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HYDROLOGY PAPERS
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ABSTRACT

Paired plot studies of soil water and snow water equivalent were conducted from 1968 to 1973 in the lodgepole pine type on the Eastern Slope of the Colorado Front Range at an elevation of 9000 feet. Small patch cuts ranging in size from 0.29 acre to 0.61 acre were cut in the fall of 1971.

Based on analysis of pre- and post-cut relationships to the paired control plots, the average increase in water potentially available for streamflow from the cut areas was 11.8 cm. Increase in snow on a relatively small part of the cut areas accounted for 21 percent of the increase. The remainder of the increase was attributed to reduced evapotranspiration as a result of tree removal. There were no significant changes in potential water yields from the adjacent uncut forest. Although the results are site-specific and for only the first full hydrologic year after treatment, there does appear to be a very high potential for water yield increase by small patch cuts from sites similar to those studied.

CHAPTER I
INTRODUCTION

General

With more and more people inhabiting the arid and semi-arid regions of the United States, the never ending problem of meeting the water requirements of these people continues. Immense storage facilities built over the last 60 years have so far been able to adequately supply agricultural and domestic users. But, in the West there is only a limited supply of useable water. In view of this, scientists and engineers have grasped upon the idea of not only storing large amounts of water, but indeed trying to produce more useable water. Such methods have included phreatophyte eradication, cloud seeding to increase precipitation, and pattern cutting in timber to increase runoff.

This study is concerned with the hydrologic effects of cutting small patches of less than one acre in size in the lodgepole pine zone of the Eastern Slope of the Colorado Front Range. There are approximately 14.5 million acres of lodgepole pine forest in the United States and approximately 2.1 million acres in Colorado. Lodgepole pine in the Front Range comprises a large segment of the snowpack zone and thus is very important in water production. Vegetation changes in this snowpack zone, whether intentionally or inadvertently, may have a significant effect on water yields.

In addition to water yield effects, vegetation changes have other environmental consequences that are important in recreation, fish, wildlife, and wood product management considerations. The studies described here attempted to incorporate these considerations in the experimental design. Plot boundaries were irregular and the plots were kept small for esthetic reasons. Plots were cleared of slash by chipping or removal and seeded with herbaceous vegetation to promote soil stability and encourage wildlife use. The study is part of a larger land management research program carried out cooperatively with a number of Federal, State, local and private institutions to develop a better understanding of natural resources and to aid in their management.

The objective of this study is to determine the effect of small patch cuts on the water balance of a lodgepole pine stand sufficient to interpret the effect to large scale application for increasing water yields from the Eastern Slope of the Colorado Front Range.

The overall objective would include answering the following questions:

1. Is there a reduction in evapotranspiration on the cut areas of the treated plots?
2. Is there an increase in snow accumulation (water equivalent) after treatment?
    a. On the treated plot as a whole?
    b. On the cut area of the treated plot as compared to the uncut?
3. What is the net effect of the cutting on potential water yield?

Much work has been done on the effect of timber harvesting in increasing water yield in lodgepole pine. However, such a study had never been undertaken on the Eastern Slope of the Front Range of Colorado. This area has a markedly different climatic regime than those areas previously studied.

Results are presented for the period 1968-1973 in Chapter III and their implications discussed in Chapter IV.

Previous Work

The general state-of-the-art of vegetation manipulation has been thoroughly discussed in recent years by Sopper (1972), and in the numerous papers published in the Symposium on Forest Hydrology edited by Sopper and Lull (1967) including especially the paper by Hibbert.

As early as 1912 it was noted by Church (1912) that small openings between trees in the forest were found to be effective in accumulating snow. Connaughton (1935) stated that ". . . forest management from the standpoint of water yield from snow should aim at numerous small openings in the stand rather than a continuous crown cover." Although Connaughton primarily worked in the ponderosa pine forest, much work has been done by others in lodgepole pine, the particular forest type of concern in this study.

Niederhof and Dunford (1942) studied the effect of openings in a young lodgepole pine forest on the storage and melting of snow. Their results indicated quite distinctly that maximum snow accumulation occurred in stands with crown openings about 17 to 18 feet in diameter, with less quantities occurring in smaller openings. In these stands the average tree height was from 17 to 23 feet.

Wilm and Collett (1940) also studied the influence of a lodgepole pine forest on the storage and melting of a snowpack.

Studies of snow accumulation in lodgepole pine stands have also been reported by Wilm and Dunford (1948), Goodell (1952), Miner and Trappe (1957) and Jeffrey (1968). They all report greater accumulation of snow in small openings than beneath the forest stand itself.

Wilm and Dunford (1948) and Goodell (1952) concluded that cutting treatments which reduced basal area per acre resulted in increased snow accumulation. In their studies in the Colorado Front Range, Meiman, Froehlich and Dils (1968) concluded that only 32 percent of the variance in spring snowpack water equivalent was accounted for by elevation and crown cover. From year to year the relative accumulation at individual snow measuring points was highly variable.

Ffolliott, Hansen and Zander (1965), while studying snow in natural openings and adjacent ponderosa pine stands on the Beaver Creek watershed in Arizona, plotted water equivalent at points out from the edge of the canopy in terms of tree height. The resulting accumulation profiles were quite similar regardless of stand condition or tree height. Some snow was held through the winter in a "zone of retention" extending from the edge of the natural openings to a distance of 1½H to 2H where H = average height of the adjacent timber. All snow beyond 2H disappeared between successive storms.

Interception represents the loss of precipitation which would otherwise reach the soil. Kittredge (1948) stated that interception losses may be large in regions of high evaporation. Interception losses also vary with forest conditions and with species and forest type (Zinke, 1967).

Leyton(1967), working with Norway Spruce subjected to stand thinning practices, concluded that there is a reduction in interception loss due to thinning. The 10 percent reduction in interception is substantially less than the 20 percent reduction in basal area.

Goodell (1963) emphasized that conclusions previously have been based on comparing snow accumulation in forested areas and adjacent openings. He points out that differences may be caused, all or in part, by the differential deposition of snow rather than losses from intercepted snow. Goodell (1963), along with Miller (1962) and Satterlund and Eschner (1965), emphasize the need for further and more analytical studies to evaluate the role of snow interception.

Hoover and Leaf (1967), in evaluating data from the Wagon Wheel Gap study (Bates and Henry, 1928), concluded that there is no evidence that interception losses in the forest reduced the winter snowpack. From their own study on the Fool Creek watershed Hoover and Leaf expected a net increase in total snow on the Fool Creek watershed. The increased snow storage before and after treatment did not reveal any change in total snow on the watershed but there was a significant redistribution of snow from the forested areas to the openings.

Hoover and Leaf (1967) commented further on the Fool Creek watershed study and concluded that there is a redistribution of snow to the open areas where initial soil-moisture deficiencies are minimum. Cutting of the forest reduced the amount of soil water withdrawn during the growing season with the result that less water is needed to recharge the soil in the spring and thus more water is available for streamflow.

In addition, soil water studies in lodgepole pine have been reported by Wilm and Dunford (1948) and by Goodell (1952). Wilm and Dunford found that the effect of partial cutting on fall soil moisture deficits was relatively small, but was greater in wet years than in dry years.

Goodell concluded also that his thinning treatments did not affect soil moisture levels. However, both Wilm and Dunford and Goodell concluded that partial cutting in lodgepole pine in Colorado should result in increased water yield.

CHAPTER II
RESEARCH DESIGN AND METHODS

Study Area

The study area is located approximately 25 miles west of Fort Collins adjacent to Colorado State University's Pingree Park Campus. Located in the drainage of the Little South Fork of the Cache la Poudre River (Fig. 1), it lies on the northern boundary of Rocky Mountain National Park. The catchment is 105 square miles in area, ranging in elevation from 6,600 feet to approximately 13,000 feet. The area is a reasonably typical forested watershed on the Eastern Slope of the Colorado Front Range. Vegetation cover is spruce-fir (17%), ponderosa pine (10%), aspen (1%) and lodgepole pine (47%). The alpine constitutes 17 percent of the total area and range and miscellaneous types account for the remaining eight percent.

The study area is climatologically representative of the Front Range of Colorado. Approximately 50 percent of the precipitation falls during the winter months as snowfall. Listed in Table 1 is the total precipitation at Pingree Park for each month from January, 1968 to April, 1973. Generally the area in this study is representative of those mountainous areas where the mean monthly air temperatures are low (Table 2) and snowmelt runoff is the major contributor to streamflow.

The Little South Watershed is being extensively studied as a "resource complex" with studies underway or completed on wildlife, fishes, timber, geology, recreation, soils, climate, and water quality in addition to water yields. The Little South drainage is described in detail in the watershed analysis of the drainage (Johnson et al., 1962).

At the Pingree Park Campus laboratory and shop facilities are available. Weather instrumentation and stream gages are maintained cooperatively by the U. S. Geological Survey and the Department of Watershed Sciences of Colorado State University. The U. S. Forest Service has assisted in stream gage installation and study coordination.

Description of the Study Sites

Three pairs of study sites in lodgepole pine were selected at an elevation of approximately 9,000 feet msl. The plots are located near the Colorado State University Forestry Camp in the basin of the Little South Fork of the Poudre River (Fig. 2). Each pair of plots consisted of a control and treatment plot.

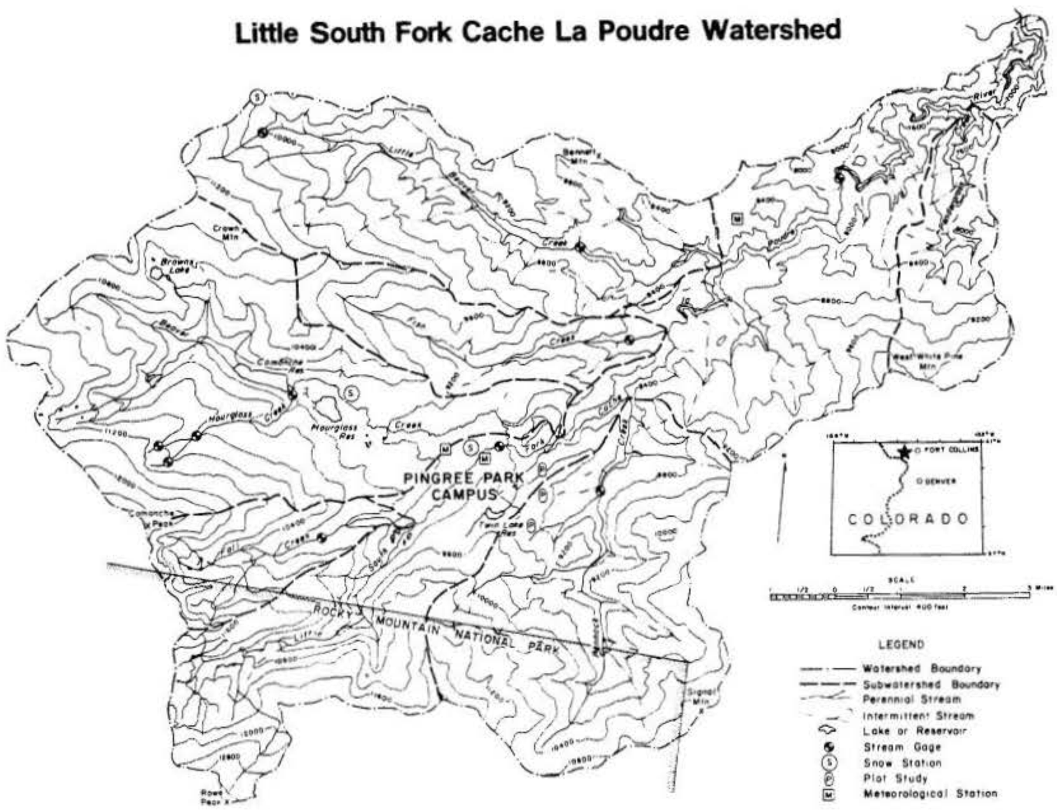

Figure 1. Little South Poudre Watershed.

Table 1. Precipitation (cm) at Pingree Park for the 5 Years of Study.

	Precipitation (cm)					
	1968	1969	1970	1971	1972	1973
Jan.	1.55	3.99	4.85	4.42	7.32	3.76
Feb.	2.77	2.34	2.90	4.27	3.45	0.89
March	3.15	4.29	9.07	3.61	4.37	4.32
April	5.08	5.36	3.40	10.13	5.99	12.07
May	6.65	15.78	1.07	5.44	3.33	
June	2.46	7.77	5.36	1.65	3.99	
July	3.73	2.08	3.33	1.75	1.68	
Aug.	4.60	3.78	5.41	4.04	6.68	
Sept.	2.84	2.64	6.17	6.20	2.36	
Oct.	1.98	14.48	5.89	2.29	4.93	
Nov.	5.11	2.06	4.62	1.63	5.00	
Dec.	1.45	3.38	1.50	2.11	3.05	
Total	41.37	67.95	53.57	47.54	52.15	

Table 2. Mean Monthly Temperature at the Pingree Park Weather Station for January, 1968 to April, 1973.

