successional stage, elevation, slope, aspect and average estimated precipitation.

DESCRIPTION OF THE EIGHT STANDS

			Species Category*									
Site	Stand	Age	%L	%L/W	%L/S	%S/L	%S	Cover Type**	Elevation	Slope	Aspect	Avg. Precip+
BUBBLING SPRINGS												
	Ba	123 years	0	0	51	41	8	LP2.5	7390'	4.5°	315°	36.5" (93 cm)
	Bb	415 years	0	0	3	92	5	SF	7380'	3°	290°	36.5" (93 cm)
DRY PARK												
	Da	49 years	4	96	0	0	0	LP0.5	7380'	7°	260°	36" (91 cm)
	Db	123 years	58	0	42	9	0	LP1.7	7460'	6°	250°	36" (91 cm)
	Dc	270 years	70	0	30	0	0	LP	7350'	13°	270°	37" (94 cm)
FARNES MEADOW												
	Fa	75 years	61	0	38	0	0	LP1.0	7440'	6°	225°	37" (94 cm)
	Fb	123 years	15	0	85	0	0	LP2.0	7400'	6°	260°	37" (94 cm)
	Fc	270 years	0	0	41	58	0	LP3.0	7390'	6°	280°	37" (94 cm)

* Percentage component of different species

L	pure lodgepole pine
L/W	majority lodgepole pine with some whitebark pine
L/S	majority lodgepole pine with some subalpine fir or Engelmann spruce
S/L	majority subalpine fir or Engelmann spruce with some lodgepole pine
S	pure subalpine fir/ Engelmann spruce

** Lodgepole pine community cover types (after Despain, 1990)

LP0	recently burned with lodgepole pine colonization
LP1	dense, young stands of small diameter lodgepole
LP2	intermediate age stands with Engelmann spruce/ subalpine fir understory
LP3	ragged canopy with larger component of Engelmann spruce/ subalpine fir
LP	climax lodgepole pine in a mature stage, few understory trees
SF	climax stands of Engelmann spruce and subalpine fir

\+ Estimated average precipitation from 1:50,000 map developed by Phil Farnes (Farnes et al. 1995)

A systematic grid was established within each of the eight stands. A stand was defined as a contiguous group of trees having the same age and vegetation structure. The grid was three sampling points wide by x sampling points long with x being a multiple of 3. More sample points were used in areas with a higher canopy variance (estimated visually). A typical sampling grid was 3 by 9 points for a total of 27 sample points. The three rows of the grid ran parallel to contours and were spaced 20 meters apart with sample points spaced 15 meters apart. A total of 270 sample points were established within all eight stand grids. Sample points were marked with a 2 meter PVC pipe coupled over re-bar. To reduce the potential for wind redistribution from stand to neighboring clearing, a buffer area equivalent to two tree heights was delineated within the perimeter of each stand (Gary 1974).

Canopy cover (density) was measured with a spherical densiometer and a photocanopyometer (Codd 1959). The spherical densiometer, with a measurement radius of 45°, was placed on a leveled tripod 1 m off the ground. Measurements from the four cardinal directions were recorded and averaged. The photocanopyometer (PCM) was placed on the same tripod head as the spherical densiometer and photographs of the forest canopy were taken. The PCM's view cone is similar to the spherical densiometer's, 45°, but were also masked to 30°. Photographs from the PCM are traditionally analyzed with a dot overlay method for evaluating canopy coverage. However, for increased accuracy and precision, a new digital technique of analyzing the photograph was employed. This procedure yielded high accuracy and was consistent when repeated (Moore 19997). Stem density was measured with a 5 basal area factor gauge (Cruz-All) to determine stand basal area.

Five categories of tree species were constructed, ranging from pure lodgepole pine to pure Engelmann spruce or subalpine fir (Table 1). Species composition was considered mixed if one or more of another species was present in the basal area count, which typically included 30-50 trees surrounding the sample point. Stand age was determined from a fire history study of the watershed (Farnes et al. 1995).

