SNOWPACK COMPARISON BETWEEN AN OPENING AND A LODGEPOLE PINE STAND

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ABSTRACT

In the fall of 1993, two snow pillows were installed at a permanent data site located at Onion Park Research Natural Area on the Tenderfoot Creek Experimental Forest in central Montana. One pillow is located in a small open meadow, and the second pillow is located 25 m away under a dense forest canopy of lodgepole pine. The two pillows were installed to standard specifications for a Natural Resources Conservation Service snow telemetry data site. Measurements of snow water equivalent (SWE) were monitored on both pillows with a continuous water level recorder from 1993 through 1995 and electronic data recorder from 1995 to present. Manual manometer levels were read during each site visit to verify data recorder values. The annual maximum SWE on the canopy pillow has averaged 77 percent of the open pillow over the winters from 1993 to 2000. Melt rates under the canopy have averaged 46 percent of that in the open. On average, final melt-out of the canopy pillow is 9 days after the open pillow. Results from this research will be used to model changes in streamflow volume and timing of peak streamflow after forest modifications in 2001. This information should also be useful for hydrologic modeling or for modeling hydrologic changes after a forest has been harvested, burned or changed in structure due to age, disease, insect infestations or blowdown.

INTRODUCTION

Numerous studies have compared periodic measurements of snow accumulation and melt between forested and open areas using the Federal snow sampler (Gary and Troendle 1982, Farnes and Hartman 1989, Skidmore *et al.* 1994). Moore and McCaughey (1997) compared snow accumulation between canopy and open snow water equivalent (SWE) on the Tenderfoot Creek Experimental Forest (TCEF) using periodic snow sampling during the 1995-96 winter. Farnes *et al.* (2001) using sampling data from Moore and McCaughey and from several other locations and studies in Montana developed a relationship between SWE and percent canopy using data from 179 stands with 129 being comprised of primarily lodgepole pine (*Pinus contorta* Dougl. var. *latifolia*). This relationship indicated that pre-melt SWE under a mature lodgepole pine forest would average 77 to 78 percent of SWE in an open area. To our knowledge, this study is the first involving continuous recording of SWE using non-destructive measurements (snow pillows) at co-located open and forested sites. The physical location of the open site is comparable to that of Snow Telemetry (SNOTEL) sites installed by the Natural Resources Conservation Service (NRCS) throughout the western United States. The canopy snow pillow in Onion Park Research Natural Area was installed within a lodgepole pine forest where the SWE would be fairly representative of the snowpacks under lodgepole pine canopies in forests throughout the Rocky Mountain West. The relationship between snowpacks under forest canopies and in openings has been an important component for modeling water yield changes. These changes are associated with removal of forest canopy through management prescriptions, wildfire, disease epidemics, insect infestations, or the opening of forest canopies through natural mortality.

STUDY AREA

The Tenderfoot Creek Experimental Forest is located in the Little Belt Mountains of central Montana, 39 km north of White Sulphur Springs and about 19 km northwest of Kings Hill on Highway 89. The nearest metropolitan area to TCEF is Great Falls, Montana, which is a 72 km drive to the northwest. The majority of the 3,692 ha experimental forest is drained by Tenderfoot Creek which flows westerly into the Smith River, a tributary to the Missouri River. The experimental forest is located within the Lewis and Clark National Forest but is administered by the Rocky Mountain Research Station (Farnes *et al.* 1995).

Established in 1961 for watershed research, TCEF has a 1961-1990 average annual precipitation of 890 mm, an elevational range from 1,838 to 2,421 m, and a mean elevation of 2206 m. Hydrologic monitoring was initiated in 1991 as part of baseline data monitoring for proposed research studies.

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The experimental forest is about 9 percent non-forested, 42 percent single-aged lodgepole pine stands, and 49 p two-aged stands that are predominately lodgepole pine mixed with subalpine fir (*Abies lasiocarpa*) and Engelmann (*Picea engelmannii*) (Barrett 1993). The oldest stands on TCEF last burned in 1580 while the most recent natura affecting a significant area was in 1902. There have been three fires since 1902 and all three combined have burne than 11 ha. Fires have occurred on TCEF an average of every 32 years over the past 420 years.

