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Hydrologic and Climatic Changes in Three Small Watersheds After Timber Harvest

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Abstract

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No significant increases in annual water yield were shown for three small watersheds in northeastern Oregon after shelterwood cutting (30-percent canopy removal, 50-percent basal area removal) and clearcutting. Average maximum air temperature increased after harvest and average minimum air temperature decreased by up to 2.6 °C. Both maximum and minimum water temperatures decreased slightly in two streams as compared with the control stream. Wind passage and velocities increased dramatically with removal of the forest cover. Both snow depth and snowpack water content increased in clearcuttings.

Keywords: Logging effects, hydrologic analysis, climatic change, watershed management, Oregon (Blue Mountains), Blue Mountains— Oregon.

Summary

This case study summarizes the effects of a 30-percent canopy-removal shelterwood cutting and clearcuttings ranging from 0.8 to 8.5 ha on some hydrologic and climatic variables of the High Ridge Evaluation Area. This area consists of four small (24.4 to 118.1 ha) calibrated watersheds within the larger Umatilla National Forest barometer watershed in northeastern Oregon. Areas were harvested in 1976 after 9 years of prelogging calibration. Changes in water yield were evaluated for the years 1976 through 1982; no significant increases in annual water yield were shown. Supplemental analysis reported elsewhere also showed no statistically significant changes in either peak or low flow from these watersheds. Average maximum air temperatures increased up to 2 °C after harvest, while average minimums decreased up to 2.6 °C. Both maximum water temperature and minimum water temperature decreased in two streams as compared with the control stream. Wind passage and velocities increased dramatically with removal of the forest cover. The increased windflow may have modified the water yield response by transporting snow beyond the watershed boundaries, by increasing evaporation from bare soils and snow surfaces, and by increasing sublimation from the snowpack. Both snow depth and snowpack water content increased in clearcuttings.

Contents

Introduction

Timber harvest in the northwestern United States is moving into higher elevations where forests occupy the primary snow catchments and act as regulators of seasonal runoff. The barometer watershed program of the Forest Service, U.S. Department of Agriculture, was designed, in part, to evaluate how forest management in these snow-zone forests influences water yield, sediment production, and streamflow. The hydrology program was initiated in 1965 by the Umatilla National Forest (headquarters at Pendleton, Oregon). In the early 1970's, the Umatilla National Forest and the Forest Service research laboratories at Wenatchee, Washington, and La Grande, Oregon, began joint studies to examine other watershed characteristics, such as climate, water quality (both chemical and biological), vegetation dynamics, and animal behavior. This case study summarizes the effects of clearcutting and shelterwood cutting on the hydrologic and climatic variables associated with the High Ridge Evaluation Area, four small calibrated watersheds within the larger barometer watershed.

A standard technique for determining changes in water yield uses paired watersheds. The selection of one of the four watersheds for a control allowed three treatment-control pairs. Predictive equations for water yield from the treated watersheds are required; such equations are based on pretreatment measurements. Changes in water yield beyond the confidence limits established from the pretreatment analysis suggest treatment effect.

When treatments for these watersheds were developed, an 11-percent (7.5-cm) increase in yield was predicted for the first year. This prediction was based on 58 percent of the watershed area being treated using 8-ha clearcuts. Literature reviewed by Anderson and others (1976) indicated potential yield increases in this forest type of 7.5 to 15.0 cm as a result of using cutting patterns that increase snowpack. For the moister climates of western Oregon, Harr and others (1982) describe annual increases that range from 60 cm on clearcut watersheds to no increase where clearcut patches totaled only 25 percent of the watershed area. Wildfire on Burns Creek watershed (Entiat Experimental Forest, central Washington) caused measured yields minus predicted yields of 7.4, 47.2, and 17.8 cm for the first, second, and third years after burning. The increase in the second year was over 100 percent of what had been predicted, partly because of an exceptionally deep snowpack (Helvey and others 1976).

Fowler and others (1979) describe the baseline hydrology and the climate of the High Ridge watersheds before treatment and discuss some of the expected changes in air and water temperature, wind, and snow accumulation.

The Study

Watershed Characteristics

The study area (fig. 1), consisted of four watersheds 22 km northwest of Elgin in the Blue Mountains of northeastern Oregon. Elevations range from 1439 to 1617 m, and aspect is generally northeast. Slopes in the study area are moderate at 2 to 25 percent.

Soils of the Blue Mountains are described in detail by Geist and Strickler (1978). Soil in the study area is derived from recent volcanic ash (less than 6,700 years old) and is Helter silt loam (Entic Cryandept) deposited over an older residual soil developed from underlying basalt rock. Both the upper and lower soil horizons are silt loams but with different physical properties. Klock and Lopushinsky (1980) report the bulk density to be near 0.65 gm/cm^3 for the upper soil and 1.3 gm/cm^3 for the buried soil. The upper soil has high water-holding capacity. Soils are generally well drained and are up to 1.5 m deep.

