LOGGING EFFECTS ON SNOW, SOIL MOISTURE, AND WATER LOSSES

by

Henry W. Anderson and Clark H. Gleason 1/

INTRODUCTION

Does yield of water from the snow zone vary when forests are logged in different ways? How much difference does it make if the timber is harvested by conventional commercial diameter-limit cutting, by strip cutting, or by group selection? Forest land managers need to know what effects on water yield these methods of logging will have so that they can be compared with methods of logging being designed to maximize water yield, delay melt, and maintain water quality (Anderson, 1958). This paper discusses some pertinent first-year results of studies designed to answer these questions.

We are studying snow accumulation, snowmelt, and soil moisture losses under a wide variety of types of logging to obtain early clues to what differences each make in water yield. The studies are part of the California Cooperative Snow Management Research Program, conducted by the Forest Service, Pacific Southwest Forest and Range Experiment Station, with the cooperation of the State of California, Department of Water Resources. The research has as its objective the development and testing of ways of managing land in the snow zone of California to improve water yield. The snow zone and the study areas now in operation are shown in Figure 1.

This report gives first results of studies in two areas. We are studying the effects of strip and block cutting at the Swain Mountain Experimental Forest in the headwaters of the Feather River, and the effects of a commercial selection logging on the Onion Creek Experimental Forest in the headwaters of the American River.

SWAIN MOUNTAIN STUDIES

The Swain Mountain study area is located about eleven miles north of Westwood, California, in the true fir forest type. The area is on a gently sloping volcanic cone. The study sites are located on 10 to 15 percent slopes, of generally northeast exposure (Figure 2). The soils range from 3 to more than 7 feet deep, and are developed from a vesicular basalt parent rock.

There are 3 study sites. Area "A" is an 18.7-acre strip cutting approximately 330 feet wide by 2,500 feet long, together with surrounding uncut forest. Area "C" is a 17.1-acre block cutting approximately 800 feet wide by 1,800 feet long, together with surrounding uncut forest. Area "D" is a small uncut block of about 4 acres contiguous to Area "C". The cut strip was 5 chains (330 feet) wide, but at one place it touched a natural opening of 5 chains. Thus the middle snow course (A2) crossing this opening sampled a strip, in effect, 10 chains wide after the cutting, while courses A1 and A3 sampled the cut strip at its 5-chain width. The study areas were logged in the summer of 1958. Slash from the tree-tops and limbs was disposed of in 3 ways: piled and burned, lopped to 18-inch height, and left as it fell.

There are several densities of forest at the study sites. Area "A" is extremely dense old growth red and white fir, averaging about 85,000 board feet per acre. Area "C" is covered by mixed age groups of fir and ponderosa pine, with about 45,000 board feet per acre. Area "D" is a stand of red fir and some lodgepole pine, aggregating some 40,000 board feet per acre. The prevailing storm wind, as indicated by blown-down trees, is southwest.

Starting in 1956 a snow course was set up to serve as a control in the studies. Measurement of snow in natural openings and in forest stands before logging started early in 1957 on about 120 sampling points. In the summer of 1958, Area "A" was clear-cut. The same summer Area "C" was block-cut; here a few poles were left standing singly and in small groups. Snow measurements were continued in the cut areas and in the adjacent forest. Soil moisture sampling was started early in the summer of 1958 and continued into early winter.

1/ Respectively, Snow Research Leader and Forester, Snow Hydrology Studies, Division of Watershed Management Research, Pacific Southwest Forest and Range Experiment Station, Forest Service, U. S. Department of Agriculture, Berkeley, California.

Reprinted from 1959 Proceedings, WESTERN SNOW CONFERENCE.

