DIFFERENCES IN WATER BALANCE BETWEEN ASPEN AND CONIFER COMMUNITIES: THE FATE OF SPRING SNOW MELT IN A NORTHERN ROCKY MOUNTAIN WATERSHED

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ABSTRACT

Differences in water balance between mature deciduous quaking aspen (*Populus tremuloides*) and evergreen conifer (e.g. *Abies concolor*, *Abies lasiocarpa*, *Picea engelmannii* and *Pseudotsuga menziesii*) forest communities occur as a result of complex physical and biological interactions. Water yield augmentation experiments have evaluated net effects of cover type on water yield by removing forest vegetation and evaluating changes in net stream water yield. However, cover type conversion experiments are limited due to the long time required for forest maturation. To better understand the potential effects of aspen conversion to evergreen conifer on watershed water yield in the northern Intermountain West, USA, we assessed several water balance transfer mechanisms, including snow accumulation, ablation, evaporation/ sublimation, soil moisture recharge, and transpiration, to determine how major differences in water balance occur in adjacent mature aspen and conifer forests during spring snowmelt. Measurements of fall sap flux were indexed to determine the annual transpiration activity period for aspen and conifer communities. Soil moisture was monitored to determine the timing of soil moisture recharge during winter snow accumulation, and field observations of snow water equivalent (SWE) and snowpack sublimation were obtained. While we found differences in water dynamics between aspen and conifer forests due to snow accumulation, transpiration, and soil moisture recharge, we found SWE was the factor most different between aspen and conifer stands, with conifer stands averaging 34% less SWE at peak snowpack than adjacent aspen stands. We conclude peak SWE is likely the most important factor affecting watershed water yield between aspen and conifer stands, but that differences in soil moisture accumulation could further enhance this difference.

INTRODUCTION

Quaking aspen (*Populus tremuloides*) and conifer tree species occur in mixed and adjacent communities throughout the Intermountain West. The absence of fire in these landscapes, coupled with excessive browsing of young aspen 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 decreasing net watershed water yield. In a meta-analysis of water augmentation experiments throughout the world, Bosch and Hewlett (1982), inferred there would be greater yield responses from coniferous (~ 40 mm/ 10% decrease in cover) compared to deciduous hardwood communities (~ 25 mm increase/ 10% decrease in cover). Several authors have suggested water yield augmentation could be achieved by type conversion from conifer to aspen communities in the west (Dunford and Niederhof ,1944; Jaynes 1978; Gifford et al., 1983 and 1984). However, because vegetation type conversion has not been adequately tested and physiographic constraints are insufficiently defined, it has not become an accepted practice (De Byle and Winokur, 1985).

Most of the precipitation in the Northern Rocky Mountains of Utah comes in the form of snow. The period of October to April comprises 69% of the annual precipitation during an average year (Richardson et al., 1989). Snow water loss mechanisms during winter accumulation and spring runoff may have the greatest impact on total differences in net water yield in Utah. Contrasting observations have been made when comparing snow accumulation and melt patterns beneath aspen and conifer stands possibly due to topographic position, aspect, fetch, and climate. Winter snowfall was approximately 75% beneath lodgepole pine (*Pinus contorta*) when compared to aspen in Colorado (Dunford and Niederhof, 1944). Snow accumulation under Douglas-fir (*Pseudotsuga menziesii*) and aspen stands were similar on south facing slopes in New Mexico. However, on north facing slopes Douglas-fir had 72% of the snow water equivalent found in aspen (Gary and Coltharp, 1967). Areas with tree cover (leafless or not) are more effective at trapping snow than open areas in windswept Southern Alberta (Swanson and Stevenson, 1971). Snow accumulation and melt also differs by aspect. Southerly exposures consistently exhibit the tendency to accumulate less snow relative to the adjacent northern aspects, thus, the hydrologic response of vegetation change is highly dependent upon aspect (Troendle et al., 1993).

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Differences in peak snow accumulation have been attributed to high canopy interception by conifers, which, increases susceptibility to sublimation and redistribution (Miller, 1962; Troendle et al., 1993). In aspen stands there is low interception by the leafless canopy during winter precipitation events. Several authors have found an inverse relationship between coniferous stand structure and maximum snow accumulation (Gary and Troendle, 1982, Skidmore et al., 1994, Moore and McCaughey, 1997). Half of the variation in snow water equivalent (SWE) in the coniferous communities of the Tenderfoot Creek Experimental Forest was attributed to canopy cover and density (Moore and McCaughey, 1997). There is an assumption that interception is a more important factor in hydrological gains than surface evaporation and total site transpiration (Dunford and Niederhof, 1944).