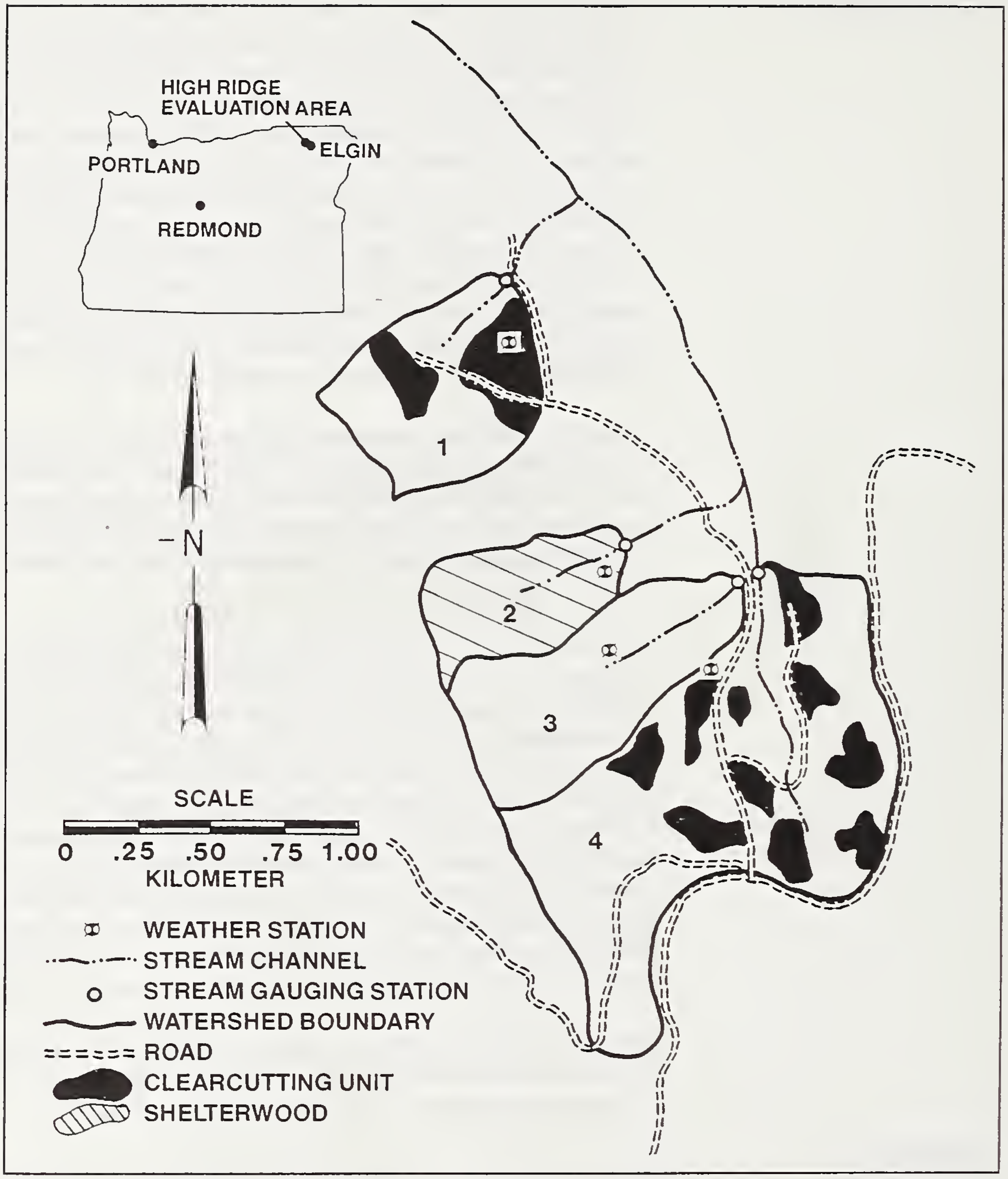

Figure 1--The High Ridge Evaluation Area, Umatilla National Forest, Oregon.

Prelogging vegetation was a dense mixture of grand fir (*Abies grandis* (Dougl. ex D. Don) Lindl.), subalpine fir (*A. lasiocarpa* (Hook.) Nutt.), Engelmann spruce (*Picea engelmannii* Parry ex Engelm.), western larch (*Larix occidentalis* Nutt.), Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco), and lodgepole pine (*Pinus contorta* Dougl. ex Loud.). Grand fir and subalpine fir were the predominant species. Trees were up to 40 m tall and had a maximum age of about 160 years. Primary understory vegetation was Columbia brome (*Bromus vulgaris* (Hook.) Shear), twinflower (*Linnaea borealis* L.), and big huckleberry (*Vaccinium membranaceum* Dougl. ex Hook.).

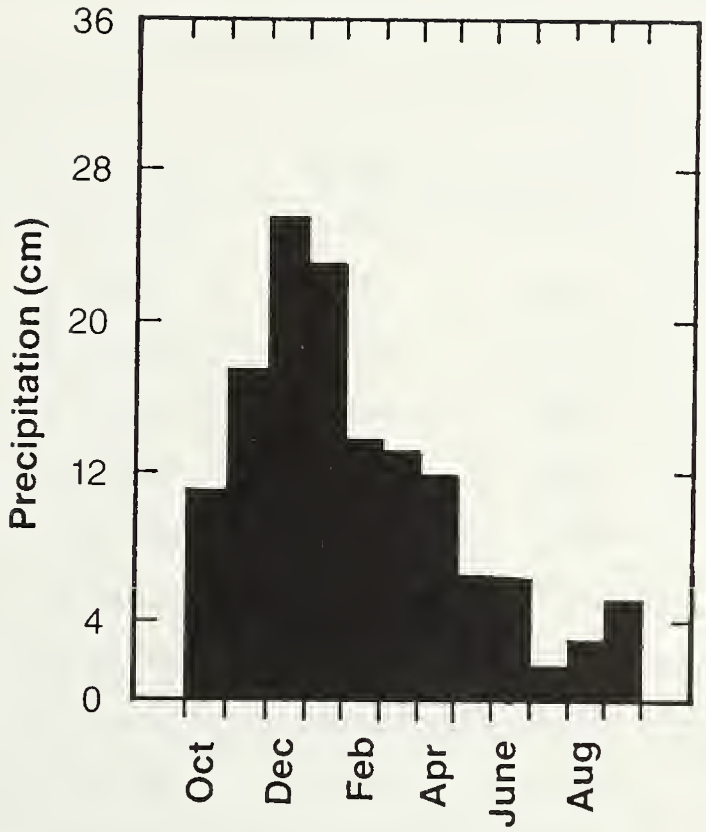

Figure 2--Average monthly precipitation.

