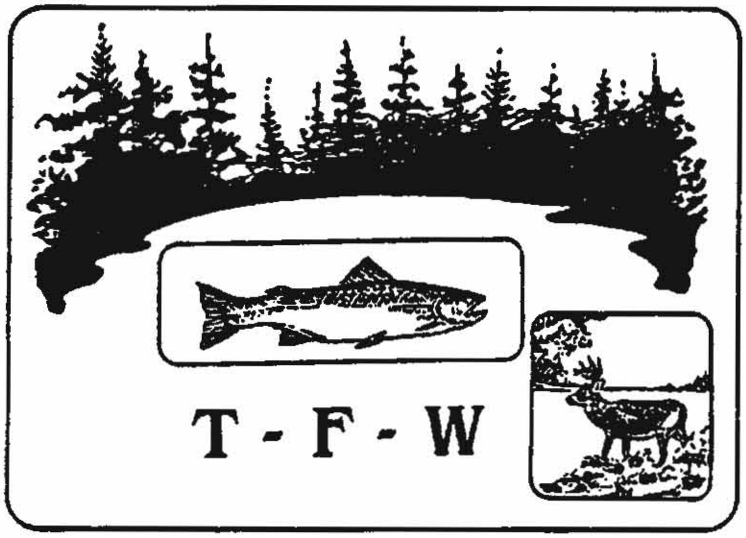
TFW-18A-89-003

TIMBER-FISH-WILDLIFE PROJECT

EFFECTS OF TIMBER HARVEST ON RAIN-ON-SNOW RUN-OFF IN THE TRANSCIENT SNOW ZONE OF THE WASHINGTON CASCADES

INTERIM FINAL REPORT



MAY 1989

EFFECTS OF TIMBER HARVEST ON RAIN-ON-SNOW RUNOFF IN THE TRANSIENT SNOW ZONE OF THE WASHINGTON CASCADES

Interim Final Report Submitted to TFW Sediment,
Hydrology, and Mass Wasting (SHAM) Steering Committee

for

Project 18 (Rain-on-Snow)

In Accordance With Cooperative Agreement No. PNW 88-593

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May 22, 1989

THIS DOCUMENT CONTAINS PRELIMINARY DATA AND REPRESENTS PROGRESS DURING THE FIRST YEAR OF A TWO- TO THREE-YEAR STUDY

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SUMMARY

A field study is being conducted to determine the effects of forest cover density on rate of water input to soils during rain-on-snow conditions in the transient snow zone of the western Cascades of Washington.

Snowmelt runoff plots are located in the South Fork Canyon Creek (South Fork Stillaguamish) drainage and in the Finney Creek/Deer Creek (Skagit and North Fork Stillaguamish) area. Plots consist of a snow collector box connected to a time-of-event recorder in a clearcut area, a mature forest stand, and a plantation >25 years old at elevations of 460 m (1500 ft), 610 m (2000 ft), and 760 m (2500 ft). A weather station is located inthe clearcut plot at each elevation.

First-year results indicate the presence or absence of forest cover had a dramatic effect on rate of water outflow from snowpacks. In the 24 hours of maximum snowmelt during two rain-on-snow events with common conditions of rainfall, wind, humidity, and air temperature, outflows from the snowpack in the clearcut plots were 84 and 90 percent greater than in the plots with mature forest. Similar outflows in plots in plantations were 37 and 40 percent greater than in plots with forest.

Such drastic changes in 24-hour water input could trigger landslides on marginally stable slopes within the transient snow zone and could affect rate of sediment delivery to and through Type 4 and 5 waters. These preliminary results suggest so-called hydrologic recovery is only about 50 percent complete in forest plantations approximately 25 years old.

The study will continue at least through the 1989-90 snow season.

INTRODUCTION

Productive commercial forest land in western Washington occupies roughly 4 million ha (10 million acres). This land not only supports the timber industry, which employs some 50,000 workers and contributes more than $7 billion to the state's economy, but also is basic to both the commercial and sport fisheries, which together contribute some $500 million to the state's economy. Indian tribes derive a major portion of their income from salmon fishing, and salmon is important to Indian history and culture. Recent court rulings have affirmed Indian rights to half the salmon and to ensure that land management does not impair salmon production. In addition, there are roughly 2.75 million inhabitants of the Puget Sound lowlands, and many of these people use commercial forest land for recreation, much of it involving streams and riparian areas. For much of the non-Indian population also, salmon is an imporant part of the region's culture.

There has been continuing controversy over the perceived incompatibility between timber harvest and the quantity and quality of fish habitat. The National Forest Management Act (NFMA) of 1976 specifies that riparian areas be given special attention and that soil and water resources are to be protected. Additionally, Washington State's 1988 Forest Practices Rules provide for riparian management zones in which trees shall be left for wildlife and fisheries habitat.

Protection of riparian zones cannot be separated from forest management activities elsewhere in the watershed because such activities may seriously affect the integrity of riparian zones and render aquatic and riparian zones unsuitable for fish habitat. In particular, high streamflows and debris avalanches and torrents during rain-on-snow conditions can remove riparian vegetation and large organic debris or deposit sediment and organic debris in such quantities so damaging to fish habitats that recovery will require many years or even decades. This appears to be especially true when harvest activities interact with these hydrometeorologic conditions to intensify them.

LITERATURE REVIEW

Rain-on-snow runoff is an integral part of several geomorphic processes operating on hillslopes and in streams in western Washington as well as elsewhere in the Pacific Northwest (Harr, 1981; Beaudry and Golding, 1983). It has also been responsible for considerable damage to riparian zones and to forest transportation systems, for downstream flooding, and for loss of human life (Rothacher and Glazebrook, 1968; Waananen et al., 1971; Skagit County Rural Development Committee, 1976).