In aspen there is greater ablation under the canopy than in treeless openings, where as in conifers there are equal or greater rates of ablation in the openings vs. under canopy. Long wave radiation under the leafless aspen canopy is greater than in the open and inversely short wave radiation is less. Snow is highly reflective of short-wave radiation and absorptive of long-wave. The leafless aspen canopy provides some shelter from advective energy exchange but is a source for increased long wave radiation (Swanson and Stevenson, 1971). Evaporation of accumulated snow in the Northern Rocky Mountains has been found to be 20% higher in aspen than conifer, however, total annual losses by evaporation accounted for less than 5% of the snow pack (Doty and Johnston, 1969). Hood and Williams et al. (1999) estimated sublimation using the aerodynamic profile method at Niwot Ridge in the Colorado Front Range. They found that total net sublimation for the snow season was 195 mm of water equivalent, or 15% of maximum snow accumulation at the alpine study site. The majority of this sublimation occurred during the snow accumulation season. The snowmelt season from May through mid-July showed net condensation to the snowpack ranging from 5 to 16 mm of water equivalent. Sublimation during the snowmelt was sometimes episodic in nature, but often showed a diurnal periodicity with higher rates of sublimation during the day. The effects of aspect slope, cloud cover and latitude physically determine the relative amount of energy received as insolation by a forest canopy.

The tree canopy is thought to reduce radiation via shading, which decreases the rate and delays the timing of ablation (Hardy and Hansen-Bristow, 1990). During spring snowmelt aspen communities remain leafless while conifers maintain high leaf area index and high shading. Extended ablation beneath conifers may affect net runoff by extending the period in which snow moisture is available for transpiration and reducing the number of days during which soil saturation leads to stream water inputs. In aspen communities increased melt rates saturate soils leading to increased flow. However, during high spring rains there was no difference in the timing of melt between 33 year old aspen and lodgepole pine stands in Colorado accelerated by 3.9 and 3.2 inches of rainfall, respectively (Dunford and Niederhof, 1944).

Transpiration has two effects on the fate of spring snowmelt. One is the direct loss of water from soil during the snowmelt season. The second is the soil moisture regime existing in fall prior to the snow accumulation period. If a soil is relatively dry in the fall prior to the snow accumulation period, it is presumed that the soil will have additional capacity to absorb and retain a greater amount of moisture during spring snowmelt. Conversely, if a soil is relatively wet in the fall prior to the snow accumulation period, it is presumed that the soil will have decreased capacity for infiltration leading to increase in stream flow. The total snowmelt contribution to soil moisture recharge can be a significant loss to stream water inputs (Julander and Perkins, 2005). Perhaps the most important area needing further definition is the amount and time pattern of transpiration in different forest communities (Gifford et al., 1984).

Several physiological processes confound the measurement and comparison of transpiration in aspen and conifer species. Conifers can transpire water during warm periods in early spring and late fall while hardwoods are leafless or only leafing out (Douglass, 1983), and conifers may begin transpiring as much as two months before aspen (Gifford et al., 1984). However, aspen has been found to have consistently higher sap flux than conifers in the early season possibly following leaf expansion. (Pataki et al., 2000) found mean estimates of whole season sap flux in aspen and conifer communities were not different (2.6 and 2.7 mm/day, respectively) in forest stands in Wyoming, although their estimates (made between June 17 and August 25) did not account for periods during initial snow accumulation and snow melt when conifers are active and aspens are dormant.

To better understand the potential effects of aspen conversion to conifer on water yield in the northern Intermountain West, USA, we assessed several factors that might result in differences in water dynamics within paired mature aspen (deciduous) and conifer (evergreen) communities that could result in differences in water yielded to surface waters. Several water transfer mechanisms, including; snow accumulation, ablation, evaporation/ sublimation, soil moisture recharge, and transpiration were measured to determine where differences in water dynamics might occur (Appendix A). The importance of these mechanisms as potentially affecting watershed water yield was then assessed.

STUDY SITE

Two blocks of paired stands of aspen and mixed conifer were selected in the Bear River Mountains in northern Utah. The stands were located in Rich county Utah near the intersection with Cache and Weber Counties on private land owned by Deseret Land and Livestock, Inc. All stands were located within the Frost Creek Watershed which drains into the Ogden River (Figures 1 and 2). The first block of paired stands was located on a northeast facing aspect and elevation 2,515 m (UTM: 12 T, NAD 83, 0464377 East, 4577098 North). The second block of paired stands was located on a north facing aspect and elevation of 2626 m (UTM: 12 T, NAD 83, 0461789 East, 4579567 North).

