THE EFFECT OF PATCH CLEARCUTTING ON THE WATER BALANCE OF A SUBALPINE FOREST SLOPE

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INTRODUCTION

Many studies have demonstrated that openings created in the forest canopy increase snow collection (Wilm and Dunford 1948, Hoover and Leaf 1967, Gary 1974, Golding and Swanson 1978, Haupt 1979, Troendle and Meiman 1984). It also has been shown that a pattern of small forest openings can significantly increase streamflow (Leaf 1975, Swanson and Hillman 1977, Golding 1981, Troendle and Leaf 1980, Troendle and King 1985).

These experiments indicate that creating holes in the canopy alters the stand aerodynamics, which, along with reduced interception, increases snow accumulation in the openings. At the same time, the evapotranspiration is reduced in the openings because of the absence of trees, resulting in less soil water depletion during the growing season. Therefore, because most streamflow from the subalpine forest comes from melting snow after soil water deficits are satisfied, water yield is greater from the openings that the surrounding forest.

Increased snowpack accumulation in an opening may partly result from redistribution of snow that otherwise would have been deposited in the surrounding forest. This may reduce snowpack accumulation in the forest, which, if not adequate to recharge the soil moisture depletion, can restrict growing season evapotranspiration from the uncut forest. Indirectly, this can contribute to streamflow increases. Because snowpack redistribution was assumed to significantly influence streamflow, water yield augmentation management prescriptions mainly used patch clearcutting (Leaf and Alexander 1975, Troendle and Leaf 1980). In recent years, studies of transpiration (Kaufmann 1985), streamflow generation (Troendle 1985), and snowpack accumulation processes (Troendle and Meiman 1984) at the Fraser Experimental Forest, Colorado, have questioned this assumption.

This paper describes a replicated plot study designed (1) to investigate the effect of a forest opening on the accumulation and melt of the snowpack in both the opening and in the surrounding forest, (2) to determine if any differences in soil moisture recharge between the forest and opening resulted from creation of the opening, and (3) to quantify the evaporative components of the hydrologic cycle for a specific site, to determine how the creation of a small opening altered the water balance.

STUDY SITE AND METHODS

The study site is a 2.9-ha area on a 35-percent north-facing slope, at an elevation of 2800 m. Initially, the site was a uniform forest of Engelmann spruce, subalpine fir, and lodgepole pine, with an average canopy height of 21 m, and dominant trees (spruce) approaching 28 m.

In 1980, the site was divided into three equal plots across the slope. Each plot was approximately 80 m wide (across slope) and 120 m long (up and down slope). Three transect lines were located in each plot. Two lines were located approximately one-fourth the plot width in from each side, and a third line was located in the middle of the plot. At five equidistant points along each of the two outside lines, both a permanent snowcourse marker and a 5-cm diameter neutron probe access tube were installed. Only the five snowcourse markers were located along the center line. In total, each of the three plots contained 15 snowcourse and 10 soil moisture sampling points. The neutron probe access tubes were installed to depths (depending on soil rock conditions) from 1.2 m to 2.7 m.

Peak water equivalent of the winter snowpack (about April 1) was measured in 1981 and 1982 at all points. Soil moisture content was measured in all tubes twice during the 1981 growing season and three times during the 1982 season. The intent was to calibrate the relationships among snowpack accumulation, soil water recharge, and soil water depletion on the three plots before cutting. In late summer 1982, the 1-ha center plot was

Presented at the Western Snow Conference, April 15-17, 1986, Phoenix, Arizona.
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clearcut, and the residual slash was lopped and scattered. This resulted in a dense layer of slash, about 0.67 m deep, uniformly distributed over the 4-tree-height opening (4-H). The 4-H opening was bounded by an equal control area on both the upwind and downwind sides. The prevailing wind is across the slope from a westerly direction at instantaneous speeds measured up to 35 $m \cdot s^{-1}$.

