DIFFERENTIAL SNOWPACK ACCUMULATION AND SOIL WATER DYNAMICS IN ASPEN AND CONIFER COMMUNITIES: IMPLICATIONS FOR WATER YIELD

Eric M. La Malfa[1], A. Joshua Leffler[1], and Ronald J. Ryel[1]

ABSTRACT

Differences in snow water equivalent (SWE) in aspen and conifer stands in winters with low to high precipitation, sublimation rates of intercepted snow by conifer branches, and dynamics of soil moisture under aspen and conifer stands were in northern Utah. For low, average and high snowpack years, conifer stands averaged 33-44% lower SWE than paired aspen stands. Sublimation rates for sunlit simulated conifer branches were up to twice that of the ground snow surface; shaded branches had similar rates to the ground snow surface. When combined with the greater surface area of snow on conifer branches, sublimation could explain all or most of the differences in SWE between conifer and aspen stands. Soil column water content was generally higher in aspen throughout all periods of the year. For 2006, aspen stands were estimated to yield 400+ mm more water than the adjacent conifer stands and have saturated soil columns. In 2007, we predict that aspen soils will nearly reach saturation while conifer soils will be 100 mm below saturation.

INTRODUCTION

Aspen and conifer tree species occur in mixed and adjacent communities throughout the Intermountain West. The absence of fire, coupled with excessive browsing of young aspen ramets (trees) by livestock and wildlife, has lead to rapid displacement of aspen communities by conifer forests throughout the west (Bartos and Campbell, 1998). It has been hypothesized that the increase in conifer-dominated lands has led to a significant decrease in net water yield throughout the Intermountain West and the Colorado River Basin (Harper et al., 1981; Gifford et al., 1983, 1984).

Researchers have investigated the question of how aspen and conifer forest cover types affect water yield. La Malfa and Ryel (2006; unpublished, in review) found the largest differences in water dynamics were related to snow accumulation and soil moisture dynamics. Peak SWE averaged 34 to 44% higher in aspen stands and was similar to open meadows. Soil moisture recharge was more rapid under aspen stands with significant recharge occurring during the winter months, unlike conifer stands that had minimal over-winter recharge.

The goal of this study was to further assess major variables affecting water dynamics in aspen and conifer stands that may affect net water yield in Northern Utah. In particular, we assessed: peak SWE in aspen and conifer stands in winters with low to high precipitation, sublimation rates of intercepted snow in conifer stands as a possible mechanism for the observed differences in peak SWE, and dynamics of soil moisture under aspen and conifer stands.

METHODS

The study area was located in montane watersheds of the Northern Wasatch Mountains, Utah, USA (Figure 1). Research Blocks were selected on North facing aspects (~2000-2500 m elev.) in eight aspen and conifer stands paired based on similar slope, aspect, and slope position. SWE was surveyed during peak accumulation (early April in 2005, 2006, early March in 2007) using a standard snow tube (Carpenter Machine and Supply, Seattle, WA, USA) within an 8 m x 20 m grid. Sublimation was measured on simulated conifer branches on 3-Mar-2007, 2 km northeast of the Utah State University Campus. Measurements were conducted on a predominately cloud free day following a fresh snowfall; temperatures ranged from -16 C to 1 C. Cut blocks of freshly fallen snow, approx 3 cm thick, were placed on six replicates of simulated "branches" made of thin plywood 200 cm^2 in area placed in shade, full sun, and full sun adjacent to a dark body (simulating adjacent conifer foliage). A full sheet of dark particle board vertically mounted 1 m above the snow surface provided shade and dark body conditions for simulated branches. Plastic pans were placed under the simulated branches to ensure that weight loss was not due to melting

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[1] Wildland Resources and the Ecology Center, Utah State University, Logan, UT 84322-5230
(eric.lamalfa@gmail.com, jleffler@cc.usu.edu, ron.ryel@usu.edu)

snow. Sublimation rates were also measured for snow placed in plastic pans embedded in the snow surface. Volumetric water content was monitored continuously in plots within Blocks 1 and 2 with a vertical stack of five capacitance probes (Hydra Probe, Stevens Water Monitoring Systems, Inc., Beaverton, OR, USA) placed at 5, 10, 20, 50, and 100 cm depths. A simple model was used to predict water yield from peak SWE (PSWE) and accumulated soil water (assuming summer precipitation is lost to evapotranspiration):

$$\text{Water Yield} = \text{PSWE} - (\theta_{Max} - \theta_{PSWE}) \qquad (1)$$

where θ_{Max} is maximum water equivalent holding capacity of the soil, and θ_{PSWE} is the equivalent depth of water at the time of peak snow accumulation.