Research results from western Oregon suggest that timber cutting, particularly clearcutting, can increase both snow accumulation and subsequent melting of snow during rainfall in the transient snow zone, the range of elevations where both rain and snow are common in most winters (Berris, 1984; Berris and Harr, 1987). Using snowmelt indices developed by the U. S. Army Corps of Engineers (1956, 1960), Harr (1981) described potential increases in rate of water delivery to soil following clearcut logging. Predicted increases were dependent primarily on estimated increases in transfer of sensible and latent heats to the snow due to higher windspeeds in logged areas.

Differences in runoff during rain-on-snow conditions were observed following clearcutting in one of a pair of small, experimental watersheds. Harr and McCorison (1979) found short-term differences in snow interception and melt caused smaller, delayed peak flows in a clearcut watershed. Snow intercepted by the forest canopy in the unlogged watershed melted relatively quickly so that that watershed's runoff occurred sooner that than in the clearcut watershed. Using data from much larger rain-on-snow events in the same watersheds, Harr (1986) found size of peak flows in the clearcut watershed were nearly double the size of those in the unlogged watershed when windspeeds and air temperatures were highest. According to estimates based on snowmelt indices, differences in rate of water delivery to soil during rain-on-snow would be greatest when windspeed and air temperatures are high (Harr, 1981).

Increases in rate of streamflow do not appear to be restricted to only small, headwater basins. Using long-term flow records and timber harvest records for adjacent large watersheds in western Oregon, Christner and Harr (1982) noted apparent increases in these watersheds' abilities to produce streamflow during major runoff events most of which resulted from snowmelt during rainfall. These increases appeared to be related to relative rates of harvest in the transient snow zones of each watershed.

The foregoing watershed studies led to the initiation of a microclimatological study in the H. J. Andrews Experimental Forest in western Oregon (Berris and Harr, 1987). The objectives of this study were to determine the difference in rate of water delivery from snowpacks in forested and clearcut areas and to measure any logging-caused changes in the energy balance of snowpacks that would explain changes in rate of water delivery. The study design was based on the occurrence of 2-6 moderate to large rain-on-snow runoff events each year as suggested by 30 years' weather records for the study area. This study showed that interception and snowmelt in the forest canopy can be equally as important as increased rate of melt in delivering more snowpack water to the soil following logging. Water equivalent of snowpacks in the clearcut plot were commonly 2-3 times greater than in the forested plot because canopy melt frequently caused the forest to route a large part of its snowmelt water offsite before a rain-on-snow event occurred. The single, moderately large rain-on-snow event during this study supported the hypothesis that wind-caused transfers of sensible and latent heats to the snowpack were substantially larger in the clearcut.

But the occurrence of only one rain-on-snow event of the size the study was designed for limited the strength of conclusions that could be drawn from the study and failed to eliminate the speculation and conjecture regarding the effect of clearcutting on rain-on-snow runoff. Furthermore, scarcity of suitably large rain-on-snow events severely restricted obtaining information on rate of recovery of logged areas after a third plot had been added in an adjacent thinned plantation.

Changes in rain-on-snow runoff and attendant erosion are obvious mechanisms whereby forest management activites may cumulatively affect stream channels, fish habitats, and riparian zones. Increased rate of water delivery to soils during rain-on-snow or major rain storms can affect landslides and high flows that can alter stream channel morphology and fish habitats. In addition, construction of forest roads and drainage systems can intercept and redirect subsurface flow onto unstable slopes during periods of high runoff. In order to combine future and past management activities into any assessment of cumulative watershed effects, information is needed on the effects of logging activities on hillslope and basin hydrology during rain-on-snow conditions.

OBJECTIVES

The objective of this study has been to determine the effects of forest cover density on rate of water input to soil during rain-on-snow conditions. This will show the initial size of the increase attributable to clearcut logging and will provide an estimate of the rate of recovery of logged areas as forest regrowth progresses. Results of this field study will supplement results of similar research conducted recently in western Oregon in that a much larger number of events will either strengthen the suspected link between logging and rain-on-snow runoff or show that it is of little importance.

METHODS

This study consists of a total of 18 plots where outflow from snow has been measured under different forest cover densities. Nine plots are located in the watershed drained by South Fork Canyon Creek, a major tributary to the South Fork Stillaguamish River near Robe, Washington (Figure 1), and nine are located in the Finney Creek and upper Deer Creek drainages (hereafter collectively referred to as the Finney Creek plots),

