PRELIMINARY INFORMATION ON SNOW INTERCEPTION, ACCUMULATION, AND MELT IN NORTHERN ROCKY MOUNTAIN LODGEPOLE PINE FORESTS

by

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ABSTRACT

Tenderfoot Creek Experimental Forest (TCEF) is located in the Little Belt Mountains in north central Montana and was established in 1961 for watershed research. Tenderfoot Creek flows into the Smith River, a major tributary of the Missouri River. In the early 1990's, the original watershed scope for TCEF was expanded to include studies of fire, fisheries, composition of vegetation and animal communities, and other physical, biological, and social factors as they relate to landscape-level management. Social factors relating to water resources are increasing in importance for research on TCEF. Information on snow interception, accumulation, and snow melt from mountain watersheds is important for stream flow management in the Northern Rocky Mountains such as the Smith, Missouri and upper Columbia river systems.

Preliminary data on snow water equivalent (SWE) in lodgepole pine stands were measured on six paired snow courses in TCEF. Two snow pillows, one in an opening and the second in an adjacent lodgepole pine stand, were installed during the fall of 1993 and SWE was recorded, for these pillows, on continuous chart recorders during the winters of 1993/94 and 1994/95. The snow pillows are also located adjacent to an open/canopy snow course pair, at the headwaters of Tenderfoot Creek. Snow water content increased an average of 38 percent in openings over adjacent stands of lodgepole pine and ranged from 19 to 85 percent. Canopy density influenced snow accumulations and redistribution of snow from lodgepole crowns to the ground. Snow melt-out occurred approximately 2 weeks later on canopied sites than on open sites.

INTRODUCTION

Information is needed on snow interception, accumulation, and melt under a variety of canopy cover conditions for accurate estimates of hydrologic inputs and outputs in northern Rocky Mountain watersheds. Lodgepole pine (*Pinus contorta* Dougl.) forests comprise important water production areas for many of our western river basins. Lodgepole pine forests cover nearly 5.3 million hectares (ha) in the Rocky Mountains of the western United States and another 20.2 million ha in western Canada (Lotan and Perry, 1983). Several studies from the Rockies have shown that snow accumulation and ablation are inversely correlated to stand density (Gary and Troendle, 1982; Gary and Watkins, 1985). Vegetation manipulation may have significant effects on water production from lodgepole pine forests. Results from other studies show that the canopy-snow relationship is sensitive to forest species, regional climate, stand age, stand size, and aspect (Berndt, 1965; Caine, 1975; Hardy and Hansen-Bristow, 1990). Ablation on south-facing aspects can be substantially greater than on north-facing slopes (Troendle et al., 1993). Crown densities of lodgepole pine stands increase during early and mid-successional stages and decrease as mortality increases at maturity and in post-maturity stages.

Climate in the northern Rockies of Montana, Idaho, and Wyoming is affected by precipitation from both continental and pacific maritime storms. Management alternatives have been developed for lodgepole stands in the southern Rockies but little has been done in the northern Rockies (Berndt, 1961; Troendle and Meiman, 1984).

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A better understanding of snow hydrology will help develop and modify models that predict water yields bases on canopy density, slope, aspect, and elevation. These hydrologic factors affect the volume and timing of runoff. Managers need the ability to accurately predict changes in runoff that might occur from timber removal, windthrow, insect infestations, or fires. Hydrologic information from work on TCEF will lead to improved watershed models and provide managers with better information for management decisions.

Tenderfoot Creek Experimental Forest comprises dense virgin stands of lodgepole pine mixed with minor components of Engelmann spruce (*Picea engelmannii*), subalpine fir (*Abies lasiocarpa*), and whitebark pine (*Pinus albicaulis*). The forest has had a long history of fires which have created a mosaic of mostly two-aged stands. Only two small fires have occurred in the last 90 years since the advent of fire suppression. Many lodgepole pine stands are greater than 100 years old and mortality due to aging is accelerating. Fire suppression has created an unnatural buildup of fire fuels which has stimulated the impetus to impose vegetation manipulation in the near future. Hydrologic input and output monitoring began in 1992 to develop baseline information prior to vegetation manipulation. Seven weirs installed from 1992 through 1994 are being used to quantify hydrologic outputs and the timing of runoff from Tenderfoot Creek and its tributaries.