Climate and Streamflow

Precipitation occurs primarily during the cool months throughout the Pacific Northwest. Strong airmass contrasts— mild, moist Pacific air and frigid continental polar air— produce vigorous winter storms. The seasonal distribution of precipitation for the High Ridge Evaluation Area as measured in watershed 1 is shown in figure 2. Eighty to 90 percent of the 142.9-cm annual total falls between October 1 and May 31; summers are relatively dry. With decreasing air temperatures in the fall, precipitation changes from rain to snow; a snowpack usually begins to accumulate by late November. The snowpack increases in depth and water content until late March or early April, then gradually melts. Usually the snow is completely melted by early June.

Streamflow has been measured on these watersheds since installation of V-notch weirs in 1966. In contrast to western Oregon, where the streamflow peaks in January or February (Harr and others 1982), peak runoff from these watersheds is in May to July. About 80 percent of the total annual flow occurs in May and June as a result of snowmelt. Flow gradually decreases throughout the summer. Infrequent rain-on-snow runoff events can occur during the winter, and peak daily flows can equal springtime maximums. The seasonal distribution of average daily flow from watershed 1 for 1967 to 1976, the prelogging calibration period, is shown in figure 3. If precipitation and streamflow are measured accurately, and if little deep seepage occurs, the difference between annual precipitation and runoff is the amount of water lost to evapotranspiration. For watersheds 1 to 4, these differences for the calibration period were 105.0, 94.7, 91.5, and 96.1 cm. Reducing evapotranspiration losses by timber harvest was expected to increase water yields. Table 1 lists water-year precipitation and yield for the watersheds.

Table 1—Precipitation and water yield for control (watershed 3) and treatment watersheds

(In centimeters)

		Yield			
Year	Precipitation	Watershed 1	Watershed 2	Watershed 3	Watershed 4
1967	—	320.8	398.0	528.6	407.2
1968	1356.4	173.0	279.4	302.5	278.6
1969	1404.6	430.5	529.6	538.5	511.8
1970	1412.2	442.7	463.6	504.7	438.6
1971	1493.5	538.0	526.8	553.2	475.2
1972	1625.6	388.1	532.4	600.7	576.1
1973	731.5	84.3	216.4	149.4	212.6
1974	1902.5	647.7	792.5	895.4	726.2
1975	1506.2	324.6	510.5	563.4	523.8
1976	1399.5	483.6	720.9	654.3	607.1
1977	843.3	59.7	90.9	166.9	195.6
1978	1409.7	417.6	552.7	476.3	522.5
1979	1021.1	396.2	503.2	472.7	450.3
1980	1191.3	251.2	372.9	355.3	43.7
1981	1229.4	289.6	460.5	436.4	319.0
1982	1618.0	492.3	63.2	714.8	588.5

— = not available.

Maximum temperatures of air (34 °C) and water (16 °C) were measured in these watersheds during the calibration period.[1] A plot of the 1974 maximum air and water temperatures for watershed 4 is shown in figure 4. From 1972 to 1976, the stream temperature in watershed 4 was between 0 and 2 °C for 59.5 percent of the time.

For six winters during the calibration period, no significant difference in snow depth at near-maximum accumulation occurred among plots in the several watersheds. The within-plot variability was high, however, because of uneven amounts of snow under the dense canopy.

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[1] A printing, digital integrator provided the average 3-hour temperatures. Air temperature sensors were 1.5 m above ground from May to October and were raised to 3.0 m for the winter.