Seven sampling periods were taken throughout the season. Sampling sessions 1 (Dec. 18, 19), 2 (Jan. 17, 18) and 3 (Feb. 20, 21) were intended for pilot studies. Sessions 4 (Mar. 17, 18), 5 (Apr. 9, 10), 6 (Apr. 27, 28) and 7 (May 13) captured the range of peak accumulation. Sampling session 6 showing peak snow accumulation was used for all analyses. At each snow survey stake, snow was sampled using a US federal snow sampler. Depth was recorded to the nearest half inch and weight was recorded to the nearest quarter ounce. A hybrid sampling system utilizing a rectangular lattice and omitting one third of all points was used (Jessen 1975). The pattern of omission rotates systematically at each sampling session.

RESULTS AND DISCUSSION

1995-96 snow season

The study season had greater precipitation than normal, based on a 30-year average of the nearby Spur Park and Deadman Creek SNOTEL sites. A small spike around early December and a series of storm events beginning in late April resulted in a net snow accumulation of 114 percent of normal for the higher elevation Spur Park and 102 percent for the lower Deadman Creek (Natural Resources Conservation Service data). The conditions at TCEF were likely to be between these two SNOTEL sites in snow accumulation since TCEF is bracketed in elevation by these two instrument stations. Peak accumulation at TCEF was likely delayed one to two weeks past the average peak; although precipitation records within the forest are not long enough to confirm this.

Variation in snow water equivalent

Maximum SWE (sampling session 6) varied substantially by stand, age since burn, and species composition (Figure 1). Mean stand SWE ranged from 22.6 to 32.1 cm (a difference of 30 percent) while sampling point SWE ranged from 13.3 to 43.8 cm (a difference of 70 percent). The boxplots comparing species were somewhat misleading, since only one stand of a very young age contained the lodgepole pine/whitebark pine (LP/WB) species description, and there are only half a dozen samples defined as pure spruce/fir (SF). This data strongly indicates that snow water equivalent varies between the eight stands representing various stages of growth, composition, and extent of canopy cover. A number of pairings showed statistically significant differences using non-parametric tests (Moore 1997); although much can be gleaned from simply examining the boxplots and shaded confidence intervals.

Variation in canopy density

Measurements of canopy density from the spherical densiometer showed little variation from stand to stand, except for the youngest stand (Figure 2). Most of the range of this measurement stemmed from one stand alone (stand Da). Mean stand canopy density values ranged from 47 percent to 70 percent. Individual measurements taken at each sampling point ranged from low canopy density (5 percent) to a very high canopy density (90 percent). It was apparent in the field that this instrument has limited accuracy. Analysis showed that SWE regression with the densiometer was not as robust as regressions with the photocanopyometer. Because of this weakness, the spherical densiometer was omitted from much of the analysis presented here.

The photocanopyometer (PCM) provided good resolution between stands and more accurately captured the percentage of canopy cover (Figure 3). The eight stands measured by the PCM showed greater variability in canopy as compared to densiometer measurements (Figure 2). Mean stand canopy density ranged from 24.5 percent to 54.4 percent. Individual measurements ranged from completely open to 82 percent.

The masked 30° view was superior to the wider 45° view. Regression analysis indicates that the 30° view was superior to the 45° view (Figures 4 and 5). The 30° view of the photocanopyometer explains over half the variation in SWE (R^2=51 percent), establishing this forest structure measurement as the principle factor affecting