	Mean Monthly Temperature - F°					
	1968	1969	1970	1971	1972	1973
Jan.	22	24	20	28	20	20
Feb.	19	20	23	18	25	21
March	24	15	19	25	33	M
April	27	34	M	33	37	26
May	38	43	42	39	43	
June	50	45	49	52	54	
July	55	55	56	53	58	
Aug.	52	56	56	54	54	
Sept.	45	48	44	30	49	
Oct.	42	29	38	36	38	
Nov.	24	24	28	26	22	
Dec.	20	21	M	19	26	

M - Missing

After three pre-treatment years in which snow was surveyed and soil water readings were taken, the treatment plots (A2, B2, C2) were cut (Figs. 3 and 4).

During the fall of 1971 the treatment plots were cut. Listed in Table 3 are the dates each plot was cut and the size of the cut area. The cut areas on the plots were originally designed to be circular in shape with a diameter of 5H (H = avg. tree height). Because of esthetic considerations the completely circular opening was altered to be irregular in shape with the maximum dimension--approximately 5H. The opening on the A2 plot approaches most nearly the original circular design. The B2 and C2 plots were altered considerably. On the B2 plot the maximum dimension is 5H; however, the plot opening on the whole is closer to 3H. The C2 plot was cut as irregular as the B2. The maximum length from east to west on the C2 is 5H and from north to south is 6H. The plot narrows from 5H on the upper end to 1H on the lower end. In terms of area, the A2 plot is the closest to the original design. The final opening for the A2 plot is 87 percent of that called for in the original plans, the B2 61 percent and the C2 71 percent.

After cutting, the slash on the A2 and B2 plots was chipped in situ, while the slash on the C2 was burned. All three plots were seeded to a mixture of grasses as recommended by Reid (1971) and plots A2 and C2 were fertilized.

The spacing of the sampling points on the grid system was determined by the average tree height on the plot. For the control plot, which consists of 31 sampling points, the distance between sampling points

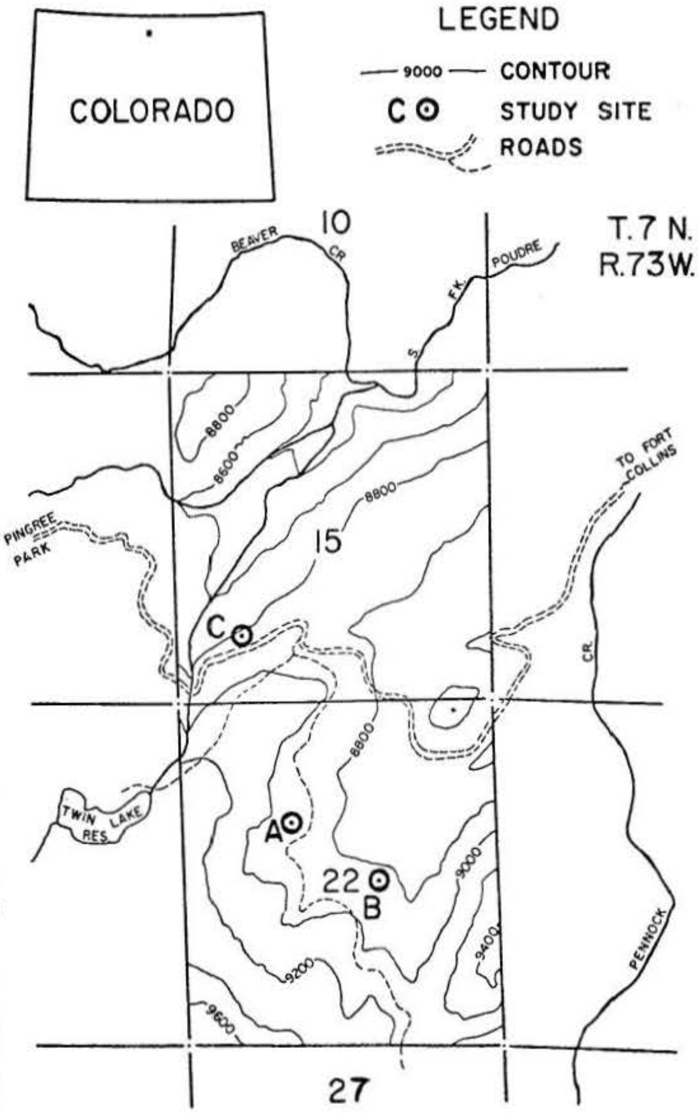

Figure 2. Plot Locations and Topography.

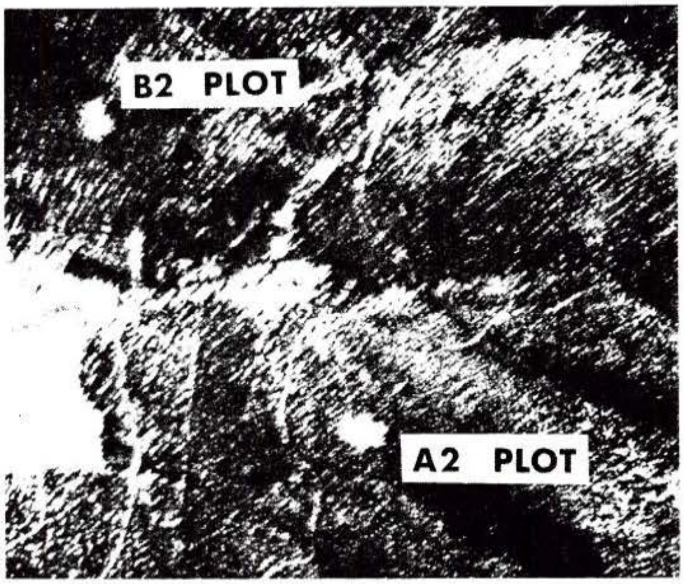

Figure 3. Aerial View of the Cut Areas on the A2 and B2 Treatment Plots.

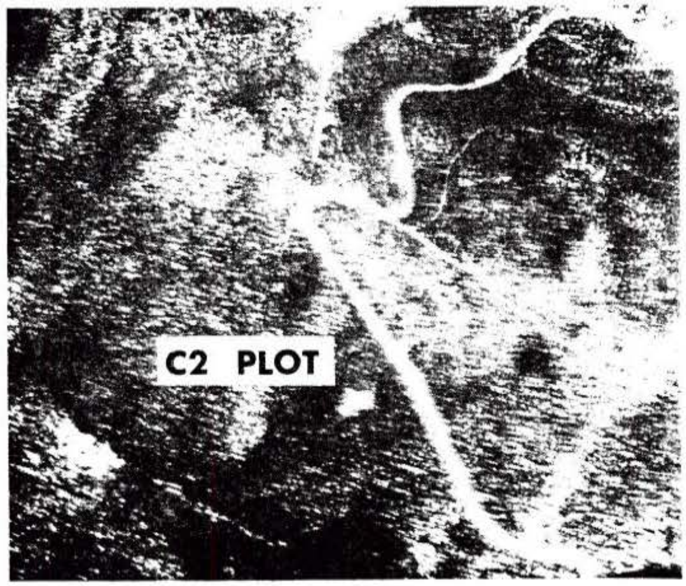

Figure 4. Aerial View of the Cut Area on the C2 Treatment Plot.

is equal to twice the average tree height. On the treatment plots (113 points) the distance between sampling points is equal to the average tree height.

The predominant forest species on each of the three sites is lodgepole pine (Pinus contorta Dougl.) with a small amount of quaking aspen (Populus tremuloides Michx.). On the plots, the major forest species are lodgepole pine and Douglas fir (Pseudotsuga menziesia) with insignificant amounts of subalpine fir (Abies lasiocarpa (Hook.) Nutt.) and limber pine (Pinus flexilis James). Each pair of plots was located as close together as possible and in areas of similar vegetative and topographical characteristics. Listed in Table 4 are the general characteristics of the three plot pairs (Burroughs, 1971).

Snow Sampling

On each of the control plots snow samples were collected at the 31 points as shown on Fig. 5.

Table 3. Date of Cutting and Area of the Patch Cuts.

Plot	Cutting Date	Area
A2	Sept. 14-Oct. 2, 1971	27,200 ft^2 (0.62 acre)
B2	Oct. 5-Oct. 16, 1971	14,700 ft^2 (0.34 acre)
C2	Sept. 9-Sept. 14, 1971	12,600 ft^2 (0.29 acre)

With the exception of the C2 treatment plot, snow samples were collected at the 113 points on the treatment plots as shown in Figs. 6 to 8 for the five years of study. On the C2 plot, however, snow readings were taken at only 31 points for the 1968-69 and the 1969-70 pre-treatment years. The grid for taking snow readings during those two years was indentical to the control plot sampling grid shown in Fig. 5. For the remaining three years, 1970-71 through 1972-73, the C2 plot was sampled at the 113 points as shown in Fig. 8.

Snow sampling was conducted after each major snow event, approximately six inches snow, and during the time of peak accumulation for the five years of study. Listed in Table 5 are the snow sampling dates for the three pairs of plots.

The snow data was entered onto punch cards for use in Colorado State University's CDC 6400 computer. Output generated for each snow measurement date included computer printouts of the snow water equivalent at the corresponding grid point for each plot. Also for each pair of plots on each measurement date the following comparisons were made and statistically compared by an unpaired t-test.

1) Treatment plot mean vs. Control plot mean
2) Cut area mean vs. Control mean
3) Uncut area mean vs. Control mean
4) Uncut area mean vs. Cut area mean

Table 4. General Characteristics of the Three Study Sites.

Site	Major Species	Mean Tree Height-m	Coefficient of Variation of Ht	Canopy Closure	Ground Slope-%	Aspect
A	Lodgepole	8.4	0.228	0.338	18.5	S86°E
B	Lodgepole	9.0	0.097	0.198	20.0	N40°E
C	Lodgepole-fir	7.2	0.253	0.229	30.0	N33°W

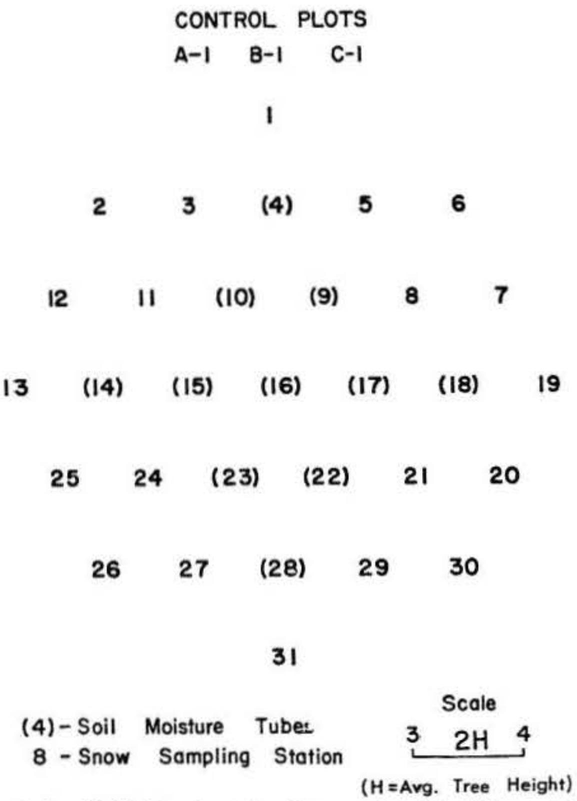

Figure 5. Grid Showing the Snow and Soil Water Networks on the Control Plots.

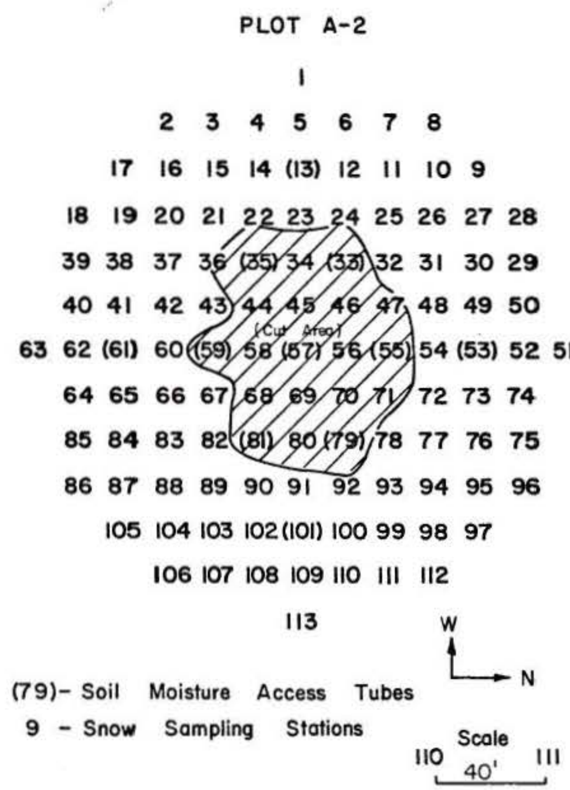

Figure 6. Grid System on the A2 Plot Showing the Snow and Soil Water Sampling Points and the Cut Area.

