MEASUREMENT OF DIFFERENCES IN SNOW ACCUMULATION, MELT, AND MICROMETEOROLOGY BETWEEN CLEARCUT AND MATURE FOREST STANDS

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ABSTRACT

To quantify the hydrologic response of forest harvesting, measurements of snow accumulation, melt, and micro-meteorological were taken in mature and harvested units of the Gifford Pinchot (GP) and Umpqua National Forests. Data were collected as part of the Demonstration of Ecosystem Management Options (DEMO) project. The study areas are located in the transient snow zone of the western Cascades of southwestern Washington and central Oregon, respectively. The GP site contains six units at approximately 900 meters in elevation (five mature secondary growth, 1 clear-cut). The Umpqua site contains five units at approximately 900 meters in elevation (four mature, one shelterwood), and three units at 1200 meters elevation, (two mature, one shelterwood). Data have been collected during the past three snow seasons. In the summer of 1997, each site's mature stands (excluding one control) will be harvested with varying retentions and additional seasons of data will be collected. Measurements of incoming and reflected shortwave radiation, incoming longwave radiation, windspeed, relative humidity, air temperature, and precipitation (or throughfall) were taken in the units. Snow accumulation and melt at the unit scale (10ha) was measured weekly throughout the winter and spring with snow courses taken on a twenty point grid. Point observations of snow pack outflow consisted of two non-weighing snow lysimeters (2.6 sq. m. each) in each unit. Comparison of lysimeter observations between shelterwood and mature units during the 95/96 season show a 56% increase in 3 day production of runoff and a greater than 150% increase in 3 day snowmelt (outflow-throughfall). The shelterwood also shows nearly a 50% increase in snowmelt during radiation-dominated spring events. Snow course data taken at the GP before and 10 days after the rain-on-snow event of February 1996 show a decrease in the average snow water equivalent of the clearcut unit from 26 to 16 cm and a decrease in an adjacent mature stand's SWE from 21 to 18 cm.

INTRODUCTION

Snowmelt is an important component of watershed hydrology in the Pacific Northwest. Harr (1981) identified rain-on-snow (ROS) events as a primary mechanism during which significant volumes of snowmelt contribute to flooding. These rain-on-snow events are typically dominated by heavy precipitation and warm, windy conditions which rapidly melt low- to mid-elevation snow packs. The primary mechanisms for melt during rain-on-snow events are sensible and latent heat fluxes to the snowpack. These fluxes are directly dependent on the windspeed above the snowpack and the gradients of temperature and humidity. Forest harvesting, via complete or partial removal of the forest canopy, increases all three of these variables and thereby exposes the snowpack to greater melt. The USFS currently has models to assess the impacts of forest harvest on rain-on-snow events and possible flood contributions. However, the current model only addresses two stand densities, mature and clear-cut. Consequently, previous rain-on-snow studies, in keeping with forest management practices, have primarily dealt with two stand densities, forested and clearcut (and occasionally, a managed plantation). As forest management practices change from clearcutting to partial harvests, the effect of canopy density on snow accumulation and melt has become an important question.

The long term goal of this study is to quantify the hydrologic effects of partial harvest on snow accumulation and snowmelt over a wide range of spatial (individual tree to entire harvest unit) and temporal (individual event to seasonal) scales. Data collection during individual events focuses both on rain-on-snow and spring, radiation dominated events. Baseline data have been collected in mature forest, shelterwood and clear-cut units since 1995. During the summer of 1997, all mature units at a

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given site (minus one control) will be harvested with varying aggregated and dispersed retentions. Additional years of data will then be collected to quantify the effects of partial forest harvest. This paper focuses on an comparison of pre-harvest baseline data collected in the existing mature, shelterwood and clear-cut units.

SITE LOCATIONS

The snow hydrology component of the Demonstration of Ecosystems Management Options Project (DEMO) focuses on two sites. The first is located in southwestern Washington in the Gifford Pinchot National Forest. This site consists of 6 units (approximately 10 ha. each) at approximately 1000 meters in elevation. Of these 6 units, 5 contained mature forest for baseline data collection and 1 was previously clear-cut. Four of the mature units will be harvested during the summer of 1997 with varying retentions. The second DEMO site contains 8 units and is located just northwest of Crater Lake in Southern Oregon in the Umpqua National Forest. Five units (4 mature and 1 shelterwood) are located at 900 m. elevation while three units (2 mature and 1 shelterwood) are located at 1200 m. elevation. Due to transient nature of snow at 900 m at the Umpqua site, results presented here only use data from the three units at 1200 m.