The Onion Park study site is comprised of a small natural opening surrounded by a dense two-age lodgepole pine stand that burned in 1765 and again in 1873. It is in the eastern part of the experimental forest and is within the 475 ha Onion Park Research Natural Area. The study site has a 1961-1990 average annual precipitation of 892 mm and the elevation is 2,259 m. The 1961-1990 estimated average April 1 SWE is 340 mm on the open pillow and 249 mm on the canopy pillow (Farnes *et al.* 1999).

Two 3.05-m-diameter, nylon-reinforced neoprene snow pillows were installed in the fall of 1993 and were filled with 400 l of antifreeze solution that was approximately 50 percent water and 50 percent methanol. One pillow is located in the open, the other is 25 m to the north under a forest canopy. The open snow pillow has no canopy within 0-30° cone as measured with the photocanopyometer (Codd 1959), while the canopy pillow has 63 percent canopy coverage. Spherical densiometer readings were 8 percent canopy for the open pillow compared to 74 percent for the canopy pillow. The basal area for the open pillow was 8 m^2/ha compared to 35.6 m^2/ha for the canopy pillow. Weather instruments at the study site measure precipitation, humidity, and air and soil temperature. Within TCEF, there are additional snow, precipitation, climate, and streamflow monitoring sites.

METHODS

Except for short periods of recorder malfunctions, a continuous trace of snow water equivalent data has been collected since the fall of 1993; missing records were estimated from relationships with nearby sites. The initial data was collected using water level chart recorders on a float and pulley system in a stilling well - in 1995 the chart recorders were replaced with an electronic data recorder. The recorders are housed in an instrument shelter along with the stilling well and manometer for each pillow. The manometer was read to the nearest millimeter during each site visit, and those manometer readings were compared to chart or electronic data recorder values. The chart and electronic recorders measured and recorded SWE to the nearest 3 mm. All measurements were corrected for specific gravity of the antifreeze solution in the pillows. The midnight SWE was determined for each pillow for each daily value. Comparisons were made between the start of snow accumulation, daily accumulation, annual maximum SWE, date of maximum accumulation, melt-out rate over comparable days, and the melt-out date.

RESULTS

The actual date snow began to accumulate varied between years depending on early season snowfall and melt. Start of accumulation began as early as October 8 and 9 for canopy and open pillows, respectively. At maximum accumulation, the canopy pillow accumulated an average of 77 percent of the snow water equivalent measured in the open during the 7-year measurement period (Table 1). At maximum snow accumulation, the canopy pillow SWE varied from a low of 66 percent of the open pillow SWE in 1998 to a high of 87 percent in 1999. Maximum canopy and open SWE ranged respectively from a high of 401 and 485 mm in 1997 (Figure 1) to a low of 216 and 318 mm in 1998 (Figure 2). The maximum snow accumulation averaged 303 mm for the canopy and 395 mm for the open snow pillow throughout the 7-year measurement period.

The date of maximum snow accumulation occurred as late as May 14 for open and May 18 for canopy pillows. The date of maximum accumulation was near or on the same date during the seven-year study period except when dates varied by almost a month in 1999 and eleven days in 2000. The average date for maximum accumulation was April 27 for open and May 3 for canopy pillows.

Average melt rates under the canopy averaged 46 percent of those in the open over comparable time periods when both pillows had melting snow. Melt rates varied from 40 percent in 1999 to 53 percent in 1997 (Table 2). Melt-out occurred under the canopy an average of 9 days after melt-out in the open and varied from 5 days in 1996 to 13 days in 1999. Figure 3 shows the 7-year average daily SWE for the open and closed canopy pillows in Onion Park. Average daily melt rates ranged from 6.0 to 13.0 mm/day for canopy and open snow pillows, respectively, for the 7-year measurement period. Snow on the canopy pillow melted-out an average of 9 days later than the open pillow.

Table 1. Comparisons between open and canopy pillows at Onion Park on the Tenderfoot Creek Experimental Forest showing start of accumulation, maximum snow water equivalent (SWE), and date of maximum SWE for the period 1994 - 2000.