Figure 7. Grid System on the B2 Plot Showing the Snow and Soil Water Sampling Points and the Cut Area.

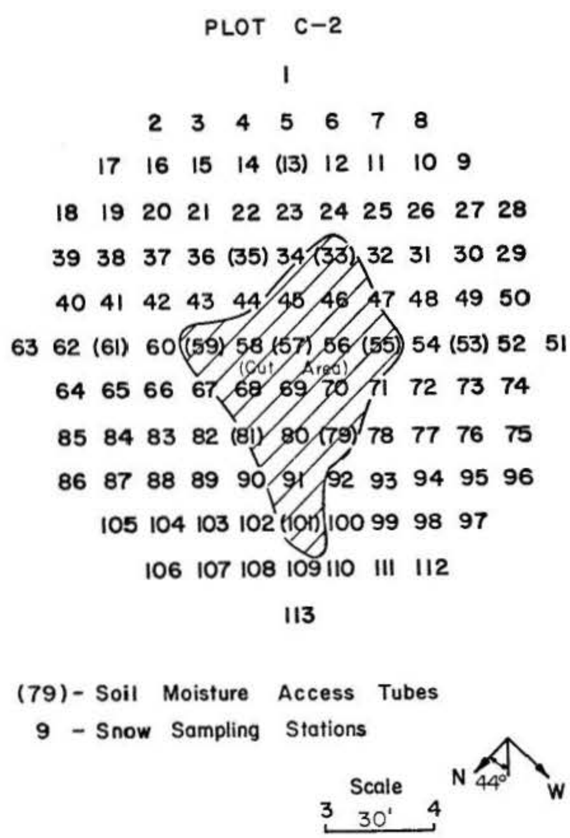

Figure 8. Grid System on the C2 Plot Showing the Snow and Soil Water Sampling Points and the Cut Area.

Table 5. Snow Sampling Dates for Each of the Pairs of Plots During the Five Years of Study.

A Plots	B Plots	C Plots
	-- Pre-Treatment --	
2/3/69	2/3/69	2/4/69
*3/29/69	*3/29/69	*3/29/69
11/26/69	11/26/69	11/26/69
1/10/70	1/10/70	1/10/70
2/7/70	2/7/70	2/7/70
*4/4/70	*4/4/70	*4/4/70
1/16/71	1/16/71	1/16/71
*3/9/71	*3/9/71	*3/10/71
	-- Post-Treatment --	
*1/15/72	*1/15/72	*2/3/72
3/14/72	3/14/72	3/23/72
11/18/72	11/18/72	11/18/72
12/14/72	12/14/72	12/15/72
1/24/73	1/24/73	1/24/73
*3/31/73	*3/31/73	*3/30/73

*Date at or near peak accumulation for each snow season.

Although snow measurements were taken throughout the winter months during the period from September, 1969 to April, 1973 only the peak accumulation values were used to test for significance between pre- and post-treatment conditions.

Since the above comparisons were found to be erratic for the pre-treatment conditions it was necessary to statistically compare the means of the ratios (e.g. Cut:Control) listed above for pre- and post-treatment conditions. The ratio means for pre-and post-treatment conditions were statistically compared for significance by an unpaired t-test.

In addition to areal comparisons made on the snow data, point by point analyses were also done. For this comparison each point value was ratioed to the corresponding control plot mean. Then the average of the pre-treatment ratios at that particular point was statistically compared with the post-treatment ratio at the same point for each post-treatment year. To clarify, an example is given below for point 55 on the C2 plot.

Pre-treatment (Point Value/Control Plot Mean) Avg = 0.617, 1972 Post-treatment (Point Value/Control Plot Mean) Ratio = 2.011.
Test for significant difference by t-test.

Pre-treatment (Point Value/Control Plot Mean) Avg = 0.617, 1973 Post-treatment (Point Value/Control Plot Mean) Ratio = 2.125.
Test for significant difference by t-test.

Snow measurements were taken using the Soil Conservation Service (SCS) or Federal Snow Sampler. This consists of a tube with an inside diameter of 1.485 inches, such that one inch of snow water equivalent weighs one ounce. The tube is made in sections to facilitate handling. Chatillon scales were used to give the snow water equivalent to the nearest tenth of an inch. Records are made of the snow depth, length of core, weights, soil conditions, and snow conditions. In the computerized analysis, all values were converted to centimeters of water equivalent.

Water equivalent measurements are subject to a variety of errors. As in any type of work where measurements are made, snow surveying data are subject to the usual observer errors such as misreading the weighing scale. The most common error is the result of incomplete coring of snow during sampling. Typical causes of incomplete coring include sticks caught in the tube or snow sticking to the tube. Bad snow samples can generally be detected by comparing the length of the core with the depth of the snow. Where frequent observations are made, such as in the case of this research project, care must be exercised to avoid holes left by prior sampling. Dirt and other foreign matter must be removed from the cutter end of the sample before weighing. The many details pertaining to snow surveying for the purpose of obtaining water equivalent of the snowpack at a given point are beyond the scope of this report; for details the reader is referred to the USDA Snow Survey Handbook (USDA, 1972).

Soil Water Measurement

Soil water measurements were taken at eleven points on each of the plots. The sampling network was set up on a grid as shown in Figs. 5 to 8. Soil water data was collected each fall and spring from October, 1970 to September, 1972.

Aluminum access tubes were installed by means of an air-truck vehicle with a pneumatic drill as described by Richardson (1966). The holes were drilled to a depth of 7½ feet to accommodate the 9 foot tube leaving 1½ feet above the ground. The hole was drilled slightly larger than the access tube and backfilled with coarse sand. The lower end of the access tube was sealed to prevent water entry.

To measure soil water a neutron probe manufactured by Nuclear Chicago was used. The measurement of the neutron flux was accomplished by two portable, battery powered scalers also supplied by Nuclear Chicago. Detailed descriptions of the principle of measurement and methodology of the neutron probe are given elsewhere (Douglass, 1962; Van Bavel, 1958; Van Bavel et al., 1963).

During the past twenty years the neutron method has gained wide acceptance. Today there is general agreement among soil scientists that the neutron probe is the most reliable method for measuring changes in soil water content (King, 1967).

When measuring soil water at different points, the error in the neutron method includes the inherent variability of the site. A study by Hewlett et al. (1964) has shown that the site variability in water content due to textural and structural differences of the soil is the main component of error in the neutron method.

Calibration of the neutron probe for this particular study was based on work done at the Pawnee National Grassland (Galbraith, 1971) for a fine sandy loam soil.

Field capacity for the soils on the plots was determined from soil water plots. The maximum values at two meters for the spring 1971 readings were averaged for each plot. This value was used as field capacity. In most cases the readings are fairly consistent and the value used as field capacity appears to be relatively good. However, in some cases the field capacity value was exceeded by the fall readings. It is not known if these high values represent higher field capacities or water content above field capacity. Higher field capacities were assumed in these cases for water yield computations and thus conservative estimates of water yield increases were obtained.

It is important to keep in mind that the soil water values from year to year are consistent in a relative sense even though the absolute amount of soil water in the column measured may not accurately be known.

Figure 9 shows the depths in meters at which soil water readings were taken.

Soil water readings taken in the fall integrate the net effect of evapotranspiration and rainfall during the active growing season except for rain during the time of soil saturation.

To test for significant changes in the soil water regime after treatment the following comparisons were made for pre- and post-treatment conditions and the means tested by an unpaired t-test:

1) Treatment plot mean vs. Control plot mean
2) Cut area mean vs. Control mean
3) Uncut area mean vs. Control mean
4) Cut area mean vs. Uncut area mean

The mean for the snow data in any given area (e.g. cut area) was determined by $\Sigma x/n$, where x = the observation at each point and n = number of observations. No weighting of individual points was done and all observations were included.

For the soil water data the mean was again calculated by $\Sigma x/n$. No weighting of individual points was done. However, on the B2 plot point 81 was left out when calculating the cut area average because it is right on the forest-opening boundary. Likewise, for the same reason, point 81 on the C2 plot was left out when calculating the cut area average.

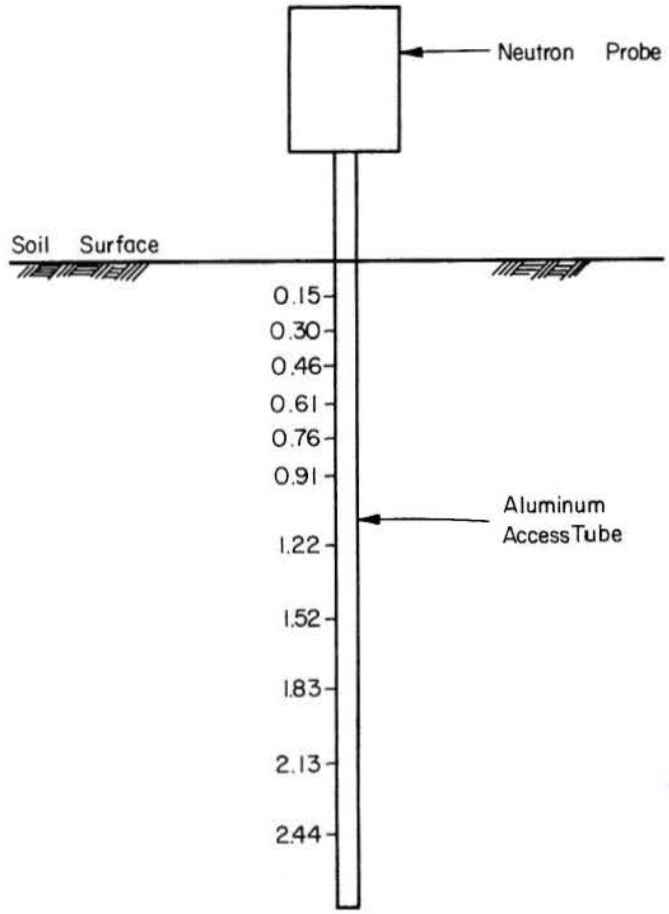

Figure 9. Sampling Depths (m) with Neutron Probe.

CHAPTER III
RESULTS

This chapter includes the summary of the individual observations and their statistical and graphical analysis along with some interpretation. The original observations are available in computer card format from the Department of Watershed Sciences. Further interpretation and integration of results are presented in Chapter IV. In presenting the results, the treatment plot refers to the plot that is eventually cut. Thus reference to the pre-treatment results for the treatment plot refers to data obtained on the to-be-treated plot before the cutting was applied. All statistical comparisons are at the $\alpha = 0.05$ level.

Soil Water

Soil water amounts are obtained by using standard calibration curves as described in Chapter II. Because the absolute amounts may be in error, relative differences or changes in soil water are used in evaluating treatment effects. All analyses are based on the amount of water in the upper two meters of soil material.

The changes in soil water content are summarized in Table 6 and presented graphically in Figs. 10 to 12. The seasonal changes in soil water are presented in Appendix A.

On all three plot pairs the cut area had a significant increase in the fall 1972 soil water content when compared to the control. These differences were 13, 15, and 12 cm on the A, B, and C plots respectively. There were no significant changes on the uncut areas for any of the treatment plots. There is some suggestion of treatment effects in the 1971 data even though the plots were not cut until September of that year.

Over the three years in which soil water data was collected there is a definite trend in the results for all the plots. During the fall of 1971 the plots were cut (Table 3), after which soil water data was collected. Even after only 1½ to 2 months there is already a change in the soil water regime on the cut areas. After one full year of post-treatment conditions, the change is sufficient so that the cut area has significantly more soil water than the control. The change on the C2 plot is even more dramatic. During the fall of 1970 the cut area had significantly less water than the control. Two months after cutting (Fall, 1971) the cut area, when compared to the control, exhibited no significant difference. By the fall of 1972 the cut area had significantly more soil water than the control.

Table 6. Significant $\alpha = 0.05$ Differences (cm) in Soil Water in the Upper 2 Meters when Compared to Control Plot.

