SNOW ACCUMULATION AND ABLATION ON ADJACENT FORESTED AND CLEARCUT SITES IN SOUTHEASTERN BRITISH COLUMBIA

by

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INTRODUCTION

In southeastern British Columbia, the accumulation and subsequent melting of snow is a major component of streamflow generation and consequently dominates the annual hydrograph. Research studies elsewhere have shown that the accumulation and melt of snow can be influenced by forest cover removal (Haupt, 1979b; Packer, 1962, 1971; Golding and Swanson, 1978; Stanton, 1966; Anderson, 1963; Troendle and Meiman, 1984; and others); hence changes in the quantity and timing of streamflow may be altered by timber harvesting (Troendle and Leaf, 1981). These changes may vary in magnitude and duration depending upon various factors such as forest type, opening size, aspect, and elevation at which the harvesting occurs. Our region of B.C. depends on a number of watersheds for both timber supply and domestic water use. Thus, the potential for impacts arising from changes in the accumulation and melt of snow needs to be better understood.

Most snow research has been undertaken on relatively small openings or narrow strip cuts with little attention given to the 20 to 80 ha clearcuts commonly created by the forest industry in our region. Research has been motivated by interest in water production by means of snowpack management. However, increasing water yield has not been identified as a major objective in our region because water is relatively plentiful. Here, the objective is to minimize deleterious changes in slope hydrology and streamflow regime that may be associated with harvesting, and, at the same time, to maximize timber resource utilization.

The variability that exists in the literature with respect to snow accumulation and melt suggests that application of other studies to our region must be done with caution. To determine the applicability of research done elsewhere and to develop and apply guidelines for timber harvesting that will minimize impacts, a synoptic survey of potential differences in snow accumulation and ablation on large clearcuts and adjacent forested sites was undertaken.

The study had the following objectives: to determine differences in snow accumulation and in the rates of net losses of snowpack as indexed by snow water equivalent on paired forested and clearcut sites; to determine if a regional pattern exists with respect to elevation and aspect; and, to make selected comparisons between opposite aspects at a given locality.

METHODS

Experimental Sites

Site selection was made within the West Kootenay area of the Nelson Forest Region (Figure 1). Adjacent forested and clearcut sites covering a range of elevations and aspects were chosen and measured for potential differences in snow accumulation (Figure 2). Where possible forest/clearcut sites were paired on different aspects within the same drainage. Forest types sampled in this study represent a variety of types that occur in this region. The effects of different forest cover types were not considered in this study.

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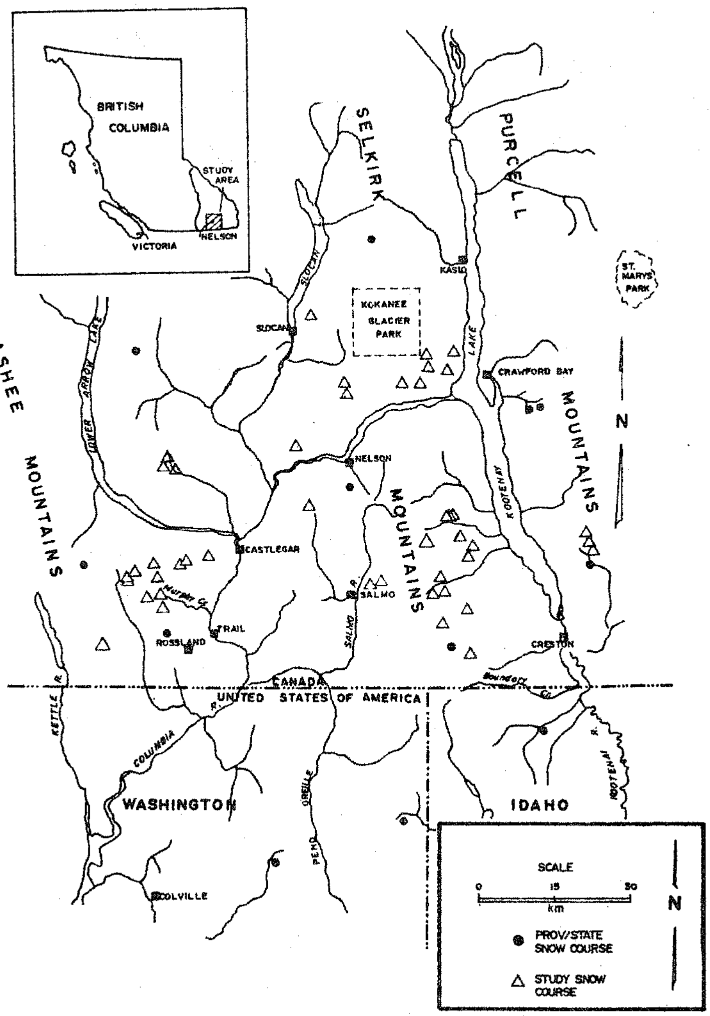

