Some Climatic and Hydrologic Effects of Wildfire in Washington State

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INTRODUCTION

BEFORE the fire on the Entiat Experimental Forest in August 1970, one main objective of research on the Forest was to document changes in quantity, quality, and timing of runoff after timber harvest. The present objective is to determine changes in these hydrologic values after wildfire. Instead of planned reduction of vegetation by logging, which was to involve no more than one-third of each watershed at one time, practically all the vegetation on the three watersheds on the Forest was destroyed within a few hours. For the first time in the Northwest, detailed hydrologic data were available from an area undisturbed by man and probably not burned by wildfire in the past 200 years. In this paper, we compare prefire and postfire data to determine changes in annual yield, chemistry, and temperature of water. In addition, some information is presented on air and soil temperature changes. Another symposium paper by Tiedemann and Klock gives a detailed description of the watersheds and the fire.

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PREFIRE HYDROLOGY

Annual precipitation at the 915-m (3,000-ft) elevation ranged from 20.3 to 78.7 cm (8 to 31 in.) and averaged 57.9 cm (22.8 in.) between 1961 and 1971. Usually, measurable precipitation falls each month, but, on the average, only 10 percent of the annual total occurs from June through September. Snow accounts for more than 70 percent of total precipitation. A snowpack usually forms by December and increases in water content until March; it usually is melted by mid-June.

Streamflow patterns are typical of areas in which precipitation is mostly in the form of snow. Snowmelt produced high flow volumes in springtime, and flow thereafter gradually declines to an annual low in September. Sometimes this pattern is altered by intense thundershowers in midsummer. Because flow rate is usually lowest in September, the water year is defined as October 1 to September 30. Average daily flow rates during calibration ranged from 0.66 to 44.3 liters per second per square kilometer (0.06 to 4.05 cubic feet per second per square mile). Additional hydrologic data from the three watersheds during calibration are presented in Table 1.

Water temperature is near freezing during winter months because stream channels are covered by snow. The streams warm gradually during summer months and reach an annual maximum in July or August. During the year before the fire, the maximum temperature recorded at the weir site was only 11° C (52° F).

Water from all three watersheds was extremely pure chemically. For example, maximum concentrations of nitrate nitrogen and total organic nitrogen measured before the fire were only 0.015 and 0.047 mg/liter,[2] respectively. The maximum concentration of total cations was 11.5, 12.8 and 14.2 mg/liter for Burns, Fox, and McCree Creeks, respectively.

RESULTS AND DISCUSSION

WATER YIELD

Three early effects of the fire on hydrologic behavior were reported by Berndt (1971). Flow rate on McCree Creek decreased

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[2] /One mg/liter is the same as one part per million or approximately 2.7 pounds per acre foot of water.

TABLE 1. Prefire hydrologic data for the three watersheds on the Entiat Experimental Forest

Hydrologic factor	McCree	Burns	Fox
Average annual yield—centimeters	11.2	15.5	17.5
(inches)	(4.4)	(6.1)	(6.9)
Maximum annual yield—centimeters	13.5	19.1	24.9
(inches)	(5.3)	(7.5)	(9.8)
Minimum annual yield—centimeters	8.6	12.2	12.7
(inches)	(3.4)	(4.8)	(5.0)
Maximum daily flow rate—liters per second	164.4	243.7	167.2
(cfs)	(5.8)	(8.6)	(4.8)
Minimum daily flow rate—liters per second	4.5	10.8	10.5
(cfs)	(0.16)	(0.38)	(0.37)

from 6.25 to 1.71 liters (0.22 to 0.06 cubic foot) per second during the 12 hours in which the fire was burning intensely. This response was attributed to "vaporization of water from live stream surfaces ventilated by strong convective currents." Another striking effect was in the diurnal pattern of flow. Before the fire, flow rates followed a regular cycle, reaching a maximum at about 0800 and a minimum at 1900 hours. After the fire, daily oscillations were virtually eliminated because vegetation along stream channels was destroyed and no longer transpiring water. The third effect noted by Berndt was a gradual increase in flow rate to a level above the prefire values. He could not detect a change in water temperature.

Helvey (1972, 1974) reported first- and second-year results of the fire on yield and temperature of water. Records collected in the headwaters of the Entiat River by the U.S. Forest Service under its Barometer Watershed Program and on the Chelan River by the U.S. Geological Survey served as control data for evaluating water yield changes. Fire did not touch the headwaters of the Entiat River, and only about 10 percent of the Chelan River drainage was burned.