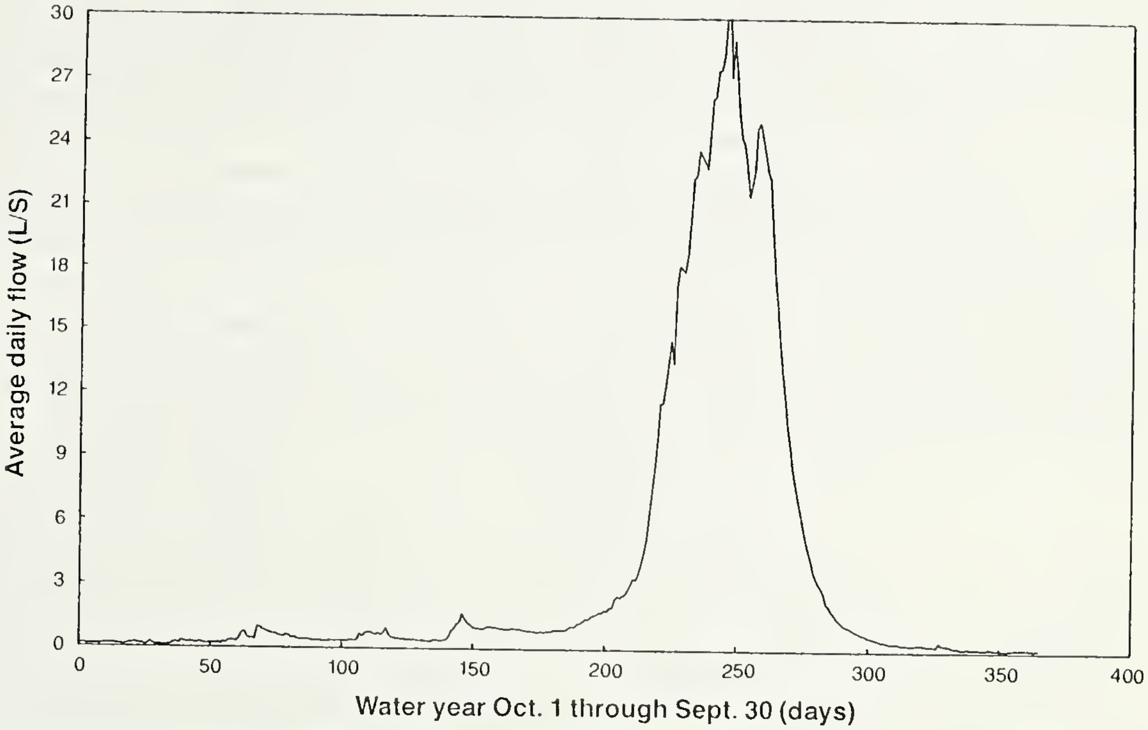

Figure 3--Average daily water yield from watershed 1, 1966-76.

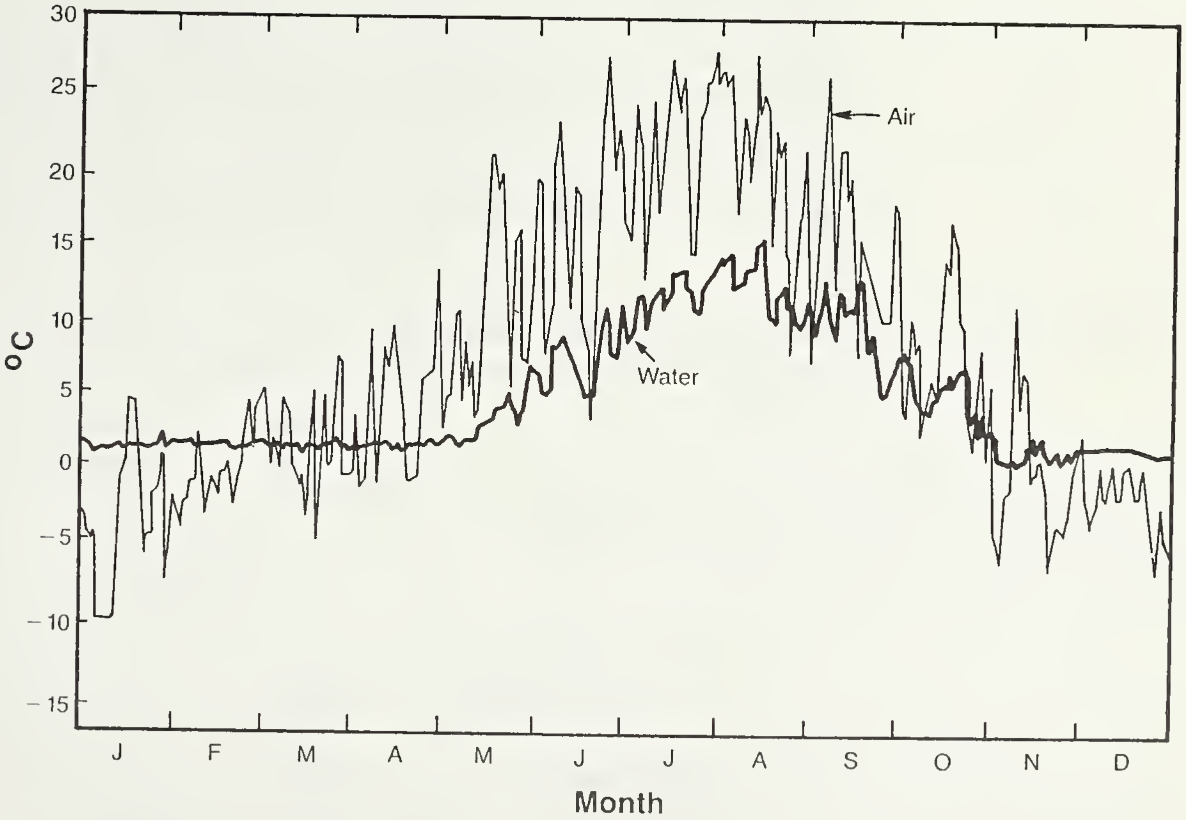

Figure 4--Maximum and minimum of 3-hour average temperatures for air and water temperatures in watershed 4, 1974.

Windspeed at 6 m above ground in three watersheds (1, 3, and 4) averaged 0.16 km/h and rarely exceeded 9.6 km/h during the calibration period. Measurements at 20 m above ground were made in watersheds 1 and 4. At 20 m in watershed 1, the measurement was under the taller (up to 40 m) trees, and average windspeed was 0.67 km/h. Trees were shorter in watershed 4, and the measurement at 20 m was at the top of the live crowns; average windspeed was 3.3 km/h. Total wind passage at this location was 23 655 km from August 14, 1975, to July 9, 1976. Wind passage was distributed among the windspeed classes as follows:

Windspeed	Total passage
(km/h)	(km)
0 – 9.59	18 076
9.60 – 16.09	4 768
16.10 – 24.09	763
24.10 – 31.19	53
31.20 – 48.29	5
48.30 +	0

Watershed Treatments

Table 2 lists the treatments for the four watersheds. Shelterwood cutting and clearcutting were appropriate harvest methods for the forest type and were selected so that their hydrologic and climatic effects could be observed. The main timber-hauling road was built during midsummer 1975. Only watersheds 1 and 4 had roads (see fig. 1). All areas were tractor-logged during July and September 1976; residue treatment and erosion control were completed by October 1976. Seedlings of Engelmann spruce, western larch, and subalpine fir were planted in 1977. Little erosion-control seeding was needed on these moderate slopes; only 4 of the 10 small clearcuts in watershed 4 and one-half of each of the large clearcuts in watershed 1 were seeded (Helvey and Fowler 1979).