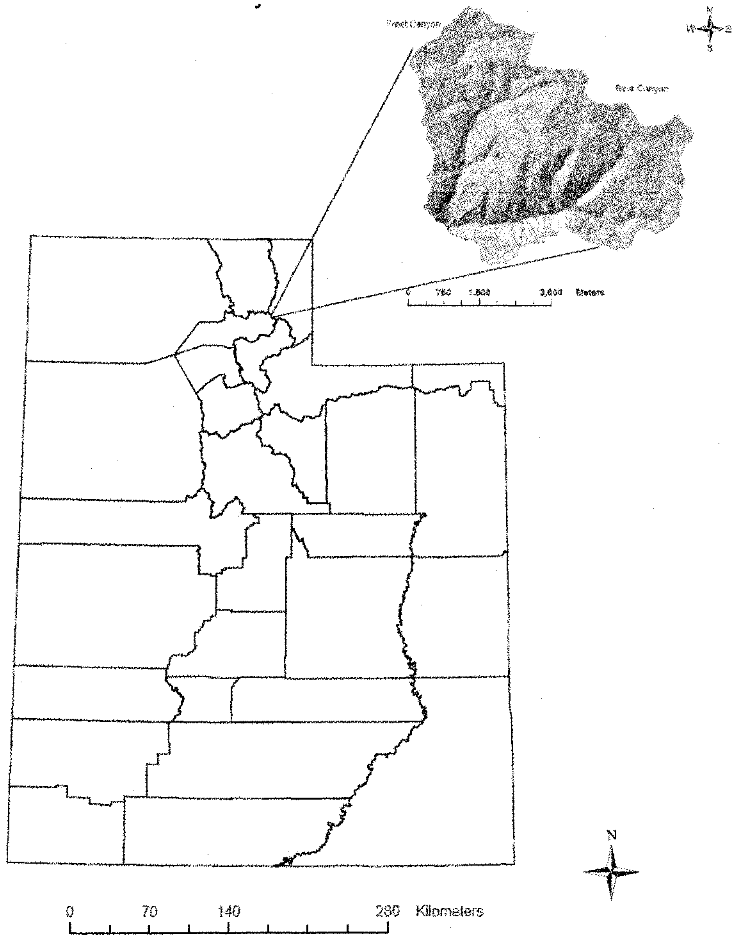

Figure 1. Northern Utah Study Site Location (B. Shakespeare 2005).

METHODS

The two blocks of paired aspen and conifer stands were sampled for snow accumulation, ablation, evaporation/ sublimation, soil moisture, and transpiration during 2005 and 2006. Other aspects were not included due to the limited range of conifers, which are primarily restricted to the cooler north facing aspects within the catchment. The comparison plots containing aspen and conifer stands within each block had similar soils, slope, slope position, and fetch (Figure 2). The conifer stands were comprised primarily of Douglas-fir (*Pseudotsuga menziesii*) and subalpine fir (*Abies lasiocarpa*).