After treatment, peak water equivalent in the snowpack was measured on April 1 of 1983, 1984, 1985, and at various times during the accumulation and melt period in 1984. In addition, two snowboard transects across the slope, with a total of 12 boards in each of the three plots, were monitored on an individual event basis during the winter of 1984-85 to determine when the increased accumulation in the opening was deposited. Posttreatment soil moisture measurements were made at approximately 1-month intervals from the time of snow disappearance in early to mid-June until the onset of snowfall in early October. Three access tubes in each plot were uncovered in April of 1984 and 1985, and were monitored prior to melt to index the soil moisture recharge. Growing season precipitation was estimated from a raingage located on a similar slope and aspect approximately 1.2 km away and 150 m higher in elevation. Use of this reference site probably overestimates precipitation; but the number and relative magnitude of events are similar.

Watershed experiments on the Fraser Experimental Forest have determined that summer or postsnowmelt precipitation has little influence on streamflow, especially the increases that occur after timber harvesting (Troendle and King 1985). Presumably, the precipitation is stored in the soil mantle or used on-site, regardless of the presence of trees. Therefore, it appears that evapotranspiration (ET) for a given soil moisture measurement interval can be estimated as the sum of the change in moisture content during the interval and the precipitation, which occurs during the same interval. This conclusion is based on the assumption that the precipitation stays on site. The resulting estimate of ET represents an upper limit or maximum value, because any losses on site to either deep seepage or streamflow result in an overestimate of ET.

RESULTS AND DISCUSSION

Effects of Timber Harvest on Snowpack Accumulation

Table 1 lists the peak water equivalent in the snowpack, by plot, for the 5 years of study. For the 2 years before clearcutting, all areas exhibited the same peak water equivalent. Based on repeated measures analysis of variance, there was a significant increase in accumulation in the clearcut in the posttreatment period (probability (P) $< .001$). The increased accumulation averaged 14.8 cm of water or 45 percent more than the amount accumulated in the upwind forest. There was no indication that the measured accumulation in the downwind forest (plot 3) changed relative to upwind control.

Table 1. Peak water equivalent (PWE) on April 1 in the three study plots.

Year	Plot 1	Plot 2	Plot 3
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1981	15.5	15.8	15.5
1982	31.0	31.8	31.8
	Harvest		
1983	30.2	43.7*	31.2
1984	37.6	54.1	36.6
1985	30.0	44.5	M

*Highly significant ($P < .0001$) difference between the mean for plot 2 (after harvest) and the other two plots. Average increase in PWE = 14.8 cm.

During the winter of 1984-85, 12 snowboards (30 x 60 cm) were placed in each of the three study plots to characterize the timing of increased accumulation in the clearcut. From January 2, 1985 until April 4, 1985, the depth of snow on the boards was measured after each storm, and the boards were cleared and then systematically moved in preparation for the next storm. When possible, they also were observed between storms or during nonstorm periods to determine if substantial redistribution occurred. During the period defined, 20 observations were made.

On average, 264 cm of snow (depth) was accumulated on the boards in the open, while only 172 cm accumulated in the forest. The range in increased accumulation for individual events varied from 19 to 116 percent. Both extremes were for small events (3-4 cm depth); the increased accumulation for larger events (25-30 cm depth) was close to the average of 54 percent more in the open. Peak water equivalent in the snowpack at the end of the snowboard monitoring period was 48 percent greater in the open than in the upwind forest. The snowboard data indicated that virtually all of the increased accumulation occurred during, not between, snowfall events. Similar observations have been made elsewhere on the Experimental Forest (Troendle and Meiman 1984).

Figure 1 represents a plot of the snow accumulation and melt pattern for the 1984 season. Greater accumulation in the opening occurred throughout the winter. However, because the rate of ablation is greater in the open, snow disappears on all areas, forest and open, at about the same time. Although the clearcut contained 44 percent more water on April 4, 1984 than the surrounding forest, all sites were virtually clear on June 5.