INSTRUMENTATION

Our experimental set-up is similar to that used by Berris and Harr (1987) and Coffin and Harr (1992). Micrometeorology is measured every minute at the 2 meter reference height (not adjusted for snow depth) and totals are recorded every 30 minutes. All season precipitation is measured to the nearest millimeter with a tipping bucket gage. Rain or snow falls into the gage and then into a reservoir which is charged with a non-toxic antifreeze solution. The antifreeze solution is a 3:2 mixture of propylene glycol and ethanol (McGurk, 1992) topped with a thin layer of mineral oil to prevent ethanol evaporation. The solution has a specific gravity of approximately 0.95 which ensures adequate mixing. The reservoir is recharged after 500 mm precipitation to limit dilution and thereby prevent freezing. Outflow from the reservoir is collected by the tipping bucket.

Windspeed is measured with RM Young photochopper totalizing or propeller anemometers. These anemometers are operated to measure wind passage over each minute and therefore effectively integrate the wind velocity over the observation interval. Incoming shortwave radiation is measured with Epply (Black and White) pyranometers. Reflected shortwave radiation is measured with Licor silicon cell pyranometers. Reflected shortwave is used to estimate albedo and to correct the Epply pyranometers when they are snow covered. Incoming longwave radiation is measured by Epply pyrgeometers. Air temperature and relative humidity are measured by Campbell Scientific Vaisala probes protected from direct and reflected radiation by 6 plate shields.

Snow pack outflow is measured every 30 minutes by a non-weighing snow lysimeter (2.6 sq m.) which is drained to a 1 liter capacity tipping bucket. The drains, piping and tipping buckets are buried to prevent freezing. The lysimeter is lined with an impermeable geo-textile lining (hypalon). To estimate melt rates from snow pack outflow, precipitation gages are placed adjacent to each lysimeter. Melt is then inferred as snowpack outflow minus throughfall. Direct observations of snow depth and snow water equivalent (SWE) are taken weekly (access permitting) in each unit. Snow courses are run over a 20 point grid (80 m by 80 m spacing) Depth measurements are collected at each point and at least 5 water equivalent measurements are also taken in each unit. Water equivalent is obtained with a standard U.S. snow tube.

OVERVIEW OF BASELINE SNOW COURSE DATA

The weekly snow courses during the baseline data collection period at the two sites have shown significant interannual variability during the accumulation season. Figure 1a shows a comparison between the average weekly snow water equivalent in the clear-cut unit and in the mature unit at the Gifford Pinchot Site for the winters of 1995/96 and 1996/97. Figure 1b shows a similar comparison between the high elevation shelterwood and the two nearby mature units at the Umpqua Site. The figures show that snow accumulation tends to be greater in open areas and ablation is more rapid during melt events at both sites. However, there is a great deal of interannual variability. During the winter of 1995/96, the differences in snow accumulation between open and mature sites is less than during 1996/97. This variability is due to different timing of winter storms during both years. During 1995/96, significant snows were not experienced until January when accumulation began during a series of intense storm events. These few large events were able to overwhelm canopy interception mechanisms and deposited equal amounts of snow in both open and forested areas. However, during the winter of 1996/97, accumulation occurred during many smaller snow storms. These small events allowed canopy interception and subsequent sublimation and melt of intercepted snow to dominate snow accumulation under the canopy, thereby greatly decreasing observed under-canopy SWE relative to the open unit. In fact, dense pine stands in an adjacent area at the 1200 m elevation in the Umpqua N.F. experienced no significant snow accumulation during the winter of 1996-97.

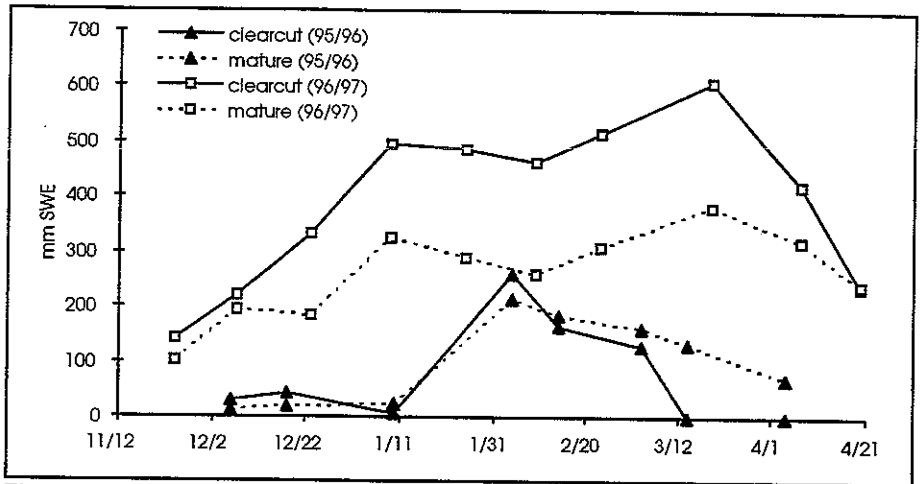

Figure 1a. Gifford Pinchot National Forest snow course data.