Figure 1 depicts differences between predicted and measured yield for water year 1971—the first year after the fire. Yield increases, based on control data from the Entiat River, were 9.4 cm (3.7 in.) for McCree, 10.4 cm (4.1 in.) for Fox, and 6.9 cm (2.7 in.) for Burns watersheds. Comparable values based on Chelan River

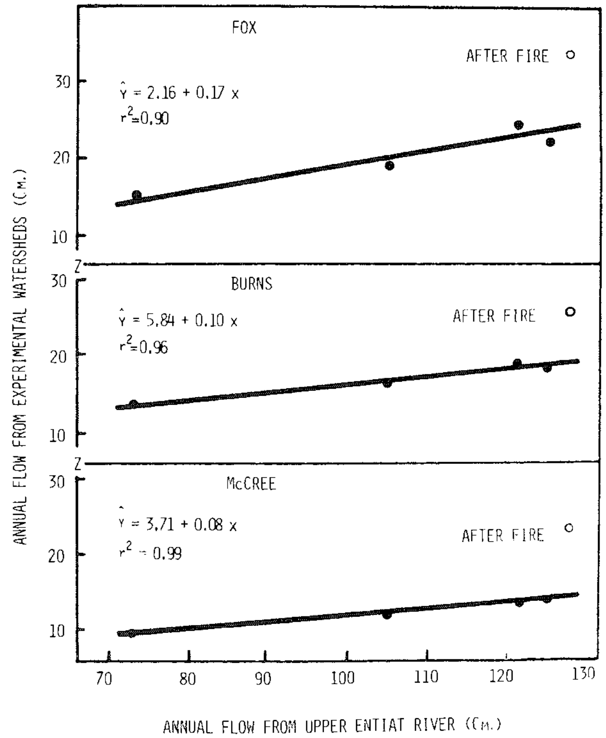

Fig. 1. Annual streamflow from the three experimental watersheds, Entiat Experimental Forest, before the fire and the first year after burning in relation to annual flow from upper Entiat River.

data were 9.1, 11.2, and 7.4 cm (3.5, 4.4, and 2.9 in.) for McCree, Fox, and Burns watersheds, respectively. Measured yield from the three watersheds totaled 1.39 x 10^6 m^3 (1,130 acre-feet). This was 50 percent more water than the predicted value based on prefire vegetation conditions. The extra water was produced during snowmelt and late summer months. Another paper by Klock and Helvey at this symposium discusses soil moisture-streamflow relationships.

Water year 1972 was characterized by much greater than normal precipitation. The snowpack was one of the deepest ever recorded in most of the Cascade Range in Washington. Snow depth on the

Experimental Forest was 150 percent of normal in mid-March 1972. Record high air temperature in mid-March increased flow rates, which in turn caused channel cutting. The weir pond on McCree Creek, which had not required cleaning during the 10-year calibration period, filled with sediment at 1- or 2-day intervals. Discharge rates of 509 liters (18 cubic feet) per second were measured during the second week of March—more than three times the maximum rates during calibration. On March 18, a side slope gave way and a torrent of soil, rock, and logging debris was carried into the main channel where it formed a dam about 1.6 km (1 mi.) above the gaging station. When water built up a sufficient head behind the dam, it broke through and a wall of water and debris about 11 m^2 (100 ft^2) in cross-section flowed down the main channel and destroyed the gaging station.

Intense rain showers on June 9 and 10 delivered 8.1 cm (3.2 in.) of precipitation within 30 hours. One burst of 3.8 cm (1.5 in.) was delivered in 30 minutes. Discharge rates increased rapidly, and Fox Creek weir was destroyed by a massive debris flow.

Another intense storm on August 15 delivered 6.6 cm (2.6 in.) of rain to parts of the watershed and caused additional debris flows on McCree and Fox Creeks. The gaging station on Burns Creek was filled with debris during the June 9 and August 15 storms, but fortunately we were able to clean it out and continue the discharge records.

Figure 2 illustrates the hydrograph on Burns Creek for the year of maximum runoff during calibration and hydrographs during the first and second years after the fire. Compared with the calibration year of 1966-67, runoff from snowmelt started about 1 month earlier in 1970-71 and about 2 months earlier in 1971-72. Possible reasons for the earlier and greater rate of snowmelt, in addition to the obvious effects of higher than normal temperature, include a lower snow albedo caused by dust from the blackened timber and increased surface exposure caused by decreased shade after the overstory was killed. Higher soil moisture levels caused by reduced evapotranspiration loss during the previous summer probably contributed to the earlier and greater rates of runoff in 1971-72.