Figure 1. Location of the study area and study sites in south-eastern B.C.

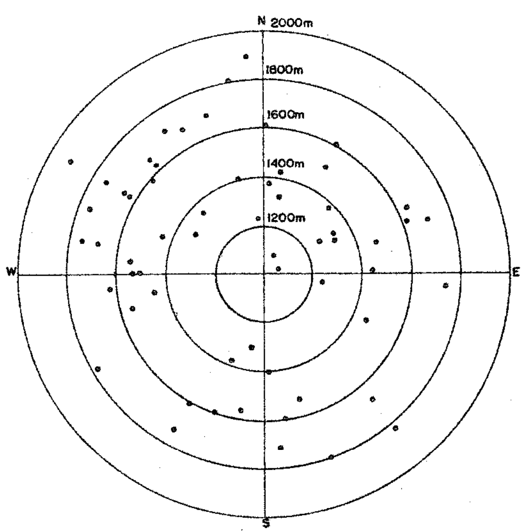

Figure 2. Elevation - aspect location of study sites.

Although the area is in the interior of B.C., the climate is strongly influenced by warm Pacific air masses. These air masses rise and cool adiabatically upon encountering the interior mountain ranges and release large quantities of snow, or to a lesser extent, rain throughout the winter. The snowpack can best be described as transitional between the warm snowpacks described by Smith (1974) and the colder more continental snowpacks typical of the Rocky Mountains.

During the 3 years of this study the accumulation in 1983 was slightly above average whereas in 1984 and 1985 it was slightly below based on long-term averages from provincial and state snow curves in and around the study area.

Measurement and Analyses

Snow accumulation and ablation as indexed by snow water equivalent (SWE) was measured with a federal snow tube. Sampling strategy followed the general design of the B.C. Ministry of Environment (1981). One transect of 10 point measurements of SWE was taken in both the forest and clearcut. The 10 point measurements were averaged to give a value of SWE for a transect. Measurements were made at fixed intervals (10 m) generally along the contour with little elevational gain or loss. All snow sampling transects were at approximately right angles to cutblock boundaries. No measurements were taken within 50 m of the forest/clearcut boundary to avoid any possible edge effect that may arise from wind or the effects of differential melt caused by back radiation.

This study had two phases. In the first phase peak accumulation was measured at adjacent forest/clearcut sites within a 14 day period, generally around April first. Over a 3 year period 89 measurements were made at 60 different sites. The second phase involved sequential sampling throughout the melt season, usually at 7 day intervals, to enable calculation of ablation rates. Measurements were made on 5 paired sites in 1983, 14 in 1984, and 15 in 1985. These sites included an adjacent pair of north and south slopes (plots 83001 and 83002) and an adjacent pair of east and west slopes (plots 83026 and 83027) that were remeasured all 3 years. These measurements facilitate a comparison of adjacent aspects and a comparison of year to year variation.