This paper presents preliminary information on snow interception, accumulation, and melt in lodgepole pine stands of north central Montana. Snow courses were used to compare snow interception and accumulation between open areas and canopied stands. Data from snow pillows provided insight on snow interception, accumulation, sublimation, redistribution, and melt rate differences between openings and canopied stands.

STUDY AREA AND METHODS

The 3,561 ha Tenderfoot Creek Experimental Forest was established in 1961 for watershed research and is the only experimental forest formally dedicated to research on the east slope of the northern Rockies. It is representative of the vast expanses of lodgepole pine found in Montana, southwest Alberta, Idaho, and Wyoming. TCEF lies in the Little Belt Mountains of north central Montana 40 air kilometers north of White Sulphur Springs, Montana. The experimental forest boundary is the hydrologic boundary of the Tenderfoot Creek headwaters which drains into the Smith River, a tributary of the Missouri River. Elevations for TCEF range from 1840 to 2421 m.

Eight study sites were selected for studying snow interception, accumulation, and melt on the experimental forest (Figure 1). An open snow course was installed at each of the eight sites with each snow course having five sampling points. The Sun Creek study site has two open snow courses for evaluation of within-site variation. Six snow course locations have a paired canopy snow course in an adjacent lodgepole pine stand: County Line, Farnes Meadow, Sun Creek, Onion Park, Bubbling Springs, and Lonesome Creek. Open snow courses were also located at Dry Park and Stringer Creek for basin-wide assessment of snow distribution. Two snow pillows were installed at the Onion Park site: an open pillow located next to the open snow course and a canopy pillow located within the lodgepole stand and adjacent to the canopy snow course.

Standard snow survey methods were used to quantify snow depth and SWE at open and canopy snow courses. Snow depth, and SWE were measured at each of the five sample points, and then averaged for the snow course. The overstory canopy was quantified using basal area and spherical densiometer methodology.

Snow pillows were used to measure snow accumulation under open and closed canopy conditions. Snow accumulation was measured with a continuous chart recorder.

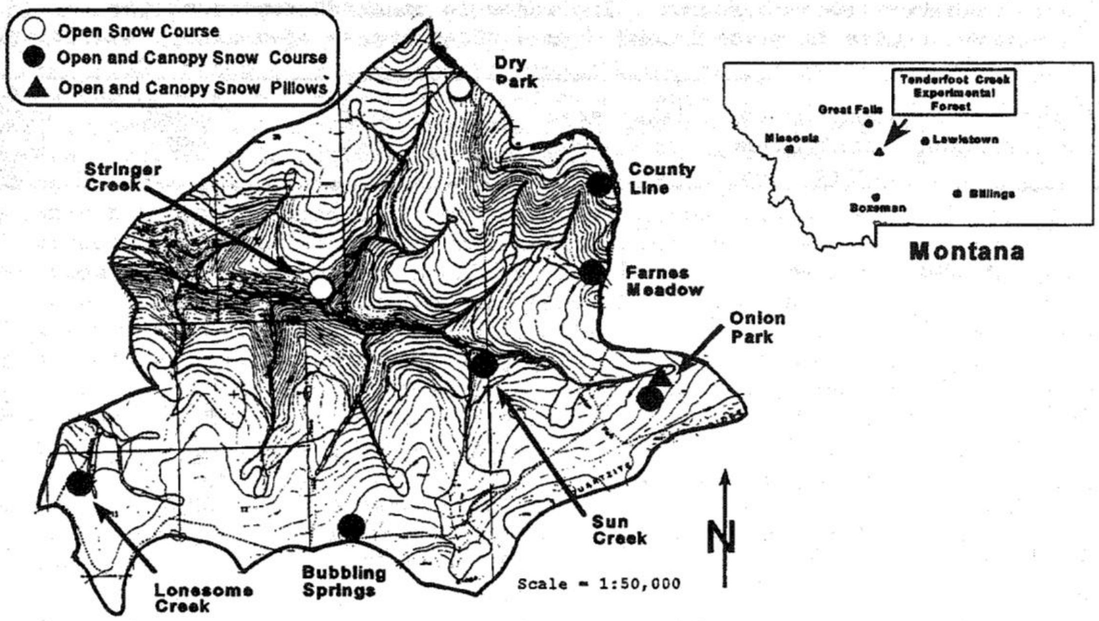

Figure 1. Location of open and closed snow courses and snow pillows on the Tenderfoot Creek Experimental Forest.