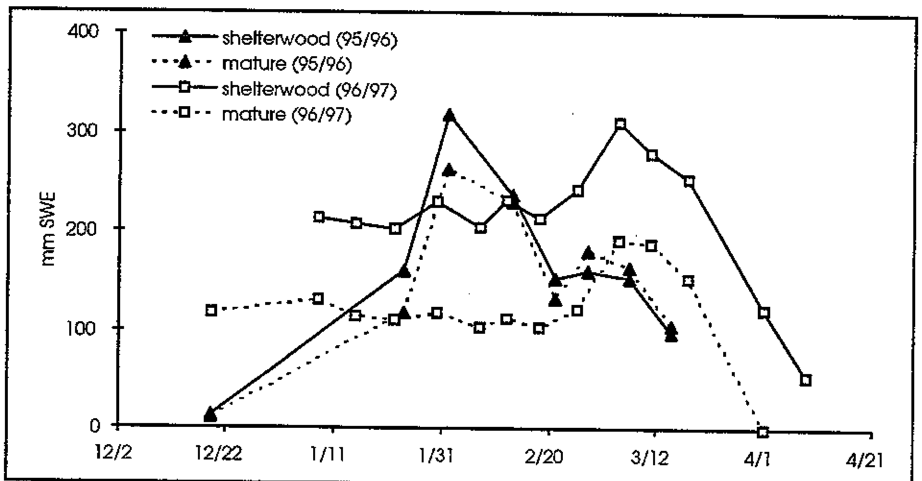

Figure 1b. Umpqua National Forest snow course data.

Although snow courses are by necessity conducted at a coarse temporal resolution, they allow direct observation in changes in SWE during events. For example, Figure 1a shows the decrease in SWE during the February 1996 ROS event (which caused floods of record in southwestern Washington) in the Gifford Pinchot units. While SWE decreased from 260 mm to 160 mm in the clearcut site, SWE in the adjacent mature units (with identical aspect and slope) decreased from 210 to 180 mm. This corresponds to 133 percent more snowmelt during and after the event in the clearcut unit than in the mature unit.

OVERVIEW OF BASELINE METEOROLOGICAL AND LYSIMETER DATA

Figures 2a and 2b show the accumulated snow pack outflow and micrometeorology for the mature and shelterwood sites for the February, 1996 ROS event at the Umpqua site. Although precipitation in the shelterwood and mature units was nearly identical during the 3 day ROS event (33 mm shelterwood, 37 mm mature), there was significantly more snow pack outflow at the shelterwood site over the 3 day event. The 2 lysimeters in the shelterwood produced an average of 95 mm of outflow while the 4 lysimeters in the mature units produced an average of 61 mm of outflow. This corresponds to an increase of 56% in outflow and 156% in snow melt (outflow minus precipitation) production due to complete canopy removal. The increase in outflow was caused by greater wind speed and air temperature in the shelterwood site relative to the mature site. Incoming longwave radiation during the event was nearly identical for both sites and shortwave radiation was negligible. Note that as the event ends and conditions clear there is a sharp drop in incoming longwave radiation at the shelterwood compared to the mature forest.

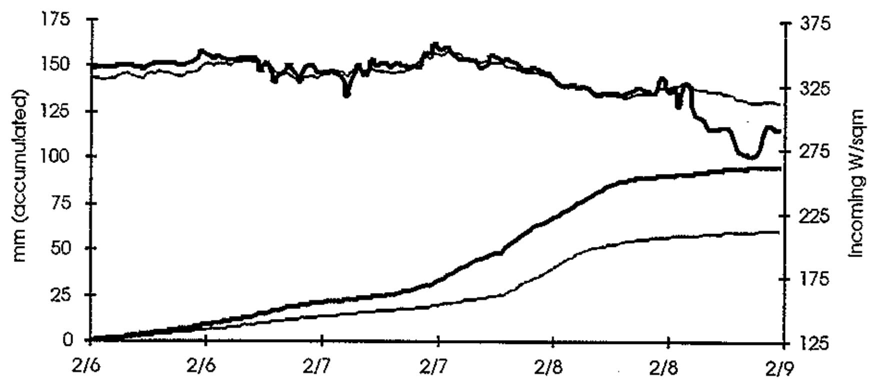

Figure 2a. Accumulated snow outflow and incoming longwave radiation during ROS event in Umpqua National Forest, 1996. (Heavy line is shelterwood, thin line is mature)