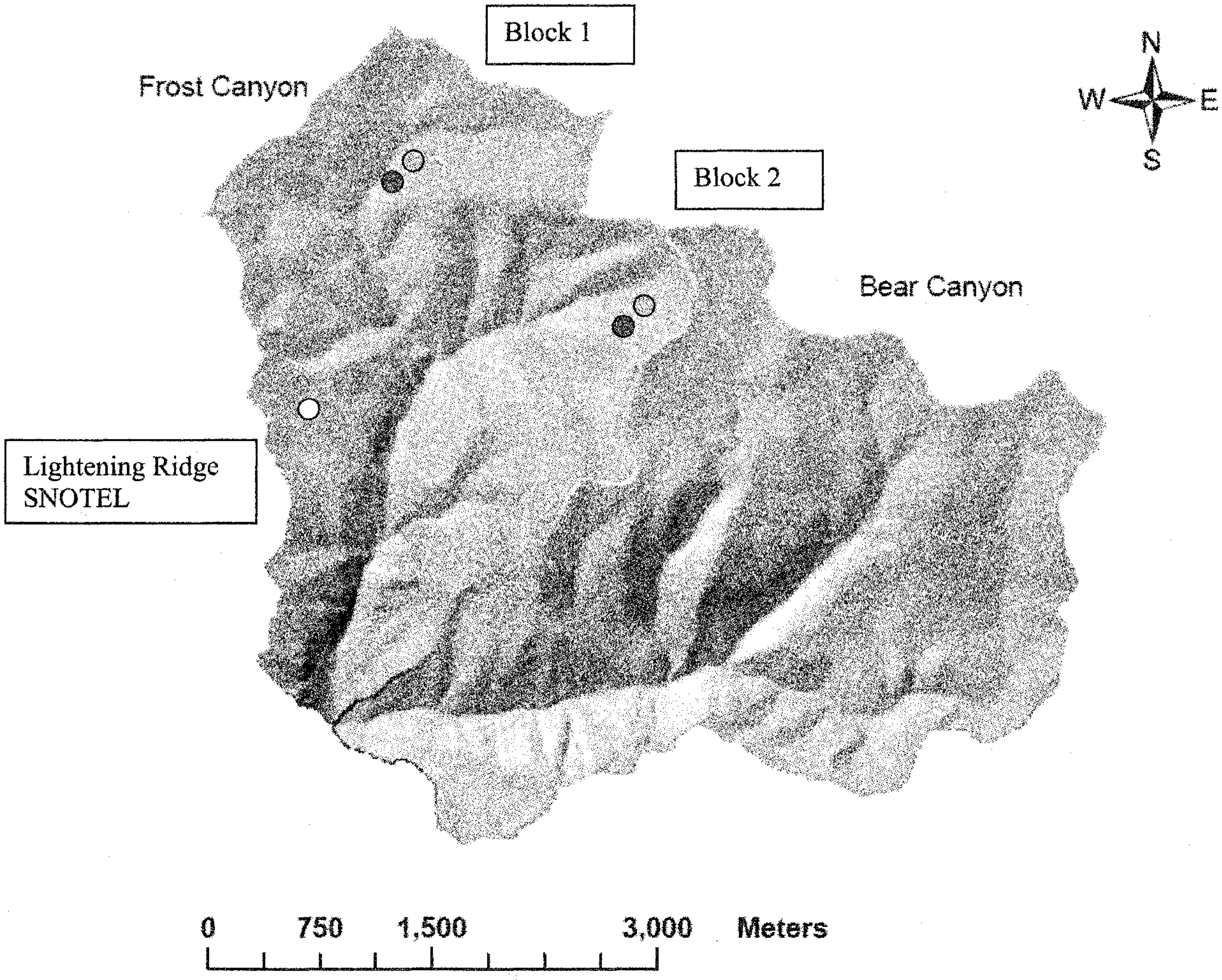

Figure 2. Locations of the two study blocks within Frost Canyon.

Snow Water Equivalent

Snow accumulation was measured within both aspen and conifer stands in each of the blocks using a snow tube (Carpenter Machine and Supply, Seattle, Washington). Within the sample blocks of paired aspen and conifer stands, several 8 x 20 m plots were delineated. The surveys consisted of four line transects oriented up-slope and 2 m apart. Snow Water Equivalent (SWE) and depth were measured every 5 m in a randomized systematic pattern. Surveys were conducted beginning at or near maximum snow accumulation (April first) as approximated by the Lightning Ridge SNOTEL site and predicted weather forecast. To assess the representativeness of these two sample blocks, an additional four blocks within the Bear River Range within 5 km of these two blocks containing paired aspen and conifer stands were also sampled.

Snow Pack Sublimation/ Condensation

Surface sublimation/ condensation estimates were estimated using evaporation pans. Bricks of snow were cut from the snow surface and placed into clear plastic food storage containers (approx. 60 len x 20 wid x 10 ht cm). The containers were weighed and installed into pits such that the top of the container was flush with the snow surface. Installation occurred early in the morning (~8 am) and the pans were left for approximately 24 hours before being weighed again. Within blocks 1 and 2, five replicated containers were measured within the aspen and conifer community types. The pans were placed in a 25 m transect oriented upslope once every 5 m. In the conifer stands the canopy cover was be noted as open or closed. Evaporation estimates were taken approximately once every two weeks throughout the melt period. The meteorological conditions including relative humidity, temperature, wind, and precipitation, and incoming solar radiation during the evaporation period were measured at the Bear Canyon meteorological station approximately 3 km southeast at a similar elevation.

Transpiration

Transpiration activity was estimated by measuring hourly sap flux. Measurements were logged using Probe 12 sap flux systems (Dynamax, Inc., Houston, Texas). This system measures sap flux using a thermal dissipation probe (TDP) as described by (Granier 1985). Within blocks 1 and 2, 16 TDP sensors were deployed, half within the conifer stand and half within the aspen stand (Fig. 3). Probes were installed 1 m above the ground and insulated using reflective bubble wrap. All exposed cables and insulation were protected from herbivore damage using schedule 40 PVC pipe and chicken wire. Sap flux was measured and recorded once every hour beginning in fall and continuing periodically into the winter until transpiration ceased.

Soil Moisture

Soil moisture recharge was measured separately in aspen and conifer plots located in blocks 1 and 2. The volumetric water content was monitored in a vertical profile to 102 cm soil depth as well as spatial profiles inside and outside of the tree wells at 10 cm soil depths. Hydra probes soil moisture sensors (Stevens Water Monitoring Systems, Inc., Beaverton, Oregon) were used to measure volumetric soil moisture content using the dielectric content. Vertical soil moisture recharge was measured using four stacks of five probes each. Two stacks were placed in each block, one in each community type plot. Each stack measured the vertical profile of soil moisture within the community beginning before snow accumulation began in the fall and continuing throughout the snow accumulation period. The probes were installed at 5, 10, 20, 51, and 102 cm soil depths to match the Natural Resource Conservation Service (NRCS) Lightening Ridge SNOTEL weather station data. Probes were monitored continuously at one-hour intervals using RS 205 and CR23X data loggers (Campbell Scientific, Logan, Utah). Spatial differences in soil moisture within the aspen and conifer tree communities were measured inside and outside of tree wells to determine spatial differences in moisture content. Twenty Hydra probes were deployed in ten pairs inside and outside of the tree wells and monitored using CR21X and CR23X data loggers (Campbell Scientific, Inc., Logan, Utah) throughout the spring snow melt. Six pairs of probes were deployed evenly between the plots in block 1 and six pairs were deployed evenly between the communities in block 2 (Figure 3).