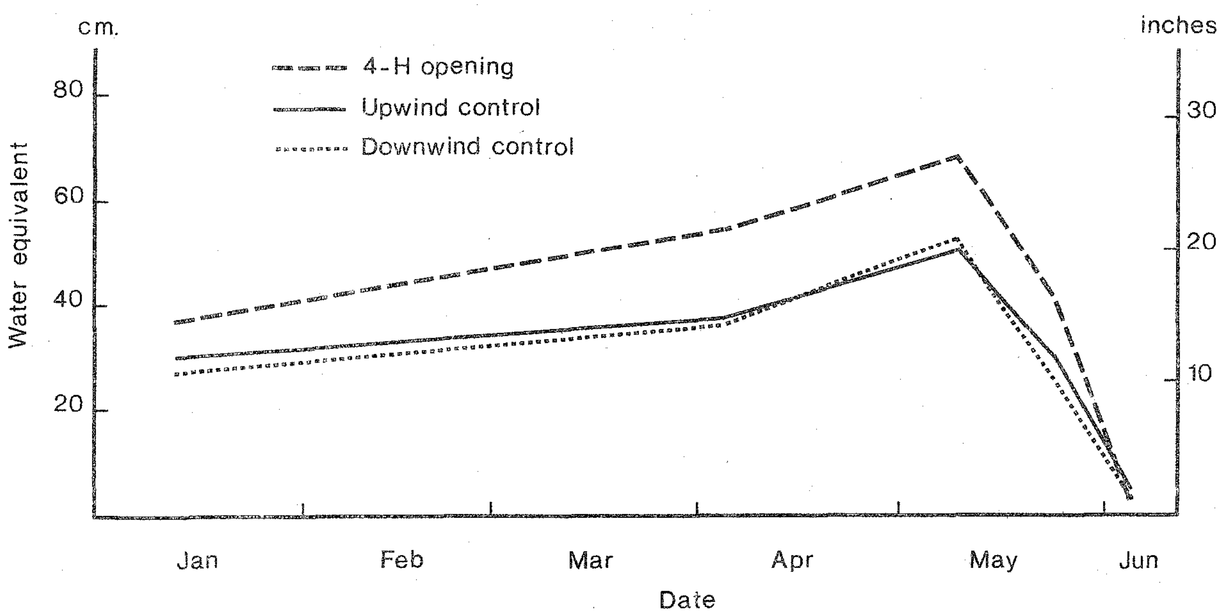

Figure 1. Snowpack accumulation and ablation on the three study plots for one (1984) posttreatment year.

<u>Effects of Timber Harvest on Soil Water Depletion</u>

Soil moisture was measured two or three times on each plot during the two growing seasons before harvest to verify that the soil water depletion patterns were comparable. All three plots were comparable before harvest, except for the fact that plot 1 was consistently drier than either plot 2 or 3. Soil moisture in plots 2 and 3 followed virtually the same depletion pattern. An example of the soil water depletion pattern for the 1982 measurement period is shown in Figure 2.

As noted, a repeated measures analysis of variance indicated that soil moisture depletion on plot 2 was significantly less than on the two forested plots. Figure 3 presents the average soil moisture content on the three plots for 1984, the second growing season after harvest. The disparity between the curves for plots 2 and 3 best represent the effect of timber harvest on soil water depletion in 1984.

Soil moisture depletion under forested conditions was relatively uniform throughout the 1.2-m profile. However, once it was clearcut, virtually all the soil water depletion from plot 2 (Figure 3) was accounted for by depletion at the 0.33-m depth.