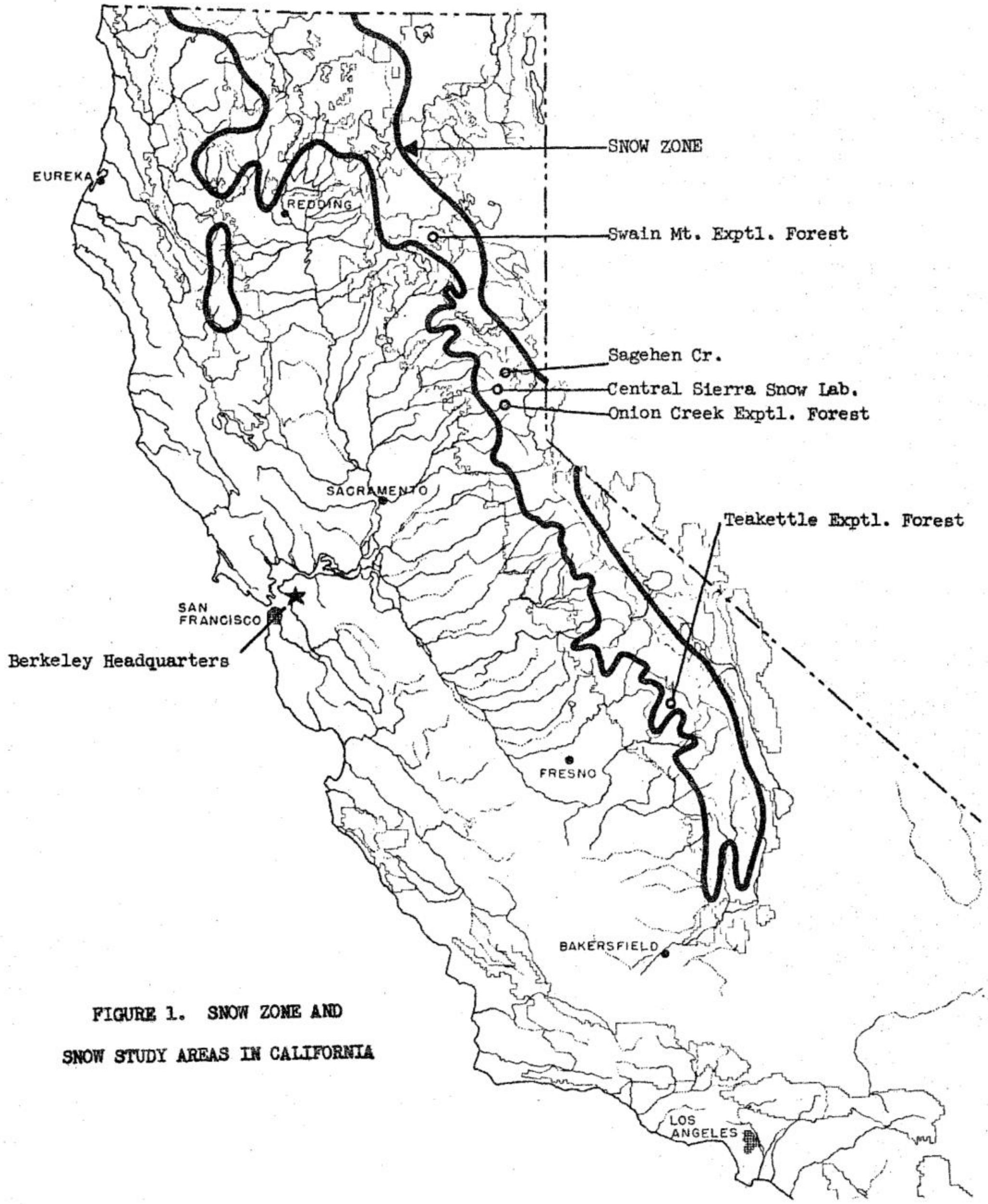


FIGURE 1. SNOW ZONE AND
SNOW STUDY AREAS IN CALIFORNIA

Figure 2
SNOW HYDROLOGY AREAS AND SNOW COURSES