RESULTS AND DISCUSSION

Snow Courses

The percent increase of April SWE between closed and open snow courses averaged 38 percent over all sites and all years measured (Table 1). This corresponds to average increases of 34.3 percent found by Troendle (1987) in the southern Rockies. Increases of SWE ranged from 19 to 85 percent with Farnes Meadow consistently having the greatest differences for both years measured. The canopy snow course at Farnes Meadow has the highest stand density of $44m^2$/ha of basal area (variable plot method) and the highest photo density of 66 percent (photocanopyometer method). The high differences in SWE may be attributable to the snow interception and sublimation from lodgepole pine crowns at the Farnes Meadow site. A study is being designed to evaluate the effects of a wide range of crown densities on snow interception. County Line has the lowest basal area of $7m^2$/ha, however, the difference in sperical densiometer was 44 percent, similar to Lonesome (48 percent). The County Line data site has a high percentage of smaller trees which were not accounted for by the basal area method because of their small diameter size.

Snow Pillows

Snow interception, accumulation and melt were measured and analyzed on snow pillows in open and closed canopy conditions at the Onion Park data site for the 1994 water year (Figure 2). Snow accumulation began in early October of 1993 for both open and closed canopy pillows. Snow accumulated more quickly in the openings than in the forest during early November and differences increased until peak snow pack in early April. This April peak date compares with data from other studies in the Northern Rockies (Beard, 1995). Accumulation differences may be caused by interception and sublimation from lodgepole pine crowns. Melt of the snow pack began in mid-April for both open and closed conditions, however, melt rates were greatest in the opening (Figure 2). Final melt-out occurred on May 24 for the open pillow and 2 weeks later on June 10 for the closed canopy pillow. Melt differences were likely due to shading effects from the forest canopy.

Table 1. April peak snow pack at open and canopy snow courses on the Tenderfoot Creek Experimental Forest. Increases in peak SWE represent the accumulative increase in SWE from a closed to an open canopy condition.

Location Aspect-Elevation	Densiometer difference from open	Basal area of closed lpp stand	Date	Open SWE	Closed SWE	Increase in peak SWE
m	%	m^2/ha		cm	cm	%
Bubbling Springs	66	33	1993	40.4	30.7	32
N - 2265			1994	38.6	32.5	19
			1995	38.1	27.9	37
County Line	44	7	1993	42.7	31.5	36
SW - 2380			1994	52.3	39.1	34
			1995	43.2	30.2	43
Farnes Meadow	66	44	1994	50.3	31.7	59
W - 2255			1995	39.9	21.6	85
Lonesome	48	37	1994	37.1	27.2	36
N - 2124			1995	34.5	27.4	26
Onion Park	59	28	1993	36.3	30.2	20
W-2259			1994	45.0	36.3	24
			1995	40.1	27.4	46
Sun Creek NE - 2146	54	34	1995	36.9	26.9	37