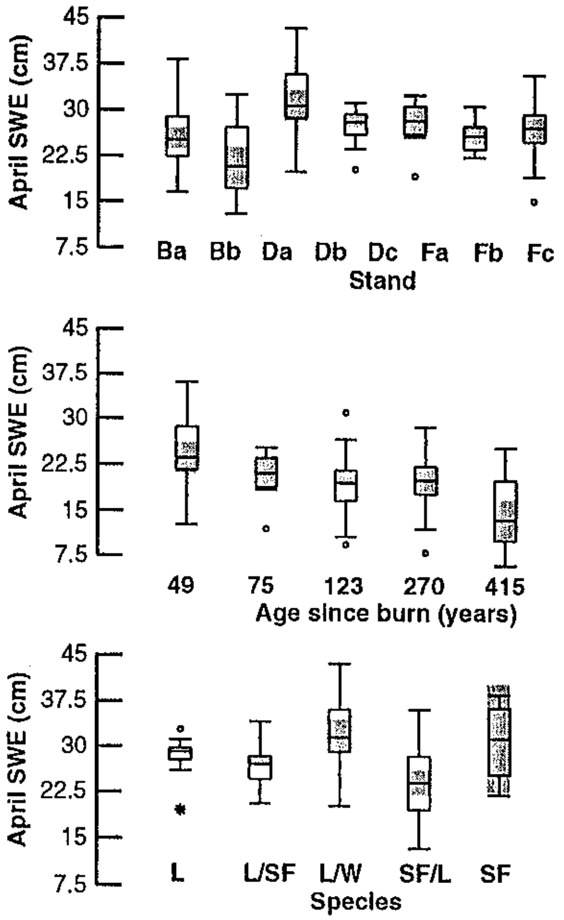


Figure 1. Snow Water Equivalent by stand, age and species composition.

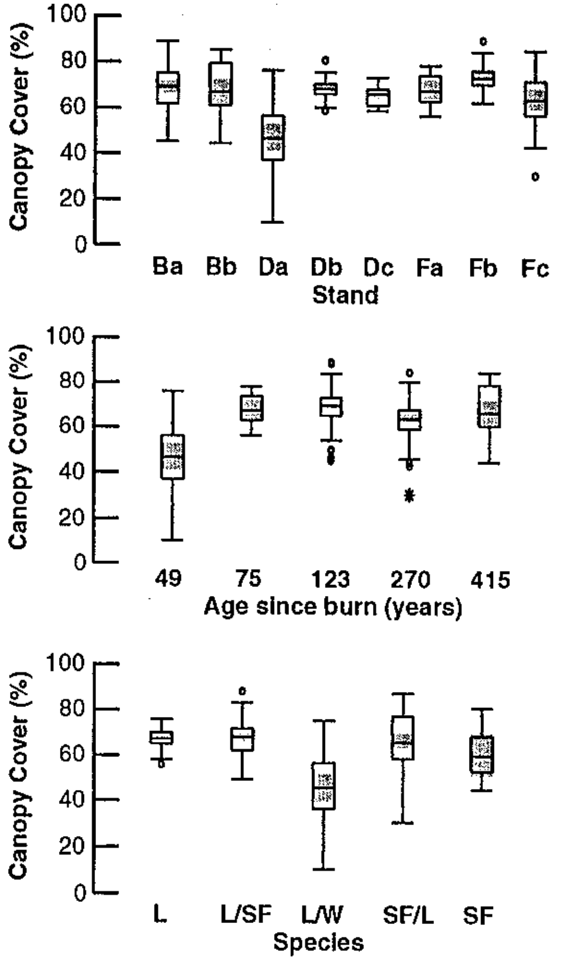


Figure 2. Canopy Density (Spherical Densiometer) by stand, age and species composition.