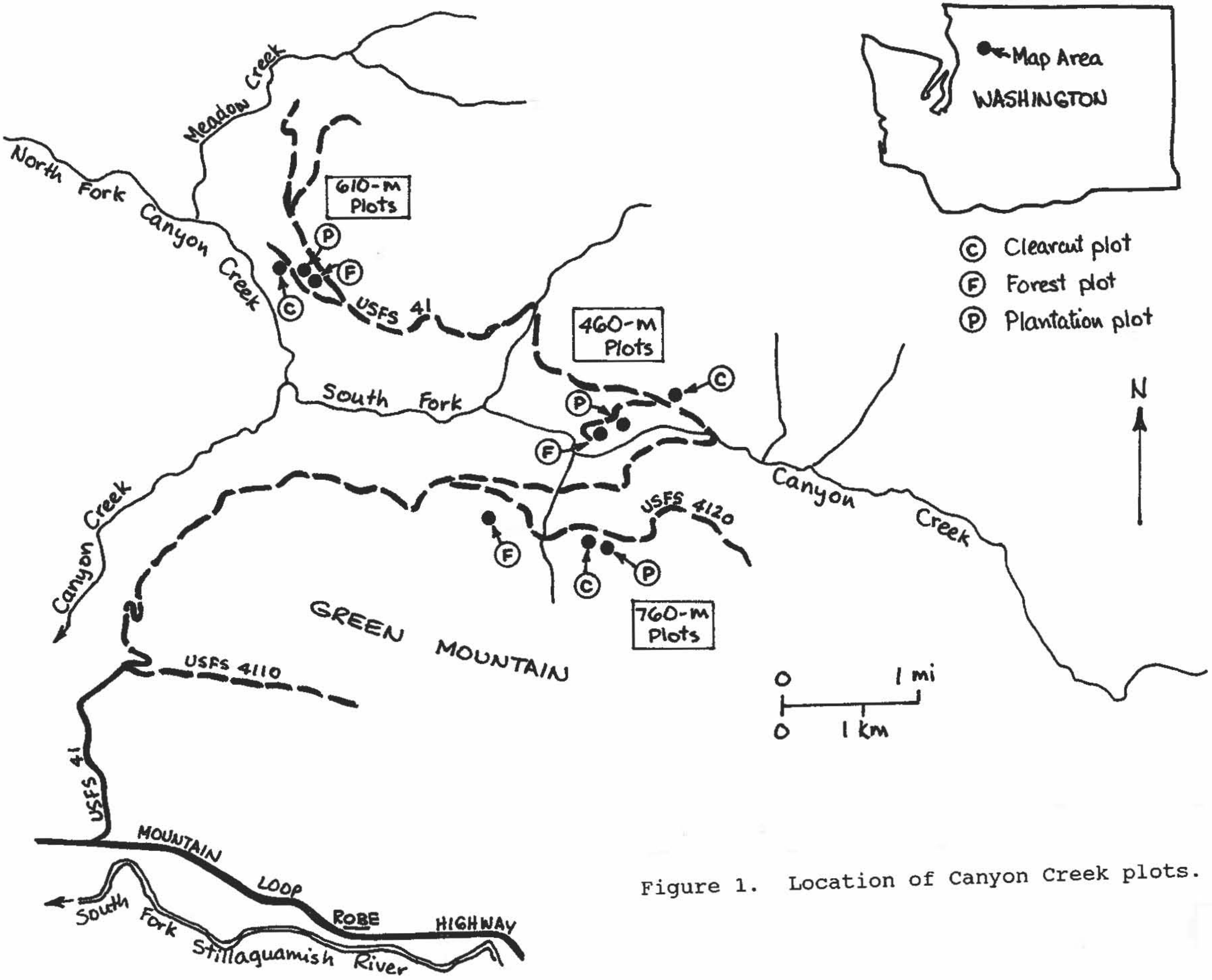

Figure 1. Location of Canyon Creek plots.

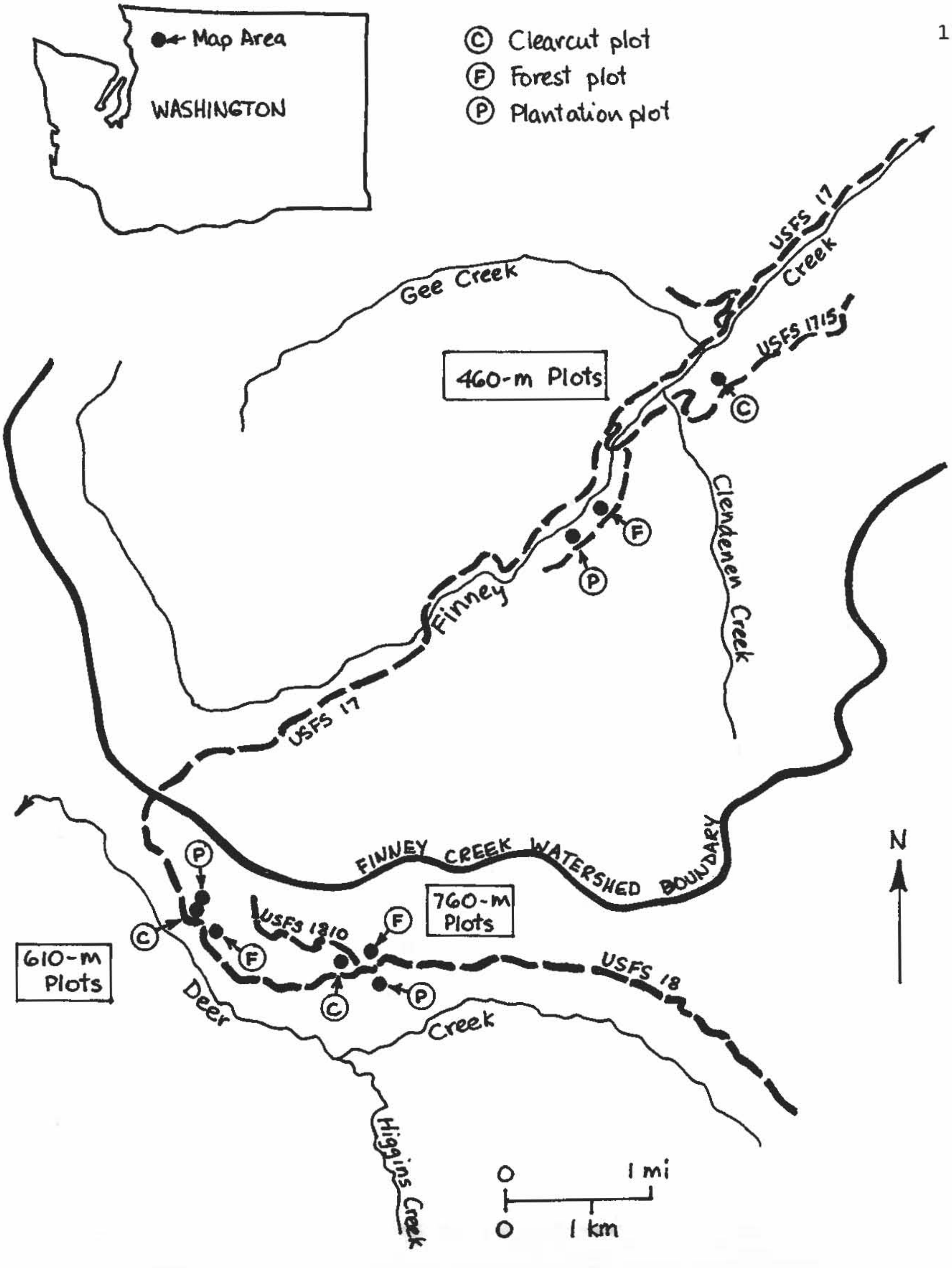

Figure 2. Location of Finney Creek plots.

tributaries to the Skagit River near Concrete, Washington and the North Fork Stillaguamish Rivers, respectively (Figure 2). Sites for plots were selected in July and August 1988, and plots were established in September 1988.