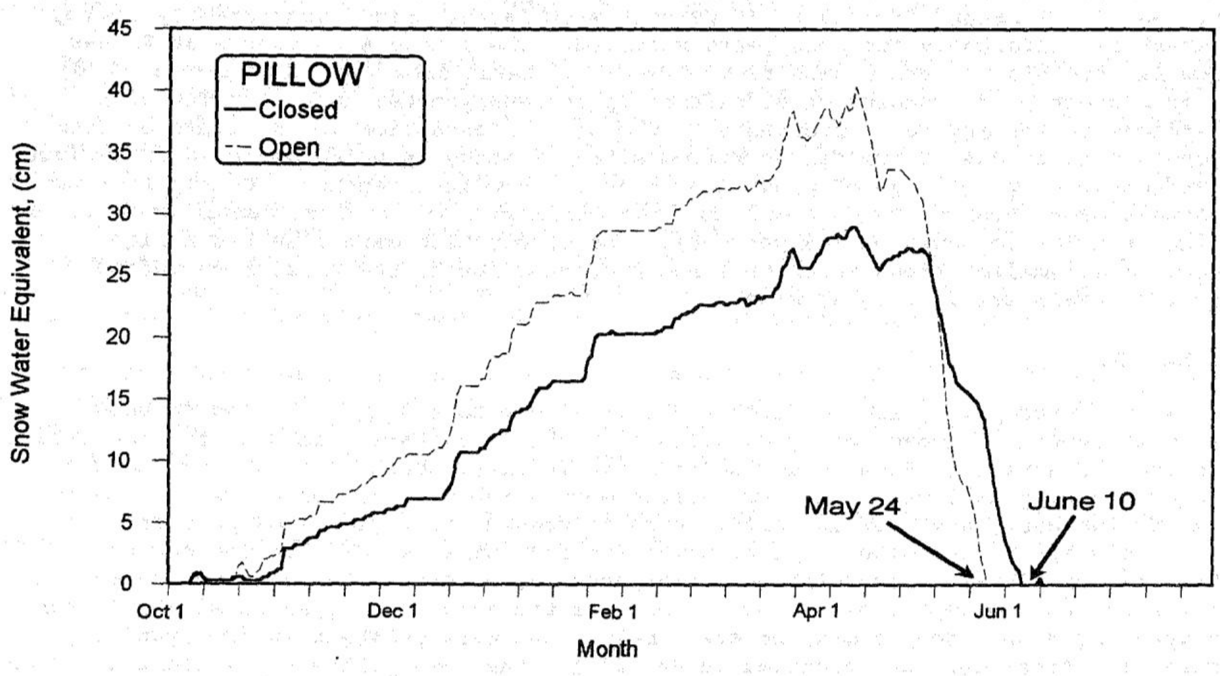

Figure 2. Snow accumulation and melt from snow pillows under open and closed canopy conditions on the Tenderfoot Creek Experimental Forest. The closed canopy snow pillow was located in a lodgepole pine stand with a basal area density of 28 m^2/ha at the Onion Park snow course site for the 1994 water year.

Three snow events (six days long each) were evaluated from the 1994 water year data on an hourly basis to examine accumulation, interception, sublimation, and redistribution in open and closed canopy conditions (Figure 3). The first snow event (Nov. 3-8, 1993) produced a substantial accumulation of 2.8 cm of SWE during a 12-hour period in the open site. Snow accumulated at a steady rate in the open but increased in small increments under the canopy toward the end of the snow sub-event. The small incremental increases in accumulation are assumed to be a result of snow shedding from the canopy to the forest floor. A second small snow event occurred in the open 12 hours later but did not accumulate on the closed canopy pillow (hour 80) for nearly 48 hours (Figure 3). This long lag in accumulation may again have been a result of canopy interception and delayed redistribution. Winds and higher or increasing temperatures' play a major role in snow redistribution (Schmidt and Troendle, 1992). Snow accumulation to the point of crown overload may also cause a sudden redistribution of snow from lodgepole crowns to the forest floor. Air temperature is measured at a weather station adjacent to the open snow pillow. More detailed evaluation of the cause of snow redistribution should be possible when wind speed and direction measurements are collected. The accumulation difference (change) increased by only 0.5 cm in SWE for the open pillow compared to the closed canopy pillow during the 6-day event shown. Sublimation of snow from the lodgepole pine crowns may account for the difference in total accumulation between the open and closed pillows at the end of a snow event.

