EVALUATION OF FOREST FIRE EFFECTS ON SNOWPACK ACCUMULATION AND MELT

by

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ABSTRACT

In July of 1991 a fire swept through the Fourth of July Creek drainage in northwestern Montana. This area has a history of rain-on-snow events producing very high runoff and severely damaging streams. This study was set up to study the effects of fire severity on the delivery of snowmelt water to the soil.

Snowmelt lysimeters were set up under four conditions a clearcut open site, a very heavily fire damaged site with a few snags left standing, an area of light burn damage and an undisturbed area that had not been logged since at least the 1920's. Two lysimeters were installed in each treatment in the summer of 1993.

Both snowmelt rates and volumes per event were compared for both snowmelt and rain-on-snow events. Usable data were collected in March and April.

Overstory and basal area reduction due to fire or timber removal will increase mean air temperature while it decreases precipitation amounts reaching the forest floor.

Different meteorologic events caused melt rates and volumes to be different for the different canopy overstory amounts.

INTRODUCTION

In the summer of 1991, a large wildfire burned two drainages of the Three Rivers District, Kootenai National Forest, northwestern Montana. Cyclone Creek drainage had 92 percent of the watershed area burned while Fourth of July Creek drainage had 55 percent of the watershed area burned. Severity varied within the fire zone with some stands being totally consumed and others only partially damaged. The Fourth of July environmental assessment was developed to identify and disclose alternatives for salvage of timber from the fire area. Both of the drainages involved in the fire had experienced significant harvest and roading in the past. The public, regulatory agencies, and the Forest Service were concerned as to how much more harvest could be conducted without causing additional channel degradation. A particularly sensitive issue was how to determine the clearcut equivalency for water yield modeling of the two different burn severities.

A method to assess differences between two burn severities, a nearby clearcut, and an uncut/unburned stand was desired. Because both the Cyclone Creek and Fourth of July Creek drainages have been monitored for years with crest stage gages (both USGS and Kootenai National Forest), and the existence of a recording stream gage at the nearby undisturbed Red Top Creek watershed, a comparison of watersheds may be possible when

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enough watershed and streamflow data are available. At the time of the fire, four long term snow survey sites were in operation in the two basins; one was destroyed by fire, another was logged, but the other two remain in operation.

This paper documents the first winter of the overall project and will focus on 1) determining the hydrologic and meteorologic factors influencing the snowpack under different canopy conditions, and 2) determining if there is a significant difference in water delivered to the soil among the different conditions in terms of total volume and rate of snowmelt for different climatic events.

BACKGROUND AND METHODS

Site Description

The Fourth of July drainage basin (Figure 1) lies within the Purcell Mountain Range of the Northern Rocky Mountain Physiographic Province. Fourth of July Creek is a 3rd order stream draining into the Yaak River, a major tributary of the Kootenai River. The drainage size is 2021 hectares (4993 acres) on a northeast-east aspect. Elevations within the drainage range from 804 meters (2640 ft) at the outlet to 1993 meters (6638 ft) at Newton Mountain. The drainage density is 1.8.

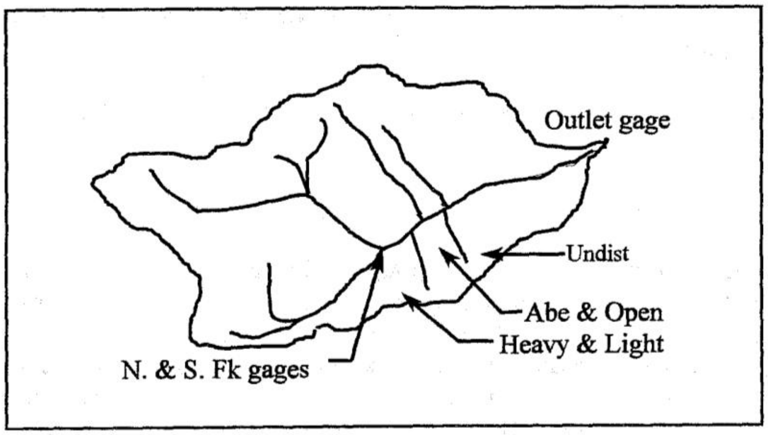

Figure 1. Map of the Fourth of July Creek watershed and data collection sites.