Precipitation during water year 1973 was in sharp contrast to

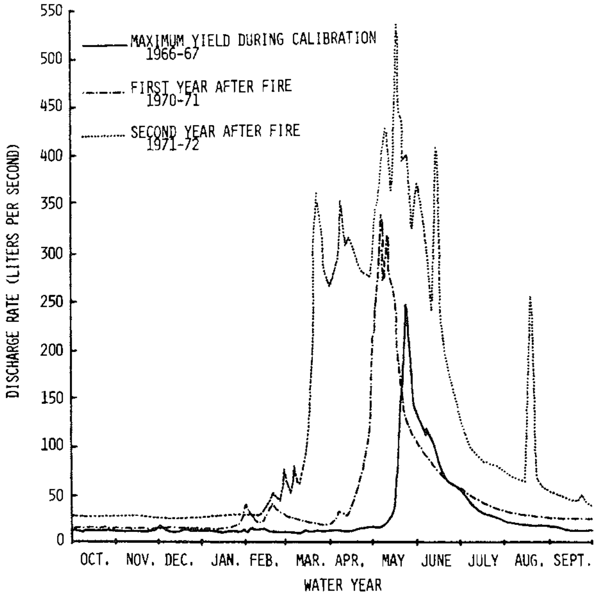

Fig. 2. Annual hydrographs for Burns Creek. Note that flow rate after the fire was much greater during snowmelt and late summer months.

that of the previous year. Precipitation in 1971-72 was one of the highest on record; in 1972-73, one of the lowest. Runoff was orderly with peak discharge rates not exceeding 170 liters (6 cubic feet) per second.

Because the stream-measuring stations on McCree and Fox Creeks were destroyed by debris flows, we do not have an annual runoff value for these streams for the 1971-72 water year. Annual water yield from Burns Creek is compared in Figure 3 with annual yield from the Chelan River. The prefire regression has a standard error of 1.4 cm (0.55 in.) at the 0.67 probability level. Measured yields minus predicted yields from Burns Creek were 7.4, 47.2, and 17.8 cm (2.9, 18.6, and 7.0 in.) for the first, second, and third years after the fire, respectively.

The computed yield increase for water year 1971-72 is suspect because measured flow from the Chelan River was considerably

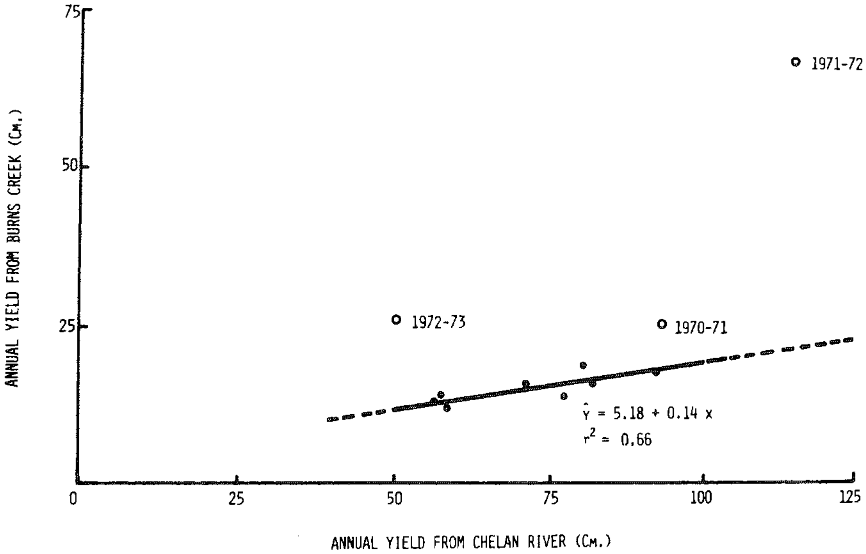

Fig. 3. Annual water yield from Burns Creek before and during the first 3 years after the fire in relation to annual yield from Chelan River.

greater than during the calibration period. Therefore, the regression requirement that prediction should not be made beyond the limits of the calibration data could not be met, and extrapolation of the prefire linear relationship probably is not justified. However, experiments in other parts of the country have shown that water yield response to tree removal varies directly with current annual precipitation (Rich, 1972). From the evidence, we conclude that yield increase due to evapotranspiration savings was greater during water year 1972 than in 1971 but probably less than the value (47.2 cm) obtained by extending the linear calibration curve and subtracting predicted runoff from measured runoff.

Water yield in 1972-73 from Burns Creek was 26.7 cm (10.5 in.), more than double the predicted value based on prefire conditions. This value was influenced an unknown amount by the high precipitation during the previous year. These watersheds apparently contain a huge soil reservoir which stores moisture and releases it gradually to streamflow. Water yield during a dry year which follows a wet year will be somewhat greater than during a similar dry year which follows a dry year. In other words, the water-yielding "dials" are not necessarily set to zero on September 30 of each year.

STREAM CHEMISTRY

Before we get into the water chemistry results, it may be wise to repeat the watershed rehabilitation treatments presented earlier in this symposium by Tiedemann and Klock.