Simple linear regression analysis was used to test relationships of peak accumulation to elevation and analysis of variance was used to evaluate the effect of aspect. Paired t-tests were used to compare seasonal and weekly melt rates between forested and adjacent clearcut transects.

RESULTS AND DISCUSSION

General Pattern of Accumulation and Ablation

The accumulation and ablation of snow on all clearcut and forested sites had a characteristic shape as illustrated by 3 years' data from paired aspect sites (Figure 3). The accumulation of snow was greater in the openings than in the forest throughout the accumulation season, which started in October and continued until early April. The melt season began with more rapid melt in the clearcut openings. After one-third to one-half of the melt season had elapsed there was an equivalent amount of snow in the forest and the clearcut. The snow continued to melt more quickly in the clearcut than in the forest, disappearing an average 8.5 days earlier in the clearcut than in the forest. This pattern is similar to that described by Anderson (1956) and other researchers (Stanton, 1966; Haupt, 1951; Packer, 1962, 1971).

Peak Accumulation Differences

Snow water equivalent during the 3 year period averaged 36.9% higher in the clearcuts than the adjacent forested sites. Percent differences during the peak accumulation period for each year are presented in Table 1.

TABLE 1. Percent differences in peak period snow water equivalent between forested and clearcut sites based on three years' data collection in the West Kootenays.

Snow Season	Number of Sites	Percent Difference *	Range of Difference
1983	27	35.3	10.7- 68.0
1984	33	42.0	8.8-118.4
1985	29	33.4	3.7- 88.9
	Average	36.9	

$$\text{* percent difference} = \frac{\text{Clearcut SWE} - \text{Forest SWE}}{\text{Forest SWE}} \times 100$$