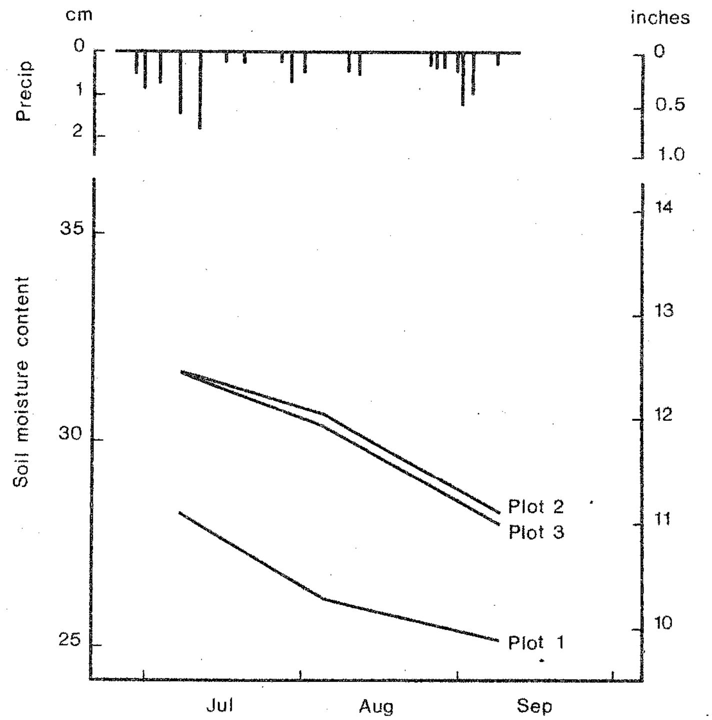

Figure 2. Soil moisture content on each of the three plots during the 1982 growing season.

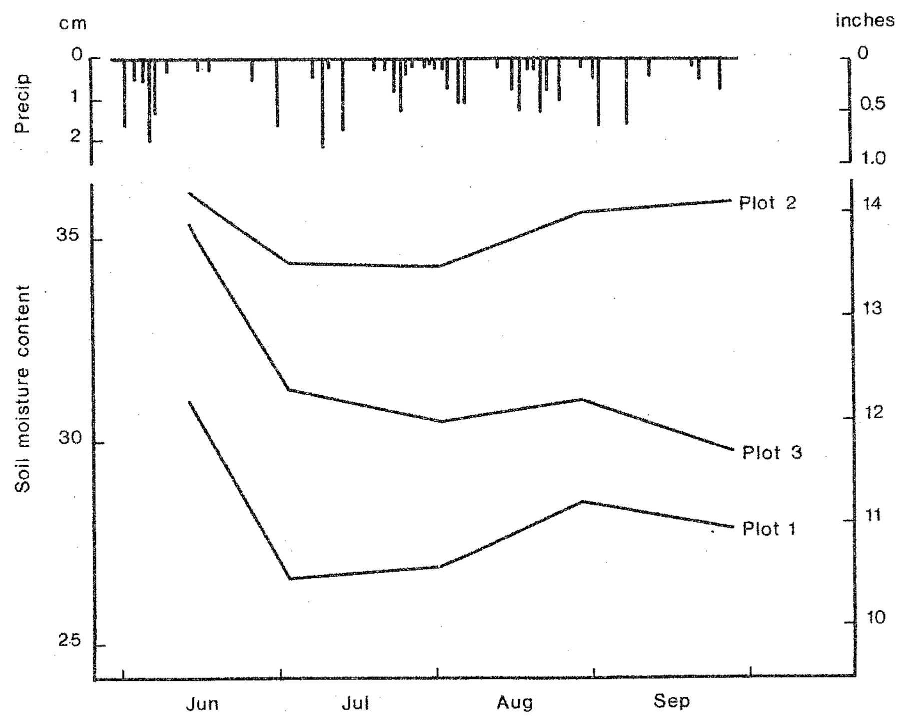

Figure 3. Soil water content on the three study plots during the 1982 growing season. Plot 2 had been clearcut.

One concern was that differential soil moisture content might result in differential soil moisture depletion, as observed elsewhere (Williams 1976). To evaluate the factors that correlate with soil moisture depletion, the incremental depletion, by access tube, was regressed on (1) moisture content at the beginning of the measurement interval in the

1.2-m profile, (2) date or day of year on which the midpoint of the measurement interval occurred, (3) precipitation during the interval, and (4) presence or absence of treatment. In summary, beginning moisture content was not significantly correlated with moisture depletion ($r = 0.04$, $P = 0.20$), while precipitation ($r = -0.71$, $P = 0.001$), date ($r = -0.40$, $P = 0.001$), and treatment ($r = .38$, $P = .04$) were significantly correlated with soil water depletion.

As noted previously, evapotranspiration for the interval is estimated as the summation of the change in soil moisture content and the precipitation. The daily rate is obtained by dividing the ET by the number of days in the interval. Table 2 presents the calculations for each of the intervals for 1 year (1984); Table 3 presents the seasonal summary for each of the 5 years. Figure 4 represents a three dimensional plotting of the relationship between daily evapotranspiration, daily soil moisture depletion, and daily precipitation. Data represents all observations for the period of study for all three plots. In those cases where one of the three values was quite different, it represented plot 2 during one of the posttreatment years.