Burns and McCree Creeks were seeded with a standard mix of grasses and legumes. Burns Creek was fertilized with 33 metric tons (72,700 pounds) of nitrogen as ammonium sulfate at a rate of 57 kg/ha (51 lb/acre) of nitrogen. Twenty-eight metric tons (61,700 pounds) of nitrogen as urea were applied to McCree Creek at the rate of 54 kg/ha (48 lb/acre) of nitrogen. Applications were made by helicopter. Fox Creek was neither seeded nor fertilized.

Stream chemistry measurements were initiated on the Experimental Forest in April 1970, 4 months before the fire. Grab samples were collected after the fire at weekly or biweekly intervals. Because all three experimental watersheds were burned, it was necessary to select another stream to serve as an unburned control. The obvious choice was Lake Creek which is physically and biologically similar to the experimental watersheds; it is located immediately west of Fox Creek. Sampling was initiated on Lake Creek in December 1971.

Precipitation was collected during the fall and winter in 114-liter (30-gal) plastic buckets. Also, prior to snowmelt in the spring, 15-cm-(6-in.-) diameter snow profiles were taken with a stainless steel tube.

We will not go into specific analytical methods for nitrogen, but the detection limit for all nitrogenous constituents is 0.001 mg/liter. Cations are measured by atomic absorption spectroscopy.

Before discussing nutrient losses, we will take a brief look at the chemical characteristics of these streams. During the period of study, hydrogen ion activity (pH) ranged from 6.7 to 8.2, electrical conductivity from 20 to 80 micro mhos/cm, and total alkalinity from 0.38 to 1.2 meq/liter.

Figure 4 illustrates monthly maximum concentrations of nitrate-N since sampling began. The trace at the top of the figure is average monthly discharge from Burns Creek. During the period of fertilization, nitrate-N concentration increased to 0.045 mg/liter on the ammonium sulfate-treated watershed and to 0.13 mg/liter on the watershed that was fertilized with urea. Concentrations remained at background levels on Fox Creek, the burned but unfertilized watershed. During the 1971 spring runoff period, nitrate-N concentration increased on all three watersheds with the highest amount, 0.21 mg/liter, occurring on the urea-fertilized watershed. By June 1971 nitrate-N concentration had returned to background level, 0.01 mg/liter.

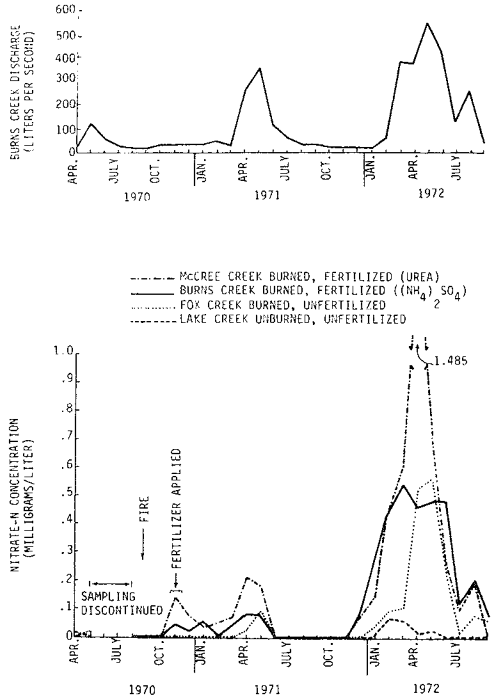

Fig. 4. Average monthly concentration of nitrate nitrogen from four streams and average monthly flow rate on Burns Creek. Note that concentration is directly related to flow rate.

During November 1971, nitrate-N concentration began to increase on all three burned watersheds, eventually reaching a peak of 0.56 mg/liter on the burned but unfertilized watershed, 0.54 mg/liter on the watershed fertilized with ammonium sulfate, and 1.49 mg/liter on the watershed fertilized with urea. By September 1972, nitrate-N concentration on all three burned watersheds had dropped to less than 0.10 mg/liter. The concentration of nitrate-N on unburned Lake Creek reached a peak of only 0.065 mg/liter in February of 1972 and declined to less than 0.01 mg/liter by June 1972.

Urea-N was observed only occasionally in these streams. Concentrations of up to 0.25 mg/liter were detected, apparently resulting from animal activity in the stream. During the period of urea fertilization of McCree Creek, no urea-N was detected in our grab samples, but Klock (1971), who sampled intensively during fertilization, observed urea-N concentrations of up to 0.66 mg/liter and noted that urea-N outflow dropped rapidly within 2 days after fertilization was completed. Sampling in the present study was apparently not frequent enough to capture urea-N peaks.

Ammonia is sometimes detected in these streams, but concentration rarely exceeds 0.01 mg/liter. The highest concentration observed was 0.04 mg/liter.