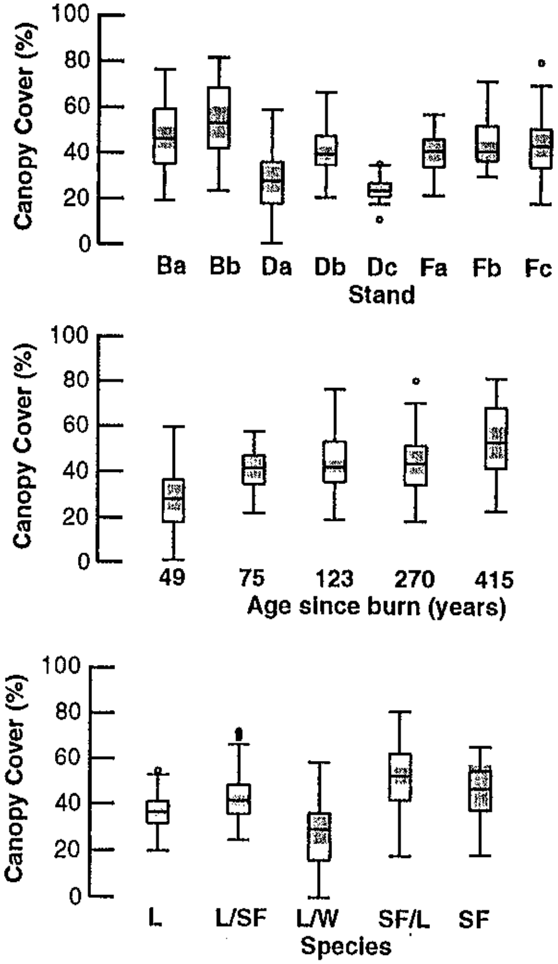


Figure 3. Canopy Densiometer (30° Photo-canopyometer) by stand, age and species composition.

Boxplots depict median (central horizontal line), 25th and 75th percentile (bottom and top of box) and lowest and highest values ("whiskers"). Outliers beyond the normal distribution of data are shown with circles or asterisks in extreme cases. The shaded portion shows a 95% confidence interval based on medians.

L= pure lodgepole pine
L/SF= lodgepole pine dominated with some Engelmann spruce/subalpine fir
L/W= lodgepole pine dominated with some whitebark pine
SF/L= spruce/fir dominated with some lodgepole pine
SF= pure engelmann spruce/subalpine fir