Swain Mountain Experimental Forest

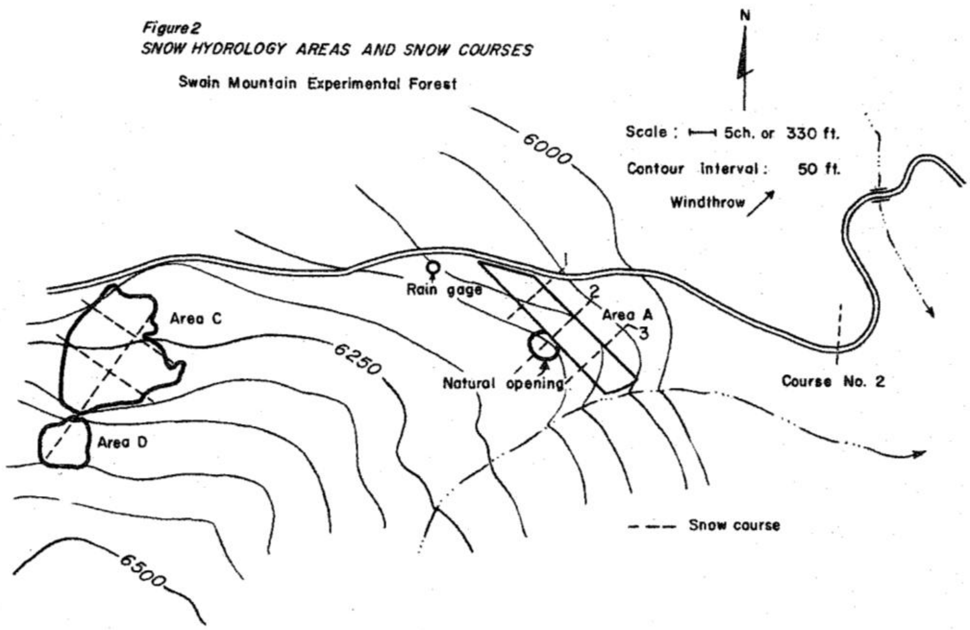
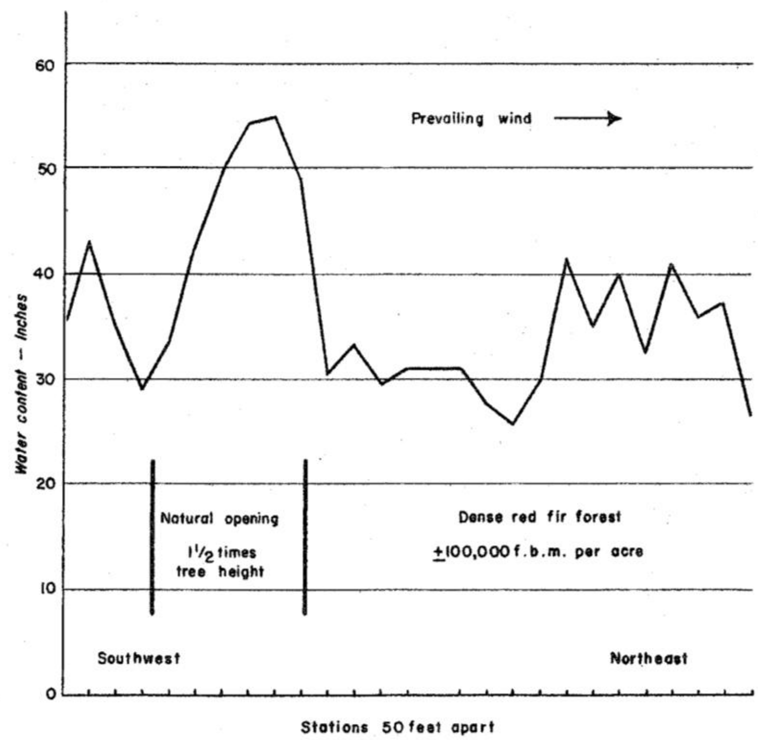