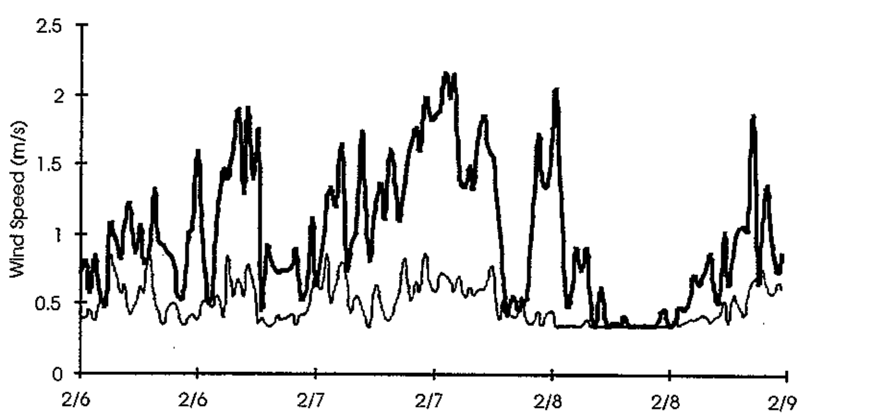

Figure 2b. Comparison of shelterwood and mature forest 2-meter windspeed during ROS event in Umpqua National Forest, 1996. (Heavy line is shelterwood)

A more significant ROS event occurred over 6 days during the end of December 1996 in the Umpqua National Forest. Figures 3a and 3b show the accumulated snow pack outflow, windspeed, air temperature and average precipitation during the event as observed in the shelterwood and mature forest units. The average precipitation recorded by 4 gages was 165 mm with no significant observed difference between shelterwood and mature sites. Average accumulated snow pack outflow from the shelterwood was 312 mm while only 250 mm of outflow was observed under the mature canopy. This corresponds to a 25% increase in snow pack outflow due to forest canopy removal. If snowmelt is inferred as outflow minus precipitation, these increases in outflow translate to a 72% increase in snowmelt. As in the February 1996 event, the observed increase in snowmelt during ROS events is due to increased sensible and latent heat transfer to the snowpack.

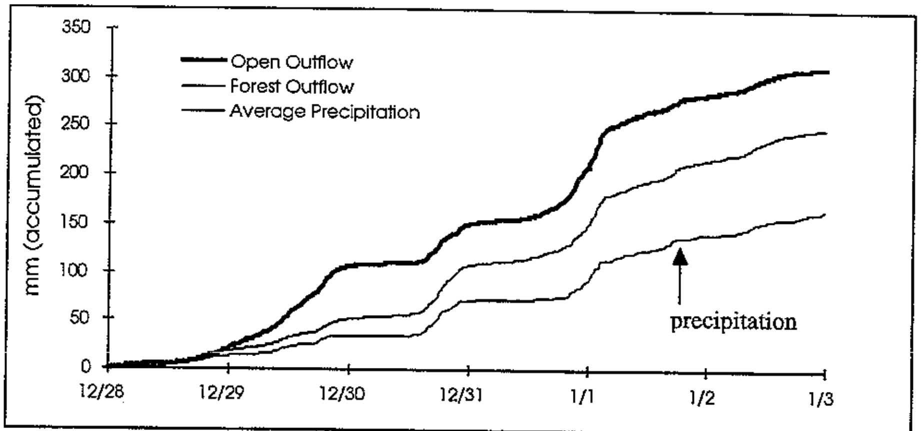

Figure 3a: Shelterwood and mature forest snow outflow during ROS event (1996/97)