Table 2. Estimate of daily evapotranspiration (ET) as the sum of the change in soil moisture content (Δ MC) plus the precipitation (P) for the interval (all units in cm) for 1984.

	Plot 1				Plot 2				Plot 3			
Interval dates	Δ MC	P	ET	ET/ day	Δ MC	P	ET	ET/ day	Δ MC	P	ET	ET/ day
6/13-7/2	-4.3	2.5	6.8	.4	-1.6	2.5	4.1	.2	-4.1	2.5	6.6	.4
7/2 -8/1	+0.3	8.5	8.2	.3	-0.2	8.5	8.7	.2	-0.8	8.5	9.3	.3
8/1 -8/28	+1.6	10.1	8.5	.3	+1.2	10.1	8.9	.3	+0.4	10.1	9.7	.4
8/28-9/27	-0.7	8.9	9.6	.3	+0.4	9.6	9.2	.3	-1.2	9.6	10.8	.4
Seasonal ET			33.1				30.9				36.4	

Several things can be noted from Figure 4. First, the plottings follow a diagonal on the X-Y plane, because the estimate of ET is dominated by the occurrence of precipitation; when precipitation is low, ET is low. Second, measured soil moisture depletion never exceeded 0.15 $cm \cdot day^{-1}$. In the absence of significant amounts of precipitation, ET dropped to only 0.20 or 0.25 $cm \cdot day^{-1}$, and was not maintained at the maximum of 0.40 $cm \cdot day^{-1}$ that was estimated during the high rainfall intervals.

Table 3. Summary of evapotranspiration (cm) estimate for measurement intervals.

			Plot 1		Plot 2		Plot 3	
Year	Interval dates	No. days	ET	ET/ day	ET	ET/ day	ET	ET/ day
1981	6/9 -7/22	43	11.2	.26	10.9	.25	12.0	.28
1982	7/7 - 9/8	63	17.4	.28	18.2	.29	18.8	.30
				Harvest				
1983	6/28-10/12	105	32.5	.31	28.2	.27	32.0	.30
1984	6/13- 9/27	116	33.3	.29	30.0	.26	35.0	.30
1985	6/4 -10/9	127	38.6	.30	32.7	.26	41.2	.32
Average ET/day 1983-1985				.30		.26		.31

Precipitation was uniformly distributed throughout the season and was similar for the three posttreatment summers. An example is shown in Figure 3. In 1983, the 27 cm of precipitation fell primarily from 41 events (in excess of 0.13 cm) that averaged 0.64 cm.

In 1984, the 39 rainfall events averaged 0.75 cm each; only 31 events occurred in 1985, although the mean storm size was 1.0 cm. Interception, with or without the overstory vegetation, could be quite great from several small events. Total precipitation was similar for all 3 posttreatment years. The estimate of ET is dominated by precipitation, as shown in Figure 4, giving the impression that, at least on this site, ET may be limited by water availability at times. This is further supported by the fact that, except for a few June measurements, soil water depletion in the absence of precipitation was quite minimal compared to the average ET estimates.