Figure 3
SNOW WATER CONTENT

Swain Mountain Experimental Forest

April 9, 1958



ONION CREEK STUDIES

The other study area, Onion Creek Experimental Forest, is located 6 miles south of Soda Spring, California, at an average elevation of 6,500 feet. The forest stands are mixed conifer—white and red fir, Jeffrey pine, and some sugar pine and incense cedar. Soils range from 2 to 6 feet deep and were developed from andesite parent rock. The soils belong to or are closely related to the Lytton soil series described by Nelson (1957). The study sites are on a 5 to 10 percent south-facing slope. The area was logged in the summer of 1957. Logging was a commercial diameter-limit cutting in which all trees over 18 inches in diameter were removed. The cut amounted to 35,000 board feet per acre, leaving scattered small trees amounting to 2,000 board feet per acre. The unlogged control area was selected nearby to be as similar as possible to the logged area. A 1/2-acre grid of 25 snow and soil-moisture sampling points was set up in each. Snow and soil-moisture samples have been taken regularly in the control and cut areas since the logging.

METHODS

Standard snow depth and water equivalent measurements were made at monthly intervals starting at the first snow accumulation and ending with the last residual snow. Soil moisture measurements were made to determine (1) summer losses from stored soil moisture and (2) interception of precipitation and evaporation following such precipitation in the fall before the snowpack started to accumulate. Precipitation was measured by Fergusson weighing-type gages in accessible locations and Sacramento storage-type gages at remote locations. Snow measurements were taken with the Mt. Rose snow tube and scale; soil- moisture measurements were taken with the new nuclear soil-moisture probe.

RESULTS

Results in 1958 and 1959 have been analyzed with respect to snow accumulation, snowmelt, and soil moisture content under natural forest conditions and after logging.

SNOW IN NATURAL OPENINGS AND STANDS

In 1958, snow accumulation and melt were measured in natural openings and in forest stands of different density at the Swain Mountain Experimental Forest. Snow accumulation was greatest in the forest openings and least in the dense stands of fir (Table 1). Open stands of fir and mixtures of old- and young-growth fir had nearly as much snow as the openings—only 1 to 2 inches less water content. Rate of spring melt was highest in the larger openings, intermediate for the open and mixed-age fir, and least in the small openings and dense forest. As a result, the maximum snow left in early June was in small openings, which had about 10 inches more water than the snow in the dense fir stands or the larger openings, and 4 to 7 inches more than in the old open fir and the young and old mixture. These results confirm again the findings that small openings store more snow at maximum accumulation (Church, 1912; Anderson, 1956; Anderson, Rice, West, 1958 a, b). The results also confirm the advantage of small openings over moderately large openings in delaying snowmelt (Anderson, 1956).

There is evidence that differences in the snow in openings and forests are related to a complexity of factors such as back eddies from southwest winds, shade by trees, solar energy that penetrates the foliage, and radiation from the trees. In Figure 3 we have plotted the snow water content across 150 feet of the forest, across 300 feet of a natural forest opening, and then 800 feet into the adjacent forest. Snow immediately to the leeward of the opening is less than the snow to the windward of the opening, and less also than the snow further to leeward in the forest. The data suggest that about half of the 13-inch greater water content in the opening was in effect "stolen" from the forest to the leeward; the other half represents differences in interception and winter melt. Similar deficits in snow in the forest to the leeward of openings and excess in the windward forest margin have recently been reported (Anderson, Rice, West, 1958 b); the maximum differences occurred on south slopes which were directly exposed to prevailing south and southwest winds. We conclude that forest openings and the adjacent forest must be taken as a whole in comparing the effects on snow of cut forests with uncut forests.