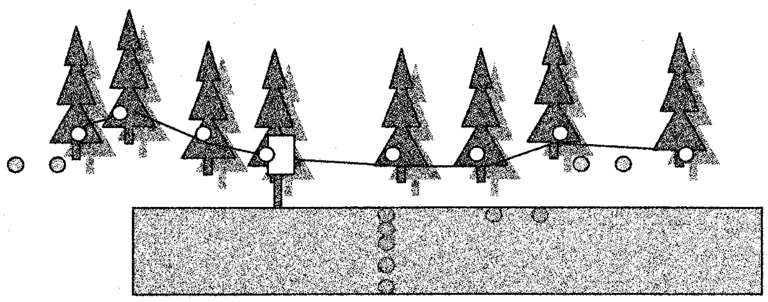

Figure 3. Schematic plot representation of transpiration and soil moisture monitoring equipment installation in a single plot.

Laboratory calibration of the Hydra probes was performed to control for potential differences in soil properties affecting the measurement of dielectric content. Two shallow soil cores were extracted from each experimental plot in blocks one and two. One core was extracted near the bole of a tree (< 1 meter from trunk), and a second core was taken in the interspaces between trees (> 2 meters from trunk). The cores were constructed of 10 cm diameter PVC pipe cut to 10.5 cm length (697 cm^2). Holes were be drilled in the bottom of the cylinders for drainage. The topsoil at each site was excavated to 5 cm depth and the remaining soil was leveled using a hand trowel. Containers were then pounded into the ground until soil was visible through the drainage holes. The soil surrounding the container was then excavated and the trowel used to turn the container upright and remove excess soil. Each container was saturated with water for 12 hr with a Hydra probe inserted into the open top. The entire apparatus was placed into a plastic pan and weighed. Repeating this process soils were allowed to air dry and then weighed for three consecutive 24 hr intervals. The final weight was taken after the soils had been allowed to air dry for two weeks. Soils were then oven dried at 70 C for 24 hr and weighed to determine soil bulk density.

RESULTS

Peak SWE was recorded April 14, 2005 at the Lightening Ridge SNOTEL station. Snow surveys were conducted from April 12 – 26, 2005 to determine differences in peak SWE between communities. Across all blocks, aspen had significantly higher SWE than the adjacent paired conifer during the spring of 2005 (Figure 4). Differences in Peak SWE within each block ranged from 47 - 322 mm (2-13 in), with conifer averaging 34% less SWE compared to adjacent aspen stands.

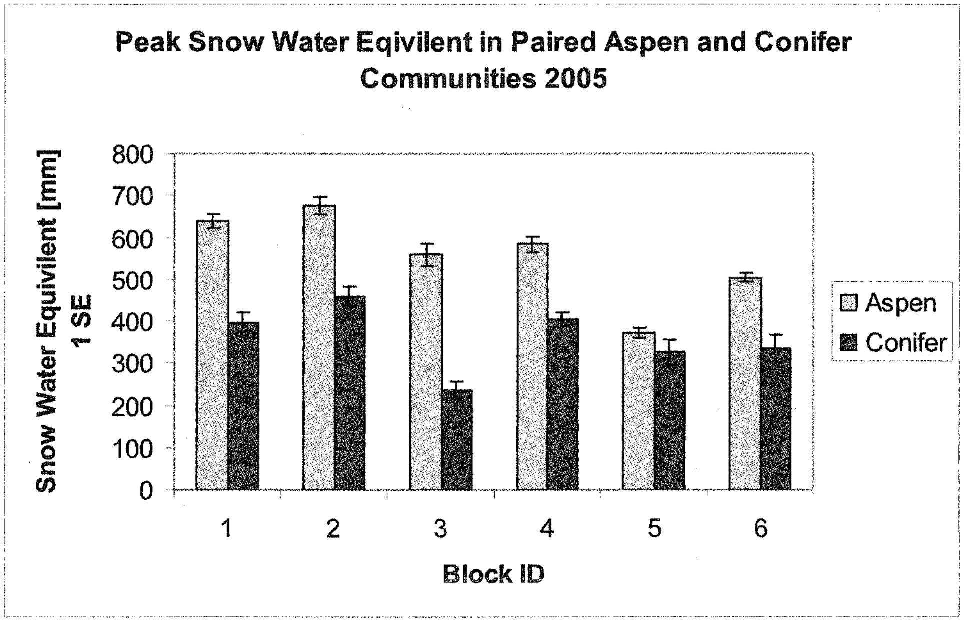

Figure 4. Differences in peak SWE between adjacent north facing aspen and conifer stands.

Condensation and sublimation pans were set out eight times during Jan-May, 2005; however, pan measurements were compromised by intercepted snow falling from the canopy and precipitation events in all but two of the measurement periods (Feb. 22-23 and May. 23-24). For Feb. 22-23, the aspen and conifer snow packs lost 0.5 and 0.36mm (0.019 and 0.014 in) of SWE, respectively, while in the May period, aspen and conifer snowpack gained 0.25 and 0.11 mm (0.009 and 0.004 in) of SWE from condensation, respectively (Figure 5).

