POTENTIAL WATER YIELD RESPONSE FOLLOWING CLEARCUT HARVESTING ON NORTH AND SOUTH SLOPES IN NORTHERN IDAHO

Richard G. Cline, Harold F. Haupt, and Gaylon S. Campbell

USDA Forest Service Research Paper INT-191
INTERMOUNTAIN FOREST AND RANGE EXPERIMENT STATION
FOREST SERVICE, U.S. DEPARTMENT OF AGRICULTURE

Headquarters for the Intermountain Forest and Range Experiment Station are in Ogden, Utah. Field programs and research work units are maintained in:

- Billings, Montana
- Boise, Idaho
- Bozeman, Montana (in cooperation with Montana State University)
- Logan, Utah (in cooperation with Utah State University)
- Missoula, Montana (in cooperation with University of Montana)
- Moscow, Idaho (in cooperation with the University of Idaho)
- Provo, Utah (in cooperation with Brigham Young University)
- Reno, Nevada (in cooperation with the University of Nevada)

USDA Forest Service
Research Paper INT-191
June 1977

POTENTIAL WATER YIELD RESPONSE FOLLOWING CLEARCUT HARVESTING ON NORTH AND SOUTH SLOPES IN NORTHERN IDAHO

Richard G. Cline, Harold F. Haupt, and Gaylon S. Campbell

INTERMOUNTAIN FOREST AND RANGE EXPERIMENT STATION
Forest Service
U.S. Department of Agriculture
Ogden, Utah 84401

THE AUTHORS

RICHARD G. CLINE earned his B.S. degree in agriculture at Cornell University, M.S. degree in soils at North Dakota State University, and Ph.D. in soils at Washington State University in 1974. From 1974 to 1975 he was a soil scientist with the Clearwater National Forest. At present, he is holding a similar position with the Nezperce National Forest.

HAROLD F. HAUPT is leader of the Water Quality Management research work unit of the Intermountain Station at Moscow. He holds a B.S. degree in forestry and M.S. degree in range ecology, both obtained at the University of Idaho. For the past 28 years, he has conducted research in the fields of snowmelt hydrology, logging-road erosion, and soil stabilization at several locations in Idaho and Nevada.

GAYLON S. CAMPBELL holds a dual appointment as an associate professor in Biophysics and associate soil scientist with the Department of Agronomy and Soils, Washington State University. He earned his B.S. and M.S. degrees at Utah State University in 1966 and a Ph.D. at Washington State University in 1968. For 6 years he has been teaching and conducting research in plant-water relations, soil physics, and agriculture meteorology.

CONTENTS

Page

INTRODUCTION. 1

BACKGROUND INFORMATION 1

DESCRIPTION OF STUDY AREA 2

TREATMENT AND CONTROL PLOTS 3

INSTRUMENTATION AND MEASUREMENTS 4

RESULTS 5

SUMMARY AND CONCLUSIONS 14

PUBLICATIONS CITED 15

RESEARCH SUMMARY

The hydrologic response of small clearcuts on north and south slopes in northern Idaho was investigated. On the north slope, substantial gains (27 to 35 cm) in potential water yield per year resulted from (a) removal of transpiring surfaces associated with plant cover, (b) elimination of snow interception by a closed-canopied forest, and (c) gradual reoccupation of the soil mantle by invading herbaceous species. On the south slope, small to moderate gains (4 to 11 cm) in yield resulted from clearcutting, at least in 1973, the year studied. In earlier years, the gains probably would have been negligible. Site factors that compensated for clearcutting kept gains in yield small to moderate on the south slope. Initial forest losses from interception were light because of the open-canopied structure of the timber and windiness at treetop level. In the clearcut, water gains from reduced transpiration were more than used up within 4 years by invading shrub species. The south slope clearcut was subjected to other sources of water loss also.

INTRODUCTION

In the heavily timbered, snow-dominated landscapes of northern Idaho, the problems of watershed management differ from those of less heavily timbered and water-short regions. "The question is not so much how to increase water yields from the snowpack, but rather, how to safely dispose of the increased water yields that accompany timber harvesting...." (Satterlund and Haupt 1972). The Forest Service in cooperation with the University of Idaho and Washington State University has a comprehensive program underway in snow hydrology and snow management at Moscow, Idaho. The research program consists of three parts: (1) studying the physical-biological processes, (2) evaluating manipulative treatments on individual plot areas, and (3) testing the most promising findings on monitored watersheds.

This paper describes one segment of the research program--a plot study to determine the effect of timber harvesting and early site recovery on potential water yield under divergent conditions existing on north and south slopes in a prime timber-producing zone. Results from this hydrologic investigation should add to the knowledge base needed to better estimate how much, where, and when to expect water yield increase from clearcutting practices.

BACKGROUND INFORMATION

Previous research on the integrated effects of timber harvest, snow hydrology, and soil water has been limited. Packer's (1962) analyses of snow data collected on the Priest River Experimental Forest in northern Idaho showed that a change in canopy density from a completely closed to a completely open condition increased the average water equivalent (WE) uniformly 10.7 cm. This average relation, according to Packer, occurred regardless of differences in year, elevation, or aspect. He inferred that increase in WE at the time of maximum snowpack was due primarily to loss by interception, and subsequent evaposublimation within tree canopies.

Anderson (1956) reported much larger gains in the central Sierra Nevada of California; on the average, the April 1 snowpack contained 28 cm more water in large open areas than in dense forest. He explained that the difference may represent the net effect of three factors: loss by interception, difference in winter melt, and blowing of snow by wind.

Recent findings in the West have challenged the importance of loss by interception, particularly in the high-elevation forests of the central Rocky Mountains (Hoover and Leaf 1967; Dietrich and Meiman 1974; Gary 1974) and of the central Sierra Nevada (Smith 1974). However, in the midelevation forest of Priest River Experimental Forest recent lysimetric data indicate that for some forest-terrain situations winter loss by interception remains important (Haupt 1972b). This latter evidence substantiates what Packer inferred in 1962 from snow course data.