Study plots were established in four canopy overstory treatments:

1) A mature forest stand characterized as undisturbed.
2) a previously mature forest stand which experienced a light severity burn in the 1991 fire.
3) a previously mature forest stand which experienced a high severity burn in the 1991 fire.
4) a clearcut or open treatment.

Within each of the four trewatments, two sites were established to measure the effects of a fire-altered forest and subsequent overstory removal on water delivery to the soil. Site characteristics are shown in Table 1. All sites are located on generally north aspect slopes of similar gradient. The site abbreviations used in this report are presented in Table 2.

Table 1. Characteristics of data collection sites

Treatment	Elevation(m)	slope(%)	aspect(°)
O1	1180	35	320
O2	1160	50	345
Abe	1170	50	330
H1	1370	40	3
H2	1345	71	340
L1	1380	50	60
L2	1315	55	40
Lprcp	1320	60	---
U1	1250	55	330
U2	1235	65	40
Uprcp	1235	65	---

Table 2. Abbreviations representing plot category and site location.

treatment	location on slope	abbreviation
open	upper	O1
	lower	O2
high severity	upper	H1
	lower	H2
light severity	upper	L1
	lower	L2
undisturbed	upper	U1
	lower	U2
light precipitation storage gage		Lprcp
undisturbed precipitation storage gage		Uprcp

Canopy Sampling Methods

The structure of the overstory was analyzed using fish-eye lens photography. This provides an image of the canopy overstory using a hemispherical lens directed up through the canopy (Welles, 1990). Percent overstory cover is calculated by determining the fraction of vegetative cover relative to the total area.

Overstory photography was taken during October 1994. The camera was held in a tripod mount that leveled the lens. Photographs were taken over each of the lysimeters and at precipitation gage sites.

Stand examinations, yielding basal areas, were also conducted at each of the study sites using a point-sampling method. This method selects trees on the basis of their size using a prism that subtends a fixed angle of view used to "site in" tree boles close enough to completely fill the sighting angle (Avery, 1975). The tree stems not completely offset by the prism were counted and converted to basal area.

Meteorologic and Hydrologic Sampling Methods

Instrumentation for measuring precipitation, air temperature, relative humidity, solar radiation, and wind speed and direction is located at the Sylvanite Work Station in the Yaak River Valley. The Abe Lincoln weather station co-located with the open sites is similarly equipped except that it has no solar radiometer. These data sets allow for future comparison between lower elevations and the study watershed. The Abe Lincoln weather station allowed for the determination of meteorologic event types in the study area.

Air temperature is measured at each of the four lower sites (H2, L2, U2, and Abe) and lysimeter pan temperatures are recorded at all eight sites. A precipitation storage gage is located at a representative location in both the undisturbed and light burn sites, and a recording precipitation gage was installed at the Abe site. Snowcourses are marked at a representative location in each of the four conditions. Measurements of snowpack depth and water content were taken using a standard Mt. Rose snow sampler.

On each site, a snowmelt lysimeter was installed to determine the water delivery to the soil. The lysimeter apparatus is made up of a ground level catchment pan and a sunken shelter containing a water collection tank and instrumentation (Figure 2). Melt water in the pan drains through a pipe down slope to the shelter where it discharges into a barrel.

A stream gaging station is located approximately 0.4 km (0.25 mi) from the mouth of Fourth of July Creek. Located higher in the drainage, upstream from the study sites and just above the stream's major confluence, are two crest stage gages, one on each major branch (Figure 1).

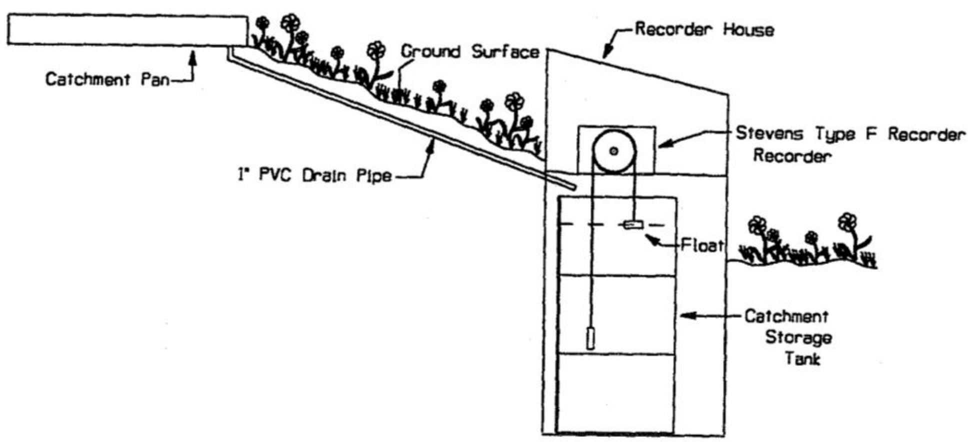

Figure 2. Snowmelt lysimeter general site plan.