		A			B			C		
		TR	CUT	UNCUT	TR	CUT	UNCUT	TR	CUT	UNCUT
OCT	1970	0	0	0	0	0	0	-5.8	-5.1	-7.2
NOV	1971	0	0	0	0	0	0	0	0	-5.9
		- - - - - Cutting Treatment Applied - - - - -								
SEPT	1972	0	+12.7	0	0	+15.3	0	0	+6.9	-7.8
Estimated Treatment Effect			+12.7			+15.3			+12.0	

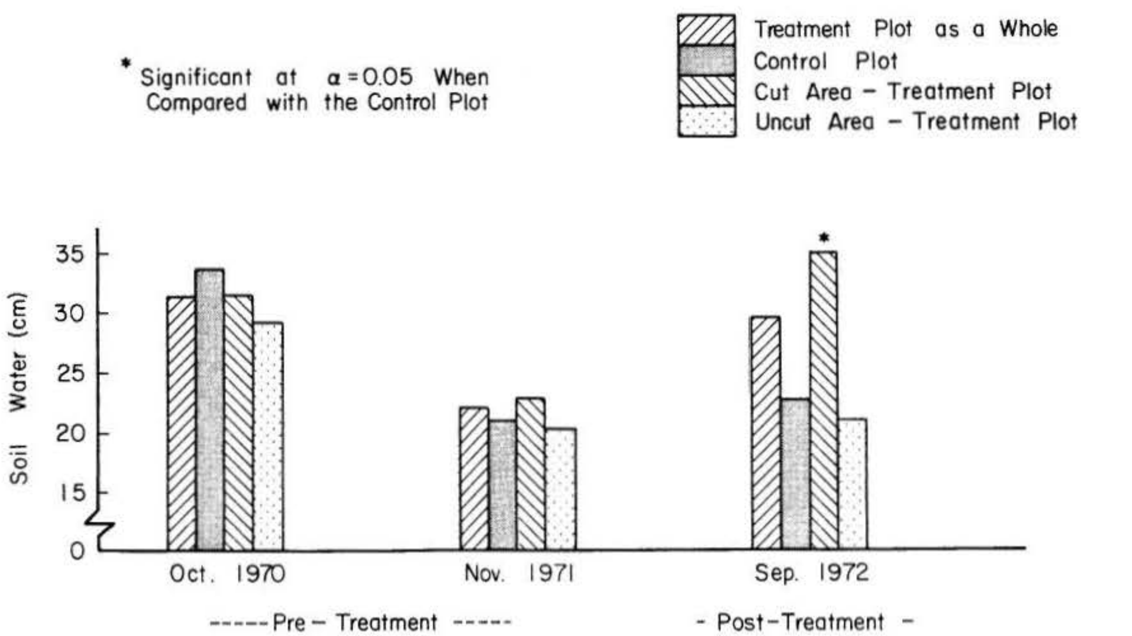

Figure 10. Significant Differences in Soil Water for the A2 Plot When Compared with the Control.

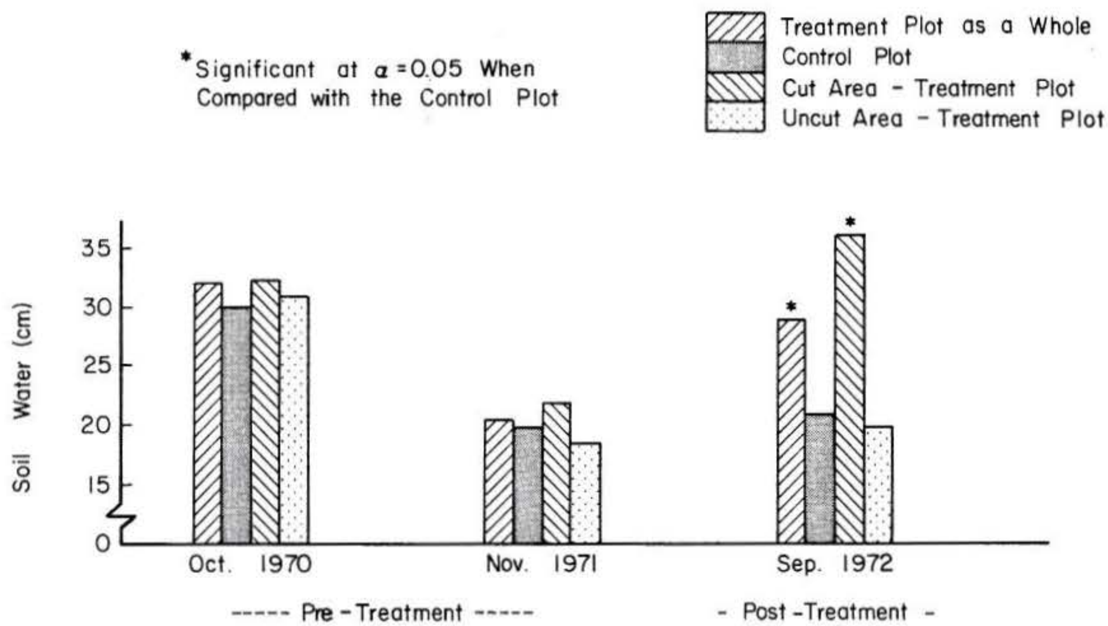

Figure 11. Significant Differences in Soil Water for the B2 Plot When Compared with the Control.

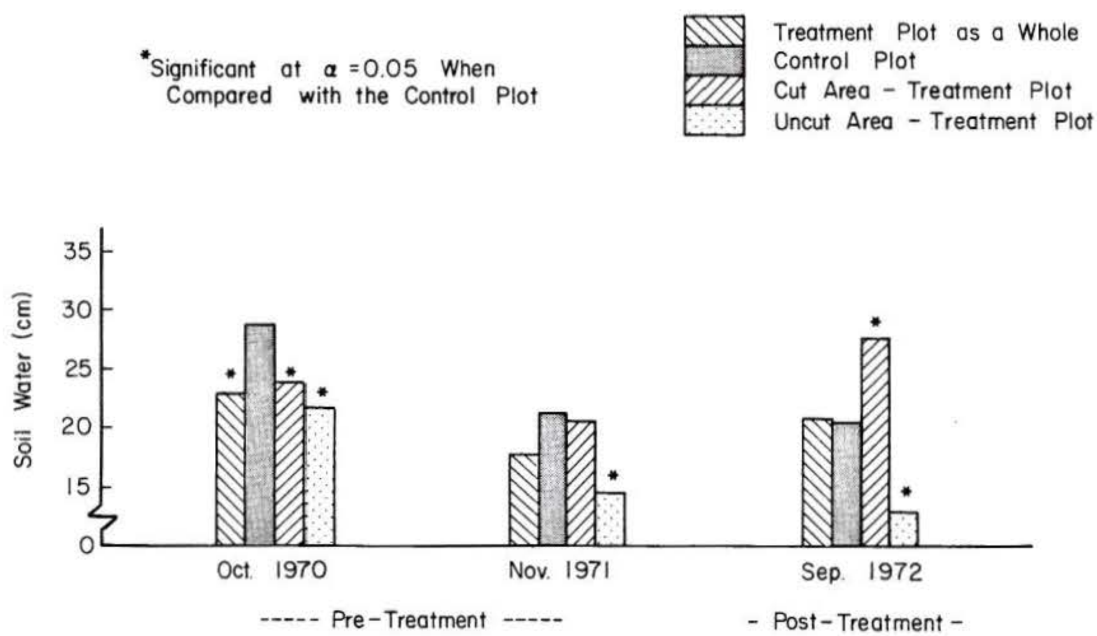

Figure 12. Significant Differences in Soil Water for the C2 Plot When Compared with the Control.

Table 7. Comparison of Treatment to Control Ratios of Peak Snowpack Water Equivalent for the Pre- and Post-Treatment Periods.

RATIOS FOR A PLOTS

Date	Ratios	Treatment	Cut/Control	Uncut/Control	Cut/Uncut
Pre-Treatment					
3/29/69		1.21	1.28	1.19	1.07
4/4/70		1.21	1.25	1.20	1.04
3/10/71		1.12	1.11	1.12	0.99
Average		1.18	1.21	1.17	1.03
Post-Treatment					
1/15/72		1.00*	0.76*	1.04^{NS}	0.73*
3/31/73		1.12^{NS}	1.28^{NS}	1.09^{NS}	1.17^{NS}
Average		1.06^{NS}	1.02^{NS}	1.07^{NS}	0.95^{NS}

RATIOS FOR B PLOTS

Date	Ratios	Treatment	Cut/Control	Uncut/Control	Cut/Uncut
Pre-Treatment					
3/29/69		0.79	0.75	0.79	0.95
4/4/70		0.86	0.82	0.86	0.95
3/10/71		0.61	0.57	0.61	0.93
Average		0.75	0.71	0.75	0.94
Post-Treatment					
1/15/72		0.68^{NS}	0.57^{NS}	0.70^{NS}	0.82*
3/31/73		0.78^{NS}	0.82^{NS}	0.77^{NS}	1.07*
Average		0.73^{NS}	0.70^{NS}	0.74^{NS}	0.95^{NS}

RATIOS FOR C PLOTS

Date	Ratios	Treatment	Cut/Control	Uncut/Control	Cut/Uncut
Pre-Treatment					
3/29/69		0.93	1.02	0.89	1.14
4/4/70		0.94	0.92	0.94	0.97
3/10/71		0.64	0.60	0.64	0.94
Average		0.83	0.84	0.82	1.01
Post-Treatment					
1/15/72		0.76^{NS}	0.51^{NS}	0.80^{NS}	0.63^{NS}
3/31/73		0.89^{NS}	1.18^{NS}	0.84^{NS}	1.40^{NS}
Average		0.83^{NS}	0.85^{NS}	0.82^{NS}	1.02^{NS}

*Significant at $\alpha = 0.05$ when compared with pre-treatment average.

NS - Non-significant.

Snow Distribution

The mean water equivalent values for each sampling date for the control, treatment plot, cut area, uncut area, and the ratios of each to the control are presented in Appendix B.

Peak snowpack water equivalent ratios for the pre- and post-treatment periods are presented in Table 7. Ratios are used to adjust for differences in treatment and control plot means that existed before treatment.

Analysis of the data presented in Table 7 indicates there was significantly less snow water equivalent on the cut area of the A plot on January 15, 1972 sufficient to effect a reduction on the treatment plot as a whole when compared to the control. A decrease in 1972 and an increase in 1973 in the cut:uncut ratio is indicated on the B plot but this is not reflected in comparisons to the control plot. Thus overall the only significant change appears to be the decrease on the cut area of the A plot in the heavy snow year of 1972.

Although the comparisons of the treatment plots, cut areas, and uncut areas with their respective control plots did not indicate any significant increases in snow water equivalent, there were obvious drift areas on the cut areas. These are shown in Figs. 13,

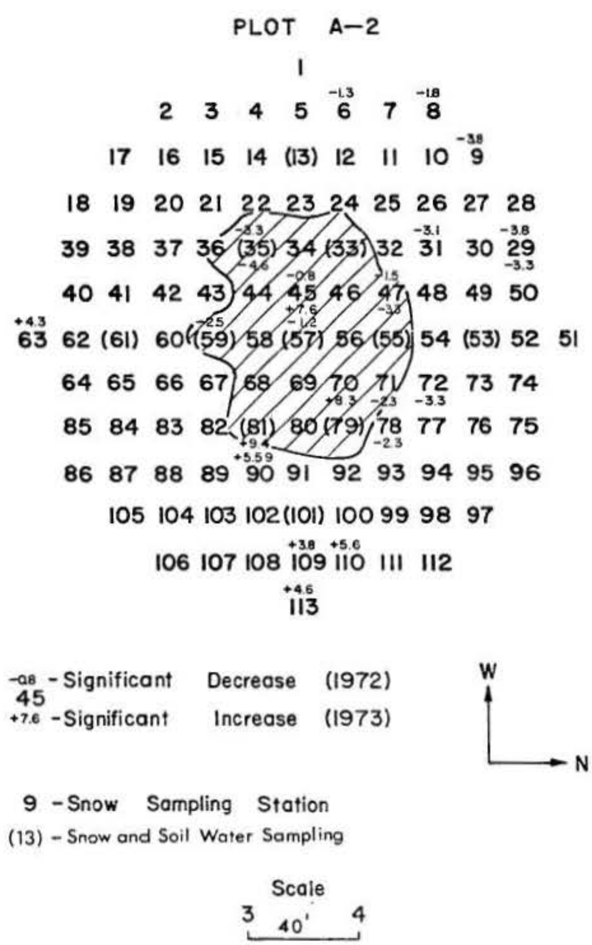

Figure. 13. Amounts (cm) for Points of Significant Snow Redistribution on the A2 Plot.

Figure 14. Photo Showing the Ablation Area on the A2 Plot During the Winter of 1972-73.