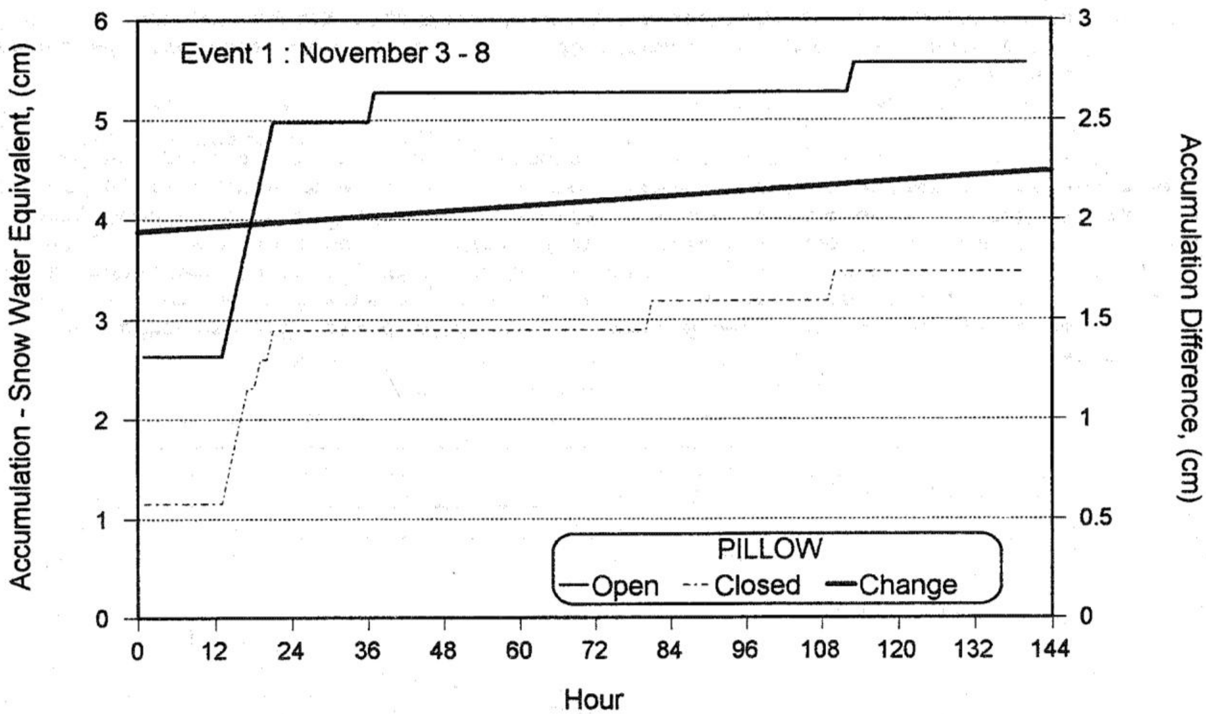

Figure 3. Six-day snow accumulation event on open and closed snow pillows in early November 1993 on the Tenderfoot Creek Experimental Forest. Change represents the trend in accumulation difference between snow pillows during the event.

The second snow event shows snow accumulation on open and closed canopy pillows throughout a 6-day period in mid-December, 1993 (Figure 4). Snow accumulated during the 6-day period in three progressively larger sub-events. The first sub-event (hours 14-24) shows that there was a 2-hour delay before the closed canopy pillow accumulated the same total as did the open pillow. Redistribution of canopy-intercepted snow is a probable cause of the delayed accumulation. During the second and third sub-events, the open snow pillow accumulated successive increments of snow while the accumulation on the closed pillow was delayed. The accumulation difference (change) between snow pillows increased by nearly 1.5 cm in SWE during the 6-day event with the open pillow accumulating snow at a faster rate than the closed pillow.

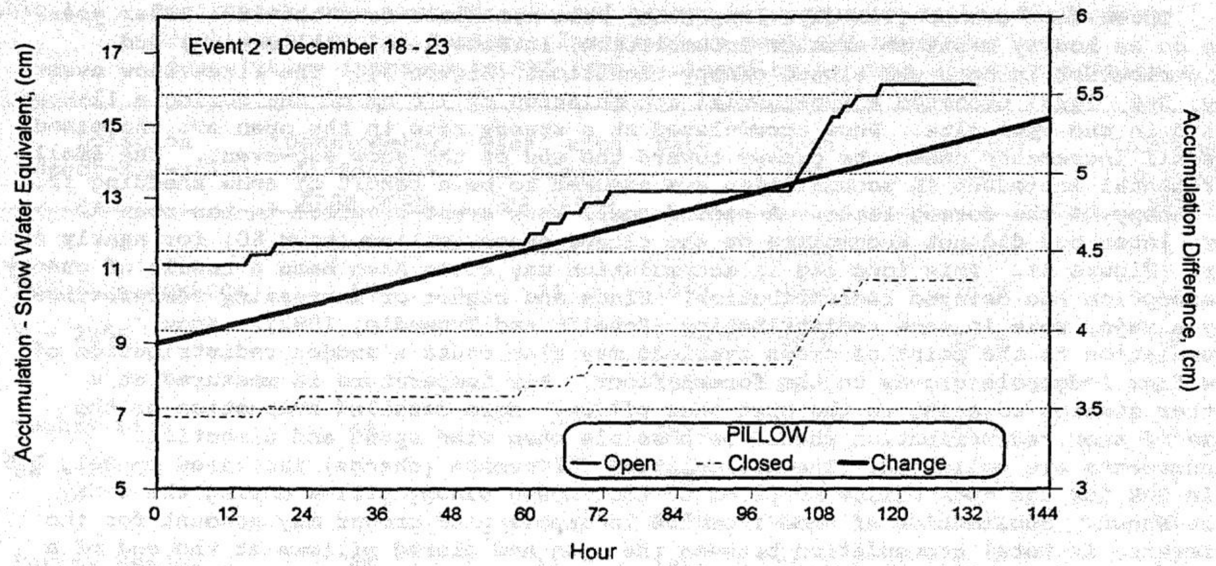

Figure 4. Six-day snow accumulation event on open and closed snow pillows in mid December 1993 on the Tenderfoot Creek Experimental Forest. Change represents the trend in accumulation difference between snow pillows during the event.