RESULTS AND DISCUSSION

Canopy overstory

As a result of steep slopes and a 180° image angle of view, the uphill portion of the slope was present in the fish-eye photographs. Since a measure of canopy overstory cover alone was desired, the angle of view was reduced to exclude topographic features. Farnes (1971) reported that forest overstory within a cone 30° from vertical influences the amount of snow accumulation on the ground. Thus a circle representing the 30° view angle was superimposed on the images along with a dot grid with a 2.5 mm (0.1 in) spacing. Percent overstory was calculated from within the circle for each forested site. Table 3 presents the overstory and basal area at each site.

Table 2. **Percent overstory and basal area of study plots.**

Site	Canopy (%)	Basal Area ($m^2\ ha^{-1}$)
H1	17	23
H2	21	37
L1	30	50
L2	39	41
Lprcp	42	--
U1	74	55
U2	71	78
Uprcp	70	--

Canopy Overstory Effects on Precipitation and Air Temperature

Precipitation storage gages were used as an indication of the burn severity effect on the amount of precipitation reaching the ground. Total amounts of precipitation under three overstory conditions (open-Abe, light severity, and undisturbed) were determined for a 97-day period of record (precipitation at the high severity was assumed to be the same as in the open site). The open site received the highest amount of precipitation, followed by the light severity site, and finally the undisturbed site (Figure 3).

Mean air temperatures generally followed a trend of decreasing temperature with increasing canopy. The trend appeared to be linear except for the open site (Figure 4).
Maximum daily air temperatures were typically highest in the open site, particularly when solar radiation was high, followed by the high severity, light severity and the undisturbed site. Minimum daily air temperatures were found to be greatest in the undisturbed condition, followed by the light severity, then the high severity, and finally the open site.

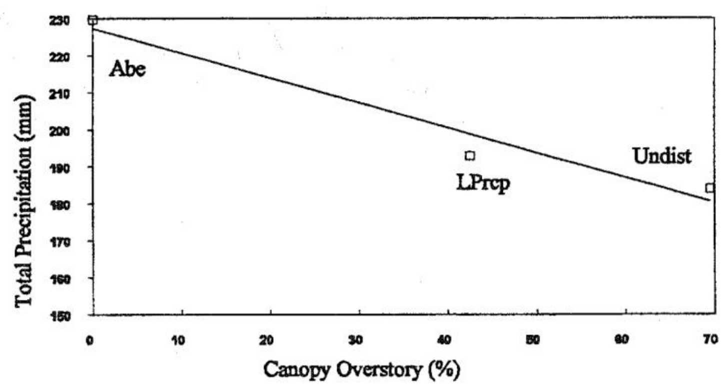

Figure 3. Canopy overstory effects on seasonal precipitation.

Lysimeter Outflow Analysis

Precipitation data were analyzed using corresponding temperature measurements to determine the form of precipitation. A study by Murray (1952) found that the air temperature approximately 1.2 m (4 ft) from the surface can be used to predict precipitation types (rain, snow or both). The U.S. Army Corps of Engineers (1956) estimated the differentiation between rain and snow by assuming rainfall to occur at air temperatures greater than or equal to 1.7°C and snowfall below that. Based on this 1.7°C 'break point' temperature, precipitation data were taken from the Abe Lincoln recording precipitation gage charts and classified into rain

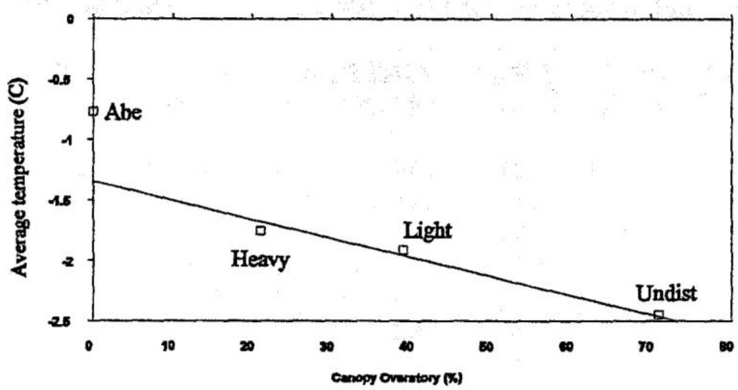

Figure 4. Canopy overstory effects on seasonal temperature.