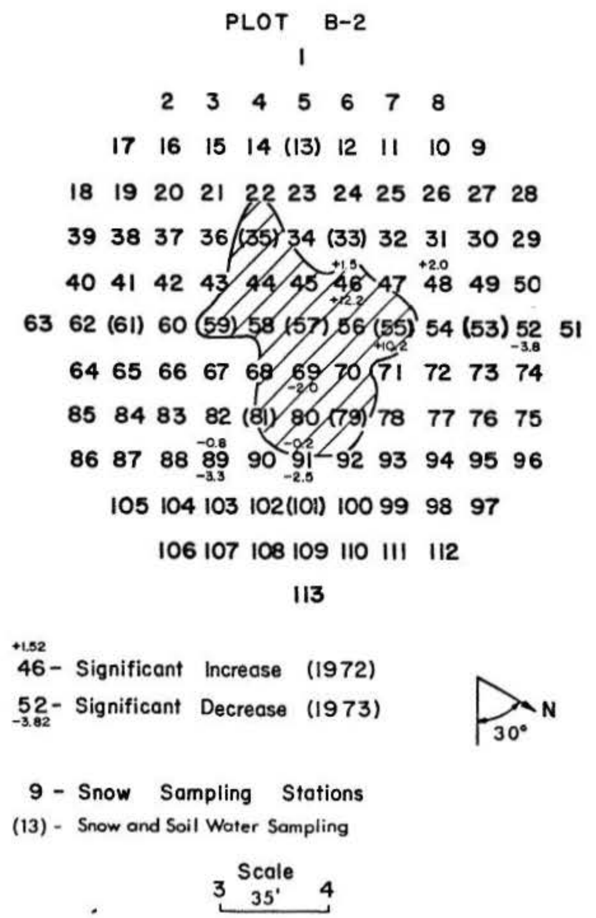

Figure 15. Amounts (cm) for Points of Significant Snow Redistribution on the B2 Plot.

Figure 16. Photo Showing the Drift Area on the B2 Plot During the Winter of 1972-73.

Figure 17. Photo of the B2 Plot Showing the Ablation Area in the Foreground and the Drifted Area on the Upper Edge of the Cut Area During the Winter of 1972-73.

15 and 18. To analyze snow accumulation changes at individual points as a result of cutting, each point on the treatment plot was compared to the mean of the control plot for the three pre- and two post-treatment years at near maximum accumulation. If the ratios of individual points to the control mean changed significantly after cutting, the change was indicated on Figs. 13, 15 and 18. An entry above the sampling point number indicates a change in 1972 and below indicates a change in 1973. The sign indicates whether the change was a gain or loss.

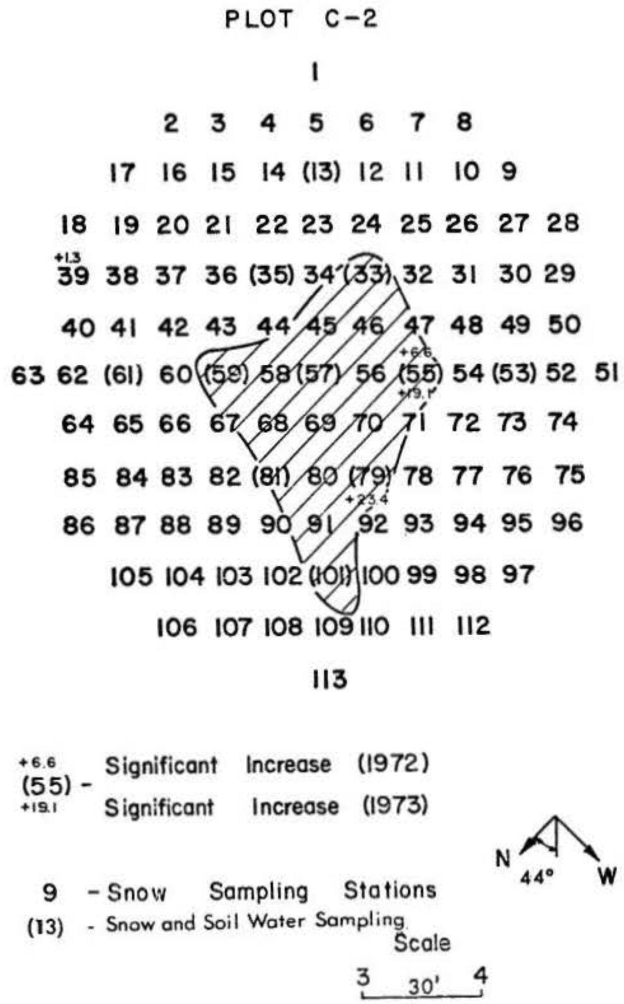

Figure 18. Amounts (cm) for Points of Significant Snow Redistribution on the C2 Plot.

Figure 19. Photo Showing Point 79 in the Drift Area on the C2 Plot During the Winter of 1972-73.

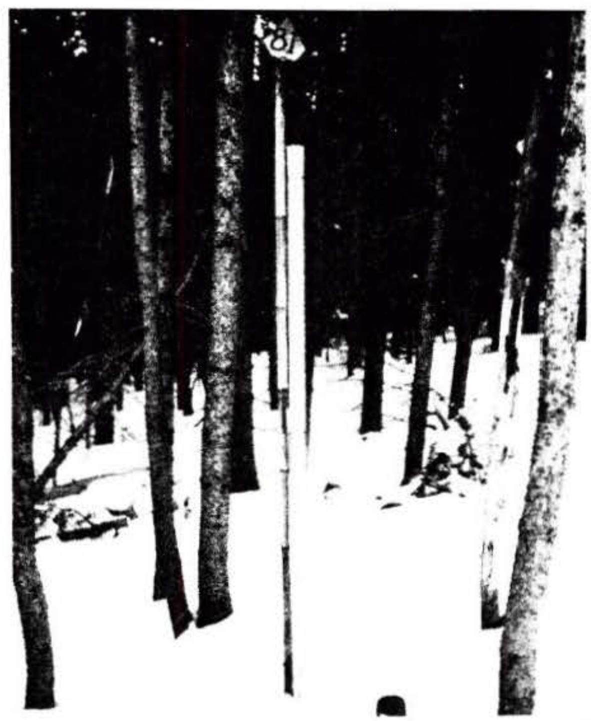

Figure 20. Photo Showing Point 81 in the Ablation Area on the C2 Plot During the Winter of 1972-73.

A look at the A2 plot (Fig. 13) suggests a gain on the lower, east end of the plot in the uncut area in 1972. It is possible that the prevailing westerly winds could have blown snow from the opening into the forest; only points 45 and 57 indicate a decrease that year. There is some indication during both years of a decrease along the northern edge of the cut area (Fig. 14), especially within the forest. This could result from increased solar radiation on this area because of the cutting. The importance of comparing values to the control plot for the pre- and post-treatment periods is exemplified by the fact that there was a definite drift area at points 33 and 34 during both pre- and post-treatment periods.

The obvious drift at points 46 and 55 on the B2 plot shows up in the data (Fig. 15) and in the photo, Fig. 16. Again the tendency for a decrease along the northern edge (Fig. 17) most exposed to increased solar radiation as a result of cutting is suggested (points 90, 91, 92).

Interpretation of the results for the C2 plot are complicated by the fact that only 31 points were sampled during the pre-treatment years of 1969 and 1970. Figure 18 clearly shows the drift along the southeast edge of the opening. Points 55, 79 and 81 (Figs. 19 and 20) also clearly reflect the drifting effect. Points 46, 47, 56, 70, 71 and 78 were not sampled during 1969 and 1970 but comparisons of these points with the mean of the control plot for 1971-73 suggests that there may have been significant redistribution at these points.

Melt Data

During both post-treatment years lysimeter data was collected at four points on the C2 treatment plot. Lysimeters were installed at three points in the cut area (55, 57 and 59) and at one point in the uncut area (53). Figure 21 shows the lysimeter in the drift area during the winter of 1972-73.

Although the A2 cut area exhibited the only significant difference in snow accumulation when compared with the control, there was a definite trend in the results for all plots.

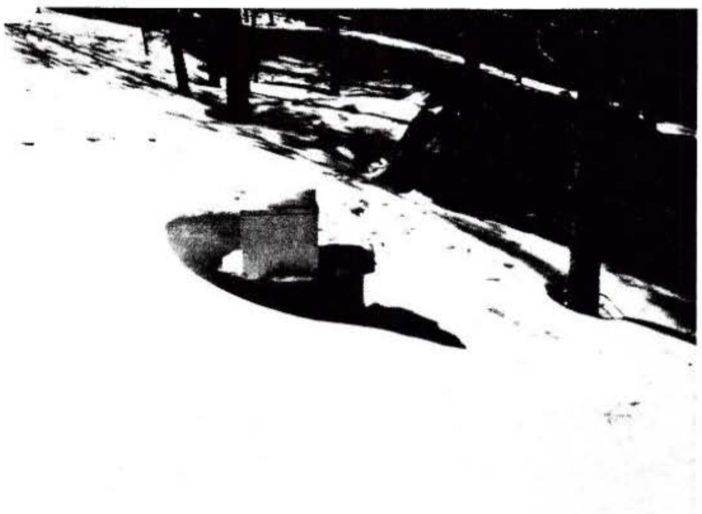

Figure 21. Photo Showing the Lysimeter in the Drift Area on the C2 Plot.

With the exception of the lysimeter in the drift area all the lysimeters started recording melt at about the same time. The delaying effect of the large amount of snow and the shade is evident in the melt rate of the lysimeter in the drift area (Point 55). The drift area on the C2 plot is on the protected western edge of the cut area and is not subject to intense solar radiation as are the other two lysimeters in the cut area.

These results suggest it is possible that, with the proper selection of cutting shapes with respect to wind and solar radiation, water yield may be delayed as well as increased.

Table 8 shows the melt recorded on the water level recorders at each lysimeter through May 29, 1973.

Table 8. Melt (mm) Recorded at Each Lysimeter on the C2 Plot from the Date of the First Occurrence of Melt Through May 29, 1973.

Date	LYSIMETER Point Number			
	59	57	55	53
4/5/73 to 4/11/73				12
4/11/73 to 4/18/73	12	33	3	18
4/18/73 to 4/26/73	6	9	0	6
4/26/73 to 5/3/73	27	24	12	6
5/3/73 to 5/8/73	37	55	15	12
5/8/73 to 5/15/73	17	219	70	79
5/15/73 to 5/22/73	79	73	79	158
5/22/73 to 5/29/73	6 (END)	6 (END)	119	110
			2/	1/

53 in Forested area.
55 in the Drifted area.
1/ additional melt until June 1
2/ additional melt until June 10

CHAPTER IV
DISCUSSION

From the results, it is evident that changes have taken place on the plots after the cuts were made. Water balances as discussed in the following refers to water potentially available for streamflow (water yield). Actual streamflow measurements were not made.

To see if the changes resulted in increased water yield, individual water balances were tabulated for each of the points on both the control and treatment plots. This was done for the eleven points where both snow and soil water measurements were taken on each of the six plots. The water balances for these points are shown in Tables 9 to 26. A summation of these results is presented in Tables 27 and 28.

For the water balances it was necessary to arrive at an estimate of the field capacity for each of the six plots. This was done by taking the average maximum value of soil water in the top two meters for the spring of 1971. In some cases the fall soil water exceeds the maximum spring soil water. The spring value was still used as an appropriate field capacity but the soil water deficit was assumed to be zero and not a positive value when computing potential water yields.

The soil water seasonal patterns in the study period are consistent from year to year (see Appendix A) but it should be re-emphasized that the soil water readings are relative and not absolute because calibration curves specific to each site were not developed.

A Plots

Looking at the A1 plot, Tables 9, 10 and 11 show that only 3 points were yielding water during the pre-treatment year 1970-71 and only one point was yielding water during the post-treatment year of 1972-73. This was in spite of the large snowpack (avg. water equivalent of 10.3 cm) during the post-treatment year of 1972-73.

This is consistent when the precipitation records (Table 1) for the period are studied. During the months of June - September, 1970 over 20 cm of rainfall was recorded at Pingree Park, in contrast to slightly less than 15 cm during the same period in 1972. There was simply less summer precipitation to satisfy the soil water deficit caused by evapotranspiration.

Table 9. Potential Water Yield (cm) for Plot A1 for 1970-71.

Point Number	4	9	10	14	15	16	17	18	22	23	28
Field Capacity	36.0	36.0	36.0	36.0	36.0	36.0	36.0	36.0	36.0	36.0	36.0
Soil Water Present Prior to Snow Accumulation	34.0	41.2	41.2	29.2	31.0	15.1	44.1	29.1	38.9	19.9	25.7
Soil Water Deficit	-2.0	0	0	-6.8	-5.0	-20.9	0	-6.9	0	-16.1	-10.3
Peak Snow Water Equivalent	0.7	0.0	1.6	2.9	0.7	2.7	2.6	1.1	0.3	1.3	1.0
Water Available for Yield - Neglecting Precipitation After Maximum Snowpack Measurements and Evaporation	-	0	1.6	-	-	-	2.6	-	0.3	-	-

Table 10. Potential Water Yield (cm) for Plot A1 for 1971-72.