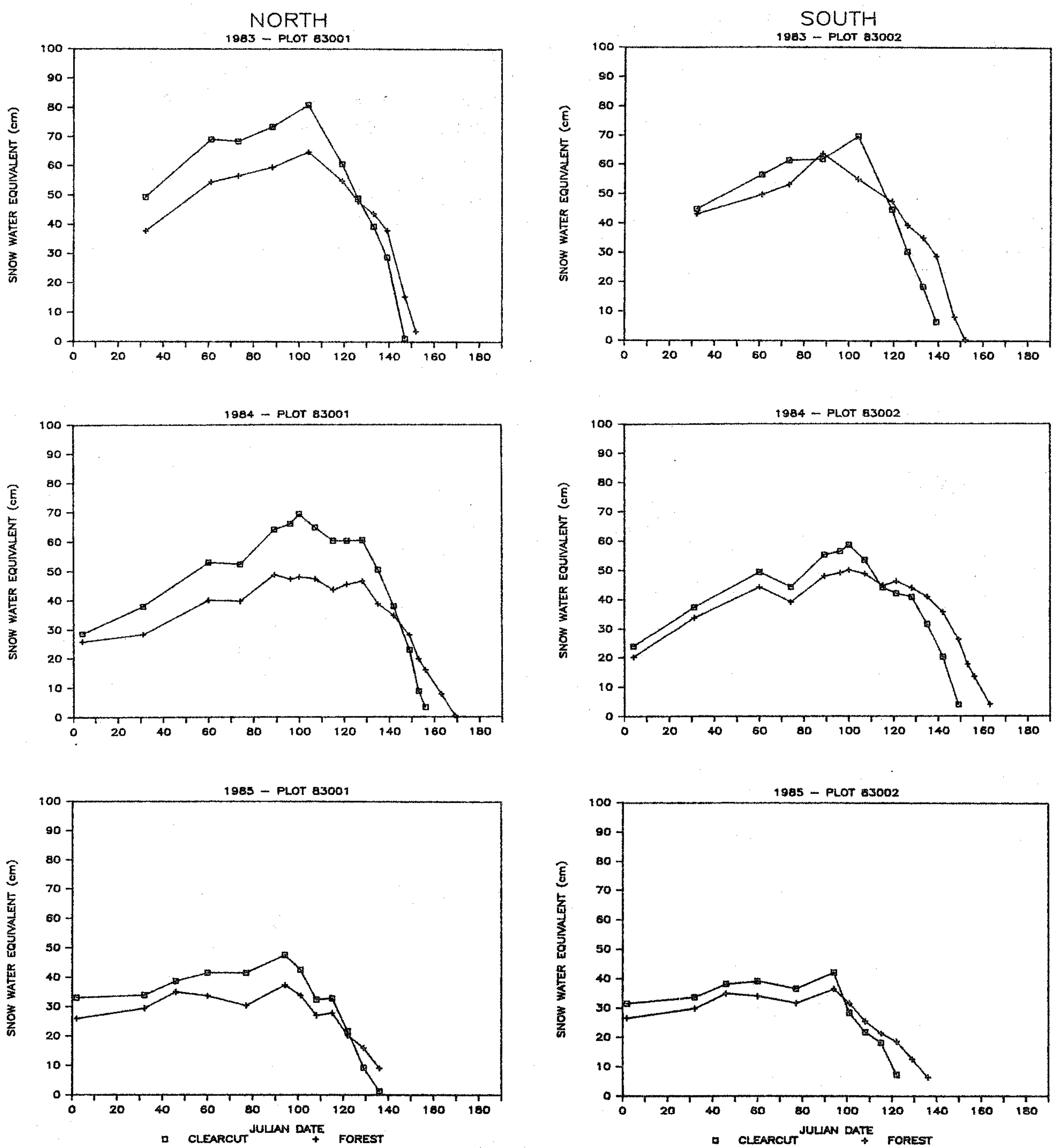

Figure 3. Snow accumulation and ablation on forested and clearcut sites as illustrated by sites on adjacent north and south slopes in 1983, 1984, and 1985.

Elevation

Rates of SWE increase per 100 m varied between 1.1 cm and 1.5 cm for forested sites and 2.1 cm and 2.7 cm for clearcut sites. Although the coefficients of determination were low, ranging from nonsignificant to 0.13, the data indicate a trend of increasing SWE with elevation. For several of the sites with the same date/aspect/slope combination, we calculated SWE/elevation relationships of 1.4 cm. and 5.6 cm increase per 100 m. The lower value compares with figures from our study, while the higher value compares well with a relationship developed by Schaerer (1970) in the same general location where he calculated a 5.8 cm increase per 100 m.

For the provincial and state snow course networks occurring in and around the study area we calculated increases of 3.2 cm to 6.0 cm per 100 m for individual study years based on April 1st data. Coefficients of determination were higher, ranging from 0.66 to 0.92.

Meiman's (1968) review of increases in snowfall with elevation indicated a wide range of increases which might be attributed to differences between major physiographic areas as well as spatial and temporal variation within a given area. Relationships have been found to be fairly consistent for a given location as suggested by Golding (1982).

Aspect

For the purpose of analysis, aspect was classified into four groups: North (316-45°), East (46-135°), South (136-225°) and West (226-315°). For all sites pooled, for each of the three years, we found no statistically significant relationship between peak SWE and aspect. Meiman (1968) and Golding (1982) noted that there is large variability in the effect of aspect on accumulation. In fact, relationships between SWE and aspect in one watershed may not hold true for an adjacent watershed.

The general relationship between aspect and SWE is that north facing slopes tend to accumulate the greatest amounts of snow while south slopes have the least, and east-west slopes having values in between. Golding (1982) suggests this relationship occurs as a result of differential melting during the accumulation phase. Haupt's (1972) findings that mean daily percolation rates are greater on south slopes than north slopes during winter support Golding's hypothesis.