Plots were located where mature forest, clearcut areas, and forest plantations are located in close proximity and at the same elevation (Figure 3). At each elevation there are plots in mature forest, a clearcut area, and a forest plantation. At each location (Canyon Creek or Finney Creek) plots were established at each of three elevations: 460 m (2500 ft), 610 m (2000 ft), and 760 m (2500 ft) to maximize the probability of having at least one forest-clearcut-plantation set in the zone of active snowmelt during any given rain-on-snow event. We had hoped to establish plots in younger, less dense plantations, but few of these could be found at the same elevation as mature forest stands and recent clearcuts. Although age and density of forest vegetation present at each plot have not yet been determined, plantations are estimated to be at least 25 years old.

Each plot consists of a 4-ft by 7-ft snow collector box constructed of plywood and 2-in by 10-in lumber (Figure 4). Each collector is lined with Hypalon, a virtually indestructible rubber-like material that can withstand punctures by falling limbs or deer hooves. Rainfall and snowmelt water drains from each collector through 2-in diameter ABS pipe to a large stainless steel tipping bucket (Figure 5) attached to an Omnidata single channel time-of-event recorder equipped with a removable data storage module (DSM). Each tipping bucket is housed in a steep-roofed A-frame shelter. All plots are located on a gentle slopes or flat benches to prevent damage to collector boxes by snow creep and to minimize measurement errors associated with water flowing into a collector box from snow not directly above it or water flowing away from the snowpack directly above a collector box.

At each elevation a weather station was established to provide information to characterize both snow accumulation and snowmelt events (Figure 6). Each weather station, which is located adjacent to the snow collector box in the clearcut area, consists of an Omnidata Easylogger to which are connected an R. M. Young wind monitor for measuring windspeed and direction, a Vaisala air temperature and relative humidity sensor, a Skye pyranometer for measuring incident shortwave radiation, and a recording raingage charged with non-toxic antifreeze to melt snow. Antifreeze displaced by rain or snow falling into a raingage is measured by a small tipping bucket. The Easylogger recorder also serves as the event recorder for the clearcut's tipping bucket. Data are stored on a 64K EPROM data storage pack (DSP). Weather stations were activated in October 1988 in Canyon Creek and in November 1988 at Finney Creek.

Figure 3. Plots were established where mature forest, recent clearcuts, and plantations were located in close proximity at the same elevation. This view looking southeast across the South Fork Canyon Creek watershed shows the clearcut and plantation where the 760-m (2500-ft) plots are located (left 1/4 of photograph).

Figure 4. Snow is collected in boxes located on nearly level ground to prevent damage to boxes from snow creep and to minimize measurement errors caused by flow of melt water being altered by sloping ice lenses in the snowpack.

Figure 5. Rain and snowmelt water are routed to a large tipping bucket measuring device.

Figure 6. Information used to characterize snow accumulation and melt periods is obtained from a weather station at each elevation. The stump in the background is a camouflaged raingage.

Because of the threat of vandalism, installation of weather equipment was delayed until the end of hunting season. Also, raingages were wrapped in redcedar bark to make them look like stumps, and all equipment was painted flat black or camouflage colors. Nevertheless, the wind monitor and raingage at the 460-m (1500-ft) elevation in Canyon Creek were damaged by bullets sometime in December or January.

We had originally planned to visit plots every month or no longer than two months if weather did not permit access monthly. Field visits were made to Canyon Creek on November 22, 1988, January 31, 1989, and March 21, 1989. Finney Creek plots were visited December 6, 1988, February 14, 1989, and March 22, 1989. Arrangements were made to use a new snowcat obtained by the Watershed Reserch Unit in Corvallis, Oregon. Difficulties encountered in delivery of the snowcat and readying a towing vehicle delayed the second field visit over three weeks during which time antifreeze in all raingages became so diluted by rain and snowfall that all raingages froze in late January. Thus, during the period of snowfall and extreme cold weather in early February, no raingages were operating.

PRELIMINARY RESULTS

Table 1 illustrates typical data from a weather station and a snow collector box in a clearcut plot for a 24-hr period. In this example, from midnight on December 12 to midnight on December 13, nearly identical amounts of rainfall (column 11) and outflow from the snow collector box (column 12) with air temperatures at 6.4-10.7 degrees C (43-51 degrees F) (column 4) indicate rainfall. December 12 was a very dark, cloudy day as illustrated by maximum hourly incident shortwave radiation of only 18.7 watts per square meter (column 8). A bright sunny day in December at this latitude would have incident shortwave radiation on the order of 300 watts per square meter.

Snowfall is indicated when air temperatures are below or slightly above freezing and rainage data are much higher than collector box outflow data. This is illustrated by Table 2, a 12-hr period from midnight December 28 to noon December 29. Between 0100 hr and 0600 hr, 17 mm (0.7 inch) of precipitation occurred as snow while air temperatures were -0.33 to 0.11 degrees C (30-32 degrees F). This represents a snow depth of roughly 17 cm (7 in).