Point Number	4	9	10	14	15	16	17	18	22	23	28
Field Capacity	36.0	36.0	36.0	36.0	36.0	36.0	36.0	36.0	36.0	36.0	36.0
Soil Water Present Prior to Snow Accumulation	M	36.5	18.7	33.5	27.5	22.2	37.6	28.0	36.5	16.4	16.2
Soil Water Deficit	M	0	17.3	-2.5	-8.5	-13.8	0	-8.0	0	-19.6	-19.8
Peak Snow Water Equivalent	1.3	0.8	1.2	1.5	1.0	1.3	1.5	1.4	1.5	2.0	2.3
Water Available for Yield - Neglecting Precipitation After Maximum Snowpack Measurements and Evaporation	M	0.8	-	-	-	-	1.5	-	1.5	-	-

M - Missing

Table 11. Potential Water Yield (cm) for Plot A1 for 1972-73.

Point Number	4	9	10	14	15	16	17	18	22	23	28
Field Capacity	36.0	36.0	36.0	36.0	36.0	36.0	36.0	36.0	36.0	36.0	36.0
Soil Water Present Prior to Snow Accumulation	M	31.1	34.5	22.9	19.4	9.5	24.8	19.5	31.1	13.1	16.8
Soil Water Deficit	M	-4.9	-1.5	-13.1	-16.6	-26.5	-11.2	-16.5	-4.9	-22.9	-19.2
Peak Snow Water Equivalent	2.7	0.0	4.2	4.5	3.0	4.2	5.3	3.7	2.4	0.5	1.0
Water Available for Yield - Neglecting Precipitation After Maximum Snowpack Measurements and Evaporation	M	-	2.7	-	-	-	-	-	-	-	-

M - Missing

In contrast, the 1970-71 pre-treatment year for the A2 plot shows only one point yielding water, while the 1972-73 post-treatment year shows seven points yielding water. This is shown in Tables 12, 13 and 14. In addition the area to be cut on the A2 plot shows an increase from 0 to 6 points yielding water after the cutting treatment.

The increase in water yields on the cut areas could result from changes in snow distribution, summer precipitation interception, and evapotranspiration during the growing season. Analysis of snow accumulation differences (Fig. 13) indicates that there was no increase on the six water balance sites on the cut area (Tables 12 and 14). Thus the 10.0 cm increase is attributable to differences in growing season ET. Point 81 (Fig. 13) did show a significant increase in snow but soil water data for this point was lost because of a bent tube, precluding water balance calculations.

Point 35 had a significant decrease in snow (Fig. 13) yet still showed an increase in water yield of 6.4 cm (Tables 14 and 27).

There was no significant change in water yield for the uncut part of the A2 plot.

B Plots

Results indicate that similar processes are taking place on the B plots.

Tables 15, 16 and 17 show four points on the B1 control plot yielding water during the 1970-71 pre-treatment year and three points yielding water during the 1972-73 post-treatment year.

Comparing this with the B2 treatment plot the number of points yielding water increases from 3 to 8 after cutting. After treatment every point in the cut area yielded water.

The average increase on the B2 cut area was 10.2cm (Tables 20 and 27). Referring to Fig. 15, of the points where water balance computations were calculated only point 55 had a significant increase in snow water equivalent. This amounted to 10.2 cm and accounted for 16 percent of the total increase in water yield from the B2 cut area.

C Plots

The average increase in water yield in 1972-73 on the cut area of the C2 plot was 15.3 cm (Tables 24-26). Snow increase (Fig. 18) was indicated on points 55 (19.1 cm) and 79 (23.4 cm). These snow increases represent 46 percent of the total water yield increase on the C2 cut area (Table 27). Points 55 and 79 are located in the high accumulation drift area. Points 59 and 81 on the northeast edge of the cut area were exposed to a relatively high amount of direct solar radiation and thermal re-radiation from the forest wall. These points did not indicate a water yield increase (or decrease) as a result of the cutting.

No significant change was indicated on the uncut area of the treatment plot.

General Discussion

It should be emphasized that these potential water yield increases are inferred from plot measurements as

Table 12. Potential Water Yield (cm) for Plot A2 for 1970-71.

Point Number	13	61	53	101	35*	33*	59*	57*	55*	81*	79*
Field Capacity	37.4	37.4	37.4	37.4	37.4	37.4	37.4	37.4	37.4	37.4	37.4
Soil Water Present Prior to Snow Accumulation	37.0	24.9	20.3	16.0	28.0	24.9	26.5	21.9	23.6	26.7	25.1
Soil Water Deficit	-0.4	-12.5	-17.1	-21.4	-9.4	-12.5	-10.9	-15.5	-13.8	-10.7	-12.3
Peak Snow Water Equivalent	11.4	4.8	2.3	1.8	3.8	8.1	2.3	6.1	6.1	3.3	4.1
Water Available for Yield - Neglecting Precipitation After Maximum Snowpack Measurements and Evaporation	11.0	-	-	-	-	-	-	-	-	-	-

*Located in the cut area of the plot.

Table 13. Potential Water Yield (cm) for Plot A2 for 1971-72.

Point Number	13	61	53	101	35*	33*	59*	57*	55*	81*	79*
Field Capacity	37.4	37.4	37.4	37.4	37.4	37.4	37.4	37.4	37.4	37.4	37.4
Soil Water Present Prior to Snow Accumulation	26.7	22.5	17.2	14.2	28.5	16.4	26.9	22.1	19.9	22.3	23.5
Soil Water Deficit	-10.7	-14.9	-20.2	-23.2	-8.9	-21.0	-10.5	-15.3	-17.5	-15.1	-13.9
Peak Snow Water Equivalent	12.2	0	3.8	5.3	4.8	2.8	5.3	2.5	2.8	5.3	3.6
Water Available for Yield - Neglecting Precipitation After Maximum Snowpack Measurements and Evaporation	1.5	-	-	-	-	-	-	-	-	-	-

*Located in the cut area of the plot.

Table 14. Potential Water Yield (cm) for Plot A2 for 1972-73.

Point Number	13	61	53	101	35*	33*	59*	57*	55*	81*	79*
Field Capacity	37.4	37.4	37.4	37.4	37.4	37.4	37.4	37.4	37.4	37.4	37.4
Soil Water Present Prior to Snow Accumulation	27.1	24.4	17.5	14.1	36.5	37.1	37.2	31.2	35.2	M	32.6
Soil Water Deficit	-10.3	-13.0	-19.9	-23.3	-0.9	-0.3	-0.2	-6.2	-2.2	M	-4.8
Peak Snow Water Equivalent	20.3	8.9	8.9	10.2	7.6	15.2	15.2	12.7	14.0	17.8	11.4
Water Available for Yield - Neglecting Precipitation After Maximum Snowpack Measurements and Evaporation	10.0	-	-	-	6.7	14.9	15.0	6.5	11.8	M	6.6

*Located in the cut area of the plot.

M - Missing

Table 15. Potential Water Yield (cm) for Plot B1 for 1970-71.

Point Number	4	9	10	14	15	16	17	18	22	23	28
Field Capacity	31.0	31.0	31.0	31.0	31.0	31.0	31.-	31.0	31.0	31.0	31.0
Soil Water Present Prior to Snow Accumulation	31.4	31.8	33.2	18.7	29.4	26.4	26.8	38.6	24.5	29.7	26.8
Soil Water Deficit	0	0	0	-12.3	-1.6	-4.6	-4.2	0	-6.5	-1.3	-4.2
Peak Snow Water Equivalent	2.0	2.4	1.4	5.9	5.8	3.8	4.2	5.1	2.6	6.2	3.3
Water Available for Yield - Neglecting Precipitation After Maximum Snowpack Measurements and Evaporation	2.0	2.4	1.4	-	-	-	-	5.1	-	-	-

Table 16. Potential Water Yield (cm) for Plot B1 for 1971-72.

Point Number	4	9	10	14	15	16	17	18	22	23	28
Field Capacity	31.0	31.0	31.0	31.0	31.0	31.0	31.0	31.0	31.0	31.0	31.0
Soil Water Present Prior to Snow Accumulation	22.1	20.1	33.6	M	25.0	22.8	23.6	34.9	19.8	25.4	22.8
Soil Water Deficit	-8.9	-10.9	0	M	-6.0	-8.2	-7.4	0	-11.2	-5.6	-7.2
Peak Snow Water Equivalent	1.0	1.5	1.2	1.4	1.9	1.2	1.0	2.2	1.2	1.6	1.5
Water Available for Yield - Neglecting Precipitation After Maximum Snowpack Measurements and Evaporation	-	-	1.2	M	-	-	-	2.2	-	-	-

M - Missing

Table 17. Potential Water Yield (cm) for Plot B1 for 1972-73.

Point Number	4	9	10	14	15	16	17	18	22	23	28
Field Capacity	31.0	31.0	31.0	31.0	31.0	31.0	31.0	31.0	31.0	31.0	31.0
Soil Water Present Prior to Snow Accumulation	18.8	22.6	26.4	M	19.8	19.3	24.8	27.0	14.1	20.1	16.6
Soil Water Deficit	-12.2	-8.4	-4.6	M	-11.2	-11.7	-6.2	-4.0	-16.9	-10.9	-14.4
Peak Snow Water Equivalent	5.7	4.1	6.1	8.5	10.0	7.5	6.8	6.7	5.7	9.0	6.6
Water Available for Yield - Neglecting Precipitation After Maximum Snowpack Measurements and Evaporation	-	-	1.5	M	-	-	0.6	2.7	-	-	-

M - Missing

Table 18. Potential Water Yield (cm) for Plot B2 for 1970-71.

Point Number	13	61	53	101	33	35*	59*	57*	55*	81*	79*
Field Capacity	34.4	34.4	34.4	34.4	34.4	34.4	34.4	34.4	34.4	34.4	34.4
Soil Water Present Prior to Snow Accumulation	22.8	33.7	23.1	24.8	19.7	14.8	34.0	27.3	28.2	30.5	26.3
Soil Water Deficit	-11.6	-0.7	-11.3	-9.6	-14.7	-19.6	-0.4	-7.1	-6.2	-3.9	-8.1
Peak Snow Water Equivalent	4.6	7.9	3.6	5.8	6.4	4.6	5.3	5.6	3.3	6.6	5.3
Water Available for Yield - Neglecting Precipitation After Maximum Snowpack Measurements and Evaporation	-	7.2	-	-	-	-	4.9	-	-	2.7	-

*Located in the cut area of the plot.

Table 19. Potential Water Yield (cm) for Plot B2 for 1971-72.

Point Number	13	33	61	53	101	35*	59*	57*	55*	81*	79*
Field Capacity	34.4	34.4	34.4	34.4	34.4	34.4	34.4	34.4	34.4	34.4	34.4
Soil Water Present Prior to Snow Accumulation	17.9	14.6	22.8	19.3	18.7	14.5	26.0	22.4	21.8	23.8	19.9
Soil Water Deficit	-16.5	-19.8	-11.6	-15.1	-15.7	-19.9	-8.4	-12.0	-12.6	-10.6	-14.5
Peak Snow Water Equivalent	1.8	2.3	0	5.3	2.0	2.3	1.5	1.3	9.4	1.0	3.8
Water Available for Yield - Neglecting Precipitation After Maximum Snowpack Measurements and Evaporation	-	-	-	-	-	-	-	-	-	-	-

*Located in the cut area of the plot.

Table 20. Potential Water Yield (cm) for Plot B2 for 1972-73.

Point Number	13	33	61	53	101	35*	59*	57*	55*	81*	79*
Field Capacity	34.4	34.4	34.4	34.4	34.4	34.4	34.4	34.4	34.4	34.4	34.4
Soil Water Present Prior to Snow Accumulation	16.4	14.2	26.7	22.3	20.2	26.2	48.0	31.0	38.1	37.6	38.2
Soil Water Deficit	-18.0	-20.2	-7.7	-12.1	-14.2	-8.2	0	-3.4	0	0	0
Peak Snow Water Equivalent	13.2	13.0	11.4	18.3	4.1	17.3	11.2	11.2	21.3	8.4	10.4
Water Available for Yield - Neglecting Precipitation After Maximum Snowpack Measurements and Evaporation	-	-	3.7	6.2	-	9.1	11.2	7.8	21.3	8.4	6.6

*Located in the cut area of the plot.

Table 21. Potential Water Yield (cm) for Plot C1 for 1970-71.