In our study where sites in the same drainage were paired on opposite aspects this relationship held true. Table 2 summarizes the results from those sites. On the four sites paired north-south and east-west, over the three-year period the "cooler" sites yielded higher SWE at peak than did the "warmer" sites. North aspects

Table 2. Effect of aspect on maximum SWE in drainages where sites were paired on opposite aspects. Plot numbers are indicated by brackets.

Site	Elevation (m)	Year	SWE (cm)			
			North (83001)		South (83002)	
			Clearcut	Forest	Clearcut	Forest
Murphy	1 375	1983	80.9	64.8	69.7	55.0
		1984	69.3	48.0	58.6	50.1
		1985	47.6	37.4	42.2	36.5
			East (83026)		West (83027)	
Eleven Mile	1 635	1983	69.7	41.5	81.9	49.3
		1984	58.6	41.2	53.0	39.0
		1985	49.9	30.6	38.4	29.5

had 16% more SWE on average over the three years than did south aspects. East-west sites had little difference between them at peak, with a slight increase on average of 3% on the cooler east aspect. Differences could be accounted for in terms of warmer temperatures on the west slope during the accumulation phase. Cooler sites North through East also exhibited a greater difference between clearcut and forested sites. Again, this would reflect the potential energy for snow melt available in the clearcut that would be absorbed in the forest canopy. The aspect/SWE relationship generally is weaker than that of elevation/SWE (Meiman, 1968). This generally held true in this study.

SNOW ABLATION PATTERNS

The differences between the ablation trends (Figure 3) in the forest and the clearcut illustrate the typical on-site changes a forest manager can affect by clearcutting a forested stand. The average seasonal ablation rates for all the sites measured was 0.8 cm/day in the forest and 1.1 cm/day in the clearcut (Table 3). These values are comparable to average rates of 0.9 cm/day recorded by Packer (1971) (for both openings and forested sites) and of 1.1 and 0.5 cm/day in clearcut and forest recorded by Haupt (1979a) more recently in the same area of northern Idaho.

Table 3. Average ablation rates for all sites followed through the melt season.

Year	Number of Sites	Seasonal Melt Rate (cm/day) All Sites	
		Forest	Clearcut
1983	5	1.1	1.4*
1984	14	0.6	1.0*
1985	15	0.7	1.0*
Mean		0.8	1.1

*Significantly different (t-test, $p < 0.05$)

Aspect

The effect of aspect on snow ablation patterns is typified by selected comparisons between aspects at a given location. For example, the difference between north and south aspects is illustrated in Figure 3 where the north and south accumulation and ablation graphs are compared. During the accumulation season the difference between forest and clearcut SWE generally increases throughout the season on the north aspect whereas the differences more or less remains constant on the south aspect. The point at which the ablation curves intersect is earlier on the south aspect and late in the season the curves diverge considerably. These differences are reflected in the snow disappearance dates which have an average separation of 7.3 days on the north aspect and 14 days on the south aspect.

The comparisons of ablation on north and south clearcuts and on forested areas is illustrated in Figure 4. During all 3 years the indicated SWE is almost identical on the adjacent forested areas whereas those SWE curves are substantially separated in the clearcut condition. With the removal of forest cover, radiation differences between aspects become more important. This separation is reflected by the differences in snow disappearance dates which over 3 years averaged 3.3 days between the north forest and south forest while they were 8.7 days apart in the north clearcut- south clearcut.

The weekly ablation rates further illustrate several differences between aspects (Table 4) . In almost all cases, rates are greater in the clearcut than the adjacent forest. The differences in peak annual ablation rates between forest and clearcut are greater on the north forest and clearcut than on the south forest and clearcut. For example, in 1983 the peak ablation rate was 25% greater in the clearcut than in the north forest, while it was smaller in the south clearcut than the south forest. This is simply a reflection of early snow disappearance on the the south clearcut, before higher temperatures and levels of solar radiation occur later in the melt season.