The studies reported by Packer and Haupt dealt only with the snowpack and snowmelt and not with changes in soil water storage. Elsewhere in the West the literature contains little data on soil water storage at different slope exposures in the timbered snow zone. Bethlahmy (1973) concluded by examining flow patterns of 14 mountain streams that north slopes, with their denser vegetative cover and deeper soils, generally will lose more water through transpiration and retain more water against the pull of gravity than south slopes. South slopes will lose less water through transpiration and will yield more water to deep seepage. On the other hand, Tew (1967) studied the effect of slope exposure on water use by aspen in central Utah and found that the largest amount of water was removed by vegetation on a western exposure. He also reported that amounts of water removed from north and south aspects were similar.

Cutting effect, or site recovery, in the snow zone may involve considerable time. Snowpack increases persist for long periods after forests are cut (Hoover 1969). In contrast to the slowly diminishing snowpack after timber removal, soil water gains tend to decrease quite rapidly. In a Central Sierra study, savings dropped by one-half in 4 years after a selection-type cutting (Anderson 1963). After clearcutting, Zeimer (1964) found that resultant increases in water stored in the soil would fall to zero by the 16th year. Neither study documented the effect that slope exposure or plant habitat type might have on the rate of site recovery.

DESCRIPTION OF STUDY AREA

The study was conducted in the midelevation zone of Priest River Experimental Forest. The specific study area overlapped onto both slopes of an east-west oriented ridge between an elevation of 1,300 and 1,400 m. The south (180°) slope includes the *Pseudotsuga menziesii/Physocarpus malvaceus* habitat type on 44 to 52 percent slope gradients. Stand heights range from 27 to 39 m with crown closure of 20 to 30 percent. The open overstory consists of Douglas-fir (*Pseudotsuga menziesii* var. *glauca* [Beissn.] Franco), western white pine (*Pinus monticola* Dougl.), western larch (*Larix occidentalis* Nutt.), and grand fir (*Abies grandis* [Dougl.] Forbes) and the understory contains a rich mixture of shrubs dominated by ninebark (*Physocarpus malvaceus* [Greene] Kuntze).

The north (335°) slope is classified as *Tsuga heterophylla/Pachistima myrsinites* habitat type (Daubenmire and Daubenmire 1968) on 38 to 48 percent slope gradients. Stand heights vary 37 to 49 m with crown closure of 90 to 100 percent. The dense overstory consists of western hemlock (*Tsuga heterophylla* [Raf.] Sarg.), western redcedar (*Thuja plicata* Donn), and western white pine, and the understory contains a trace of low, herbaceous plants.

Soil profiles on both slopes are similar except for thickness and composition of the lower horizon. The upper mineral horizon, some 2 cm thick, was derived from recent volcanic ash; the next horizon, about 46 cm thick, is dominated by ash from the 6,700 BP Mazama eruption. Both are silt loam in texture. Glacial till, containing coarse fragments of granite and schist, lies below the wind-laid horizons and extends to a depth of more than 100 cm on the north slope, but less on the south slope. On the south slope, this horizon contains more rock fragments. The fourth horizon on the north slope is composed of granite and schist materials which are more weathered than those in the glacial till immediately above. This implies a fourth depositional event since the bedrock is believed to be quartzite. This layer is not present on the south slope. Average depth to bedrock is greater on the north slope (163 cm) and shallower on the south slope (137 cm).

The climate is influenced by the Pacific Ocean some 500 km to the west. Winters are cool and wet. Storms and accompanying winds generally move in from the south, southwest, and west. Summers are dry and most of the annual precipitation, 104 cm, falls during winter in the form of snow and rain. Precipitation for the study year, 1973, was 72 cm, the lowest total recorded since 1940. The summer months, June, July, and August, were extremely dry.

TREATMENT AND CONTROL PLOTS

The treatment plots were located in north-facing and south-facing clearcuts, both having been logged earlier in 1968 and 1969, respectively. Plots were located during autumn 1972 and, therefore, the information reported in this paper deals primarily with the postperiod, November 1, 1972, through November 19, 1973.

Each clearcut was small, 61 by 198 m, with its long axis oriented north-south. The north slope clearcut (station 44) opened onto the lower side of a much larger unit; the replication on the opposite slope (station 50) opened onto the larger unit at the crest of the main ridge (fig. 1).

Slash on the south clearcut was removed by skidding during autumn 1969; consequently, much of the deciduous woody shrub understory was severely broken, crushed, or grubbed out, but not burned. Understory vegetation was almost absent on the north slope; slash there was piled by tractor into a windrow during autumn 1968 and burned.

The treatments consisted of a "revegetated" plot where the vegetative cover was in the process of recovering, since slash disposal, and a "bare" plot on which the vegetative cover was physically removed in 1972 (but not burned) for the second time. The bare plot was assumed to approximate the ground surface condition the first year following disposal of slash when ground cover was at a minimum. Each treatment plot, about 25 m square, was positioned near the center of the clearing.

The forested or "control" plots represented by stations 47 and 42 were deep in the uncut forests west of the treatment plots (fig. 1).

Figure 1.--Stations 42 and 44 (north slope) and stations 47 and 50 (south slope), Priest River Experimental Forest. Arrow denotes general wind direction south to west.

INSTRUMENTATION AND MEASUREMENTS

Rainfall and snowfall were indexed near each plot location from November 1, 1969, through October 31, 1973, by means of snow courses, recording rain gages, and snow lysimeters. Two parallel snow courses, located on the contour of each slope, traversed the clearcut and adjacent forest. Each course included 16 nonrandom snow sampling areas (10 in the clearcut and 6 in the forest). Water equivalent was measured periodically with a federal-type sampler during the accumulation-melt period, but only those readings taken at peak snowpack are discussed.

Precipitation in the clearcut opening and through-fall in the forest were recorded by a Belfort rain gage equipped with stereo orifice and modified windshield (Haupt 1972a). A single gage was positioned midway across the clearcut and another under the tree canopy on each forested plot.

Percolate was collected from snow lysimeters (Haupt 1969), which were operated from November 1 through May 31. Lysimeters provided point measurements of net precipitation--precipitation that percolated through the snowpack during rainy periods or ultimately entered the soil mantle as the snowpack melted. They were positioned near the rain gages. In the forest, they were located beneath a canopy configuration similar to that above each rain gage.