The average concentration of total organic-N in streams from the three burned watersheds increased from 0.047 mg/liter before the fire to 0.064 mg/liter and 0.103 mg/liter the first and second years after the fire, respectively.

Calcium is the predominant cation in streams from these watersheds, ranging from 2 to 21 mg/liter. Average calcium concentration on the three burned watersheds declined from 8.8 mg/liter in 1970 to 7.3 in 1971 and 5.0 in 1972. Average magnesium concentration declined from 1.5 mg/liter in 1970 to 1.3 in 1971 and 0.9 in 1972. Sodium concentration ranged from 0.6 to 4.2 mg/liter and declined from an average of 2.9 mg/liter in 1970 to 2.3 in 1972. The range for potassium was 0.2 to 2.6 mg/liter, with a drop in concentration between 1970 and 1972 from 1.3 to 0.9 mg/liter.

The average monthly concentration of the four major cations on the Experimental Forest and Lake Creek is shown in Figure 5. The average concentration on the burned watersheds decreased from

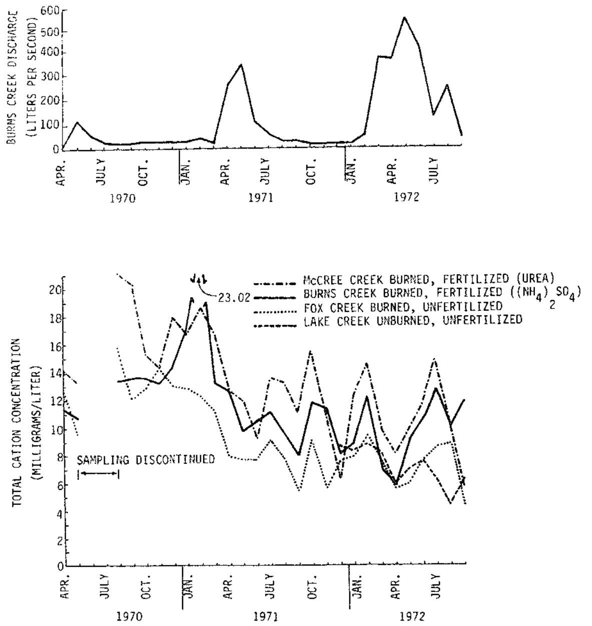

Fig. 5. Average monthly concentration of total cations from four streams and average monthly flow rate on Burns Creek.

14.5 mg/liter in 1970 to 12.5 in 1971 and 9.1 in 1972. Average concentration of the four cations in unburned Lake Creek in 1972 was 6.2 mg/liter—substantially lower than in streams from the Experimental Forest.

Because of the mineralizing effect of fire on metal ions that had been incorporated in plant tissue, we had anticipated an increase in cation concentration. Grier (1973) estimated that ash on the Experimental Forest immediately after the fire contained 217 kg/ha (194 lb/acre) of calcium, 59 kg/ha (53 lb/acre) of magnesium, 39 kg/ha (35 lb/acre) of potassium, and 7 kg/ha (6 lb/acre) of sodium. Apparently, any increase in the amount of cations moving to the streams was partially compensated by the dilution effect caused by increased runoff resulting from the fire, and cation concentrations were not as expected. Helvey (1974) estimated that these three watersheds yielded an average of 9 cm (3.5 in.) more runoff during 1971 than if the area had not been burned. During 1972, runoff from Burns Creek was 350 percent of the maximum observed during calibration.

From the above results, it is evident that concentration values do not give the total indication of the impact of fire or fertilization. Although there appears to be a decline in cation concentration since 1970 on the burned watersheds, comparison with unburned Lake Creek in 1972 indicates the possibility of an increase in cation concentration.

Total loss of each constituent was calculated for each water year from concentration and stream discharge data for each Experimental Forest watershed. As we mentioned earlier, two gaging stations were destroyed by debris avalanches in the spring of 1972. Between June and September 1972, discharge data for McCree and Fox Creeks were adjusted to their previous relationship to Burns Creek discharge, the only gaging station left intact. Lake Creek is not gaged, so we have no data for total losses.

Nutrient losses from Fox Creek, the burned, unfertilized watershed, were greater after fire than before, with nitrate-N showing the greatest loss—from 0.008 kg/ha (0.007 lb/acre) in water year 1970 to 1.92 kg/ha (1.71 lb/acre) in water year 1972. Total losses of cations more than doubled between 1970 and 1972 on this watershed.

McCree Creek, burned and fertilized with urea, had the highest losses and the greatest change in loss between water years 1970 and 1972. Nitrate-N loss increased from 0.0002 kg/ha (0.00018 lb/acre) to 3.28 kg/ha (2.93 lb/acre). Cation losses increased four times from 15.4 to 62.7 kg/ha (13.7 to 55.9 lb/acre).