Snowmelt during rainfall is represented by outflow from the snowpack (column 12) being greater than rainfall (column 11). For example, Table 3 shows an 18-hr period from midnight to 1900 hr on January 3, 1989. During this period, 97 mm (3.8 in) of water flowed from the snowpack while rainfall totaled 36 mm (1.4 in).

Table 1. Weather and snow collector outflow data for 460-m (1500-ft) elevation clearcut plot at Finney Creek, December 12-13, 1988.

Column Number*											
1	2	3	4	5	6	7	8	9	10	11	12
12	12	100	7.38	0.14	2.19	1.01	-1.2	95.2	233.1	2.0	2.5
12	12	200	7.57	0.15	1.78	0.90	-1.2	94.9	230.5	1.0	0.8
12	12	300	7.14	0.44	0.53	0.82	-1.2	95.6	129.0	0.0	0.0
12	12	400	6.66	0.14	0.02	0.10	-1.2	96.5	104.9	0.0	0.4
12	12	500	6.53	0.13	0.07	0.27	-1.2	96.6	154.8	0.0	0.0
12	12	600	6.45	0.13	0.00	0.04	-1.2	96.6	246.0	1.0	0.0
12	12	700	6.34	0.11	0.05	0.19	-1.2	96.7	126.8	1.0	1.3
12	12	800	6.38	0.12	0.00	0.00	-1.1	96.7	115.8	0.0	0.4
12	12	900	6.40	0.14	0.01	0.05	1.3	96.7	209.8	1.0	1.3
12	12	1000	6.70	0.19	0.00	0.00	17.0	96.7	89.4	1.0	0.8
12	12	1100	7.03	0.14	0.00	0.00	18.7	96.5	281.2	2.0	1.3
12	12	1200	6.96	0.12	0.00	0.00	14.9	96.6	342.1	2.0	2.1
12	12	1300	6.95	0.13	0.10	0.27	11.2	96.6	299.2	3.0	3.0
12	12	1400	6.80	0.11	0.02	0.11	5.2	96.7	335.2	6.0	5.1
12	12	1500	6.60	0.10	0.28	0.55	1.6	96.7	237.3	5.0	5.1
12	12	1600	7.80	0.56	1.63	1.07	-0.2	96.4	117.6	2.0	1.7
12	12	1700	10.06	0.52	2.77	1.70	-1.2	95.3	270.6	1.0	0.8
12	12	1800	10.69	0.23	3.21	1.76	-1.2	94.4	260.9	1.0	0.8
12	12	1900	10.22	0.33	4.65	2.11	-1.3	95.5	262.9	1.0	3.0
12	12	2000	9.61	0.22	4.59	1.74	-1.3	95.8	266.4	5.0	6.4
12	12	2100	8.68	0.72	6.48	3.30	-1.3	94.8	257.6	4.0	5.1
12	12	2200	6.77	0.45	5.65	2.25	-1.3	92.0	241.5	3.0	3.0
12	12	2300	6.57	0.20	6.06	2.06	-1.3	85.7	236.5	1.0	0.4
12	13	0	5.97	0.51	5.62	1.91	-1.3	87.4	252.7	0.0	0.4

*

Column 1: Month
Column 2: Day
Column 3: Hour
Column 4: Mean air temperature (degrees C)
Column 5: Standard deviation of air temperature (degrees C)
Column 6: Mean windspeed (m/sec)
Column 7: Standard deviation of windspeed (m/sec)
Column 8: Mean shortwave radiation (watts/square meter)
Column 9: Mean relative humidity (percent)
Column 10: Wind azimuth (degrees)
Column 11: Precipitation (mm)
Column 12: Snow collector outflow (mm)

Table 2. Weather and snow collector outflow data for 760-m (2500-ft) elevation clearcut plot at Finney Creek, December 29, 1988.

Column Number*											
1	2	3	4	5	6	7	8	9	10	11	12
12	29	100	-0.67	0.07	1.38	1.42	-1.5	95.1	249.2	0.0	0.0
12	29	200	-0.33	0.15	1.79	1.53	-1.4	94.4	203.3	5.0	0.0
12	29	300	-0.27	0.07	1.67	1.35	-1.4	94.9	223.3	3.0	0.0
12	29	400	-0.23	0.07	1.17	1.18	-1.5	95.3	250.6	3.0	0.0
12	29	500	-0.13	0.05	0.98	0.96	-1.4	95.5	289.9	3.0	0.0
12	29	600	0.11	0.09	0.80	0.79	-1.5	95.6	37.9	3.0	0.0
12	29	700	0.21	0.14	0.73	1.12	-1.4	95.8	23.8	0.0	0.0
12	29	800	0.47	0.06	0.95	0.94	-1.5	95.9	254.9	0.0	0.0
12	29	900	0.62	0.15	0.63	0.83	-0.3	95.9	346.7	0.0	0.0
12	29	1000	0.73	0.21	0.51	0.63	4.0	95.7	61.7	0.0	0.0
12	29	1100	1.25	0.29	0.73	0.69	10.8	95.2	24.4	0.0	0.0
12	29	1200	1.29	0.23	0.56	0.64	13.3	94.7	343.0	0.0	0.0

*
Column 1: Month
Column 2: Day
Column 3: Hour
Column 4: Mean air temperature (degrees C)
Column 5: Standard deviation of air temperature (degrees C)
Column 6: Mean windspeed (m/sec)
Column 7: Standard deviation of windspeed (m/sec)
Column 8: Mean shortwave radiation (watts/square meter)
Column 9: Mean relative humidity (percent)
Column 10: Wind azimuth (degrees)
Column 11: Precipitation (mm)
Column 12: Snow collector outflow (mm)

There were four periods of snowmelt during rainfall that are usable for the objectives of this study. Only two periods will be described here: January 2-4, 1989, and January 15-18, 1989. The March 2-4, 1989 event occurred after the severe cold weather of February and is omitted from analyses because of the presence of extensive layers of ice in the snowpack. The fourth event, which is probably the largest of the four, occurred April 5-6, 1989 and was responsible for minor flooding on several major rivers in the western Cascades and flood watches on several others. The data during this latter period have not been retrieved, because at the time this report was written, the final field visit of the 1988-89 snow season had not been attempted because snow still precludes access by four-wheel drive. (The snowcat is no longer available.)