or snow based on air temperature recorded at each lysimeter site. Lysimeter runoff (melt events) occuring during rain were considered rain-on-snow events. Any lysimeter runoff occurring at air temperatures below this point was classified as base-melt (groundmelt and pack drainage). When temperatures were above 1.7°C with no precipitation, the melt event was classified as temperature melt. Only periods during March and April with good data for at least one site in each treament were used.

One of the objectives was to determine if there were differences in melt among the four different sites. To do this, the hourly lysimeter outflow data were tested for difference among sites using autoregression and analysis of variance. Analysis of variance was conducted using the site mean plus the autoregression residuals as the independent variable. Clock time in hours, burn severity, and a nested design of site within burn condition were designated as dependent variables. Site and burn were used as categorical data in the model.

The first test was to determine if there was a difference among the rates and volumes of runoff for the four treatments for the three different meteorologic events. There were significant differences in lysimeter outflow amounts among sites at a probability value of 0.25 or less during rain-on-snow events and base-melt only. Rates of outflow were found to be different when the period of record was taken as a whole and for the separate event types of rain-on-snow and temperature melt (Table 4). Only those events shown to be significant in this analysis were subsequently analyzed.

Table 4. Effect of event type on lysimeter outflow - all sites grouped

	Amounts	Rates	No. of events
all events	>0.25	**0.025***	45
rain-on-snow	**0.10**	**0.10**	14
base-melt	**0.025**	>0.25	14
temp. melt	>0.25	**0.10**	17

* bold numbers represent acceptable levels of significance.

The above analysis shows there is a difference in the amount or rate of outflow among the four treatments for the some type of events. In order to determine a ranking of those treatments where significant differences were found to exist, a Tukey pairwise comparison was performed on the burn severity.

The pairwise analysis shows the probability of each treatment being different from another and the mean difference (in mm) between each pair. Probability values of 0.25 and below were defined as significant for differences between sites. All comparisons were made with respect to the undisturbed condition. The mean differences between a treatment and the undisturbed forest were used to rank the water delivery to the soil for each event type.

Table 5 shows the rate of outflow for all events grouped togeter for the light burn severity resulted in the greatest mean difference, followed by the heavy burn severity, then the open condition. Additionally, it was found that the light and open and the heavy and light treatments were different from each other. Mean differences showed greater outflow from the light condition in both cases.

Table 5. Probabilities (α) and differences (x) in lysimeter outflow rates for all events.

	open		heavy		light		undisturbed	
	α	x	α	x	α	x	α	x
open	1	0						
heavy	.33	0.20						
light	**.04***	**0.60**	**.12**	**0.40**	1	0		
undisturbed	**.09**	**-0.36**	**.03**	**-0.56**	**.01**	**-0.96**	1	0
Ranking:	3		2		1		4	

* bold values represent significance at the .25 level or higher.

The pairwise analysis for volume of outflow during rain-on-snow events (Table 6) show a significant difference between means from the open, heavy and light burn conditions when each are compared to the undisturbed. The ranking is open followed by the heavy, then the light and finally the undisturbed.

Table 6. Probabilities (α) and differences (x) in lysimeter outflow volumes for 14 rain-on-snow events.

	open		heavy		light		undisturbed	
	α	x	α	x	α	x	α	x
open	1	0						
heavy	.82	-0.23	1	0				
light	.63	-0.33	.98	-0.10	1	0		
undisturbed	**.08***	**-0.93**	**.16**	**-0.70**	**.23**	**-0.61**	1	0
Ranking:	1		2		3		4	

* bold values represent significance at the .25 level or higher.

The pairwise analysis for rate of outflow during rain-on-snow events (Table 7) shows the heavy burn severity to have the greatest difference with respect to the undisturbed treatment in water delivery to the soil, followed by the light burn severity, then the open condition.