Point Number	4	9	10	14	15	16	17	18	22	23	28
Field Capacity	29.0	29.0	29.0	29.0	29.0	29.0	29.0	29.0	29.0	29.0	29.0
Soil Water Present Prior to Snow Accumulation	29.3	31.7	28.7	26.2	25.7	30.6	34.5	32.5	21.0	31.5	28.3
Soil Water Deficit	0	0	-0.3	-2.8	-3.3	0	0	0	-8.0	0	-0.7
Peak Snow Water Equivalent	2.5	5.7	0.8	3.9	4.8	5.4	4.1	2.5	2.6	1.9	4.1
Water Available for Yield - Neglecting Precipitation After Maximum Snowpack Measurements and Evaporation	2.5	5.7	0.5	1.1	1.5	5.4	4.1	2.5	-	1.9	3.4

Table 22. Potential Water Yield (cm) for Plot C1 for 1971-72.

Point Number	4	9	10	14	15	16	17	18	22	23	28
Field Capacity	29.0	29.0	29.0	29.0	29.0	29.0	29.0	29.0	29.0	29.0	29.0
Soil Water Present Prior to Snow Accumulation	19.6	24.8	23.7	21.9	21.4	25.6	34.7	29.2	20.6	28.7	26.7
Soil Water Deficit	-9.4	-4.2	-5.3	-7.1	-7.6	-3.4	0	0	-8.4	-0.3	-2.3
Peak Snow Water Equivalent	0.5	4.2	1.0	2.2	3.5	2.1	2.5	1.4	1.9	1.1	2.3
Water Available for Yield - Neglecting Precipitation After Maximum Snowpack Measurements and Evaporation	-	-	-	-	-	-	2.5	1.4	-	0.8	-

Table 23. Potential Water Yield (cm) for Plot C1 for 1972-73.

Point Number	4	9	10	14	15	16	17	18	22	23	28
Field Capacity	29.0	29.0	29.0	29.0	29.0	29.0	29.0	29.0	29.0	29.0	29.0
Soil Water Present Prior to Snow Accumulation	18.1	21.4	19.4	19.4	18.9	18.9	28.3	24.9	16.1	21.9	22.1
Soil Water Deficit	-10.9	-7.9	-9.6	-9.6	-10.1	-10.1	-0.7	-4.1	-12.9	-7.1	-6.9
Peak Snow Water Equivalent	4.5	3.5	1.5	6.0	9.0	6.0	5.5	4.5	5.0	4.5	4.0
Water Available for Yield - Neglecting Precipitation After Maximum Snowpack Measurements and Evaporation	-	-	-	-	-	-	4.8	0.4	-	-	-

Table 24. Potential Water Yield (cm) for Plot C2 for 1970-71.

Point Number	13	35	61	53	33*	59*	57*	55*	81*	79*	101*
Field Capacity	26.5	26.5	26.5	26.5	26.5	26.5	26.5	26.5	26.5	26.5	26.5
Soil Water Present Prior to Snow Accumulation	18.3	12.8	13.5	18.4	19.8	18.1	25.9	17.8	18.5	15.1	14.5
Soil Water Deficit	-8.2	-13.7	-13.0	-8.1	-6.7	-8.4	-0.6	-8.7	-8.0	-11.4	-12.0
Peak Snow Water Equivalent	4.3	4.8	8.4	6.4	6.9	4.1	8.1	3.3	5.1	2.0	5.1
Water Available for Yield - Neglecting Precipitation After Maximum Snowpack Measurements and Evaporation	-	-	-	-	0.2	-	7.5	-	-	-	-

*Located in the cut area of the plot.

Table 25. Potential Water Yield (cm) for Plot C2 for 1971-72.

Point Number	31	35	61	53	33*	59*	57*	55*	81*	79*	101*
Field Capacity	26.5	26.5	26.5	26.5	26.5	26.5	26.5	26.5	26.5	26.5	26.5
Soil Water Present Prior to Snow Accumulation	14.4	15.3	13.3	14.2	24.9	14.5	24.9	19.8	14.7	18.9	16.6
Soil Water Deficit	12.1	-11.2	-13.2	-12.3	-1.6	-12.0	-1.6	-6.7	-11.8	-7.6	-10.0
Peak Snow Water Equivalent	2.8	2.0	3.0	4.6	1.8	0	0	16.5	0	10.9	3.0
Water Available for Yield - Neglecting Precipitation After Maximum Snowpack Measurements and Evaporation	-	-	-	-	0.2	-	-	9.8	-	3.3	-

*Located in the cut area of the plot.

Table 26. Potential Water Yield (cm) for Plot C2 for 1972-73.

Point Number	13	35	61	53	33*	59*	57*	55*	81*	79*	101*
Field Capacity	26.5	26.5	26.5	26.5	26.5	26.5	26.5	26.5	26.5	26.5	26.5
Soil Water Present Prior to Snow Accumulation	13.2	14.4	10.9	14.0	27.2	17.1	35.9	33.8	11.9	26.3	26.6
Soil Water Deficit	-13.3	-12.1	-15.6	-12.5	0	-9.4	0	0	-14.6	-0.2	0
Peak Snow Water Equivalent	8.9	8.9	8.9	14.0	14.0	3.8	8.9	26.7	1.3	30.5	15.2
Water Available for Yield - Neglecting Precipitation After Maximum Snowpack Measurements and Evaporation	-	-	-	1.5	14.0	-	8.9	26.7	-	30.3	15.2

*Located in the cut area of the plot.

Table 27. Average Water Yields (cm) for Pre-Treatment (1970-71) and Post-Treatment (1972-73).

	Control Avg.	Treatment Avg.	Cut Avg.	Uncut Avg.	Est.Treatment Effect on Cut Area
		A Plots			
1970-71	0.4	1.0	0.0	2.7*	NA
1972-73	0.3	7.2*	10.3*	2.5*	10.0
		B Plots			
1970-71	1.0	1.3	1.3	1.8	NA
1972-73	0.5	6.8*	10.7*	1.9	10.2
		C Plots			
1970-71	2.6	0.7	1.1	0.0*	NA
1972-73	0.5	8.8*	15.8*	0.4	15.3

NA - Not Applicable
* - Significant at $\alpha = 0.5$

Table 28. Percent of the Plots Yielding Water Before and After Treatment.

	A1	A2	B1	B2	C1	C2
% of plot cut	0	16.8	0	12.4	0	14.8
% of plot yielding water in the pre-treatment year (1970-71)	27.3	9.0	36.4	27.3	90.9	18.2
% of plot yielding water in the post-treatment year (1972-73)	10.0	70.0	30.0	81.8	18.2	63.6
% of cut area yielding water						
a) 1970-71	NA	0.0	NA	33.3	NA	28.6
b) 1972-73	NA	100.0	NA	100.0	NA	71.4

NA - Not Applicable

of 3/31/73 and are for only one year - the first year that the cutting has had the opportunity to influence all phases of the hydrologic cycle. The results are thus specific to the weather conditions of that year. Furthermore the results are specific to the sites studied and must be extrapolated with careful attention to topographic, vegetation, soil, and microclimatic conditions. Finally it should be emphasized that the cut areas are small and that with larger cut areas decreases in snow could result from snow blowing out of the cut areas. This is an especially critical consideration in the very windy Front Range conditions. Nevertheless, the effect of cutting on potential water yield increase is of such magnitude that in spite of the above limitations, patch cutting appears to be a very real management alternative to increase useable water supplies by a significant amount on the Eastern Slope of the Colorado Front Range.

The average increase in potential water yields for the three plots as indicated by comparison with the control as of 3/31/73 was 11.8 cm. Approximately 21 percent of this increase or 2.5 cm is attributable to snow accumulation effects. The remainder is the result of a reduction in evapotranspiration during the growing season. This increase is especially striking when compared to the average control plot yield for 1972-73 of 0.4 cm. Water yield on both the control and treatment plot would be expected to be larger than that indicated by the 3/31/73 readings because of heavy precipitation (> 12 cm) during April and May.

A very important finding for lodgepole pine at 9000 feet in the Front Range is that there is only a very small (3.0 cm or less) water yield in the uncut condition. Removal of the lodgepole forest by small patch cutting can result in water production from sites that otherwise would not produce any water in addition to increasing water yields on sites that are producing only minimal amounts.

The cost of water produced by such harvest practices would depend on the operational cost of forest removal and associated returns from the wood products. Under current marketing conditions much of the lodgepole pine is only marginally attractive as a source of wood products.

The desirability of patch cutting from an esthetic standpoint is debatable depending on the type of recreational use. The advantages of irregular openings in the landscape as compared against undisturbed forest remains an issue. From a wildlife standpoint the increase in variation in cover conditions and increase in herbaceous vegetation should be desirable. There should be no detrimental effects on water quality if the patch cutting is carefully supervised.

The length of the effect of water yield increase depends on the density, type, and root characteristics of the succeeding vegetation. Because a large part of the increase in potential water yield is a result of reduced evapotranspiration losses, it is likely that the yield increases would diminish with the re-establishment of lodgepole pine or other vegetation with prolific and deep-penetrating roots. Maintenance of herbaceous vegetation should prolong the potential water yield increases. There are several options open after cutting. These include maintenance of herbaceous vegetation (Reid, 1971), allowing natural regeneration of lodgepole pine, or encouraging the spread and establishment of existing aspen sprouts. Although no final decision has been made, the last option has many attractions from a research standpoint.

Also, the water yield increase was evaluated by considering only those points that indicated a positive water yield. A minus water yield was assumed to be zero. What happens later to the excess water at those points yielding water is not known.

CHAPTER V
SUMMARY AND CONCLUSIONS

From September 1969 to May 1973 a study was conducted in the Front Range of Colorado at 9000 feet elevation to determine the potential for increasing water yield by small patch cuts in lodgepole pine. The experimental area consisted of three pairs of plots, which were similar in vegetation and topography. After three pre-treatment years in which snow and soil water data were collected, patch cuts were made on the treatment plots. These varied in size from 0.29 acres to 0.61 acres and also in shape to reduce esthetic impact. After cutting, snow and soil water data was collected for the remaining two years of study.

The major conclusions from this study are listed below.

1) There was a significantly greater amount of soil water on the cut areas in the fall of 1972 based on comparison with control and pre-treatment data. The average increase in water content of the top 2 meters of soil was 13.3 cm. There was no significant change in soil water on the adjacent uncut areas as a result of the cutting.
2) There were individual sampling points that had significant increases or decreases in snow as a result of the cutting. The increases were associated with local drift areas and the decreases were associated with those parts of the cut area that had relatively greater exposure to direct solar and re-radiated thermal radiation.
3) Water yield computations were calculated by combining the fall soil water measurements with the peak snow accumulation at each 11 points on each plot. For these computations the increase in water available for streamflow was evaluated. For the 1972-73 water year the estimated increase on the cut areas averaged 11.8 cm. Approximately 21 percent of this increase is the result of increased snow at selected points in the cut areas. These numbers do not reflect additional changes in precipitation that might occur after the peak snowpack measurements.
4) Although the results are site specific and for only the first full hydrologic year after treatment, there does appear to be a very high potential for water yield increase by small patch cuts from sites similar to those studied.

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APPENDIX A

SOIL WATER DATA

Table A1. Fall Soil Moisture Integrated to Two (2) Meters for Pre- and Post-Treatment Conditions for the A1 (Control) and A2 (Treatment) Plots.

	Date	Soil Water (Cm)	Deviation from Control (Cm)	Percent
Pre-Treatment		Fall 1970		
Control	10/70	33.4		
Treated Plot	"	31.2	-2.2	-6.6
Cut Area	"	31.4	-2.0	-6.0
Uncut Area	"	30.6	-2.8	-8.4
		Fall 1971		
Control	11/71	20.2		
Treated Plot	"	23.0	+2.8	+13.9
Cut Area	"	24.2	+4.0	+19.8
Uncut Area	"	21.0	+0.8	+4.0
Post-Treatment		Fall 1972		
Control	9/72	22.3		
Treated Plot	"	29.3	+7.0	+31.4
Cut Area	"	29.3	+12.7*	+57.0
Uncut Area	"	20.8	-1.5	-6.7

*Significant at $\alpha = 0.05$

Table A2. Fall Soil Moisture Integrated to Two (2) Meters for Pre- and Post-Treatment Conditions for the B1 (Control) and B2 (Treatment) Plots.

	Date	Soil Water (Cm)	Deviation from Control (CM)	Percent
Pre-Treatment		Fall 1970		
Control	10/70	29.9		
Treated Plot	"	31.8	+1.9	+6.4
Cut Area	"	32.2	+2.3	+7.7
Uncut Area	"	30.6	+0.7	+2.3
		Fall 1971		
Control	11/71	19.9		
Treated Plot	"	20.2	+0.3	+1.5
Cut Area	"	22.3	+2.4	+12.1
Uncut Area	"	19.5	-0.4	-2.0
Post-Treatment		Fall 1972		
Control	9/73	31.0		
Treated Plot	"	29.0	+8.0*	+38.1
Cut Area	"	36.3	+15.3*	+72.9
Uncut Area	"	20.0	-1.0	-4.8

*Significant at $\alpha = 0.05$

Table A3. Fall Soil Moisture Integrated to Two (2) Meters for Pre- and Post-Treatment Conditions for the C1 (Control) and C2 (Treatment) Plots.