The differences in ablation pattern between a pair of sites on east and west aspects were by comparison rather minor. There were some subtle differences, however. During the peak melt season the melt rates were usually significantly different between forest and clearcut for both east and west aspects. There were no significant differences between east and west forests or between east and west clearcuts.

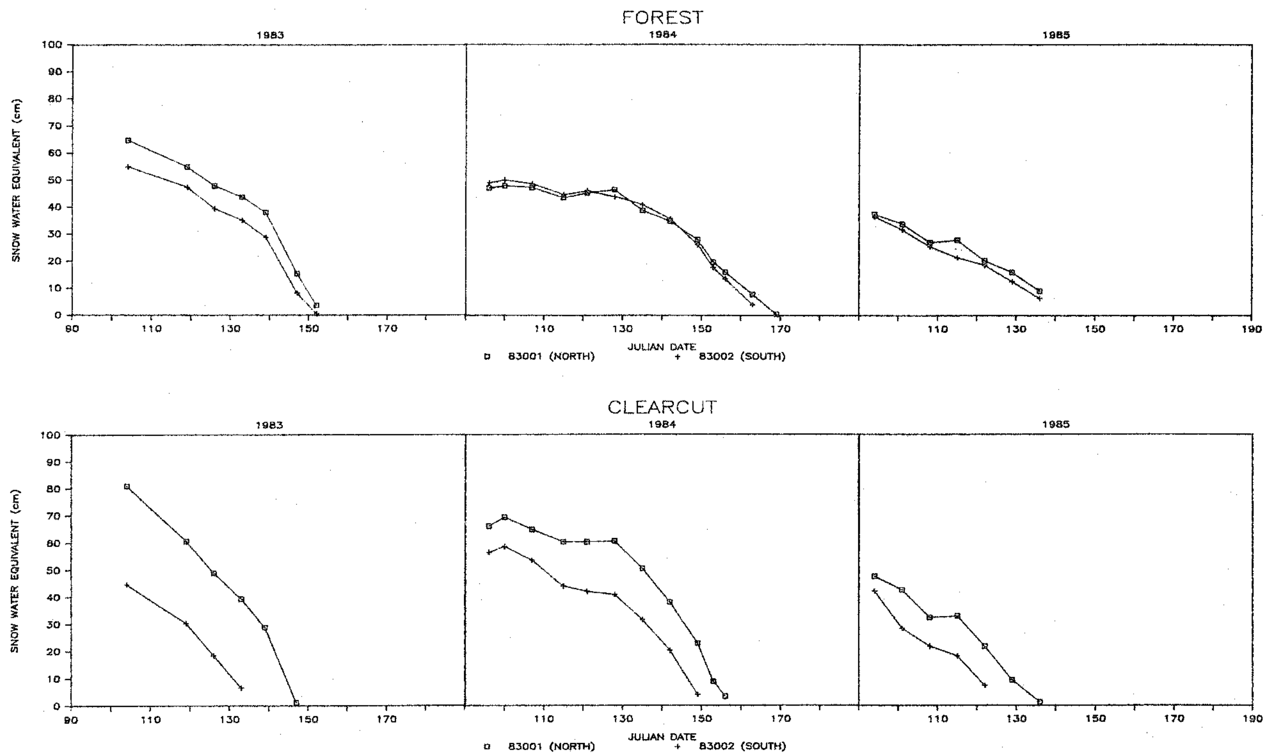

Figure 4. A comparison of snow ablation on adjacent north and south aspects in the Murphy Creek drainage during 1983, 1984, and 1985.

Elevation

A pair of transects separated by 255 m on a north slope and a pair of transects separated by 125 m on a west slope allowed for a comparison of effects of elevation on snow ablation. As might be expected the ablation was initiated later on the higher elevations and the snow disappeared later. Snow disappearance was separated on average by 2.9 days/100 m on the north slope and 3.6 days/100 m on the west slope. A similar separation in initiation of melt was noted. These differences in initiation and disappearance of melt are comparable to the 3.9 days/100 m difference in timing of melt reported by Packer (1971).