	Start of Accumulation		Maximum SWE			Date of Maximum Accumulation	
Water Year	Open	Canopy	Open mm	Canopy mm	Canopy as % Open	Open	Canopy
1994	10/19	10/08	404	290	72	4/16	4/16
1995	10/15	10/15	457	325	71	5/14	5/14
1996	10/23	10/20	399	320	80	5/11	5/11
1997	10/09	10/17	485	401	83	5/08	5/09
1998	10/09	10/05	318	216	66	4/23	4/22
1999	10/28	11/05	330	287	87	4/19	5/18
2000	10/15	11/21	373	279	75	4/07	4/18
Average	10/17	10/22	395	303	77	4/27	5/03

Table 2. Comparisons between open and canopy snow pillows at Onion Park on the Tenderfoot Creek Experimental Forest showing average melt-rates calculated over the period when both snow pillows were melting and melt-out dates for the period 1994 - 2000.

	Melt-Rates			Melt-Out Dates		
Water Year	Open mm/day	Canopy mm/day	Canopy as % Open	Open	Canopy	Days Difference
1994	10.6	4.7	44	5/24	6/03	10
1995	14.3	6.2	43	6/15	6/25	10
1996	18.3	9.1	50	6/07	6/12	5
1997	18.0	9.6	53	6/04	6/12	8
1998	10.2	4.3	42	5/24	6/02	9
1999	10.2	4.1	40	6/03	6/16	13
2000	9.4	4.2	45	5/27	6/07	11
Average	13.0	6.0	46	6/02	6/11	9

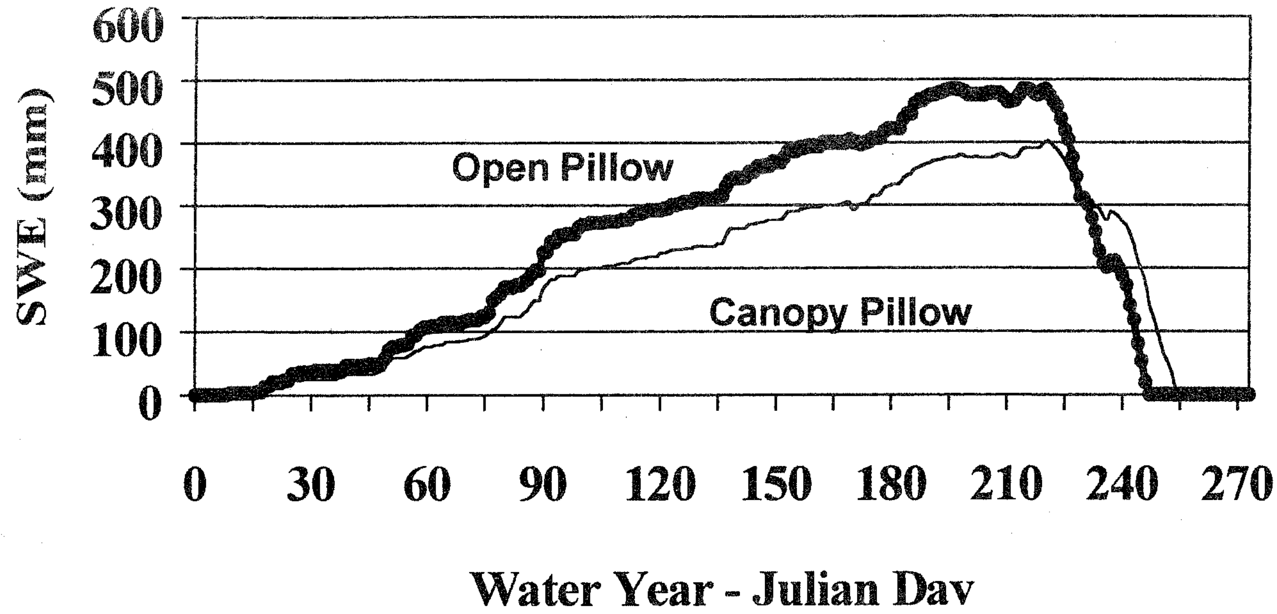

Figure 1. Daily snow water equivalent (SWE) at Onion Park on the Tenderfoot Creek Experimental Forest for open and canopy snow pillows for the 1997 water year (water year begins October 1).