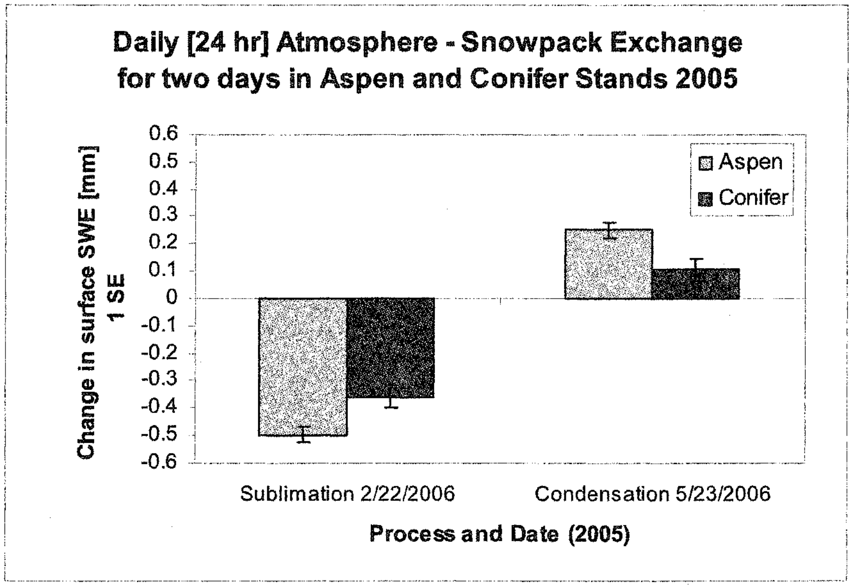

Figure 5. Snowpack sublimation and condensation in aspen and conifer stands for two 24 hr periods.

Fall transpiration activity in the aspen community ceased at the onset of leaf senescence (~ second week in October), while the conifers continued to transpire on favorable days through the second week of November (Figure 6). The shallow soil moisture in both aspen and conifer plots was extremely dry during the early fall. Several precipitation events during September failed to increase the shallow soil moisture content. The precipitation events that occurred in October increased shallow soil moisture content after aspen leaf senescence and diminishing transpiration activity of conifers had occurred. The increase in shallow soil water content was less in the conifer community relative to the aspen community (Figure 7).

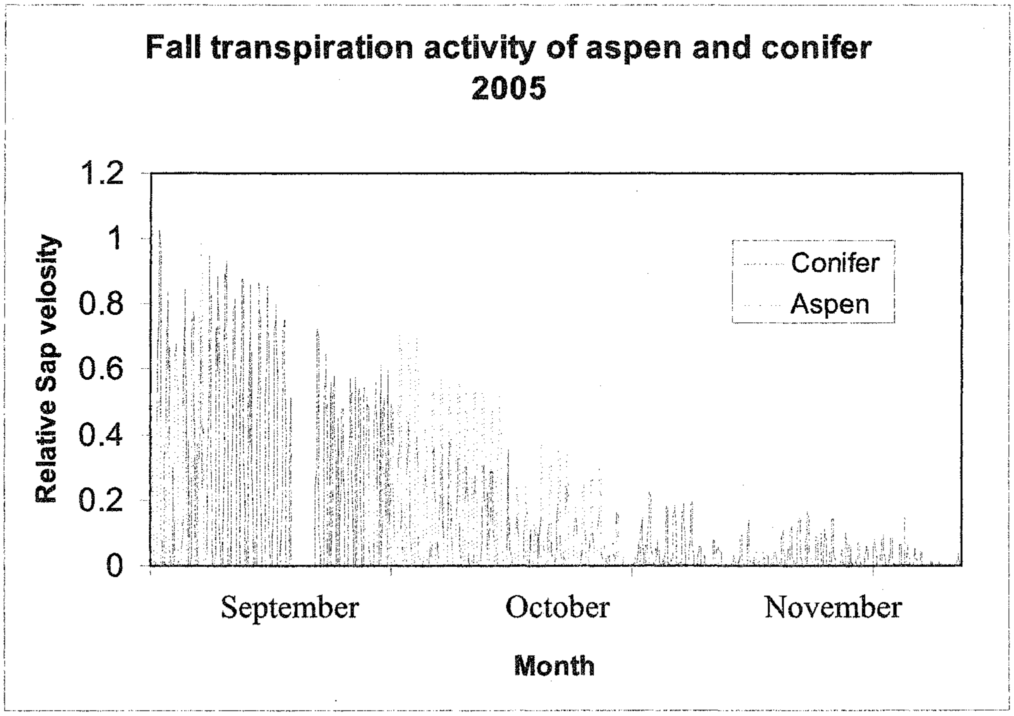

Figure 6. Transpiration activity in aspen and conifer.