Table 2—Watershed treatments

Watershed	Type of cut	Area	Area logged	Stand removed	Volume removed
		———Hectares	*Hectares———*	*Percent*	*Cubic meters*
1	2 large clearcuts; 3.6 ha, 8.5 ha	29.6	12.1	43	2910
2	Shelterwood	24.4	24.4	50	5540
3	None	53.3	0	0	0
4	10 small clearcuts, 0.8 to 2.4 ha	118.1	19.9	22	3690

Results and Discussion

Annual Water Yield

Figure 5, A, B, and C, presents the relations for annual water yield between the control watershed (3) and the treatment watersheds (1, 2, and 4). The solid dots represent water years 1967 to 1976. The calibration equations are shown where X is the control watershed yield and Y is the predicted yield for the treatment watershed. The coefficient of determination (R^2, or the ability of the predictor equation to explain the observed yields) varies between 0.83 and 0.94. For this type of paired comparison, the smaller the scatter of data points, the higher the value of R^2 and the more sensitive the comparisons between pretreatment and posttreatment phases. (For the western Oregon watersheds analyzed by Harr (1982), R^2 values of 0.99 and 0.98 were observed.) A computed 95-percent confidence interval for individual measurements is shown above the regression line. Posttreatment increases must lie beyond this level to be statistically significant at the 95-percent probability level. For watershed 1, increased yields of 17 cm or greater (more than twice the originally predicted response) would be required

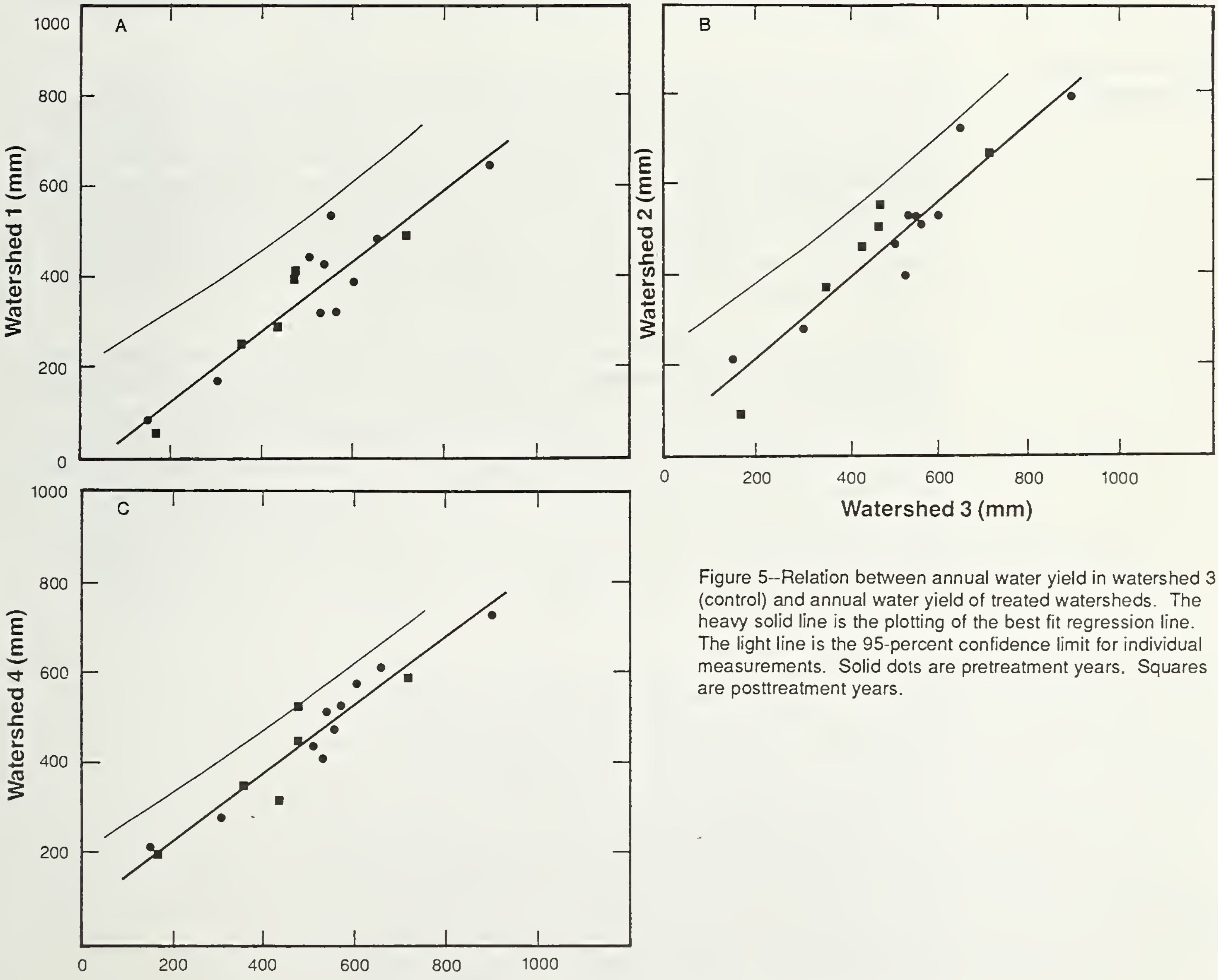

Figure 5--Relation between annual water yield in watershed 3 (control) and annual water yield of treated watersheds. The heavy solid line is the plotting of the best fit regression line. The light line is the 95-percent confidence limit for individual measurements. Solid dots are pretreatment years. Squares are posttreatment years.