Table 4. Weekly ablation rates on adjacent north and south aspects.

Date (end of period)		Snow Ablation Rate (cm/day) North (83001) Forest	Clearcut	South (83002) Forest	Clearcut
1983	April 29	0.7	1.4	0.5	1.7**
	May 6	1.0	1.7*	1.2	2.0
	May 13	0.6	1.4	0.6	1.7*
	May 19	1.0	1.8**	1.1	2.0*
	May 27	2.8	3.5**	2.6	0.8
	June 1	2.4	0.2	1.4	
	June 7	0.6		0.1	
1984	May 15	1.1	1.4	0.4	1.3
	May 22	0.6	1.8**	0.7	1.6
	May 29	1.0	2.2**	1.4	2.3**
	June 2	2.1	3.5**	2.1	1.0**
	June 5	1.2	1.8	1.4	
	June 12	1.2	0.5	1.4	
	June 18	1.2		0.7	
1985	April 11	0.5	0.7	0.7	2.0
	April 18	1.0	1.5	0.9	0.9
	April 25	-0.1	-0.1	0.6	0.5
	May 2	1.1	1.6	0.4	1.6*
	May 9	0.6	1.8*	0.9	1.0
	May 16	1.0	1.1	0.9	

*Significant difference between forest and clearcut (t-test, $p < 0.05$)
**Same as above (t-test, $p < 0.01$)

FOREST MANAGEMENT CONSIDERATIONS

Haupt (1979a) recommended that forest harvesting be planned so that water delivery is desynchronized from the various aspects. To consider this suggestion, the water delivery potential on the four available combinations of north and south clearcuts and forests in an upper basin were compared. The assumption is that the catchment consists entirely of two adjacent north and south slopes and the averaging of the ablation rates is a reflection of the water delivery to the channel. The results are illustrated in the graphs shown in Figure 5. It can be seen in the 1983 graph that water delivery early in the season was lowest when both aspects were forested and highest when both were clearcut. This trend continued until the fifth week when the north forest-south clearcut and the north forest-south forest combinations had the highest delivery rates. In this case, the south clearcut had a significant desynchronizing effect. Conversely, the north forest-south clearcut had a synchronizing effect and produced the highest delivery rate of the season. It is also interesting to note that the highest delivery rate of the season was greater in the forest-forest combination than the clearcut-clearcut combination simply because snow was retained until later in the melt season when warmer weather prevailed.

A similar pattern was evident in 1984, except that the order of the highest seasonal delivery rates was changed slightly with the north clearcut-south clearcut combination having the second highest delivery rate and the north forest-south forest having the third highest delivery rate. Once again, the lowest water delivery rate was from the north forest-south clearcut combination and occured because snow had disappeared from the south forest by the time high levels of melt were occurring elsewhere.

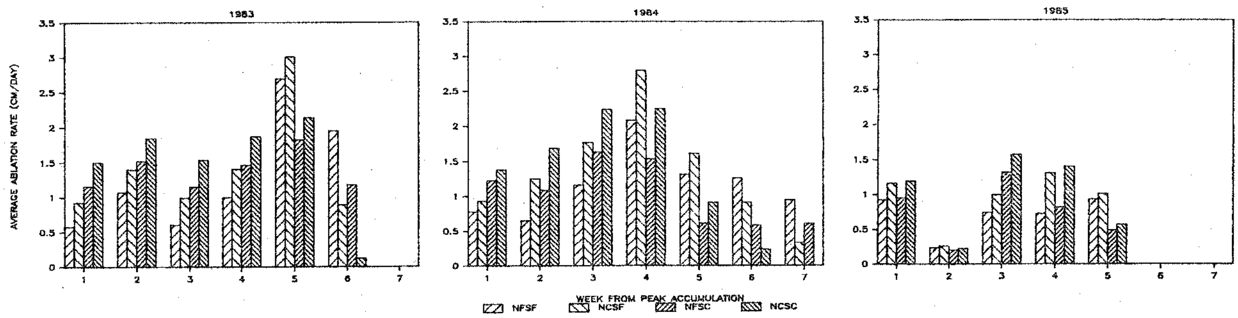

Figure 5. Projected weekly water delivery rates of four forest-clearcut combinations: 1) north forest/south forest (NFSF), 2) north forest/south clearcut (SFNC), 3) north forest/south clearcut (NFSC), 4) north clearcut/south clearcut (NCSC).