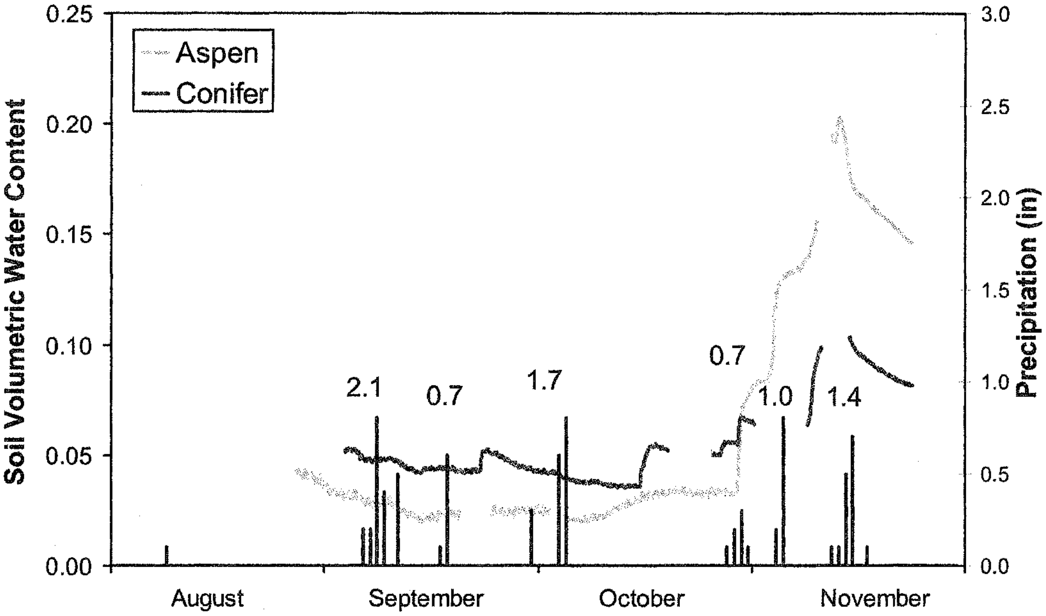

Figure 7. Shallow soil moisture content in aspen and conifer.

Soil moisture recharge between fall 2005 and spring 2006 occurred throughout the snow accumulation period in aspen and while soils remained relatively dry in the adjacent conifer stands. In the fall, aspen and conifer soils had approximately 124 and 130mm (4.9 and 5.1 in), respectively, of soil moisture stored within the soil profile to the 102 cm (40 in) depth respectively. At the time of peak snow accumulation aspen soils became nearly saturated to 56 cm (20 in) depth storing approximately 269 mm (10.6 in) of moisture within the profile (Figure 8). Conifer soils remained relatively dry at the peak snow accumulation period storing 160mm (6.3 in) of water (Figure 9). The combined difference in soil water storage and peak snow water equivalent (~April 1st) results in a 42% reduction in total water stored in conifer stands relative to the adjacent aspen stands (Figure 10).

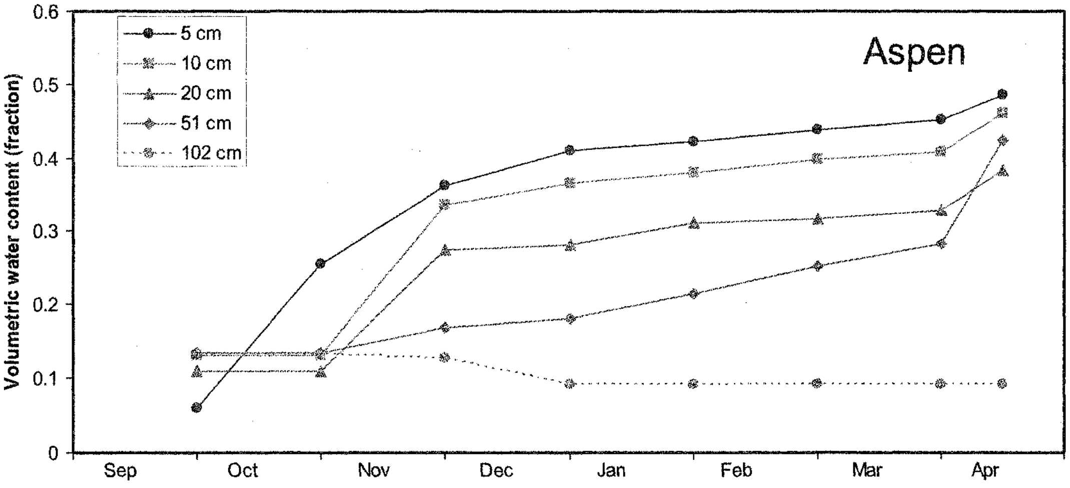

Figure 8. Vertical soil moisture profile in aspen in fall 2005 to spring 2006. Soil moisture is depleted in late fall and begins to recharge through the snow accumulation period.