Table 1.—Snow water in forests and openings, Swain Mountain Experimental Forest, 1958

FOREST CONDITIONS	DATE		
	April 10	June 5	Melt
	- - - - - inches water - - - - -		
Old Dense Fir (100,000 fbm/A.)	34.6	3.8	30.8
Old Open Fir (50,000 fbm/A.)	45.0	8.3	36.7
Young-Old Fir (12,000 fbm/A.)	46.0	11.2	34.8
Opening (1-1/2 tree heights)	47.4	3.9	43.5
Small Openings (1/2 tree height)	47.4	14.9	32.5

LOGGING EFFECTS ON SNOW

Strip Cutting

Strip cutting effects on snow accumulation for strips 5 and 10 chains wide (2 and 4 tree heights across) are shown in Figure 4. The cutting removed all of the timber—about 85,000 board feet per acre. The cut strip ran northwest-southeast, at right angles to the prevailing southwest winds. At maximum snow accumulation, we see that snow piled up in the cut strip. On the strip 5 chains wide there was 7 inches more snow water than in the forest to windward, and about 10 inches more than in the forest margin to leeward. On the strip 10 chains wide, there was also 7 inches more water than in the forest to windward, and about 9 inches more than to leeward.

Effect of Slash Disposal

Along Course A1 (Figure 4) the slash was piled and burned. On Course A3 the slash was lopped. Course A2 extended from the forest into a natural opening occupied by low rabbit brush, then entered the cut strip where the slash was left as it fell.

We measured 3.8 inches more snow water in the strip where all the logging debris was piled and burned than in the area where the limbs and tops were merely lopped. Comparing points with equal tree cover north and south of the point under the three conditions of slash disposal, unmelted snow water on May 4, 1959 was zero for the lopped area, 1.1 inches for the unlopped, and 4.2 inches for the area cleared and burned. For reasons that are not clear, the maximum snow water of 8.4 inches on May 4 was found in the opening with low rabbit-brush. Because of the wide variability in snow from point to point, these differences were not statistically significant; however, they are of sufficient interest to encourage further study.

Block Cutting

Block cutting had less effect than strip cutting on maximum snowpack at Swain Mountain; there were 5.1 inches more water in the 17-acre cut block than in the uncut forest. This block cutting removed about 45,000 board feet per acre.

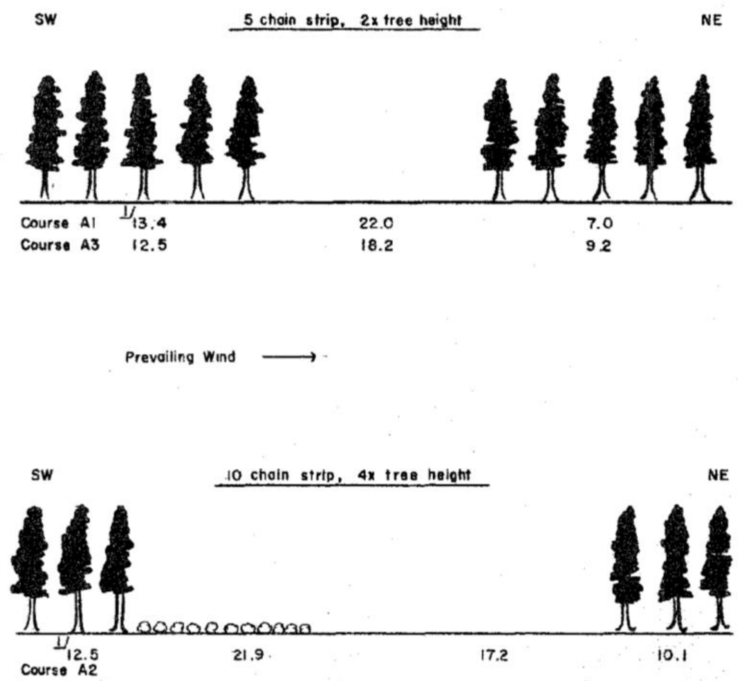
Commercial Diameter-Limit Cutting

Commercial selection-cutting on the Onion Creek area in 1957 removed 35,000 board feet per acre from a pre-logging stand of 37,000 board feet. This cutting increased snow water at the time of maximum accumulation by 7.1 inches in 1958 (Table 2). The corresponding increase in 1959, with about one-half the precipitation, was 6.3 inches. Snowmelt in the cut area was faster, so there was slightly more snow, 0.6 inches, left in June 1959 in the uncut than in the cut. The differences at the last spring snow measurement in 1959 was nearly identical, 0.9 inches more water in the uncut forest.