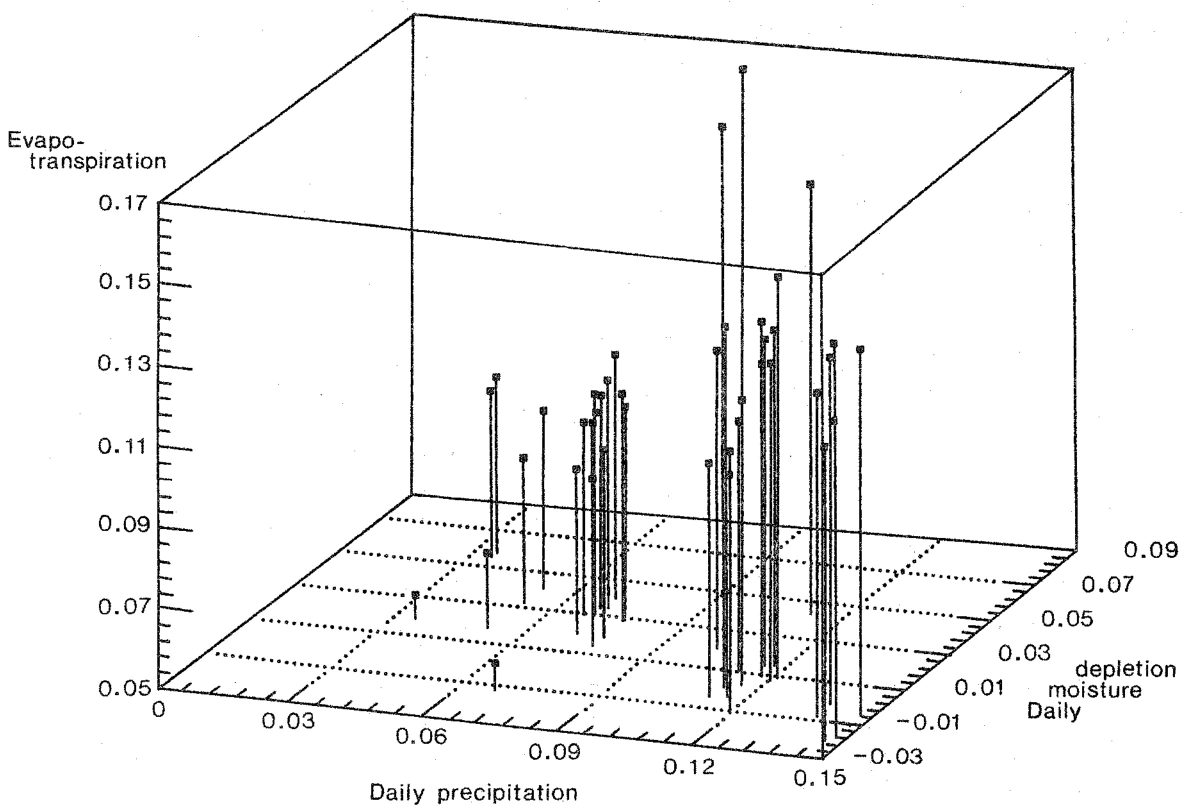

Figure 4. Three dimensional plot showing relation between daily evapotranspiration estimates and daily soil moisture depletion and daily precipitation.

The potential impact that the creation of the opening had on the water balance of the site can be estimated by summing the ET savings and the changes in snowpack peak water equivalent. Table 4 presents these estimates for the 3 posttreatment years. They represent conservative estimates of potential change, because any errors in the working assumptions would underestimate the impact. However, the 19.9-cm mean increase in water available for streamflow shown in Table 4 compares well with the observed increases on nearby Deadhorse Creek for the same time period and for the same percentage of area cut (33 percent). The 19.9-cm increase estimated on site for the clearcut represents a 6.6-cm increase over the entire study area. This potential increase is similar to the observed increase resulting from a similar harvesting practice on the North Fork of Deadhorse Creek. The comparison does not include any savings which may have occurred in April and May on the study plot, however.

SUMMARY

In the most recent analysis of data from the nearby Fool Creek, also on the Fraser Experimental Forest, Troendle and King (1985) noted that the increase in flow after timber harvest was most strongly correlated with winter snowpack accumulation, which increased about 10 percent after timber harvest. The increased flow was significantly correlated with spring precipitation (April 1-July 1) but not correlated with summer precipitation (July 1-October 15).

Table 4. Estimation of potential change in water balance (in cm) following clearcutting.

Year	ET difference	PWE difference	Minimal change
1983	4.0	12.4	16.4
1984	4.1	17.5	21.6
1985	7.2	14.5	21.7
$\bar{x}$	5.1	14.8	19.9

Therefore, because all summer precipitation is stored or used on-site for purposes of this study, the evapotranspiration estimates are high whenever the precipitation is high for the interval. The analysis implies that summer precipitation will be evaporated with or without the presence of vegetation, at least immediately after clearcutting, as long as a dense layer of slash persists. Soil water depletion below 0.33 m appears to occur only where there is vegetation.

The data presented here are for 3 posttreatment years that were above average in precipitation. However, the estimate of seasonal ET and the change in ET estimated after timber harvest compare well with water balance estimates made on nearby gaged watersheds.

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