Because of the capital of nutrients available, these losses probably will not adversely affect future productivity of these ecosystems. After nitrogen was applied, for example, on Fox Creek where the total N capital is approximately 1000 kg/ha, less than 3 kg/ha (2.7 lb/acre) were lost in 1972. Nitrogen losses from McCree Creek indicate that, despite the severe disturbance, these watersheds still conserve applied nitrogen very effectively. Even with application of 54 kg/ha (48.2 lb/acre) of nitrogen as urea, only 3.28 kg/ha (2.93 lb/acre) were lost from McCree Creek.

Nutrient ion losses are partially offset by input from precipitation. Snow on the Experimental Forest contains an average annual input of 1.1 kg/ha (1.0 lb/acre) of nitrogen and 8.5 kg/ha (7.9 lb/acre) of the four cations. If the snow chemistry was the same before the fire, this results in a net accrual of nitrogen to the system and a net loss of cations. After fire there is a small net loss of nitrogen unless fertilizer is applied.

STREAM TEMPERATURE

Stream temperature measurements were made at the mouth of each watershed about a year before the fire. Starting in the fall of 1972, stream temperature was measured at three additional sites and air temperature at seven sites on Burns and Fox Creeks. Also, stream and air temperatures were measured at three sites on Lake Creek.

Increases in stream temperature at the gaging site were evaluated from control data from the Entiat River (Fig. 6). Increases of 5.5° C (9.9° F) were measured during midsummer, but water temperature still did not exceed 16.7° C (62° F).

Figure 7 illustrates fluctuations of stream temperature at four sites on Fox Creek from June through October 1973. The upper site is located near the point where surface water originates. Water temperature fluctuated through the narrow range of 5.8 to 8.8° C (42.4 to 48° F). The second site, located about 1.5 km (1 mile) from the source, is below a steep gradient on a south aspect. Stream temperature fluctuated between 3.4 and 20° C (38.1 and 68° F). The third station is located in a deeply dissected valley where the stream receives considerable topographic shading as well as some shading from live trees. Temperature fluctuated between 4.6 and 15.4° C (40.3 and 59.7° F). The fourth station is located immediately below a stream reach which has a steep gradient and virtually no shading. Stream temperature ranged from 1 to 21° C (33.8 to 69.8° F).

Stream temperature measurements in Fox Creek (Fig. 7) show the

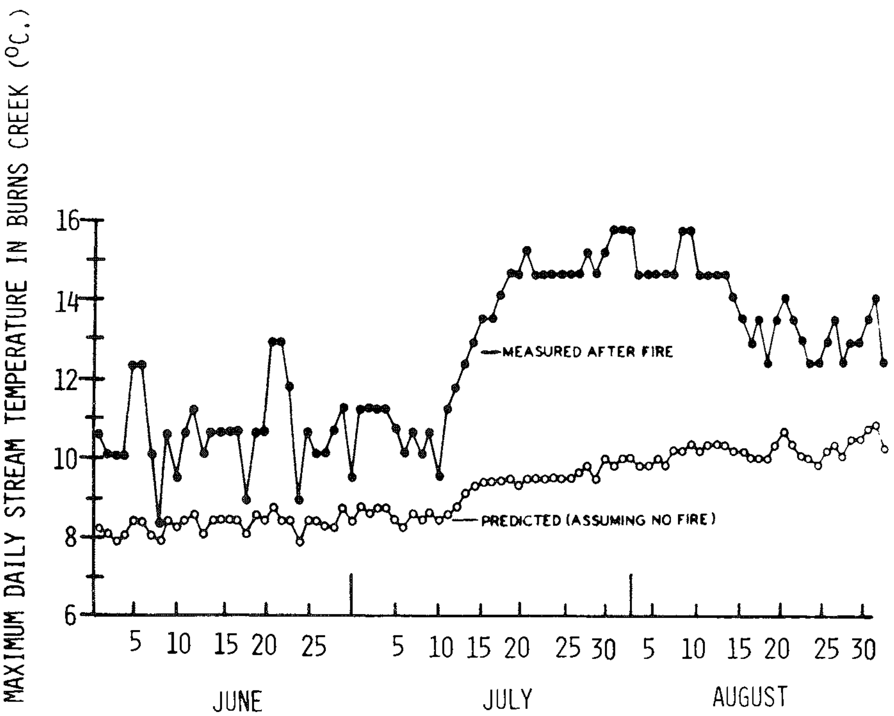

Fig. 6. Measured temperature in Burns Creek during the summer of 1971 and expected values if the forest had not been destroyed by fire.

effect of streamside and topographic shade. Reduction of exposure at middle sites, for example, causes seasonal maximum temperatures to appear earlier than at the lower weir site. The effect of continually decreasing flow rates during late summer complicates the relationship between these sites. Low flow, however, favors the higher temperatures at the exposed weir site and amplifies the energy input-temperature response. The increased flow rate due to evapotranspiration reduction plays a secondary but compensating role in stream temperature control compared to shade reduction caused by destruction of the forest stand.