The climatic record also included temperature, wind travel, incoming solar radiation, and atmospheric relative humidity at each station. The relative humidity and temperature were obtained with a hair and bimetallic hygrothermograph, radiation with a mechanical pyranograph, and wind travel with a three-cup totalizer. These data were used to calculate potential evapotranspiration (PET) using the Penman equation with the wind function of Wright and Jensen (1972).

During autumn 1972, neutron probe access tubes were installed by means of a method described by Cline and Jeffers (1975). These tubes were laid out in a random pattern about 10 m apart with three tubes in each forested plot, revegetated plot, and bare plot. A few tubes were placed to a depth of 183 cm, but bedrock forced termination of most tubes at a shallower depth. Despite these limitations, probe readings were taken in each tube to a depth of at least 137 cm.

To measure soil water, a neutron probe manufactured by Troxler Electronic Laboratories, Inc., was used. Calibration was performed with volumetric samples from special calibration plots. Because of good consistency between volumetric samples and readings from the manufacturer's rating curve, no correction was needed. Soil water data were collected at 15-cm depth increments in autumn 1972 and spring, summer, and autumn 1973.

The study design did not include the statistical sensitivity of taking pretreatment measurements to determine if inherent site differences existed. The drastic treatments used were assumed to overcome these. This proved to be the case in a Colorado study by Dietrich and Meiman (1974).

RESULTS

Soil water.--A graphic presentation of soil water content from April 4 to November 19, 1973, is shown in figure 2. The three plot conditions are presented in each part (A and B) of the figure and represent the average of three tubes in each plot. Examination with reference to the bare plots suggests that water contents in the profile had begun to stabilize by the first part of June after fluctuating in early spring. Drainage from these soils was assumed to be substantially reduced and field capacity approached due to decreasing hydraulic conductivity (Baver and others 1972, p. 381-384). June 4 was chosen as the beginning of the drawdown season for both slopes and estimated evapotranspiration (ET) water losses were determined for the six profiles from this date to August 27 when they contained the least water.

A Duncan's Multiple Range Test at the 5 percent level of significance was applied to the means (water loss), and results are given in table 1. These mean losses do not include 2.5 cm of rain received during the first 3 weeks of June. The June storms provided the last important period of rain until August 30 when 1.8 cm of rain fell. Table 1 shows that, of the revegetated-forested plots, the north slope revegetated plot lost the least water to ET during this period.

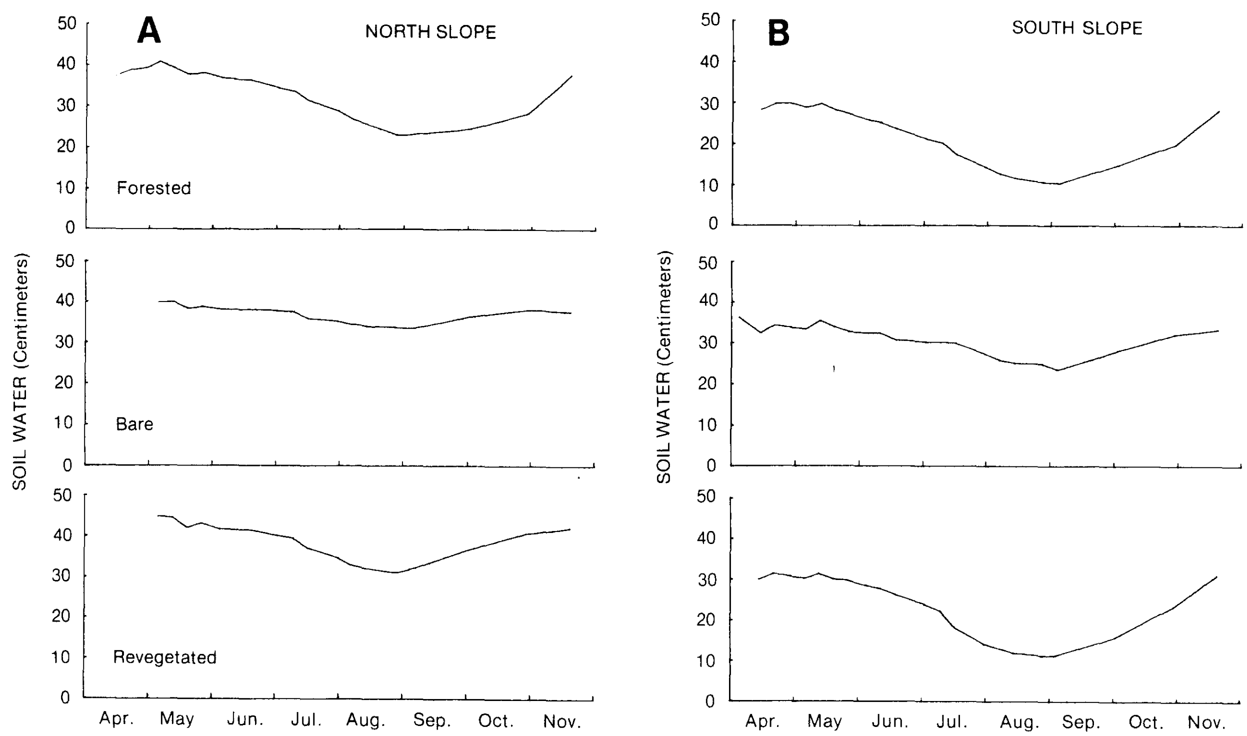


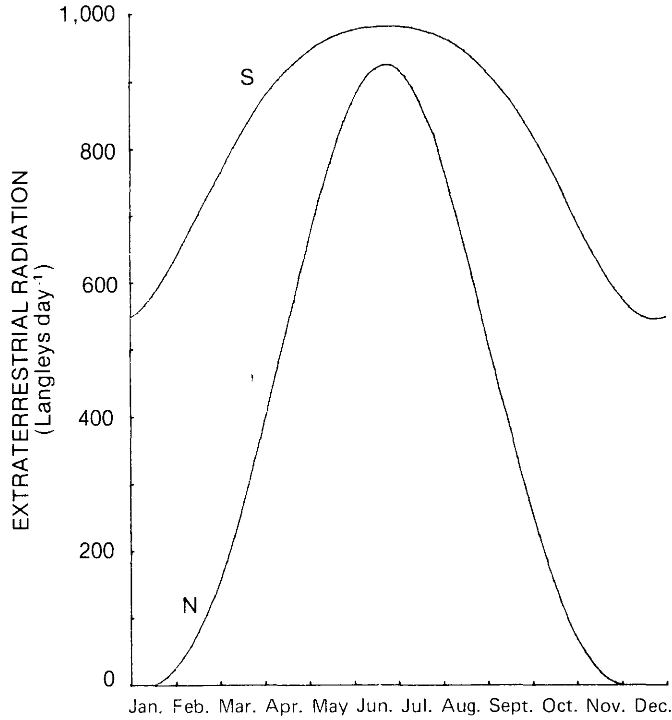
Figure 2.--Seasonal water content in 137-cm profile for (A) north slope plots and (B) south slope plots.