Table 3. Weather and snow collector outflow data for 760-m (2500-ft) elevation clearcut plot at Finney Creek, January 3, 1989.

Column Number*

1	2	3	4	5	6	7	8	9	10	11	12
1	3	100	3.17	0.16	1.46	1.16	-1.5	96.0	304.8	0.0	0.0
1	3	200	3.32	0.24	1.41	1.15	-1.5	96.6	278.6	0.0	0.4
1	3	300	3.65	0.11	1.48	1.22	-1.5	96.7	232.4	0.0	2.5
1	3	400	3.75	0.16	1.21	0.88	-1.6	97.0	257.2	3.0	2.5
1	3	500	3.94	0.14	0.92	0.97	-1.5	97.1	254.4	0.0	4.2
1	3	600	4.21	0.13	1.36	1.28	-1.6	97.1	240.4	3.0	5.5
1	3	700	4.34	0.12	1.79	1.35	-1.6	97.2	241.1	3.0	8.5
1	3	800	4.58	0.14	2.16	1.49	-1.3	97.3	211.0	1.0	7.2
1	3	900	4.72	0.17	1.90	1.40	0.7	97.4	206.5	2.0	4.7
1	3	1000	5.16	0.18	2.59	1.58	2.2	97.5	197.8	0.0	3.0
1	3	1100	5.37	0.15	2.98	1.82	7.7	97.4	224.0	0.0	3.0
1	3	1200	5.91	0.36	2.91	1.77	12.3	96.2	222.5	0.0	2.5
1	3	1300	6.28	0.21	3.12	1.98	12.0	95.0	190.4	0.0	3.0
1	3	1400	5.99	0.17	3.25	2.16	6.2	95.5	192.9	0.0	3.8
1	3	1500	5.42	0.14	2.70	1.83	6.0	97.1	189.0	3.0	10.2
1	3	1600	5.10	0.15	2.10	1.45	4.1	97.3	199.3	12.0	16.6
1	3	1700	4.21	0.70	1.32	1.14	-1.0	97.3	217.5	3.0	11.0
1	3	1800	2.38	0.47	0.63	0.80	-1.6	97.3	225.1	1.0	5.1

*
Column 1: Month
Column 2: Day
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Column 9: Mean relative humidity (percent)
Column 10: Wind azimuth (degrees)
Column 11: Precipitation (mm)
Column 12: Snow collector outflow (mm)

Neither of the two January events resulted in high runoff downstream because significant snowmelt and snowpack outflow was restricted to only narrow bands of elevation--insufficient proportions of watersheds to cause high flows. They did, however, result in substantial differences in outflow from snow collectors among the clearcut, forest, and plantation plots. Precipitation and air temperature data indicate snow accumulated at all plots throughout January 1 and early January 2. For example, at the time rainfall began around 0800 hr on January 2, roughly 30 cm (12 in) of snow containing 5-8 cm (2-3 in) of water equivalent had accumulated at the 460-m (1500-ft) elevation at Finney Creek. Air temperature rose to 5.0 degrees C (41 degrees F) by 1400 hr as light rain continued falling (Figure 7). Around 0600 hr on January 3, windspeeds tripled as air temperature climbed to 8.9 degrees C (48 degrees F) and rainfall rate increased. By 1500 hr, rainfall had ceased, but moderate windspeeds persisted as air temperature remained at 3.3-4.4 degrees C (38-40 degrees F) and snow continued to melt although at a reduced rate.

Tables 4 and 5 compare outflow from collector boxes among the three plots at the 460-m (1500-ft) elevation in Finney Creek and Canyon Creek, respectively. During the January 2-4 event at Finney Creek, outflow from the snowpacks in the clearcut and plantation plots were respectively 57 percent and 35 percent greater than in the forest plot. At Canyon Creek, outflow from the clearcut and plantation plots respectively were 24 percent and 15 percent greater than from the forest plot.

Table 4. Rainfall and outflow from snow collectors in plots at the 460-m (1500-ft) elevation at Finney Creek, January 2-4, 1989.

		Collector Outflow		
Date	Rainfall	Clearcut	Forest	Plantation
	mm	mm	mm	mm
Jan. 2	15	14	16	21
Jan. 3	28	83	45	63
Jan. 4	1	5	4	4
Totals	44	102	65	88
	(1.7 in)	(4.0 in)	(2.5 in)	(3.4 in)

Of particular interest here are the differences in outlfow on January 3 when the warmest and windiest conditions occurred.

During this 24-hour period at Finney Creek, outflow from the snowpack in the clearcut was 84 percent greater than in the forest and 90 percent greater in the clearcut than in the forest at Canyon Creek. At Finney Creek, outflow in the plantation was 40 percent greater than the forest while at Canyon Creek, it was 37 percent higher.