During 1985, the synchronization-desynchronization was not as evident. The north clearcut-south clearcut combination had the highest water delivery rate. In general, all of the delivery rates were much lower during this year. Obviously, a watershed is much more complex with many aspects and a range of elevations and this complexity should be considered when applying recommendations for synchronization or desynchronization of melt rates. Clearly, there is a need for watershed modelling techniques that allow one to project potential synchronization and desynchronizqtion impacts over a broad range of options.

Satterland and Haupt (1972) considered the same problem, namely the application of guidelines to reduce the concentration of snowmelt runoff following timber harvest. They suggested that it was feasible to develop a model of snowpack accumulation and melt that would operate within the constraints of available data and would improve our capability to design strategies of timber harvesting that are compatible with snowpack management objectives. Since then, forest hydrologists involved in operations have begun extensively applying several predictive models for considering the impacts of alternative harvesting scenarios. These procedures are the WRENSS procedure (Troendle and Leaf, 1980) and the USFS-Region One Water Yield Increase Model (U.S.D.A. Forest Service, n.d.). These are based on the principles of water balance and water yield increase associated with harvesting.

Despite these moves to quantitative analysis, there still is not available an adequate operational modelling procedure that capitalizes on differential melt rates arising from timber harvesting on various aspects. Such a model would allow managers to identify harvesting patterns that would allow for a desynchronization of peak flows to meet water management objectives.

No attempt was made to study the effect of opening size; however, several inferences can be made based on the fact that our measurements were made in relatively large openings. Troendle and Leaf (1980) proposed a relationship in which the rate of snow retention in a clearcut as compared to a forest increases to a width of 5H (H is tree heights) and thereafter decreases. Beyond 14H the snow retention is less than in the adjacent forest. The data collected in this study showed no indication of decreasing accumulation with increased clearcut size in that the accumulations in the openings were in all cases greater than those in adjacent forested sites. The opening diameters utilized in this study varied between 6 H and 42 H and averaged 21 H with several measurements as part of much larger continuous clearcuts.

The basis for the relationship proposed by Troendle and Leaf (1980) is that snow is redistributed from downwind locations. On the other hand, the studies of Haupt (1979a, b) in nearby northern Idaho attribute the increased accumulation to interception savings. Haupt attributed the differences of his results from those of the Colorado Rockies and the Sierra Nevada to differences in climate. Quite simply the snow persists in the canopy for long periods until finally being released as wet clumps. Our findings are consistent with those of Haupt.

SUMMARY

A synoptic survey of adjacent forested and clearcut sites was undertaken to determine differences in snow accumulation and rate of ablation and to investigate regional patterns with respect to elevation and aspect. Snow accumulation as measured on 60 sites over a 3 year period averaged 37% greater on clearcut sites than forested sites. Snow ablation rates as measured on 15 sites were 38% faster on the clearcut sites. Synoptic relationships of accumulation to aspect and elevation were generally weak. Local comparisons between adjacent north and south slopes indicated a 16% greater accumulation on north slopes than south slopes. The weekly snow ablation rates varied between aspects with peak seasonal ablation occurring earlier on the south aspect than the north aspect. Also, the snow disappearance was 7 and 14 days earlier on the south than the north forest and clearcut, respectively. These differences in melt rates and disappearance dates between high energy and low energy aspects can be used to purposefully desynchronize water delivery to channels.

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