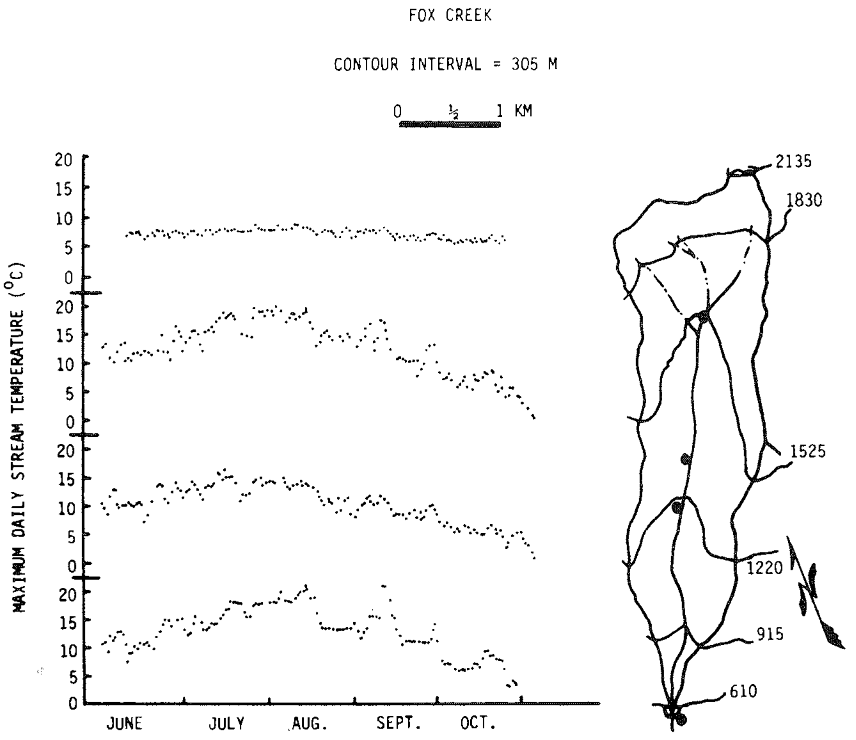

Fig. 7. Stream temperature fluctuations at four points on Fox Creek during the summer of 1973.

AIR TEMPERATURE

Air temperature measurements on the prefire forest were made at one site, the Burns Creek weir, from 1966 to present. One meteorological station, completed on August 22, 1970, on schedule for the future planned experiments, was destroyed by fire on August 24. Another installation was subsequently destroyed during the 1970-71 winter, crushed by snowdrifts from record-breaking snowfall.

Figure 8 shows monthly average temperatures for the Burns Creek

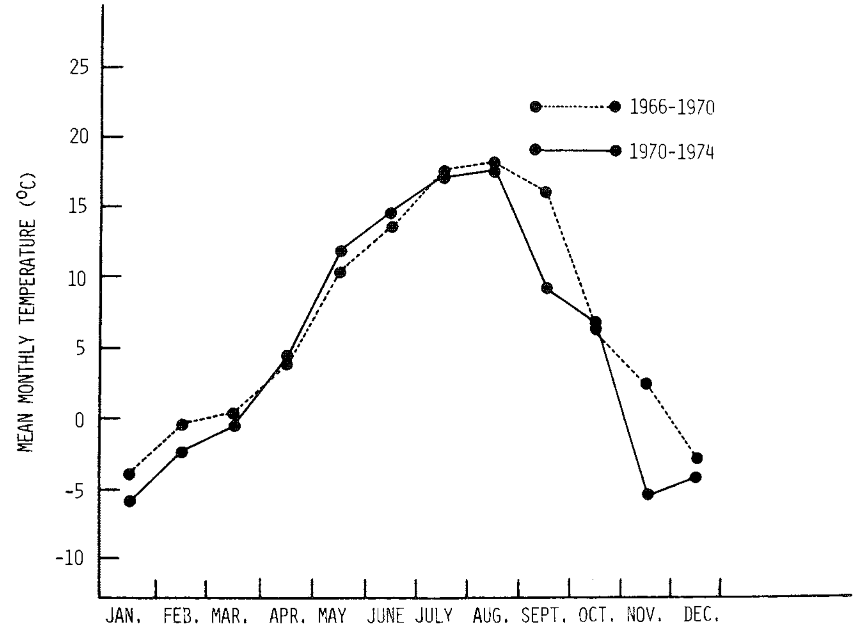

Fig. 8. Mean monthly temperatures for prefire and postfire periods at Burns Creek weir.

site for 1966 through 1970 and 1970 through 1974. Dashed lines represent prefire data. Although the curves suggest cooler postfire mean monthly temperatures in most months except May and June, the length and overall quality of record suggest caution at making any definitive statement.