	Date	Soil Water (Cm)	Deviation from Control (Cm)	Percent
Pre-Treatment		Fall 1970		
Control	10/70	28.9		
Treated Plot	"	23.1	-5.8*	-20.1
Cut Area	"	23.8	-5.1*	-17.6
Uncut Area	"	21.7	-7.2*	-24.9
		Fall 1971		
Control	11/71	21.4		
Treated Plot	"	16.9	-4.5	-21.0
Cut Area	"	17.8	-3.6	-16.8
Uncut Area	"	15.5	-5.9	-27.6
Post-Treatment		Fall 1972		
Control	9/72	20.9		
Treated Plot	"	21.0	+0.1	+0.5
Cut Area	"	27.8	+6.9*	+33.0
Uncut Area	"	1	-7.8*	-37.3

*Significant at $\alpha = 0.05$

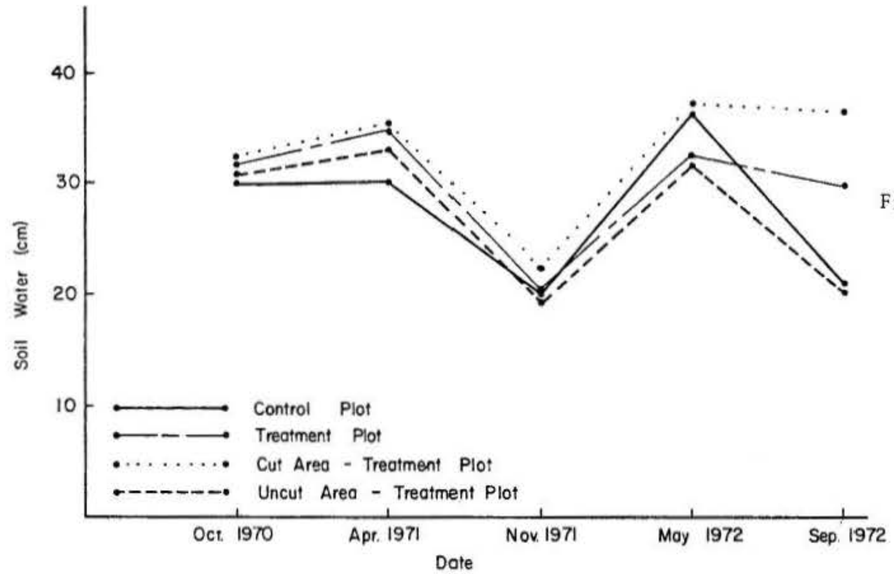

Figure A1. Average Soil Water in the Top 2 Meters for the A Plots from October 1970 to September 1972.

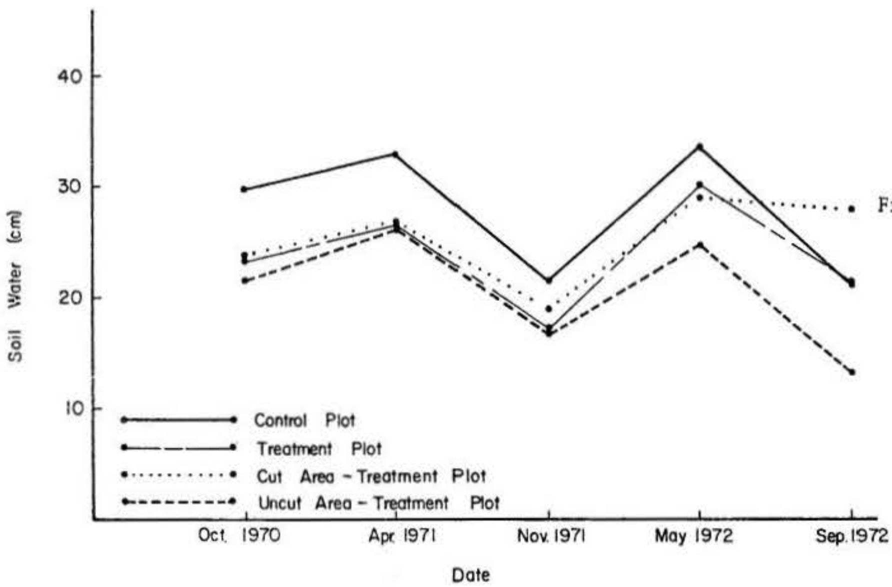

Figure A2. Average Soil Water in the Top 2 Meters for the B Plots from October 1970 to September 1972.

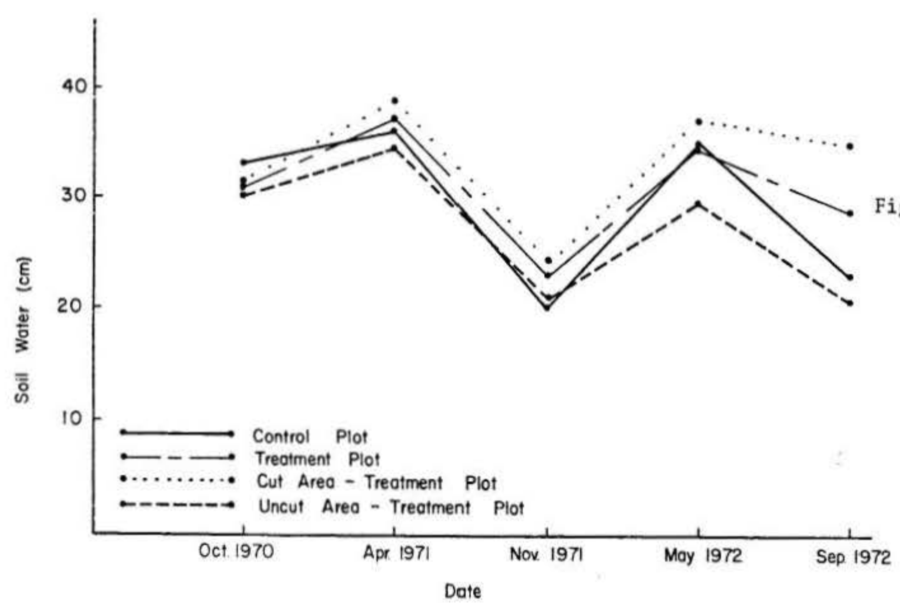

Figure A3. Average Soil Water in the Top 2 Meters for the C Plots from October 1970 to September 1972.

APPENDIX B

SNOW WATER DATA

Table B1. Average Snow Water Equivalents (cm) and Ratios.

A - PLOTS

Date	Control	Treatment	Cut	Uncut	Treatment/Control	Cut/Control	Uncut/Control	Cut/Uncut
				-- Pre-Treatment --				
2/4/69	4.70	4.27	4.37	4.24	0.91	0.92	0.90	1.02
3/29/69	4.34	5.23	5.56	5.18	1.20	1.28	1.19	1.07
11/26/69	3.05	4.93	6.45	4.62	1.62	2.11	1.51	1.39
1/10/70	3.63	5.00	4.80	5.03	1.38	1.32	1.38	0.95
2/7/70	6.81	8.84	8.59	8.89	1.30	1.26	1.30	0.96
3/28/70	12.24	13.79	14.68	13.64	1.13	1.19	1.11	1.07
4/4/70	14.05	16.97	17.50	16.87	1.21	1.24	1.20	1.03
1/16/71	3.58	3.91	3.96	3.91	1.09	1.10	1.09	1.01
3/10/71	4.88	5.46	5.44	5.46	1.12	1.11	1.11	0.99
				-- Post-Treatment --				
1/15/72	4.39	4.39	3.35	4.57	1.00	0.76	1.04	0.73
3/23/72	.94	1.65	.33	1.91	1.76	---	MELT EFFECT	---
11/18/72	2.39	1.96	2.34	1.91	0.82	0.97	0.79	1.22
12/14/72	5.94	5.87	6.43	5.77	0.99	1.08	0.97	1.11
1/24/73	8.69	8.64	9.20	8.53	0.99	1.05	0.98	1.07
3/31/73	10.29	11.48	13.13	11.18	1.12	1.28	1.09	1.18
				-- Average --				
Before	6.35	7.60	7.93	7.52	1.17	1.21	1.16	1.03
After	5.33	5.21	5.31	5.18	1.06	1.02	1.07	0.96

Table B2. Average Snow Water Equivalents (cm) and Ratios.

B - PLOTS

Date	Control	Treatment	Cut	Uncut	Treatment/Control	Cut/Control	Uncut/Control	Cut/Uncut
				-- Pre-Treatment --				
2/4/69	5.39	4.17	3.91	4.22	0.95	0.96	0.94	1.02
3/29/69	7.90	6.22	5.97	6.25	0.93	1.02	0.89	1.14
11/26/69	8.97	8.51	8.51	8.48	0.97	1.06	0.95	1.11
1/10/70	11.58	8.51	9.65	8.56	0.81	0.75	0.82	0.92
2/7/70	14.73	12.19	11.81	12.22	0.81	0.81	0.80	1.02
3/28/70	21.51	18.95	19.25	18.90	0.92	0.91	0.91	0.99
4/4/70	24.84	21.39	20.52	21.49	0.94	0.92	0.94	0.97
1/16/71	6.68	4.09	4.19	4.06	0.51	0.45	0.51	0.87
3/10/71	10.03	6.17	5.79	6.20	0.64	0.60	0.64	0.94
				-- Post-Treatment --				
1/15/72	3.73	2.57	2.16	2.62	0.76	0.51	0.80	0.63
3/23/72	5.46	3.05	1.75	3.20	0.52	---	MELT EFFECT	---
11/18/72	3.96	3.07	4.09	2.95	0.80	1.29	0.72	1.79
12/14/72	11.58	6.07	6.27	6.05	0.86	1.01	0.83	1.21
1/24/73	11.86	10.14	10.26	10.11	0.98	1.12	0.95	1.17
3/31/73	17.20	13.39	14.17	13.28	0.89	1.18	0.84	1.40
				-- Average --				
Before	12.40	9.00	9.78	10.03	0.83	0.84	0.82	1.01
After	7.77	5.46	5.69	5.41	0.83	0.85	0.82	1.02

Table B3. Average Snow Water Equivalents (cm) and Ratios.

C - PLOTS

Date	Control	Treatment	Cut	Uncut	Treatment / Control	Cut / Control	Uncut / Control	Cut / Uncut
				-- Pre-Treatment --				
2/4/69	3.86	3.66	3.71	3.63	0.95	0.96	0.94	1.02
3/29/69	6.13	5.77	6.38	5.59	0.93	1.02	0.89	1.14
11/26/69	6.73	6.55	7.14	6.40	0.97	1.06	0.95	1.11
1/10/70	8.46	6.86	6.43	7.00	0.81	0.75	0.82	0.92
2/7/70	11.99	9.65	9.83	9.60	0.81	0.81	0.80	1.02
3/28/70	17.32	15.88	15.77	15.90	0.92	0.91	0.91	0.99
4/4/70	20.19	19.03	18.64	19.13	0.94	0.92	0.94	0.97
1/16/71	6.07	3.07	2.74	3.15	0.51	0.45	0.51	0.87
3/10/71	8.41	5.36	5.11	5.39	0.64	0.60	0.64	0.94
				-- Post-Treatment --				
1/15/72	4.80	3.66	2.46	3.86	0.76	0.51	0.80	0.63
3/23/72	3.73	1.96	1.91	1.98	0.52	---	MELT EFFECT	---
11/18/72	2.92	2.34	3.79	2.11	0.80	1.29	0.72	1.79
12/14/72	7.11	6.12	7.21	5.94	0.86	1.01	0.83	1.21
1/24/73	9.63	9.45	10.85	9.22	0.98	1.12	0.95	1.17
3/31/73	12.55	11.18	14.83	10.57	0.89	1.18	0.84	1.40
				-- Average --				
Before	9.91	8.41	8.41	8.41	0.83	0.84	0.82	1.01
After	6.10	5.39	6.07	5.28	0.83	0.85	0.82	1.02

KEY WORDS: Hydrology, lodgepole pine cutting, vegetation change, water yield improvement.

Paired plot studies of soil water and snow water equivalent were conducted from 1968 to 1973 in the lodgepole pine type on the Eastern Slope of the Colorado Front Range at an elevation of 9000 feet. Small patch cuts ranging in size from 0.29 acre to 0.61 acre were cut in the fall of 1971. Based on analysis of pre- and post-cut relationships to the paired control plots, the average increase in water potentially available for streamflow from the cut areas was 11.8 cm. Increase in snow on a relatively small part of the cut areas accounted for 21% of the increase. The remainder of the increase was attributed to reduced evapotranspiration as a result of tree removal. There were no significant changes in potential water yields from the adjacent uncut forest.

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