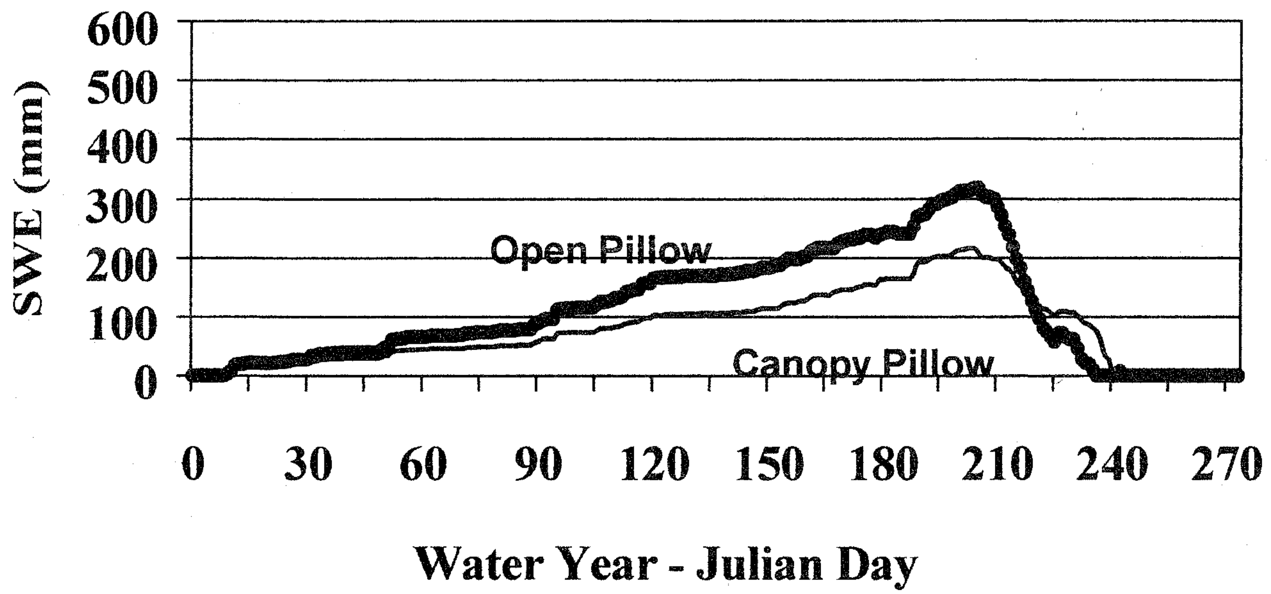

Figure 2. Daily snow water equivalent (SWE) at Onion Park on the Tenderfoot Creek Experimental Forest for open and canopy snow pillows for the 1998 water year (water year begins October 1).