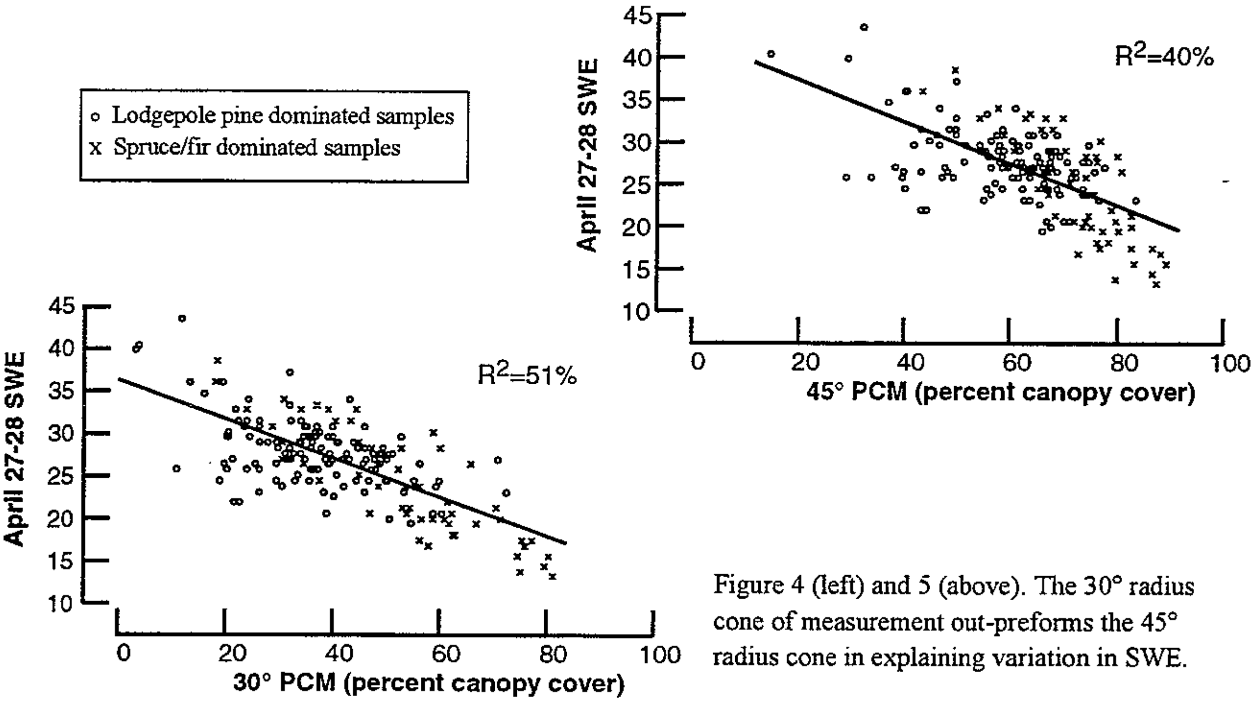


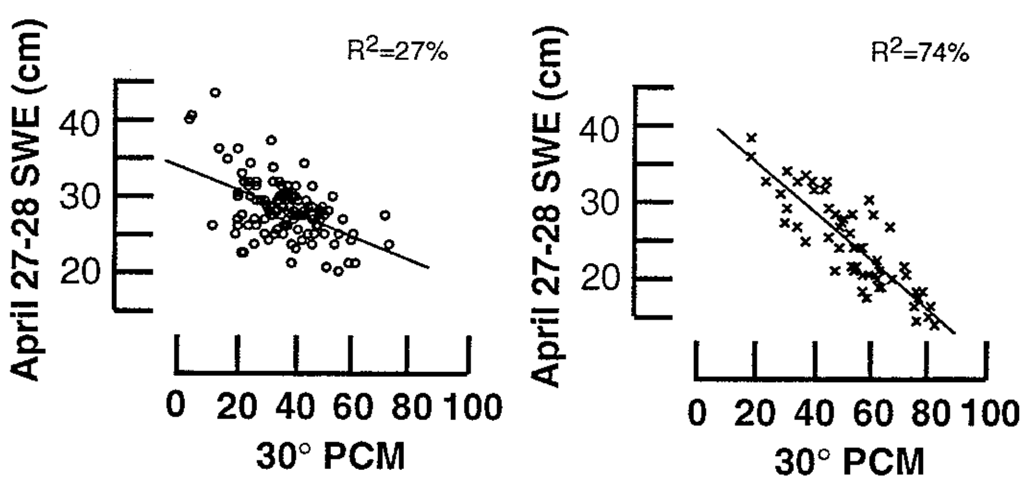
Figure 4 (left) and 5 (above). The 30° radius cone of measurement out-preforms the 45° radius cone in explaining variation in SWE.

snow accumulation. A decrease in snow water equivalent of 2.3 cm (6.4 percent of max SWE) occurs per 10 percent increase in canopy density. This equation approximates work done by Farnes and Hartman (1989) indicated a 5 percent decrease in SWE per 10 percent increase in canopy density. Adding corresponding data from three open meadows at Bubbling Springs, Farnes Meadow, and Dry Park (NRCS snowcourse data) increases regression R^2 values to 55 percent.

Two more regression analyses were done comparing different species (Figures 6 and 7). Snow accumulation for spruce/fir dominant samples (including pure spruce/fir samples) was much better predicted than snow under pine dominated samples. R^2 values for the spruce/fir snow water equivalent were 74 percent for the PCM–based measurements. On the other hand, regression statistics for lodgepole pine dominated samples were less impressive. There, the PCM–based measurements could only account for 27 percent of the variation in snow.

<u>Variation in basal area</u>

Figure 6 (right) and 7 (far right). Species specific comparison between 30° photo-canopyometer and SWE. The relationship between pine canopies and SWE (right) is not as close as the relationship between spruce/fir canopies and SWE (far right).