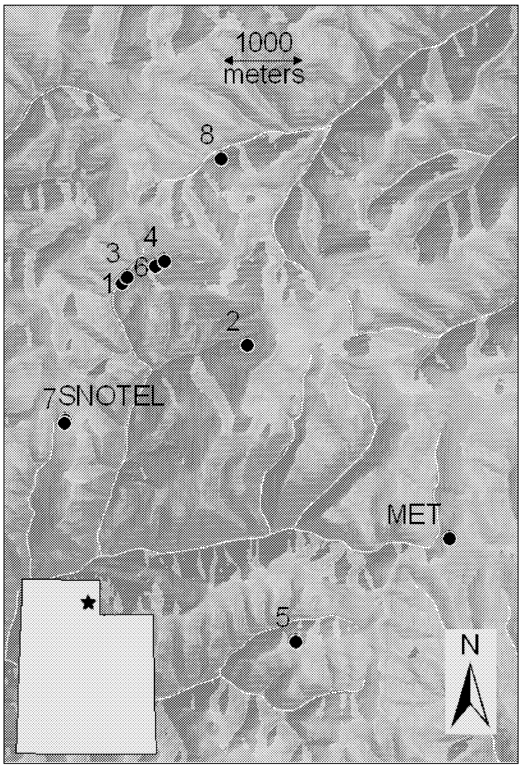

Figure 1. Location of eight research blocks, Lightning Ridge SNOTEL station and weather station (MET) within the study area in Northern Utah.

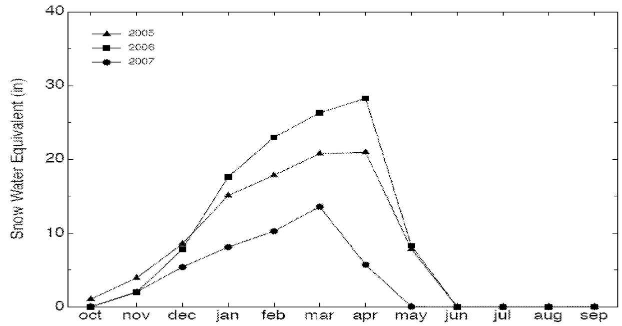

Figure 2. Monthly SWE for 2005-2007 measured at Horse Ridge SNOTEL station, 5 km south of the study site. Average peak SWE for Horse Ridge SNOTEL for the period 1979-2007 was 24.3 in.

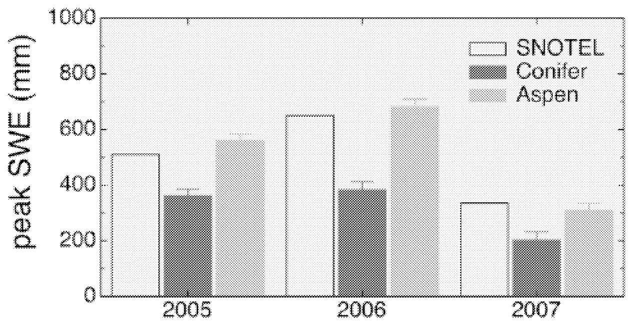

Figure 3. Peak SWE during average (2005), above average (2006), and below average (2007) snow years. Observations were made at the Lightning Ridge SNOTEL station and in adjacent aspen and conifer stands.