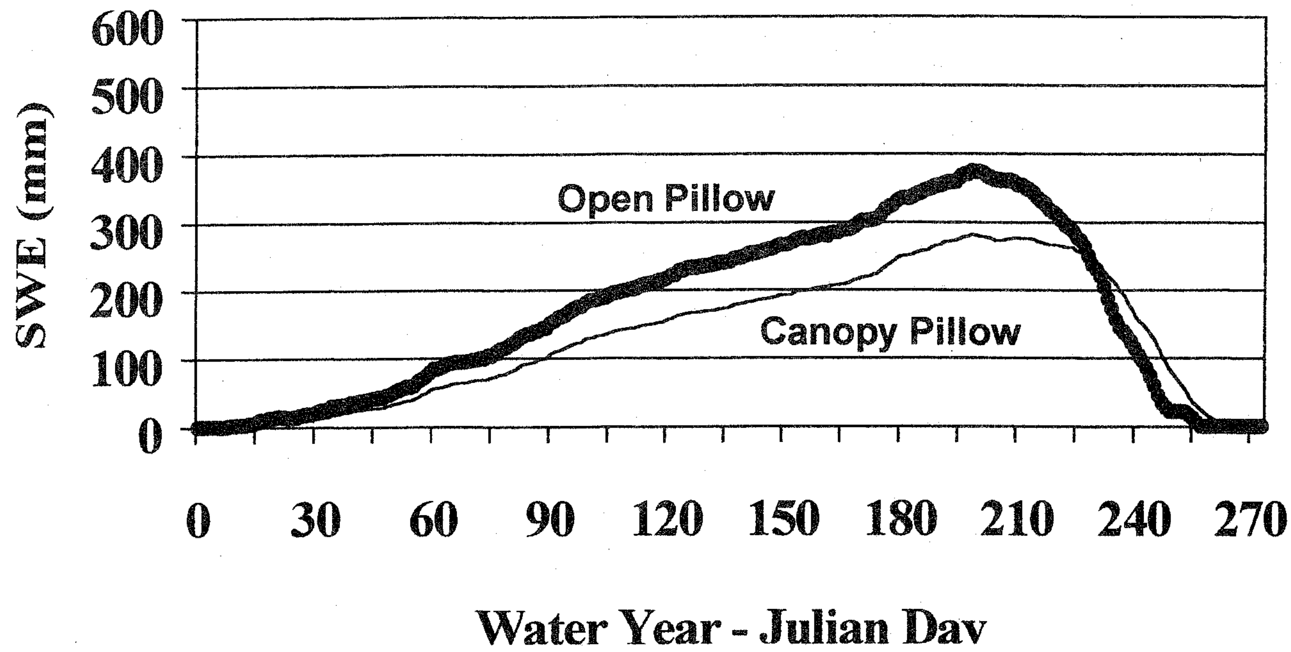

Figure 3. Average daily snow water equivalent (SWE) for the period 1994 - 2000 at Onion Park on the Tenderfoot Creek Experimental Forest for open and canopy snow pillows. Water year begins October 1.

DISCUSSION

There were measured differences in start date of snow accumulation, maximum SWE accumulation, average melt-rates and melt-out dates between the open and canopy pillows. The date of maximum accumulation varied by only a day between the open and canopy pillows, except in 1999 and 2000. From 1994 to 1998 the first melt-out period occurred immediately following the peak accumulation date, and, except for occasional minor snow accumulation periods, continued on a downward trend until melt-out. However, heavy snows came in late April and early May of 1999 and 2000 following the first melt period, and in 1999 the maximum accumulation on the canopy pillow exceeded the earlier accumulation prior to the first melt period. This second, higher peak accumulation prior to final melt-out occurred in 1999, only on the canopy pillow, due to lower melt-rates caused by shading from the forest canopy. In 2000, the pillow response was akin to 1999 except for a shorter time between peak accumulations. Both pillows responded similarly during these melt/accumulation periods.

The quantified differences from the open and canopy pillows are needed to model effects of canopy removal and crown development of subsequent regeneration on seasonal snowpacks. Replicated research harvest treatments were implemented in two sub-watersheds on the Tenderfoot Creek Experimental Forest in 2000. Treatments included different crown removal levels and patterns of a two-aged harvesting system in nearly pure stands of lodgepole pine. Half of the research treatments will be prescribed burned in 2002. Changes in water yield and timing of snow melt and resulting runoff will be modeled using relationships developed between the open and canopy pillows along with other climatic and hydrologic data collected on the experimental forest. Predicted water yield will be compared to changes observed in the measured streamflow between two treatment sub-watersheds and adjacent control sub-watersheds that were not altered. The information from the two snow pillows at Onion Park on the Tenderfoot Creek Experimental Forest should be extractable to other Rocky Mountain forests that are predominately lodgepole pine.

Recent studies indicate that the majority of the accumulation difference between the canopy and open pillows is due to sublimation and not redistribution of snow (Schmidt and Troendle 1992, Pomeroy and Schmidt 1993, and Schmidt *et al.* 1998). Additional work needs to be done with precipitation throughfall and evapotranspiration to evaluate all the components affecting the hydrologic cycle in forested communities.

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