Table 1.--*Duncan's multiple range test of six water loss means at the 5 percent level of significance*

Treatment	Mean (cm of water)[1]				
North slope, bare soil	4.2	A			
South slope, bare soil	7.7	A	B		
North slope, revegetated (5 years since logging)	10.4		B	C	
North slope, forested	13.5			C	D
South slope, forested	15.4				D
South slope, revegetated (4 years since logging)	18.4				D

[1]Means followed by any letter are significantly different from those means not having that letter.

Figure 3.--Extra-terrestrial solar energy on (S) south slope plots and (N) north slope plots.



Although not significant at the 5 percent level, the ordering of the last three means in table 1 is reasonable in light of conditions existing on these plots. The greater rate of ET loss from the revegetated and forested plots on the south slope is understandable due to greater solar radiation (fig. 3) and therefore greater potential evapotranspiration; the greater rate of loss from evapotranspiration may also be due to vegetative structure. The forested north slope plot contained primarily coniferous tree species with no shrub understory (fig. 4), whereas the forested south slope plot contained substantial amounts of deciduous woody shrubs in addition to trees (fig. 5). Cline and Campbell (1976) and Gates (1968) suggest greater leaf diffusive conductances in deciduous species than in coniferous trees. This could contribute to the greater apparent use of soil water in plots with significant amounts of deciduous brush.

In spite of variations in spring maximum water content of as much as 25 cm several similar soil profiles on north and south exposures in the Priest River Experimental Forest contained about 10 cm of water at their driest (Cline 1974). From this and from results in table 2, we concluded that both forested and revegetated plots on the south slope had depleted soil water reserves to this minimum by August 27. This conclusion is also supported by the water content curves (fig. 2B) that inflect toward the horizontal starting in late July.

However, north slope plots did not lose water to a minimum of 10 cm nor did the loss rate of the forested plot appear to decrease as did those on the south slope during August. The curve for the north slope revegetated plot did inflect in August (fig. 2A), but the minimum water content of the profile was considerably higher than that of the forested plot. This suggests that, unlike the south slope which appeared to be completely reoccupied within 4 years, a 5-year period was not sufficient time for vegetation to completely reoccupy the soil volume after clearcutting.

The bare plots in figure 2 lost more water at the beginning of the growing season season than they did as the soil surface dried. Starting in mid-July, the south bare plot shows an increased rate of water loss not shown by its north slope counterpart. The shrubs on the south aspect were characterized by extensive fibrous, horizontal root systems. The tendency of shrubs adjacent to the bare plot to branch their roots may account for the accelerated water losses in July and August, particularly in the