RESULTS

Peak SWE was above average in 2006, near average in 2005 and below average in 2007 (Figure 2). Significant differences in peak SWE occurred between aspen and conifer across all three years (ANOVA, $F_{3,5} = 14.92$, $p < 0.01$). Yearly difference in SWE averaged 33% to 44% higher in aspen compared to conifer stands (Figure 3). Sublimation was found to vary among simulated "branch" treatments (Figure 4). Sublimation was highest for the branches adjacent to the dark body (1.3 mm d^{-1}) and in the open (1.0 mm d^{-1}). Similar sublimation rates were found for branches in the shade and for the ground snow surface (0.68 and 0.71 mm d^{-1}, respectively).

Soil column water content was generally higher in aspen throughout all periods of the year (Figure 5). Near the end of September 2005 and 2006 growing seasons, both aspen and conifer had equally depleted the majority of available soil water. In both years, October rainfall recharged only the aspen soils. At the time of peak snow accumulation aspen soils had more water in the soil column. Evapotranspiration estimated from soil column water depletion and precipitation was higher in aspen (451 mm yr^{-1}) than in conifer (343 mm yr^{-1}), largely reflecting differences in soil column porosity. Using equation (1) for 2006, aspen stands would yield 410 mm (Block 1) and

442 mm (Block 2) more water than the adjacent conifer stands. In 2007, we predict that aspen soils will nearly reach saturation while conifer soils will be 100 mm below saturation.

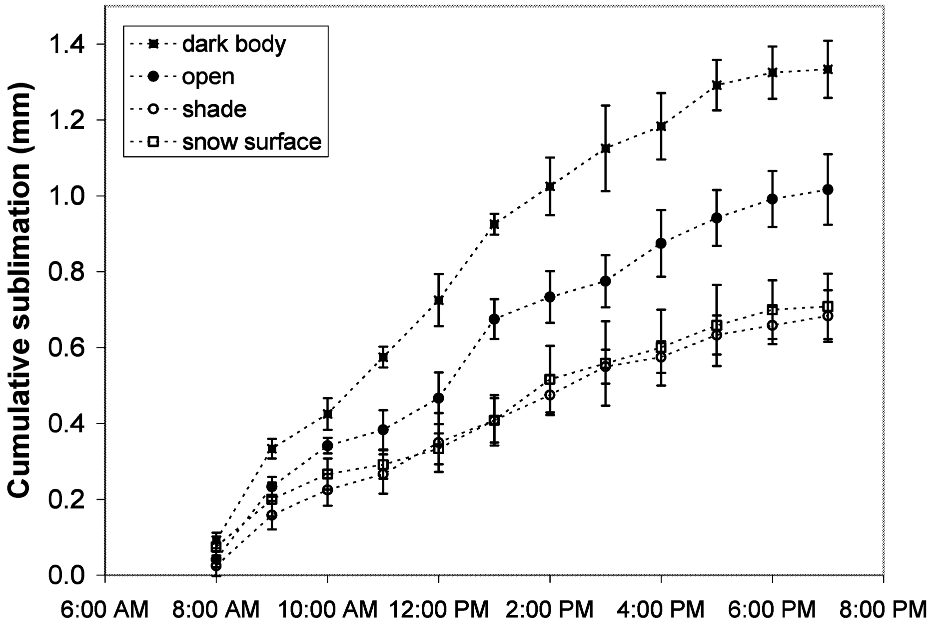

Figure 4. Cumulative sublimation (mm) for simulated "branches" located in full sun (open), full sun adjacent to a dark body (dark body), and in shade (shade), and sublimation for the ground snow surface (snow surface).