Figure 4
EFFECT OF STRIP CUTTING ON SNOW ACCUMLATION

Swain Mountain Experimental Forest

April 2, 1959



1/ Figures show snow water content in inches.

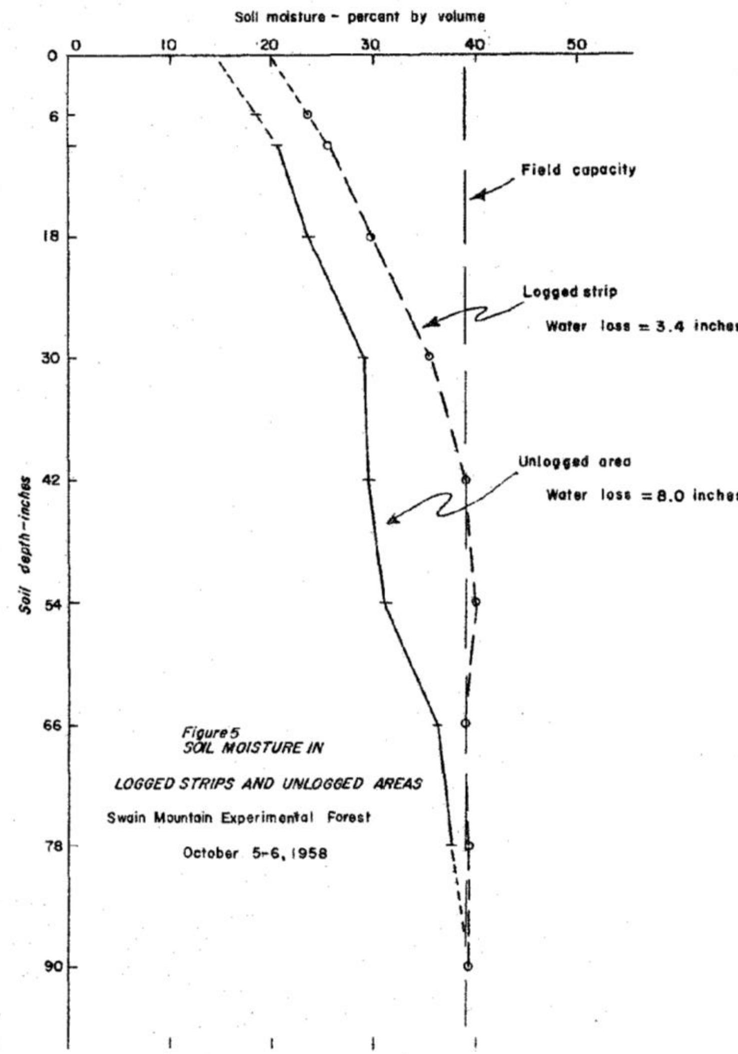


Figure 5
SOIL MOISTURE IN

LOGGED STRIPS AND UNLOGGED AREAS

Swain Mountain Experimental Forest

October 5-6, 1958

Table 2.—Logging effects on snow accumulation and melt, Onion Creek Experimental Forest, 1958 and 1959

Year and treatment	Jan. 17	Feb. 28	Apr. 25	May 6	May 27	June 20
			Water equivalent - Inches			
1958						
Forest Uncut	10.0	27.5	51.2	43.5	24.6	1.7
Forest Cut	13.0	33.1	58.3	48.4	23.2	1.1
Difference	+ 3.0	+ 5.6	+ 7.1	+ 4.9	- 1.4	-0.6

	Mar. 9	Apr. 6	May 7
		Water equivalent - Inches	
1959			
Forest Uncut	20.1	15.5	7.7
Forest Cut	26.4	21.5	6.8
Difference	+ 6.3	+ 6.0	-0.9

SOIL MOISTURE LOSSES

Soil moisture was measured to answer two questions: How much soil-moisture loss occurs under logged and unlogged condition during the summer months? And how much water is lost during the fall months because of differences in interception and evaporation under these two conditions?