to satisfy this criterion. Squares represent the posttreatment water years, 1977 to 1982. None of the posttreatment data for all watershed pairs exceed the confidence interval; a null hypothesis of no observed effects due to treatments in these watersheds cannot be rejected.[2]

No significant increases in water yield could be shown in a similar analysis that compared precipitation (the gauge was in watershed 1) and water yield from these watersheds for the pretreatment and posttreatment periods. Felix[3] showed, in an independent analysis, no statistically significant changes in either low or peak flows in the posttreatment period.

Klock and Lopushinsky (1980) found that clearcuts in these same watersheds had about 20 cm more available water in the profile than did corresponding unlogged areas at time of maximum water depletion (August or September). Ross (1971), however, did not find reduced depletion of soil water for all years in clearcuttings at similar elevations on these soils.

Temperature of Air, Water, and Soil

Departure of the maximum and minimum temperatures for air and water in treated watersheds from those in the control watershed during the pretreatment and posttreatment periods are shown in figure 6. A point plotted above the zero line indicates that the treatment is warmer than the control; a point plotted below the line indicates that the treatment is cooler than the control. Before treatment, average maximum and minimum temperatures for air and water in the planned treatment watersheds were within ±1 °C of the control. Posttreatment changes in average maximum air temperature showed that the treatments were then warmer; minimums were much cooler (2.6 °C) in watershed 4 and somewhat cooler (0.5 °C) in watershed 2.

Except for an increase in the average maximum water temperature in watershed 2, all watersheds showed water temperatures (both average maximums and minimums) to be lower after treatment. It seems reasonable with these north- and northeast-facing watersheds that increased nocturnal cooling after timber removal, an increased snowpack, and possibly a delayed melt affecting stream volume and timing were responsible for the lowered stream temperatures. Maximum soil temperatures during 1976 (pretreatment) were 21 °C at 2.5 cm and 16 °C at 10 cm in watershed 4.[4] Soils at these depths remained isothermal (near 0 °C) from November to early to mid-June. Only the initial response to clearcutting was monitored in watershed 1. Figure 7 presents a

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[2] If harvest year 1976 is excluded from these comparisons, the 552.7-mm annual yield from watershed 2 during 1978, the second year after harvest, exceeded the confidence interval by 9.9 mm.

[3] Unpublished Administrative Report, 1984, "Effects of Timber Harvest on Streamflow Response," by Ernesto N. Felix, U.S. Department of Agriculture, Umatilla National Forest, 2517 S.W. Hailey Avenue, Pendleton, OR 97801.

[4] Litter and vegetative cover in the uncut old-growth forest was essentially 100 percent. Disturbance from the logging was severe. In September 1978, 2 years after harvest, litter and vegetative cover averaged only 62 percent in thirteen 0.4-m^2 plots in the unseeded area in the smaller clearcut in watershed 1. In the seeded section of this clearcutting in 14 plots, total cover averaged 88 percent of the area.