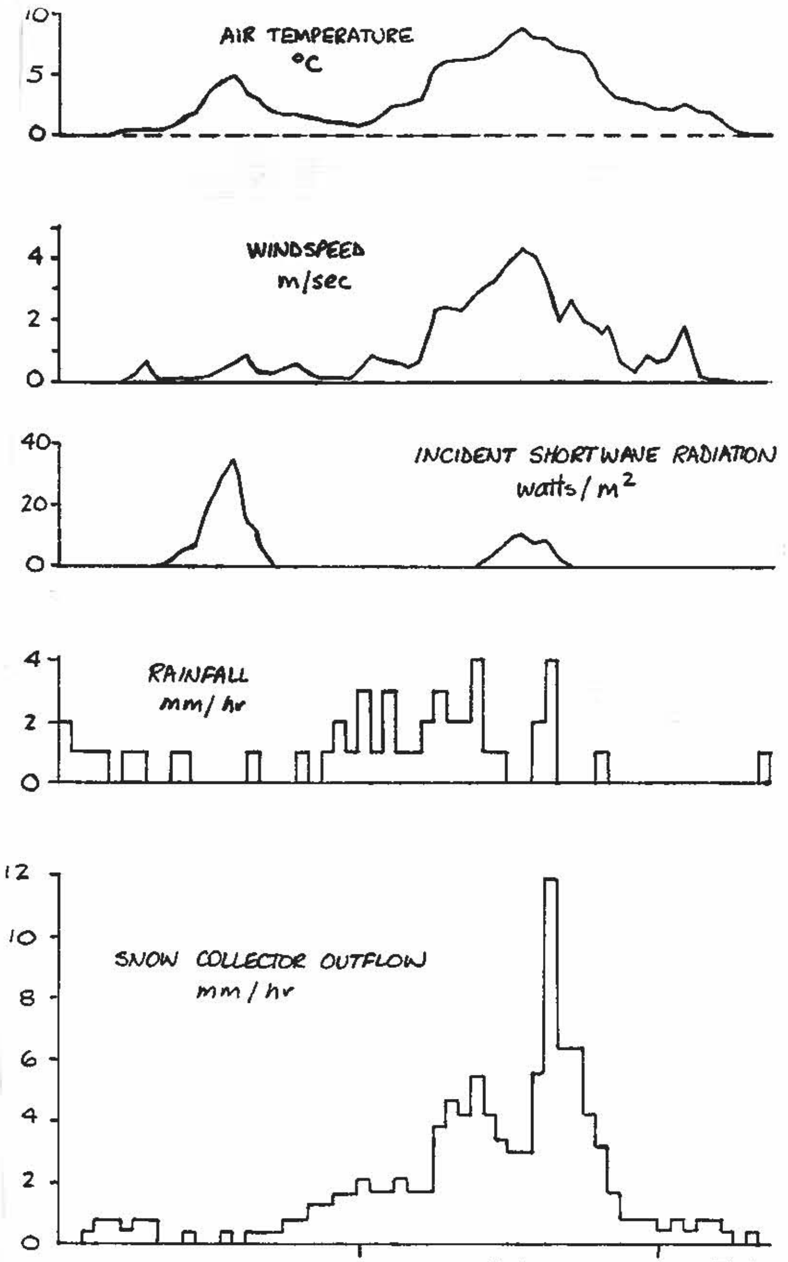

Figure 7. Air temperature, windspeed, incident shortwave radiation, rainfall, and collector outflow in the 460-m (1500 ft) clearcut plot at Finney Creek, January 2-4, 1989.

A major difference between the 460-m (1500-ft) plots at Finney Creek and those at Canyon Creek is that the Finney plantation consists of thinned Douglas-fir and the Canyon Creek plantation consists of unthinned western hemlock. The open condition of the Finney plantation had been expected to produce a much higher rate of snowmelt than the forest plot at this elevation because less dense vegetation would aid air movement and the transfer of latent and sensible heat to the snow. The rates of outflow in the Canyon Creek plantation plot relative to those in the forest plot was not expected. We will look closely at the characteristics of vegetation at each site for an explanation of the relatively high rates of snowmelt during rainfall in the Canyon Creek 460-m (1500-ft) plantation plot.

Table 6 compares outflow among plots during the January 15-18, 1989 event at the 460-m (1500-ft) elevation at Finney Creek. For the event as a whole, outflows in the clearcut and plantation plots respectively were 19 percent and 23 percent greater than in the forest plot. As in the January 2-4 rain-on-snow event, maximum differences among plots occurred the day of maximum air temperatures and windspeeds, in this case, January 16. During this 24-hr period, outflows from the clearcut and plantation plots were respectively 30 percent and 20 percent greater than from the forested plot. The data in Table 6 suggest that no snow remained in the collector boxes in any plot after January 16; rainfall and collector pan outflows are all roughly the same on January 17 and 18.

Table 5. Rainfall and outflow from snow collectors in plots at the 460-m (1500-ft) elevation at Canyon Creek, January 2-4, 1989. Rainfall data are from the 610-m (2000-ft) plot.

		Collector Outflow		
Date	Rainfall	Clearcut	Forest	Plantation
	mm			
Jan. 2	29	33	46	43
Jan. 3	21	92	50	69
Jan. 4	23	11	14	15
Totals	73	136	110	127
	(2.9 in)	(5.4 in)	(4.3 in)	(5.0 in)

The January 15-18 event did not produce appreciable outflow from the snowpack at the 760-m (2500-ft) elevation at either the Canyon Creek or Finney Creek locations. At both locations, air temperatures rose to 3.3 degrees C (38 degrees F) and average hourly windspeeds up to 3.8 m/sec (8.6 miles per hour) were recorded at Finney Creek and 5.3 m/sec (11.9 miles per hour) at Canyon Creek. This caused substantial melt at the snow surface, but snowpacks were on the order of 60-90 cm (2-3 ft) deep and were initially capable of retaining all the meltwater in addition to the 16 cm (6.3 in) of rain that fell during this event. Consequently, the snowpack on the south aspect at this elevation at Finney Creek did not yield any water until January 27 and then at only a very low rate. Outflow from the pack increased markedly on January 30 as the water-holding capacity of the snowpack was finally exceeded during more rapid snowmelt in response to air temperatures above 5.1 degrees C (41 degrees F) and 1.1 in of rainfall in six hours. As the Arctic air mass moved into the area, outflfow ceased abruptly early on January 31. During the next few days, temperatures at this site dropped to -19.6 degrees C (-3 degrees F), the lowest temperature recorded at any site. At all locations, the top 15 cm (6 in) of the pack froze solid.