Table 7. Probabilities (α) and differences (x) in lysimeter outflow rates for 14 rain-on-snow events.

	open		heavy		light		undisturbed	
	α	x	α	x	α	x	α	x
open	1	0						
heavy	.57	0.26	1	0				
light	.98	0.07	.76	-0.19	1	0		
undisturbed	**.15***	**-0.54**	**.05**	**-0.80**	**.10**	**-0.61**	1	0
Ranking:	3		1		2		4	

* bold values represent significance at the .25 level or higher.

For events that occurred during base-melt periods, the open and light treatments were determined to have a significant difference in <u>volume</u> of outflow from the undisturbed treatment with the largest difference shown by the light treatment (Table 8). Additionally, the heavy burn severity is different from the open condition with less runoff than the open treatment. The light and the heavy burn severities were also found to be different. Greater outflow resulted from the light condition than the heavy

Table 8. Probabilities (α) and differences (x) in lysimeter outflow volumes for 14 base-melt events.

	open		heavy		light		undisturbed	
	α	x	α	x	α	x	α	x
open	1	0						
heavy	**.15***	**-0.20**	1	0				
light	.85	0.06	**.07**	**0.25**	1	0		
undisturbed	**.04**	**-0.32**	.43	-0.12	**.02**	**-0.38**	1	0
Ranking:	2				1		3	

* bold values represent significance at the .25 level or higher.

Table 9 shows that the <u>rate</u> of outflow during temperature melt events is different for the means from the open and both burn conditions when each are compared to the undisturbed. The light burn treatment had the greatest difference followed by the open condition, then the heavy burn severity.

Table 9. Probabilities (α) and differences (x) in lysimeter outflow rates for 17 temperature melt events.

	open		heavy		light		undisturbed	
	α	x	α	x	α	x	α	x
open	1	0						
heavy	.99	-0.03	1	0				
light	.38	0.58	.35	0.61	1	0		
undisturbed	**.19***	**-0.70**	**.20**	**-0.67**	**.07**	**-1.28**	1	0
Ranking:	2		3		1		4	

* bold values represent significance at the .25 level or higher.

This analysis shows that there are significant differences among burn severities as they effect both the amount and rate of melt. Since the hydrologic condition of the forest is commonly used as the basis for characterizing the hydrologic condition of a logged site (Coffin and Harr 1992), it is felt that the results of the pairwise comparison analysis allow for a ranking of the differences in water delivered to the soil based on comparisons of disturbed sites to an undisturbed site.

SUMMARY

The first objective of this report was to determine the hydrologic and meteorologic factors influencing the snowpack under different canopy conditions.

Based on this analysis it can be concluded that differences in canopy overstory cover and basal area have a significant influence on precipitation amounts. The reduction of forest canopy due to fire and timber salvage results in more precipitation reaching the forest floor. Air temperature also varied among treatments. Overstory and basal area reduction due to fire or timber removal will increase mean air temperature.

The second objective of this report was to determine if there is a significant difference in the amount and rate of water delivered to the soil under different canopy conditions of snowmelt for different climatic events.

This study shows that timber removal, as a result of wildfire and subsequent salvage logging, decreases the rate at which water is delivered to the soil on north aspect slopes (Table 10) when the type of the event is not considered.

During rain-on-snow melt events amount and rate of water delivered to the soil are significantly different between an undisturbed site and one where forest overstory and basal area has been altered due to fire and/or timber harvest. Under these conditions the outflow volumes were found to decrease with increasing overstory and basal area while rates of outflow did not follow any trend with canopy cover.

For amounts of water delivered to the soil during base-melt events, the open and light burn severity were found to have significant differences when compared to the undisturbed treatment. Significant differences were also found between the heavy burn and the open condition, as well as the light and the heavy burn severities.

For snowmelt during periods of no rain each of the altered conditions produces outflow significantly different than the undisturbed forest. The greatest mean water delivery to the soil occured in the light burn severity, followed by the open and finally the heavy burn.

Table 10. Summary of study results.

Water Delivery to the Soil					
Event Type	LOWEST			HIGHEST	
All events					
Rates:	undisturbed	open		heavy	light
rain-on-snow					
Amounts:	undisturbed	light	heavy	open	
Rates:	undisturbed	open	light	heavy	
Base-melt					
Amounts:	undisturbed	open		light	
Temp-melt					
Rates:	undisturbed	heavy	open	light	

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