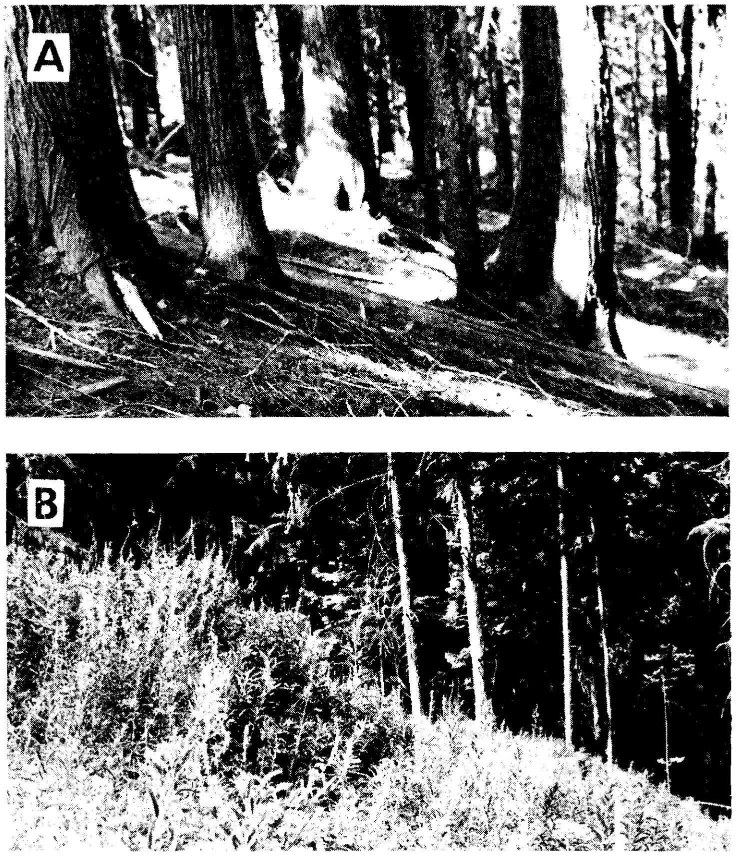


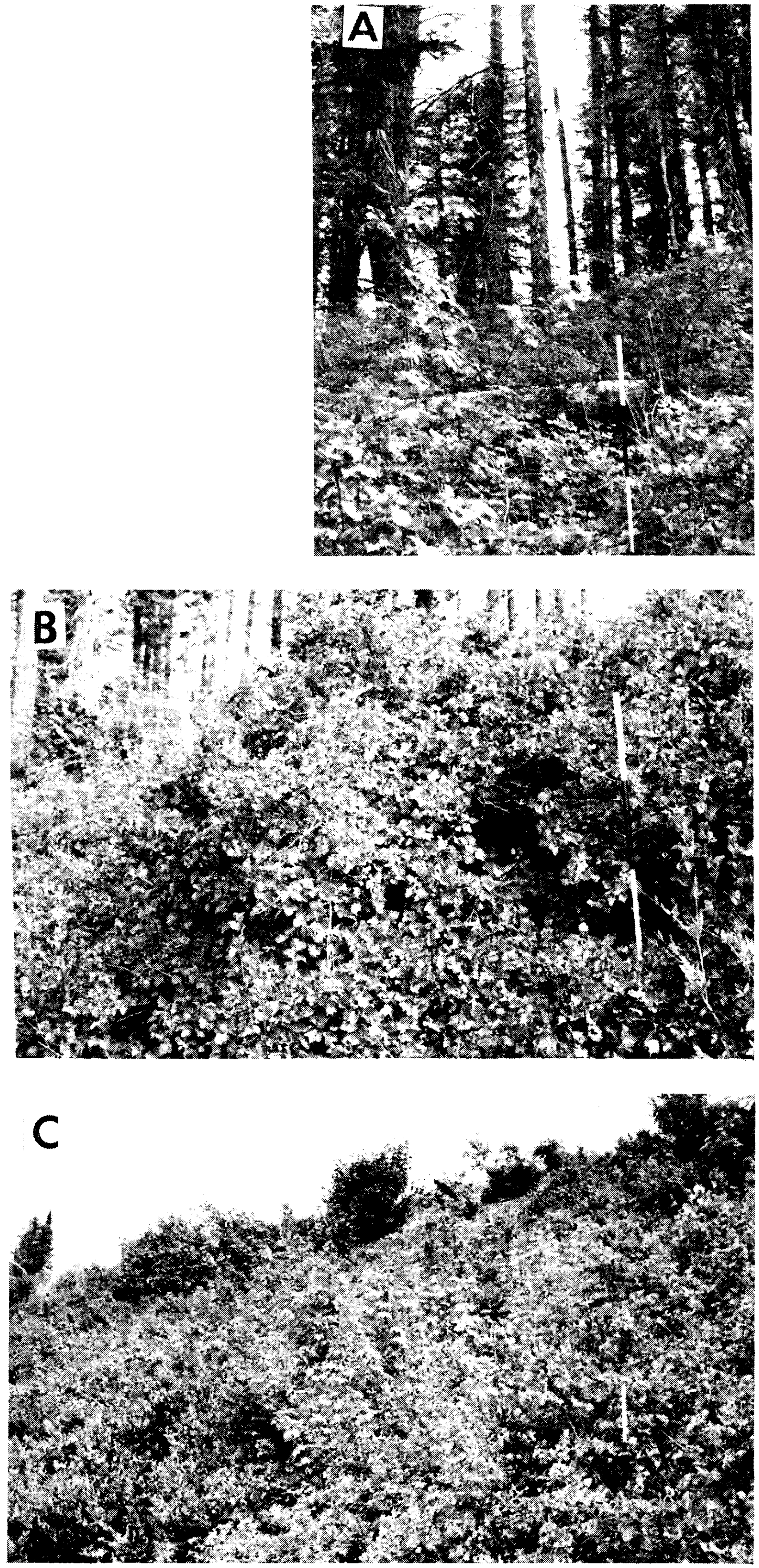
Figure 4.--(A) Undisturbed forested plot on north slope. (B) Revegetated plot on north slope clearcut. Note dominance of herbaceous species, fireweed (Epilobium angustifolium L.).

Table 2.--*Water content in 137-cm profile at spring field capacity and summer minimum*

Treatment	North slope				South slope			
	Spring field capacity		Summer minimum		Spring field capacity		Summer minimum	
	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
	Cm		*Cm*		*Cm*		*Cm*	
Forested	36.7	3.5	23.2	1.1	25.4	3.8	10.0	3.2
Bare	38.2	3.3	34.0	4.0	33.4	2.2	25.7	3.0
Revegetated	41.5	4.0	31.1	4.5	29.4	4.5	11.0	2.8

30- to 60-cm depth zone. (The borders of the bare plot were not trenched to sever roots.) Shrubs on sites like this may recover the total volume of soil water in less than 4 years largely because of their ability to grow back rapidly from root stocks. These shrubs will recover quickly even where aboveground foliage is completely destroyed by broadcast burning after logging (fig. 5).

Figure 5.--(A) Undisturbed forested plot on south slope. (B) Revegetated plot on south slope clearcut. Note dominance of deciduous woody brush, ninebark. (C) Adjacent large clearcut where understory brush and logging slash were broadcast burned the fall of 1968.



Frequent rains between August 30 and November 19 succeeded in recharging the soils to water levels observed the previous spring. The profiles with greatest water contents at the end of August tended to recharge more quickly (fig. 2, bare plots and north revegetated plot) than those that had been depleted of water by trees and dense brush. In the fall, the tree-covered and dense-brush plots recharged slowly at first, then more rapidly, suggesting that higher order vegetation was still removing water from these profiles. By the time the first snows covered the ground in mid-November, the soils were almost fully charged and in condition to add ground water reserves.

Winter precipitation.--Soil water storage is but one component to consider in determining the potential water yield budget. At Priest River, where a major portion of the precipitation falls during the dormant season, snow storage, winter release (rain percolate and melt from winter snowpack), and spring melt are important considerations. For the period November 1, 1972, through May 31, 1973, the mean peak snowpack (WE) and seasonal totals of precipitation and lysimeter percolate are presented in table 3. To illustrate the effectiveness of timber harvest, a comparison of gains in the clearcut is shown in table 4.

From November 1 to May 31, the lysimeter in the north forest registered the least amount of total percolate, but the north clearcut measured the most. The south forest and south clearcut ranked between the two extremes. The north clearcut showed the greatest gain (19.6 cm) after timber removal; in contrast, the south clearcut showed but a slight increase (2.9 cm).