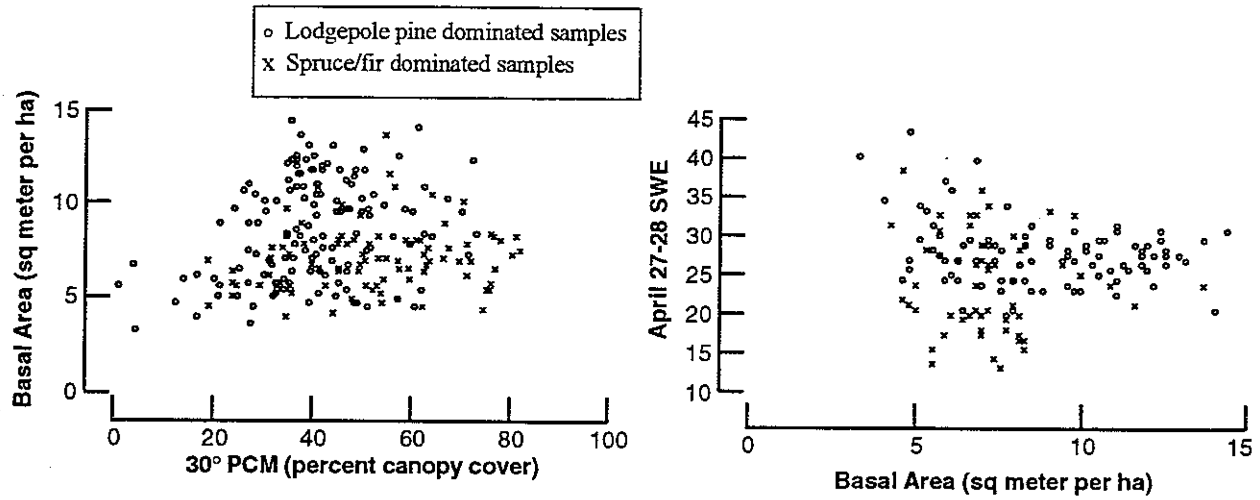


Figure 8 and 9. Basal was a poor substitute for canopy cover, nor did it have much relationship to peak SWE.

Basal area measures the density and diameter of stems in a forest and varied substantially from one stand to another. Values ranged from 6.0 m^2 per ha to 11.2 m^2 per ha. Highest median values were found at the Dry Park B stand, the 123 years since burn age category, and the lodgepole pine species category. Lowest median values were found in the Dry Park A stand, the 49 years since burn age class, and the lodgepole pine/whitebark pine species category (all three of which are the same stand). Previous studies of canopy effects upon snowcover have identified basal area and canopy cover both as suitable predictors of snow interception or net accumulation (Gary 1979; Gary and Watkins 1985). Basal area has been thought of as a substitute for canopy coverage. Figure 8 shows a poor correlation between canopy density as measured by the 30° PCM and basal area. Basal area was not a controlling factor of snow accumulation (Figure 9). The data presented here does not support either utility of basal area measurements.

SUMMARY

Peak snow water equivalent, the initial input into the montane hydrologic cycle, is influenced by forest canopy. Timber harvest, insect infestations, disease, age and fire frequency alter canopy cover, and are linked to montane water production. This research indicates that canopy interception of snowfall and subsequent loss to the atmosphere are significant processes on the Tenderfoot Creek Experimental Forest. These relationships may be applicable to other forested landscapes.

The opportunity exists for subsequent hydrologic research to build upon the results of this study. The results here, combined with watershed inventories of forest structure and precipitation inputs, can be used to build a simple model estimating total net winter precipitation. Using successional stage as an driving variable may reduce the field work required to build such a model. Such a study could produce net winter precipitation values for a forested watershed based on a few well placed precipitation gauges or snow courses.

Other forest structure variables, yet to be measured, may be secondarily influencing snow accumulation. One recommendation would be to quantitatively assess the structural characteristics of successional stages, then compare that to SWE. The concept of succession may embody many variables such as age, tree height, branch height, understory component, and stem spacing. The answer to the remaining variation in snow water equivalent may also lie in the realm of ablation and radiation effect, not in accumulation and interception. Instrumentation for the purpose of comparing stand microclimate is another potential avenue of research.

Additionally, this research within the Tenderfoot Creek Experimental Forest will allow comparison between net precipitation and streamflow discharge. A network of stream gauges and precipitation recording devices are in place on the experimental forest. The difference between net precipitation and unit stream discharge as calculated by stream gauges will yield valuable insight into the multiple fates of snow precipitation (evapotranspiration, runoff, groundwater recharge, soil infiltration, and throughflow). Planned forest treatments, such as timber harvest using even-aged and uneven-aged systems along with thinning and burning, will provide comparisons to this study which establishes a baseline for the ALBA/VASC habitat type.

Hopefully this research will better outline the hydrologic impacts of vegetation changes within a watershed, giving resource managers a tool in building contingency tables and mitigating negative impacts.

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