Soil-moisture losses were taken as the difference in stored moisture at the end of snowmelt in the spring and at the beginning of the winter storms. Summer and fall precipitation were added to these losses. The 1958 summer was slightly cooler than normal; the fall longer than normal, extending into early December.

Strip cutting saved 3.2 inches of water in summer soil-moisture losses from the average soil depth of 48 inches (Table 3). For the deepest soils, 90 inches deep, the summer losses were 8.0 inches in the unlogged area and 3.4 inches in the logged strip (Figure 5), a difference for the strip cutting of 4.6 inches of water saved by the logging. Fall soil moisture deficit was, of course, correspondingly less in the logged area.

Table 3.—Summer soil-moisture losses, soil 48 inches deep, 1958

	Logged	Unlogged	Difference
	- - - - - - - - -	inches	- - - - - - - - -
SWAIN MOUNTAIN			
Strip-Cut	3.4	6.6	3.2
Block-Cut	4.6	7.3	2.7
ONION CREEK			
Commercial Selection	7.5	8.4	0.9

Block-cutting reduced loss of water by 2.7 inches for a 48-inch-deep soil (Table 3).

The commercial cut had little effect on soil moisture losses during the first two summers after logging. A saving of only 0.9 inches was measured in 1958 (Table 3), and a similar difference was indicated for 1957 when gravimetric soil sampling was used.

WATER YIELD

These data on snow accumulation, snowmelt, and soil-moisture losses can be used in making some first estimates of expected differences in water yield resulting from logging. In making these estimates, we supplement the data with snow evaporation data from Kittredge (1953) and West and Knoerr (1959), and with snow interception measurements of Rowe and Hendrix (1950) and West and Knoerr (1959).

Water yield under logged and unlogged conditions at Swain Mountain and Onion Creek for the year starting April 15, 1958 are compared in Table 4. They were obtained from the usual water balance equation: yield is equal to precipitation minus interception and evapotranspiration. Summer and fall precipitation in storms too small to cause percolation are counted as losses. Yearly precipitation at the three sites was almost the same, 46 to 47 inches, so differences in water losses attributable to the logging methods can be compared. We see that water yield increased with each of the logging methods, the increases ranging from 3 to almost 9 inches. The strip cut was the most effective in saving water; the block cutting next, and the commercial cut least.

Table 4.--Logging effects on water balance, Swain Mountain and Onion Creek Experimental Forest, April 15, 1958 - April 14, 1959[1]

ITEM	FOREST CONDITION					
	Strip Cut		Block Cut		Commercial Cut	
	Logged	Unlogged	Logged	Unlogged	Logged	Unlogged
FOREST COVER - PERCENT						
Hemispherical cover (Hc)	42	87	49	79	63	82
WATER BUDGET - INCHES						
Total precipitation	46.15				47.08	
Winter and spring						
Precipitation	38.1	38.1	38.1	38.1	41.1	41.1
Interception losses[2]	0.4	3.8	0.9	3.2	2.1	3.7
Evapotranspiration[3]	0.9	2.9	1.2	2.5	1.8	2.7
Summer						
Precipitation	6.9	6.9	6.9	6.9	4.7	4.7
Soil moisture losses[4]	3.4	6.6	4.6	7.3	6.5	7.4
Fall						
Precipitation	1.2	1.2	1.2	1.2	1.3	1.3
Total losses	12.8	21.4	14.8	21.1	16.4	19.8
Water yield	25.3	16.7	23.3	17.0	24.7	21.3
Difference	8.6		6.3		3.4	

1/ Seasonal delineation: Winter and spring = Apr. 15-30, 1958; May 1-31, 1958; Nov. 1, 1958 - Apr. 14, 1959. Summer = June 1 - Aug. 31, 1958. Fall = Sept. 1 - Oct. 31, 1958. Differences in snowpack on April 15, 1958 and April 14, 1959 not included in yield--add 25 inches for Swain Mt. and 32 inches for Onion Creek.