Table 3.--*Mean peak snowpack (WE)*[1] *and seasonal*[2] *totals of precipitation and lysimeter percolate for study plots, water year 1973*

WE		Modified Belfort rain gage		Lysimeter percolate	
		Centimeters			
North forest	14.0	South forest	42.9	North forest	38.9
South forest	18.3	South clearcut	49.4	South forest	51.2
South clearcut	25.9	North forest	49.5	South clearcut	54.1
North clearcut	32.3	North clearcut	60.9	North clearcut	58.5

[1]Clearcut means based on 20 samples, forest means based on 12 samples.
[2]November 1, 1972, through May 31, 1973.

Table 4.--*Comparison of gains in clearcut based on three indexing techniques for the period November 1, 1972, through May 31, 1973*

Slope exposure	Mean peak snowpack	Modified Belfort rain gage	Lysimeter percolate
		Centimeters	
North	+18.3	+11.4	+19.6
South	+ 7.6	+ 6.5	+ 2.9

The snow courses, which provided broad spatial sampling of the plots, showed an identical order of ranking in terms of WE. Again, the north forest proved the least effective in storing snow at any time during winter. With timber removal, the WE increased by 18.3 cm on the north clearcut. The difference between south forest and south clearcut was much less, 7.6 cm, but exceeded the same comparative difference between lysimeters.

Precipitation totals collected in rain gages deviated from the above pattern; both south slope gages caught less precipitation than gages on either the north forest or north clearcut (table 3). The south slope catch became suspect early. In a previous report, Haupt (1972a) ascribed the lower catch to aerodynamic (shear) stresses associated with rain gages on windswept, exposed (south) slopes. A more subdued effect of wind on gage catch was noted on sheltered (north) slopes.

The relatively large difference (10.4 cm) between the north forest rain gage and north forest lysimeter was not expected, however, because both instruments had been placed under very similar tree canopies. This relationship held for previous years of record (1969-72) although the differences were not as great (unpublished data on file, Forestry Sciences Laboratory, Moscow). Perhaps the canopies above the rain gage became more porous during snow loading, allowing greater through-fall, and/or that the surface of the snow column forming in the lysimeter was subjected to some minor wind scouring and evaposublimation, resulting in some loss in total percolate. In view of the lower readings for snow courses in the north forest, the conclusion was that the lysimeter total was probably more representative of conditions under the timber stand than precipitation.

The anomalous reading given by the south forest rain gage notwithstanding, it is significant that less snow storage and lysimeter percolate occurred in the dense north forest than in the less dense south forest. There is no evidence to show that precipitation incident to the south slope was substantially greater than that which fell on the north slope. Rather, the disparity is attributed to greater tree interception in the north forest and to subsequent evaposublimation exchange between the canopies and atmosphere.

The physical processes involved are complex and detailed examination is beyond the scope of this paper. Several conditions probably contributed to greater interception losses in the north forest. First, and perhaps most important, the north forest, which had greater crown closure and thicker canopies, was capable of catching and holding considerably more snow (or rain) during a storm. Second, the north forest was afforded topographic shelter from prevailing winds and, as a consequence, less snow (or rain) was scoured or shaken from the canopies by this force. Third, less solar energy was received after storms in the north forest; so less canopy-held snow was transformed into drip and more remained intact in the canopies (Haupt 1972b). Fourth, the three conditions above provided more surface area and exposure hours for canopy-held snow to be acted upon between storms by evaposublimation processes. Finally, the north slope timber, in particular the south-facing portion of the upper tree crown, received adequate amounts of radiant energy at periods that were optimum for evaposublimation (not measured). During the dry winter-spring of 1973, optimum periods were numerous because of the low storm frequency. Over the 7-month period, total loss back to the atmosphere was estimated to be high.

The lower snow storage efficiency of the south clearcut, compared to that of the north clearcut, appeared to be closely associated with its position near the ridgetop and exposure to wind and energy sources. For instance, mean wind travel (1969-73) at ground level was twice that in the north clearcut (table 5). Prevailing winds scoured snow in the opening, carried some of it over the ridge, and deposited it in a cornice to the lee of the ridgetop. In years prior to 1973, the cornice had accumulated significantly more WE by mid-March than would have occurred if the opening had not

Table 5.--*Four-year mean*[1] *seasonal wind travel at ground level in clearcut and forest, by aspect*

Wind travel	Clearcut	Forest
	Meters minute^{-1}	
North	51	25
South	103	47

[1]November 1 through May 31, water years 1970-73.

existed on the south slope (Haupt 1973). This accumulation implies that some "losses" from the south clearcut may have reappeared as "gains" in the cornice. Because the north clearcut measuring sites were located well downslope and slightly upwind (fig. 1), it is unlikely that any of the eroded snow from the south clearcut was moved beyond the cornice and redeposited there.

The increased wind movement in the south clearcut also suggests the possibility of accelerated evaporation losses from the snowpack. By assuming exposure conditions similar to those reported by West (1959) for windy locations near ridges, the expected evaporation losses (not measured) could have been a few centimeters greater in the south clearcut than in the north clearcut and south forest.

Potential water yield.--Increases in potential water yield could not be estimated without first determining ET loss from the soil profile during the complete growth period, spring through fall. The approach followed was an adaptation of the water-budget technique, in which losses to the atmosphere and to drainage were considered simultaneously. This is at best a tenuous approach associated with assumptions that may not be correct.

The ET withdrawal from April 1 (arbitrarily set as the earliest date for any substantial ET) to June 4 was obtained by comparing actual soil water loss during a week of high evaporative demand in mid-May with potential evapotranspiration (PET) calculated from on-site radiation and other meteorological data. This soil water/PET relationship was then used to estimate ET for the early, snow-free spring period. These values may have overestimated ET loss during the period when deciduous, understory plants were leafing out. The estimated losses appear reasonable, ranging from 3.6 to 6.8 cm (table 6). Greater loss would be expected on south slopes, which receive more solar radiation and wind.

The assumption that drainage from the 137-cm zone was essentially zero by June 4 and that ET became the major component in water loss after this date was applied for the summer period. Little or no rain fell until August 27; so the values in tables 2 and 6 are good estimates of ET for this period.