The third snow event showed that snow accumulation on open and closed canopy pillows occurred throughout a 3½ day period (hours 18-88) in late January (1994) in two sub-events (Figure 5). There were delays in accumulation on the closed canopy pillow at the beginning and end of each sub-event. Accumulation on the closed snow pillow lagged behind the open and accumulation ended 24 hours (hour 98) after the second sub-event ended. Accumulation differences (change) between the snow pillows increased by nearly 1.0 cm in SWE during the 6-day period with the open pillow accumulating snow at a faster rate.

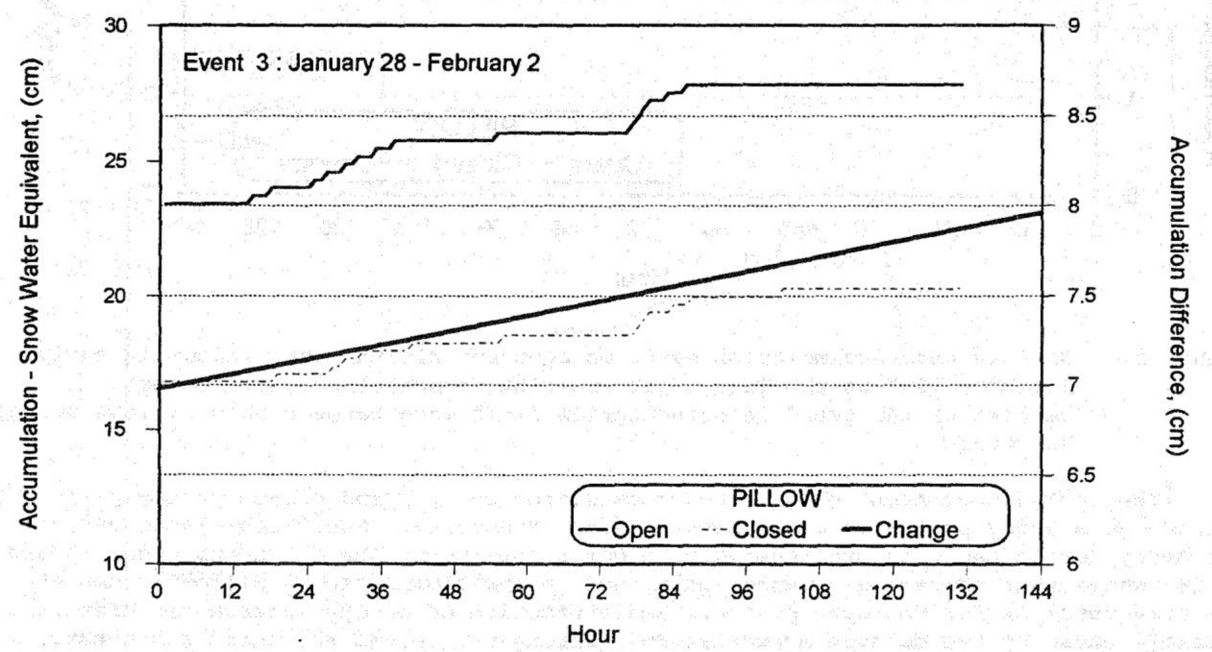

Figure 5. Six-day snow accumulation event on open and closed snow pillows in late January 1994 on the Tenderfoot Creek Experimental Forest. Change represents the trend in accumulation difference between snow pillows during the event.

SUMMARY

Snow accumulation in northern lodgepole pine forests begins in October, peaks in early to mid-April, and melts out in late May or early June. Interception and redistribution of snow probably occur from wind, thermal, and snow loading events. Snow accumulation in openings averaged 38 percent more than in adjacent stands of lodgepole pine. Redistribution of snow from crowns to the forest floor occurred within the first two days and in some cases within the first few hours following a snow event. Preliminary information from Tenderfoot Creek Experimental Forest needs to be expanded before snow budget models can be developed and used for watershed analysis in the Northern Rockies.

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