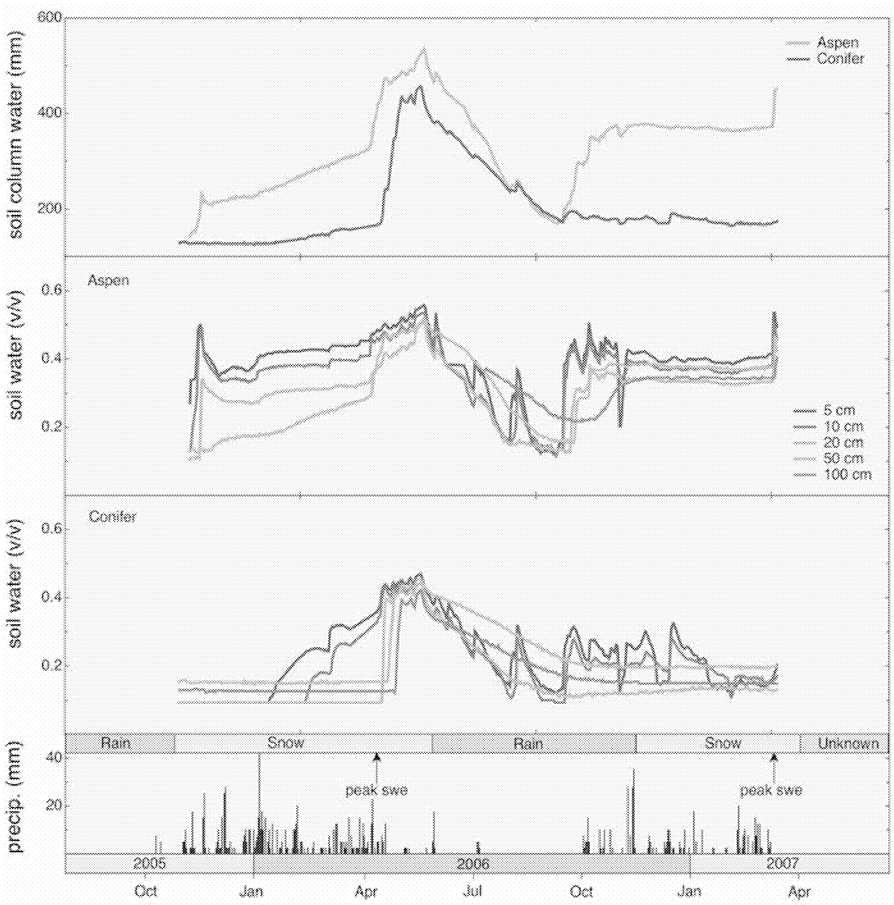

Figure 5. The equivalent depth of water stored in Block 1 aspen and conifer soil columns (top). Soil volumetric water content by depth in aspen and conifer plots (two middle panels). Daily precipitation (rain or snow) at the Lightning Ridge SNOTEL station and time of peak SWE (bottom).

DISCUSSION

Prior work has indicated that western aspen forests can accumulate more water at peak snowpack than similarly positioned conifer forests (Gifford et al., 1983; La Malfa and Ryel, 2006). However, the effects of annual snowfall accumulation have not been adequately addressed. This work indicates that the reduction in snow water accumulation in conifers forests may be a relatively constant proportion of that accumulated under aspen forests regardless of the total accumulated snowfall. The relative constancy of this proportion under low, average and high peak snowpacks suggests similar mechanisms that reduce snow accumulation under conifer stands.

Lower SWE at peak snowpack in conifer stands could result from either wind redistribution (Gary, 1974) or sublimation (Pomeroy and Schmidt, 1993) of snow intercepted by conifer branches. Our experiment indicates that sublimation rates can double when sunlit snow is associated with dark surfaces, such as evergreen conifer branches, and that snow on shaded branches has similar sublimation rates to the sunlit snow surface, indicating that sublimation rates of snow on tree canopies would equal or exceed that of the snow surface per area of exposed snow surface. Given that the surface area of intercepted snow on conifer trees can be 60 to 1800 times greater than the ground snow surface for the same projected area (Pomeroy and Schmidt, 1993), our measured sublimation rates would be sufficient to account for all or most of the lost SWE in conifer canopies.

Soils under aspen stands were found to recharge earlier and to greater extent than soils in adjacent conifer stands. Dynamics of soil moisture during summer will affect fire risk caused by summer drought. We found that aspen stands maintained higher soil water content during much of the 2006 summer fire season (June – August) despite higher evapotranspiration rates. We predict in 2007, a below-average snow year, soils in conifer stands may not fully recharge soils during snowmelt, due to low snow accumulation. Thus, we infer that conifer stands will have higher potential for drought stress and fire disturbance than aspen in low to moderate snowfall years.

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