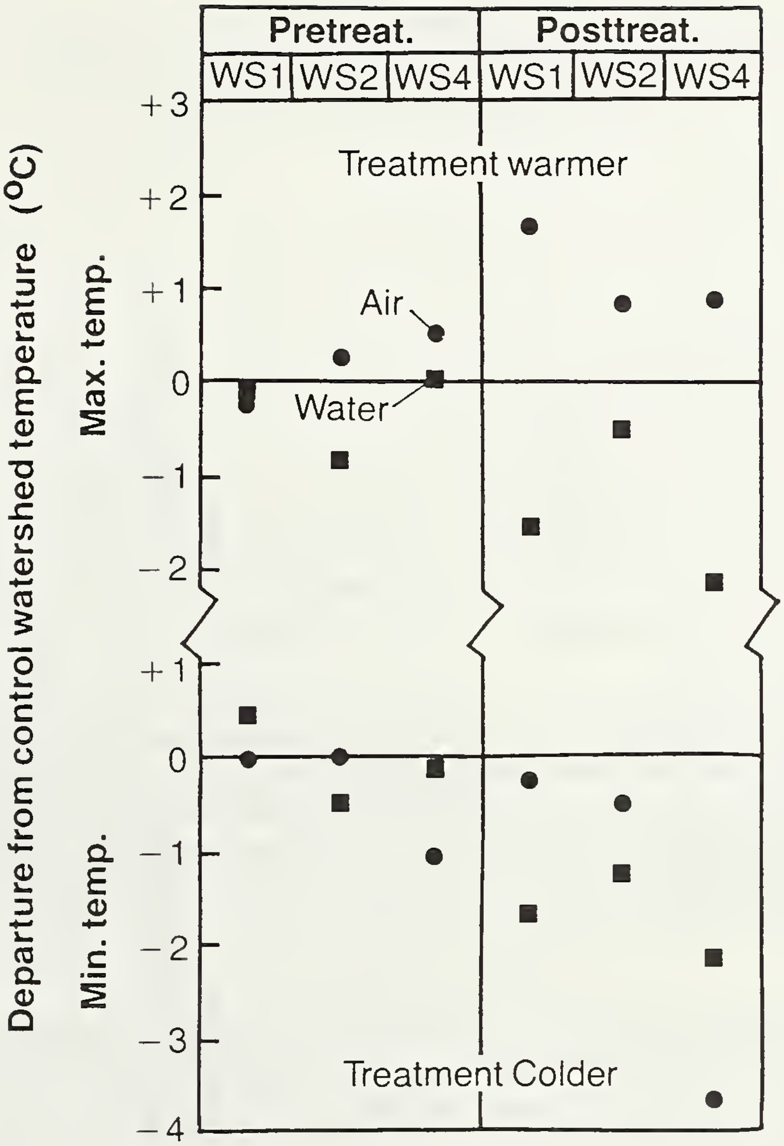

Figure 6--Differences in average maximum and minimum temperatures between control and treated watersheds for pretreatment and posttreatment periods.

14-day record of soil temperatures at 2.5 cm in the logged and unlogged stands. Canopy removal expanded the diurnal range: maximums increased and minimums decreased compared with the unlogged stand.

Wind

Immediate and substantial changes in total wind passage and average windspeeds accompanied removal of the forest stand. Figure 8 presents data from roughly equivalent 11-month periods during pretreatment and posttreatment. Data presented above describing wind passage in various windspeed classes during the pretreatment period at 20 m above ground in watershed 4 are shown as 4(20)A in this figure. Posttreatment wind passage in the six windspeed classes at this location is shown as 4(20)B. Slightly less wind passage is shown in the posttreatment period at the higher windspeeds. As we noted above, only rarely during pretreatment was wind passage at other sites observed at windspeeds of 9.6 to 16 km/h and none at higher windspeeds. Plots 4(6)A, 1(20)A, and 1(6)A show the pretreatment data at 6 m above ground in watershed 4 and at 20 m and 6 m above ground in watershed 1. Plots 4(6)B, 1(20)B and 1(6)B show the posttreatment data. Even at 6 m above ground in the clearcutting in watershed 1, more wind passage in any windspeed class was observed than at 20 m in watershed 4.

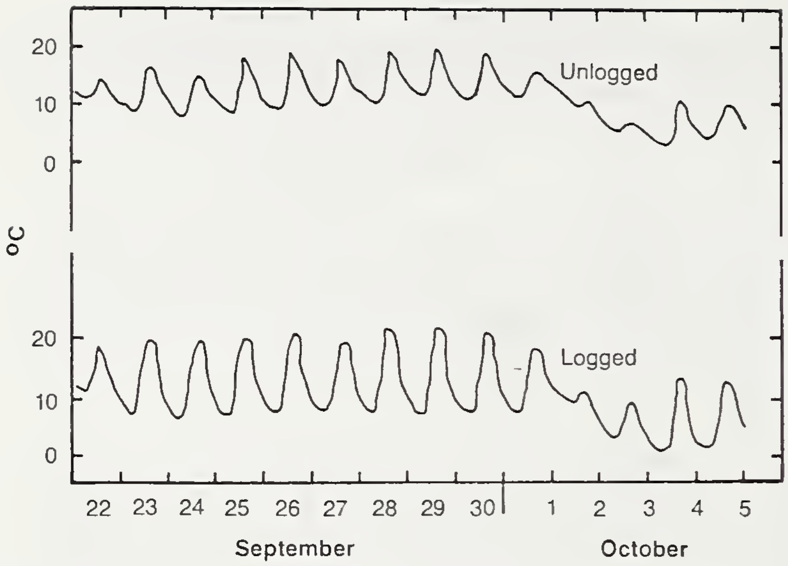

Figure 7--Soil temperature at 0.025 m in logged and unlogged areas, by day.

These dramatic changes in wind passage and windspeed could (1) affect snow distribution within these small watersheds (even to the extent of moving snow beyond watershed boundaries), and (2) change the relative values of evaporation and sublimation from the snowpack and of evaporation from the exposed soil surface that resulted from harvest and residue treatments.[5] Both effects could reduce the relative gains in water yield expected from biomass removal.

Snow Accumulation

Snow accumulation in untreated stands during the pretreatment period was not significantly different among the five measurement plots.[6] During the first winter after harvest, 1976-77, no snow measurements were taken because that winter was one of the driest on record and only patchy snow accumulated. During the 1978 water year, although generally more snow accumulated in openings than in forest stands, a credible measurement of snow water content could not be made at maximum snow accumulation. Numerous ice layers and up to 0.75 m of granular snow and ice at the soil surface gave no structure to the pack.

Snow accumulation and water content were close to average in 1979. An analysis of variance of snow depth and water content measurements taken on March 1, 1979, showed a highly significant difference ($P<0.01$) among plots. The combined average snow depth in treated plots, 220.9 cm, was significantly greater ($P<0.05$) than the average for untreated plots, 182.2 cm. Water content was also significantly greater in treated plots, 68.1 cm, as compared with untreated controls, 57.4 cm.

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[5] Soil temperatures were measured only in watersheds 1 and 4.

[6] Two plots in the larger clearcut in watershed 1, one plot in watershed 3 (untreated), and two plots (one treated, one untreated) in watershed 4.