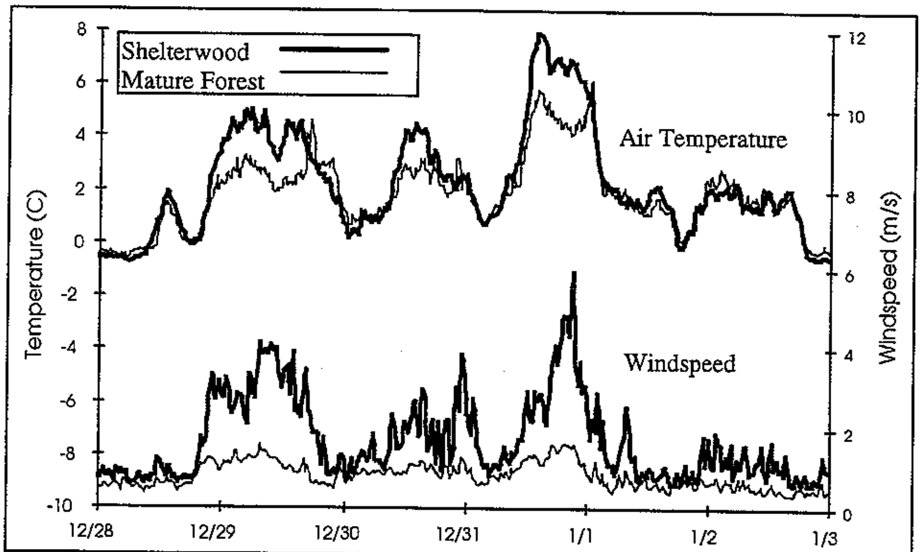

Figure 3b. Air temperature and windspeed during ROS event (1996/97)

To remove the limitations of inferred snowmelt, direct continuous measurement of SWE by three weighing lysimeters was initiated at the Umpqua units during the winter of 1996-97. Two of these lysimeters (25 sq. m. each) were installed under the forest canopy and one (13 sq. m.) was placed in the nearby shelterwood. Direct observations of changes in SWE show a decrease in SWE in the shelterwood from 240 to 140 mm while the SWE under the mature canopy decreased from 132 to 63 mm. Thus actual losses of SWE increased 47% due to forest canopy removal.

Figure 4 shows a comparison of incoming radiation and accumulated snow melt between the shelterwood and mature sites during a precipitation-free radiation dominated snowmelt event at the Umpqua site. Three day snowmelt volumes are 44% greater in the shelterwood site. This increase is due to the greater incoming shortwave radiation during the day. Total shortwave radiation during the 3 day event was 300% greater in the shelterwood than under the mature canopy. However, since longwave radiation in the shelterwood was less than under the mature forest canopy during the event, total incoming radiation was only 11% greater in the shelterwood. The greater longwave radiation under the canopy can lead directly to greater melt rates under the canopy in the absence of shortwave radiation. Figure 4 shows that during the evening of March 7 and early morning of March 8, snowmelt rates under the mature canopy were greater than in the shelterwood unit.

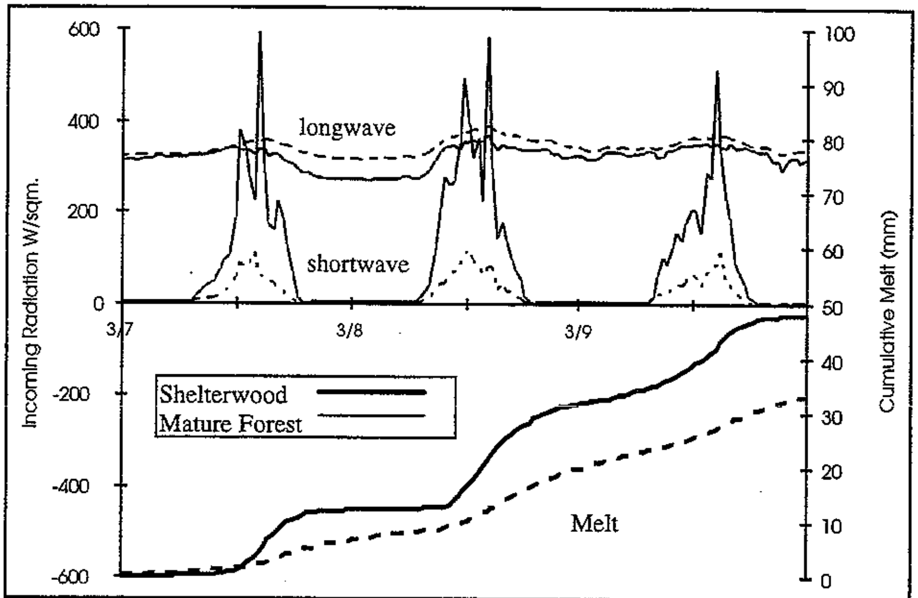

Figure 4. Accumulated outflow and incoming radiation during spring snowmelt event in the Umpqua National Forest, 1996. Dashed line is mature, Solid line is shelterwood

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