2/ Winter and spring estimated from: Interception loss = 0.2 x Precipitation x $[(Hc - 37)/100]$.

3/ Estimated from Evaporation (E) plus Transpiration (T), where $E = 1.5(1-Hc/100)$ and positive values only of $T = 6[(Hc-42)/100]$.

4/ For soil 48 inches deep.

About half of the differences between the commercial cut water saving and the strip and block cut savings are in soil moisture losses. The increases in soil moisture carried over will result in greater water yields with the first winter melt, or sometimes with late fall floods. Thus, if we cut timber to get more water, we may get some of the water when we don't want it.

Can other logging methods, ones designed specifically to give greater water yield or delay yield longer, improve on these results? Other studies are under way to develop and test "better" methods.

CONCLUSIONS

First year results show that all three methods of logging--strip-cutting, block-cutting, and commercial selection-cutting--increased maximum snow accumulation and decreased annual water losses.

At maximum snowpack there was 10 inches more water in 5- and 10-chain wide cut strips than in the adjacent uncut forest; the block cut and commercial diameter-limit cut areas had 5 to 7 inches more than the uncut forest.

Snowmelt rate in spring was greater in the commercial cutting area than in the uncut. Small amounts of snow remained longer in the uncut forest.

Summer soil moisture losses in soils 48 inches deep were decreased by logging: 3.2 inches by the strip cutting, 2.7 inches by the block cutting, and 0.9 inches by the commercial cutting.

Annual yield of water from precipitation of 46 to 47 inches was estimated to be increased by 8.6 inches in strip cut areas, by 6.3 inches in block cut areas, and by 3.4 inches under commercial cutting.

ACKNOWLEDGMENTS

The help of Donald T. Gordon, David C. Maul, and Oscar E. Stark in designing and conducting the treatments and in collecting the snow measurements at Swain Mountain, and of Leonidas Liacos in analyzing the soil moisture data is gratefully acknowledged.

LITERATURE CITED

ANDERSON, HENRY W. 1956. Forest-cover effects on snowpack accumulation and melt, Central Sierra Snow Laboratory. Trans. Amer. Geophys. Union 37(3):307-312.

1958. Progress in snow management research in California. 26th Ann. Proc. Western Snow Conference, pp. 12-21.

RICE, RAYMOND M., and WEST, ALLAN J. 1958a. Forest shade related to snow accumulation. 26th Ann. Proc., Western Snow Conference, pp. 21-31.

RICE, RAYMOND M., and WEST, ALLAN J. 1958b. Snow in forest openings and forest stands. Proc. Soc. Amer. Foresters, pp. 46-50.

CHURCH, J. E. 1912. The conservation of snow: Its dependence on forest and mountains. Sci. Amer. Sup. 74:145, 152-55.

KITTREDGE, JOSEPH. 1953. Influence of forests on snow in the ponderosa-sugar pine-fir zone of the central Sierra Nevada. Hilgardia 22:1-96.

NELSON, ROBERT E. 1957. Soil-vegetation survey of a Central Sierra Snow Zone watershed. Calif. For. and Range Expt. Sta. Misc. Paper 21, 43 pp.

ROWE, PERCY B., and HENDRIX, T. H. 1951. Interception of rain and snow by second-growth ponderosa pine. Trans. American Geophys. Union 32(6):903-908.

WEST, ALLAN J., and KNOERR, KENNETH R. 1959. Water losses in the Sierra Nevada. Jour. Amer. Water Works Assn. 51(4):481-488.