From August 27 to October 31, precipitation and the rate of recharge became significant parameters in evaluating ET loss. The date that soil water content reached the June 4 value was used as the cutoff point for shifting water loss from ET to potential water yield. An estimate of water loss was then based on rates of water loss shown in figure 2, since these values account for net precipitation. By October 31, any additional water needed to recharge the profile constituted a deficit. By these calculations, the four vegetated plots and the south-slope bare plot had soil water deficits on October 31, whereas the north-slope bare plot produced drainage prior to that date (table 6). Deficits or gains were added algebraically to the seasonal (1972-73) lysimeter outflow in order to close the bookkeeping procedure.

Table 6.--*Determination of potential water yield for the period of November 1972 through October 1973*

Land type	Lysimeter percolate Nov. 1 - June 4	Estimated evapo-transpiration Apr. 1 - June 4	Accumulated soil water deficit on last day of period		Potential water yield Aug. 27 - Oct. 31	Potential water yield (annual)	Potential gains due to treatment
			June 4 - Aug. 27	Aug. 27 - Oct. 31			
	Centimeters						
			NORTH SLOPE				
Forested	38.9	4.6	13.5	8.4	0.0	25.9	0.0
Bare	58.5	3.6	4.2	.0	6.1	61.0	+35.1
Revegetated	58.5	4.7	10.4	.7	.0	53.1	+27.2
			SOUTH SLOPE				
Forested	51.2	6.8	15.4	6.0	.0	38.4	0.0
Bare	54.1	4.2	7.7	.2	.0	49.7	+11.3
Revegetated	54.1	6.5	18.4	4.8	.0	42.8	+ 4.4

The dense north forest had a potential water yield of 25.9 cm, or 12.5 cm less than the more open south forest (table 6). On the other hand, the last column in table 6 indicates that the greatest gain (35.1 cm) and the most sustained gain (27.2 cm) occurred on the north slope as a result of clearcutting. More modest gains, 11.3 cm and 4.4 cm, respectively, were registered on bare and revegetated plots on the south slope.

Would potential water yields have been comparable in earlier years prior to the soil water study? Evapotranspiration losses vary from year to year, being largely dependent upon energy input in spring and fall and upon rain in summer. The soil profile probably would not hold more than a fixed amount of water. Consequently, the supply available for plant use would be limited until water was added. Since the year (1973) was extremely dry during late June, July, and August and precipitation was above average during September and October, ET estimates are no doubt conservative. In wetter summers, rain input would most likely be lost to the atmosphere; little or no water would be added to deep drainage, thus increasing seasonal ET.

If the above reasoning is accepted, the measurement that best correlates with potential water yield would be lysimeter percolate measured during winter release and spring snowmelt. Differences in lysimeter percolate between forest and clearcut on the north slope were consistently large in previous years of record (1969-72); consequently, gross gains in potential water yield would be expected to be consistently large (unpublished data on file, Forestry Sciences Laboratory, Moscow).

On the south slope, conditions were highly variable. In 2 previous years (1971, 1972) there were no gains in lysimeter outflow in the south clearcut; in fact, compared with the south forest, less outflow was produced. This decline was probably due to greater snow scouring and evaposublimation loss. In 1970, lysimeter outflow in the south clearcut was comparable to the 1973 outflow (unpublished data on file, Forestry Sciences Laboratory, Moscow).

SUMMARY AND CONCLUSIONS

The practice of clearcutting forested lands to improve water yield is widely accepted. The data presented in this study suggest that under certain circumstances potential water yield increase may be high; under other conditions, the increase can range from negligible to moderate. Slope orientation and wind exposure, as well as forest stand density and structure, are important considerations in defining potential water yield increase.

The north slope in this study responded to removal of a mature old stand (western hemlock-western redcedar/pachistima habitat type) by supporting greater depths of snow, higher percolation from the snowpack, and greater amounts of water draining through the soil mantle to ground water reserves. After tractor piling and slash burning, gradual reoccupation of the soil mantle by invading herbaceous species (primarily fireweed) sustained a large part of the soil water gains for at least 5 years.

Greater storage of snow was due primarily to removal of tall, mature, closed-canopied timber that before cutting suspended a large amount of winter snowfall (and rain) in the foliage. This intercepted precipitation, held high overhead, was vulnerable between storms to radiation sources and wind movement at treetop level. It seems reasonable to suggest that the net result was considerable evaposublimation loss back to the atmosphere. The residual snow left in the canopies eventually fell to the forest floor to add to the reduced snowpack.

Removal of the mature old stand (Douglas-fir/ninebark habitat type) on the south slope had a considerably smaller effect on potential water yield. In the first year after clearcutting, the yield increase was only 32 percent of that measured on the north slope. The invading shrub species (primarily ninebark) rapidly reoccupied the soil mantle. After 4 years of recovery, the shrub monoculture extracted probably more water from the soil during the extremely dry summer than did the original tree overstory-shrub understory. Had there not been greater snow storage during the dormant season to compensate for water removal, a small increase in potential water yield would not have resulted.

Clearcutting on the south slope created less favorable conditions for storing additional snow and producing an excess of percolate into the soil mantle. Because of more open spacing of mature trees, snowfall easily penetrated to the ground surface. Furthermore, the prevailing winds and high incident solar radiation caused more of the intercepted snow to either blow off and descend to the forest floor or melt in place and fall as drip. By inference, less evaposublimation occurred and therefore the potential for interception savings to accrue after timber removal was also greatly reduced. In addition, the exposed clearcut received the brunt of the wind and lost snow by scouring and perhaps by accelerated surface evaposublimation. At the end of melt season, the net effect was a slight excess of percolate over that which occurred in the south slope forest. In earlier years, under different weather patterns, an excess of percolate might have been nonexistent.

These results apply only to one unreplicated set of three study plots in each of two climax habitat types and under the sequence of climatic events recorded. If the specific data on potential water yield increase are extrapolated to other old-growth timber sites with similar terrain and habitat type, it should be done with the above limitations in mind. However, the principles underlying the occurrence of these data can be readily applied elsewhere.

PUBLICATIONS CITED

Anderson, H. W.
1956. Forest-cover effects on snowpack accumulation and melt, Central Sierra Snow Laboratory. Am. Geophys. Union Trans. 37:307-312.