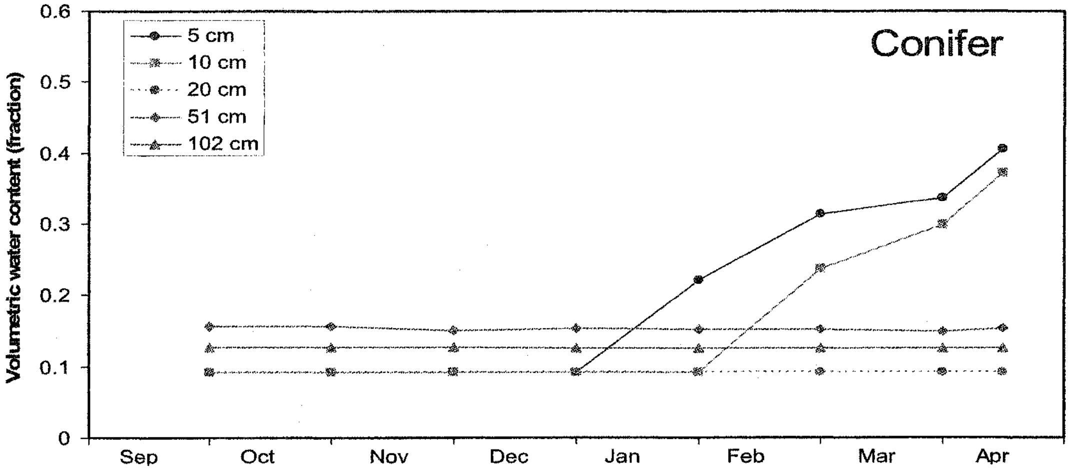

Figure 9. Vertical soil moisture profile in conifer in fall 2005 to spring 2006. Soil moisture is depleted in late fall and begins to recharge in January.

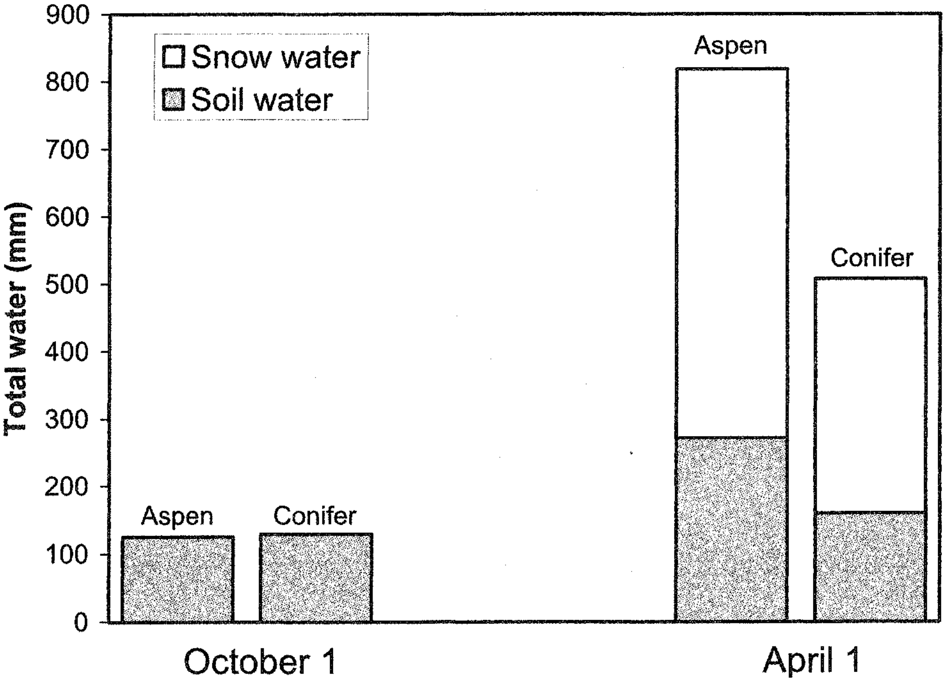

Figure 10. Water in soil and snow in aspen and conifer stands in Oct, 2005 and April, 2006.

DISCUSSION AND CONCLUSIONS

Differences in snow accumulation between north-facing aspen and conifer forests appear to be the largest water balance discrepancy in this system. The sublimation of snow intercepted by the conifer canopy is presumed to be the mechanism causing such discrepancy; however, the redistribution of snow could contribute to surface accumulation patterns. Sublimation and condensation of the snowpack were not found to differ significantly between aspen and conifer forests for two observation periods. Our results concur with the findings of Doty and Johnston (1969), and suggest that surface sublimation and condensation do not account for a significant portion of the water balance. Transpiration activity in conifer continued for several weeks beyond the senescence of the aspen leaves, and fall precipitation events were more effective at saturating shallow soil layers in the leafless aspen stand due to decreased interception and transpiration. However, the depletion of soil water during this period is minimal, indicating that the extended period of transpiration may have limited effect on subsequent water yield. Finally, soil moisture recharge occurred during the snow accumulation period in aspen and was delayed in the conifer system leading to a large difference in total water storage. In conifer, a colder snowpack and/or a thin layer of ice observed between the soil and snow interface could have reduced snowmelt and/or inhibited the infiltration of melting water during the winter snow accumulation period.

While we found differences in water dynamics between aspen and conifer forests due to snow accumulation, transpiration, and soil moisture recharge, our results suggest that the greatest factor affecting watershed water yield would likely be the difference in SWE of the corresponding snowpacks at time of the peak accumulation in early to mid-April. Further research could focus on the mechanisms that contribute to these differences in surface snowpack accumulation and physical variables which control the mid-winter sublimation or redistribution of intercepted snow. Other aspects and elevations should be included in the evaluation of physical variables to ultimately quantify differences in water yield resulting from aspen and conifer stands across the western U.S.

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Appendix A. Hypothesized differences in snow water balance between aspen and conifer forests.