DISCUSSION

The preliminary results described here agree with and supplement results of recent and similar research conducted in western Oregon. Berris and Harr (1987) reported a 21-percent increase in total water input to soil during the largest rain-on-snow event of their study. The 19- to 57-percent increases in total water input reported here can be explained by much more prolonged windy conditions during relatively high temperatures. According to differences in microclimatology reported by Berris and Harr (1987), differences in water outlfow between clearcut and forested areas should be maximized when windspeeds and air temperatures are highest. This is the time of maximum differences in rate of energy exchange between the snow pack's environment and the snow surface.

For the most part, the weather conditions described here are very common in the transient snow zone of the western Cascades of Washington and Oregon. The rainstorms that resulted in appreciable snowmelt were all of a size that usually occurs several times a year. Wind, air temperature, and humidity conditions during the rain-on-snow events also were not unusual. The arrival of the Arctic air mass in late January and its persistence through most of the first week in February was unusual, and, as a result, data from the remainder of February and most of March are not reliable because of frozen snowpacks and frozen raingages and snow collector drains.

As stated earlier, the differences in outflow among the various plots during the time of maximum melt are of great interest. Increases on the order of 80-90 percent may be common for water outflow from snowpacks in clearcut areas. This has serious implications for slope stability in that the rate of input of water to marginally stable slopes can be increased drastically. In situations where subsurface flow conditions do not allow movement of this water downslope quickly, positive pore-water pressures would probably be much higher than would be the case without the additional water input during rain-on-snow conditions following timber harvest. More frequent triggering of landslides could result.

For a site in the H. J. Andrews Experimental Forest in Oregon, Harr (1981) reported that an 8-percent increase in 24-hr water input (rainfall plus snowmelt water) to soil resulting from harvest effects on rain-on-snow conditions would double the return period of the water input event. For example, weather conditions that would cause a water input event with a return period of 10 yr with forest would, after logging, cause a water input event with a return period of 20 yr. In other words, a water-input event of a size expected to occur on the average once every 20 yr before logging would be expected occur on the average once every 10 yr after logging. Simply removing forest vegetation could make rare water-input events much more common. In general, the amount of erosion that would be caused by a rain-on-snow event is inversely related to the frequency of occurrence of that size event; more landslides and other erosion would be associated with a 20-yr event than with a 10-yr event.

Although frequency analyses of water input events have not yet been made for sites in the transient snow zone of western Washington, such analyses would probably be similar to that described by Harr (1981) for a site in western Oregon. It remains to be seen how such a frequency analysis would be altered by logging-induced increases in water input on the order of 84-90 percent as the preliminary results of this study suggest might be common.

Observations made during field visits indicate more snow in clearcuts than in the forest as was reported by Berris (1984). The depth of snow in clearcuts in this study has been fairly uniform, especially when compared to snow depth in plantations. As was the case in the western Oregon study (Berris and Harr, 1987), snow depth in plantations has been highly variable. Periodic unloading of snow intercepted by trees resulted in donut-shaped piles around individual trees (Figure 8).

CONTINUING WORK

Work will continue for at least one more year on this study that has been jointly funded by TFW, the Pacific Northwest Research Station, and the University of Washington's Center for Streamside Studies and College of Forest Resources. In early June we will remove all equipment and camouflage the sites. All instruments will be brought in for cleaning, maintenance, repair, and recalibration. During the summer, data from DSPs and DSMs will be transferred to microcomputer files, and data analyses will continue. Density of vegetative cover and physiographic characteristics of each plot will be determined. Raingages will be modified to minimize freezing, and the A-frame shelter and tipping bucket damaged when an old-growth tree fell on them will be repaired. In November 1989, we will reinstall equipment and reactivate the study. Data collection will continue through the 1989-90 snow season and possibly a third year if the 1989-90 winter season does not have any suitable rain-on-snow events.

Figure 8. Snow in plantations is extremely variable because snow caught by tree canopies is unloaded in donut-shaped piles around individual trees.

ACKNOWLEDGMENTS

We wish to thank the following individuals who have helped in various aspects of this study: Roger Nichols, Freda Tepfer, and Al Zander of the Mt. Baker-Snoqualmie National Forest for providing maps and for their assistance in locating suitable study sites; Craig Creel of the Pacific Northwest Research Station, Corvallis, Oregon for his help in constructing instrument shelters; and Al Levno, Pacific Northwest Research Station, Corvallis, Oregon for his assistance in field installations and as snowcat driver during winter site visits.

This study has been funded by TFW, the Pacific Northwest Research Station, the College of Forest Resources at the University of Washington, and the University of Washington's Center for Streamside Studies.

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APPENDIX

Figure 9. Weather station at the 760-m (2500-ft) clearcut plot at Finney Creek, March 22, 1989. The raingage is located at the far left, and the snow collector is located out of the photograph to the right.

Figure 10. Weather station at the 760-m (2500-ft) clearcut plot at Canyon Creek, March 23, 1989. The snow collector is on a flat bench to the right of the raingage. The plantation plot is located at the same elevation in the trees in the middle ground of this photograph.

Figure 11. Snow collectors in plots under mature or old-growth trees accumulated less snow than collectors in clearcuts. Here 3-5 cm of snow is shown in the collector at the Canyon Creek 460-m (1500-ft) plot on January 31, 1989.

Figure 12. In late January, the top 15 cm (6 in) of the snowpacks froze solid. This January 31, 1989 view of the Canyon Creek 610-m (2000-ft) plantation plot shows the variable snow depth characteristic of plantations.

Figure 13. Snow collector and weather station at Canyon Creek 460-m (1500-ft) clearcut plot, March 21, 1989. The raingage is located just to the right of the person in the center of the photograph.