Anderson, H. W.
1963. Managing California's snow zone lands for water. USDA For. Serv. Res. Pap. PSW-6, 28 p. Pac. Southwest For. and Range Exp. Stn., Berkeley, Calif.

Baver, L. D., W. H. Gardner, and W. R. Gardner.
1972. Soil physics. 489 p. John Wiley and Sons, New York.

Bethlahmy, N.
1973. Water yield, annual peaks and exposure in mountainous terrain. J. Hydrol. 20:155-169.

Cline, R. G.
1974. Seasonal, diurnal, and spatial water use and water relations of selected forest species. Ph.D. Thesis, Wash. State Univ., Pullman, 59 p.

Cline, R. G., and G. S. Campbell.
1976. Seasonal and diurnal water relations of selected forest species. Ecology 57:367-373.

Cline, R. G., and B. L. Jeffers.
1975. Installation of neutron probe access tubes in stony and bouldery forest soils. Soil Sci. 120:71-72.

Daubenmire, R., and J. B. Daubenmire.
1968. Forest vegetation of eastern Washington and northern Idaho. Wash. Agric. Exp. Stn. Tech. Bull. 60, 104 p. Pullman, Wash.

Dietrich, T. L., and J. R. Meiman.
1974. Hydrologic effects of patch cutting of lodgepole pine. Colo. State Univ. Hydrol. Pap. 66, 31 p.

Gary, H. L.
1974. Snow accumulation and snowmelt as influenced by a small clearing in a lodgepole pine forest. Water Resour. Res. 10:348-353.

Gates, D. M.
1968. Transpiration and leaf temperature. Am. Rev. Plant Physiol. 24:515-570.

Haupt, H. F.
1969. A simple snowmelt lysimeter. Water Resour. Res. 5:714-718.

Haupt, H. F.
1972a. Improved instrumentation for measuring melted precipitation on windswept topography. Proc. Int. Symp. on Distribution of Precipitation in Mountainous Areas, p. 73-85. WMO, Geilo, Norway

Haupt, H. F.
1972b. The release of water from forest snowpacks during winter. USDA For. Serv. Res. Pap. INT-114, 17 p. Intermt. For. and Range Exp. Stn., Ogden, Utah.

Haupt, H. F.
1973. Relation of wind exposure and forest cutting to changes in snow accumulation. Proc. Banff Symp. on the Role of Snow and Ice in Hydrology. UNESCO, Paris, 10 p.
Hoover, M. D., and C. F. Leaf.
1967. Process and significance of interception in Colorado subalpine forest. *In* Forest hydrology, p. 213-223. W. E. Sopper, and H. W. Lull, ed. Pergamon Press, New York.
Hoover, M. D.
1969. Water yield improvement for the timber snow zone of the central Rocky Mountain area. *In* Proc. Workshop on Snow and Ice Hydrology, p. 111-116. Colo. State Univ., Fort Collins.
Packer, P. E.
1962. Elevation, aspect, and cover effects on maximum snowpack water content in a western white pine forest. For. Sci. 8:225-235.
Satterlund, D. R., and H. F. Haupt.
1972. Vegetation management to control snow accumulation and melt in the northern Rocky Mountains. *In* Proc. Natl. Symp. on Watersheds in Transition, p. 200-205. Colo. State Univ., Fort Collins.
Smith, J. L.
1974. Hydrology of warm snowpacks and their effects upon water delivery...some new concepts. *In* Advanced concepts and techniques in the study of snow and ice resource, p. 76-89. Natl. Acad. Sci., Washington, D.C.
Tew, R. K.
1967. Soil moisture depletion by aspen in central Utah. USDA For. Serv. Res. Note INT-73, 8 p. Intermt. For. and Range Exp. Stn., Ogden, Utah.
West, A. J.
1959. Snow evaporation and condensation. Twenty-seventh Annu. West. Snow Conf. Proc., p. 66-74.
Wright, J. L., and M. E. Jensen.
1972. Peak water requirements of crops in southern Idaho. J. Irrig. Drainage Div., Proc. Am. Soc. Civ. Eng. 98:195-201.
Zeimer, R. R.
1964. Summer evapotranspiration trends as related to time after logging of forests in Sierra Nevada. J. Geophys. Res. 69:615-620.

☆U.S. GOVERNMENT PRINTING OFFICE: 1977-0-777-023-6

Cline, Richard G., Harold F. Haupt, and Gaylon S. Campbell
1977. Potential water yield response following clearcut harvesting on north and south slopes in northern Idaho. USDA For. Serv. Res. Pap. INT-191, 16 p. Intermt. For. & Range Exp. Stn., Ogden, Utah 84401.

The hydrologic response of small clearcuts on north and south slopes in northern Idaho was investigated. On the north slope, substantial gains (27 to 35 cm) in potential water yield per year resulted from (a) removal of transpiring surfaces associated with plant cover, (b) elimination of snow interception by a closed-canopied forest, and (c) delayed reoccupation of the soil mantle by invading herbaceous species. On the south slope, small to moderate gains (4 to 11 cm) in yield resulted from clearcutting, at least in 1973, the year studied.

KEYWORDS: soil moisture content; clearcutting; snowmelt infiltration; canopy interception; logging hydrology

Cline, Richard G., Harold F. Haupt, and Gaylon S. Campbell
1977. Potential water yield response following clearcut harvesting on north and south slopes in northern Idaho. USDA For. Serv. Res. Pap. INT-191, 16 p. Intermt. For. & Range Exp. Stn., Ogden, Utah 84401.

The hydrologic response of small clearcuts on north and south slopes in northern Idaho was investigated. On the north slope, substantial gains (27 to 35 cm) in potential water yield per year resulted from (a) removal of transpiring surfaces associated with plant cover, (b) elimination of snow interception by a closed-canopied forest, and (c) delayed reoccupation of the soil mantle by invading herbaceous species. On the south slope, small to moderate gains (4 to 11 cm) in yield resulted from clearcutting, at least in 1973, the year studied.

KEYWORDS: soil moisture content; clearcutting; snowmelt infiltration; canopy interception; logging hydrology

NATIONAL FOREST SYSTEM
COOPERATIVE FORESTRY
FORESTRY RESEARCH
FOREST SERVICE
U S
DEPARTMENT OF AGRICULTURE