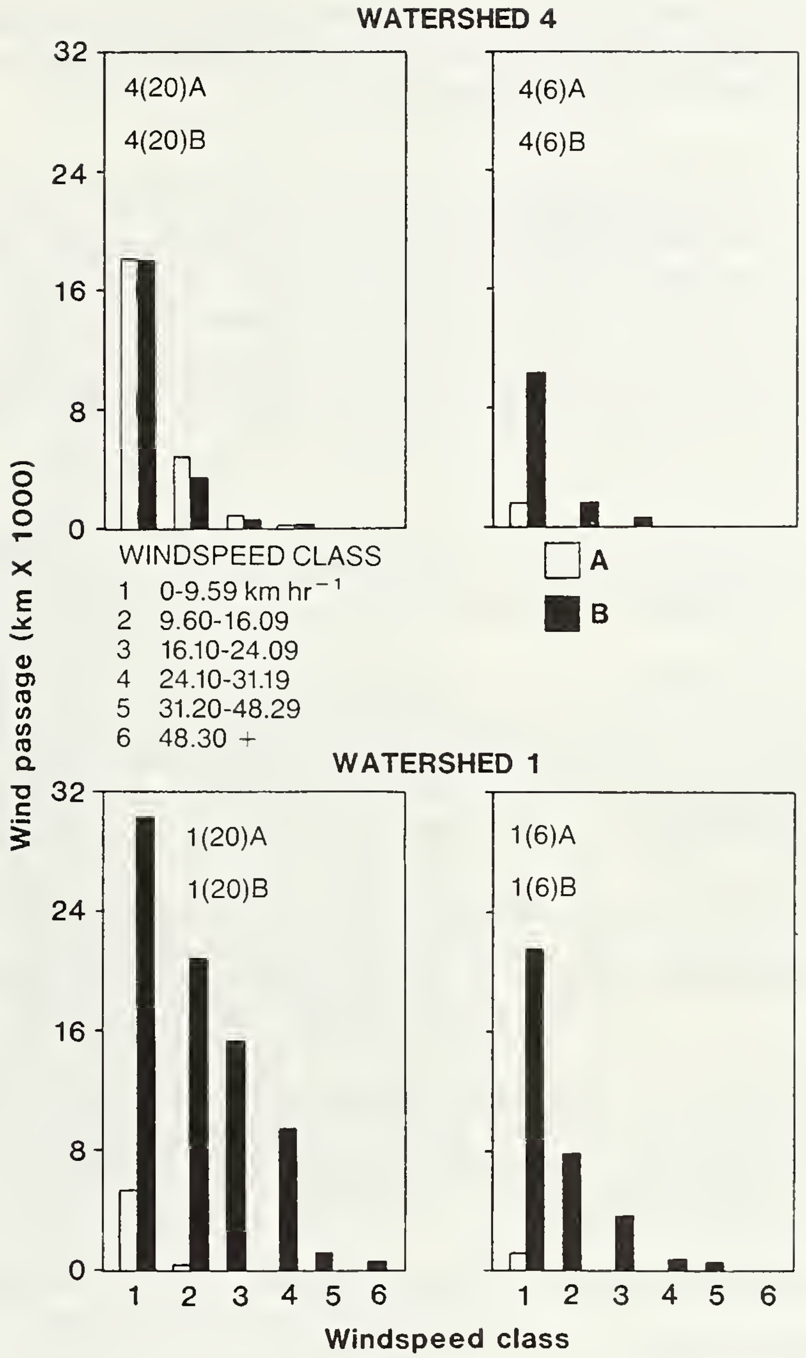

Figure 8--Wind passage in six windspeed classes at 6 and 20 m in watersheds 4 and 1 during two 11-month periods--one before and one after treatment.

Conclusions

Because this study is unreplicated, observations apply only to the study area. In this watershed complex, the hydrology was relatively insensitive to timber harvest. Although an increased soil water content, up to 20 cm, and increased snow water content, up to 11 cm, were observed in clearcut stands, no increase was observed for annual water yield that fell outside the 95-percent confidence intervals established during the calibration period; similarly, no significant response in low or peak flows was observed. Snow redistribution and enhanced evaporation and sublimation could have moderated any yield increase. These watersheds on fractured basalt may be subject to considerable deep seepage, and the control stream was relatively insensitive as compared with treatment streams. With the exception of watershed 2 where timber harvest occurred in the riparian zone, wide buffer strips adjoined the permanent streams. How effective these forested areas were in capturing any increased intransit flow to the stream channels is also unknown.

More predictable than the water-yield response were the responses of wind and of air and soil temperatures. Dramatic increases in wind passage and windspeeds occurred. Evidence of increased diurnal range in air temperature, especially the lowering of average minimums in the small clearings, may indicate thermal problems for tree regeneration. Additional research is needed on the microclimate of these high-elevation stands and on the dynamics of revegetating plant communities. The USDA Forest Service Forestry Sciences Laboratory at Wenatchee is doing this research.

English Equivalents

To convert:	To:	Multiply by:
Millimeters	Inches	0.03937
Centimeters	Inches	0.3937
Meters	Yards	1.094
Kilometers	Miles	0.6214
Hectares	Acres	2.471
Liters per second	Cubic feet per second	0.03531
Celsius	Fahrenheit	(9/5 °C) + 32
Grams per cubic centimeter	Pounds per cubic feet	62.43
Square meters	Square yards	1.196
Cubic meters	Cubic feet	35.31

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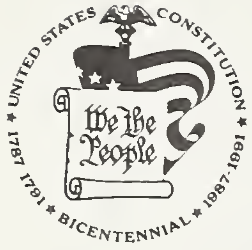

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