An alternate procedure is to use control data from stations located outside the fire's zone of influence and test for changes in the treatment data. The double mass plot is frequently used for such an analysis. Simply, a cumulative value of some element at a base station or stations and at the point of interest is analyzed. The plotted summary usually maintains a relatively constant slope if both stations are reasonably close in space and experience similar weather cycles. A degree hour summary for July at the Burns Creek site is compared with the summary from Stehekin and Chelan, two nearby National Oceanic and Atmospheric Administration stations. July was chosen for this analysis as the month expected to be most influenced by the changing vegetal patterns on the watersheds and because July data are more complete. Data for the baseline are smoothed by averaging the summaries for the reference stations. Degree hours were computed with the equation:

$$\text{Degree hours} = \frac{12(\text{T max} - \text{T critical})^2}{\text{T max} - \text{T min}}$$

T critical was chosen as 0° C (32° F). Wang (1967) should be consulted for various techniques of degree hour summation.

The double mass plot (Fig. 9) for Burns Creek compared with the baseline station illustrates the constancy of the prefire relationship (r^2 of the regression equation 0.9999) and the changes in the postfire period. Visual inspection of the two curves suggests a change of slope, but a statistical check shows the difference in slopes to be nonsignificant at the 0.05 level. Additional data are required to determine if the temperature trends that appear to be established will continue.

SOIL TEMPERATURE

Changing amounts of overstory shade with fire and later tree removal obviously affected the energy input at the soil surface. Surface coverings, blackened initially by fire, suffered a range of disturbances during subsequent logging. Varying amounts of subsurface soil were exposed with burial and mixing of the original surface material.

Examination of the temperature response of material typically found in postharvest or postfire conditions to solar heating and nocturnal cooling gives some insight into the observed postfire surface temperature response. As part of a study on residue and its effect on the microclimate, temperatures were measured during exposure on a clear, calm June day and the following night. Figures 10 and 11 show the temperature record measured with an infrared thermometer as the material was rotated beneath the fixed temperature sensor.

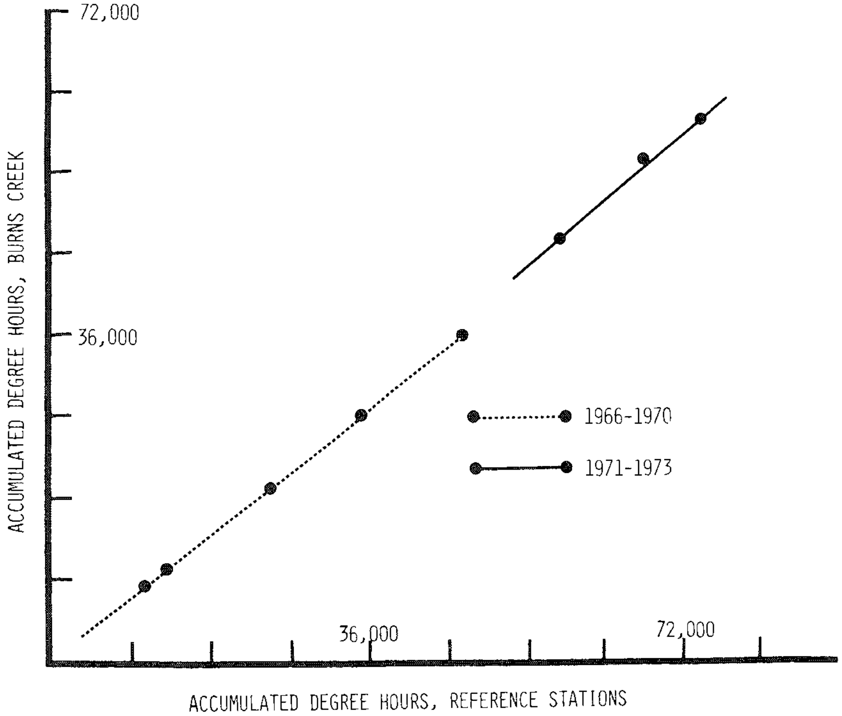

Fig. 9. Double mass plotting of air temperature before and after the fire from control data of stations outside the burned area.

The daytime response (Fig. 10) indicates that, because of more efficient absorption of solar radiation, darkened materials, such as charcoal or sand with a thin coating of charcoal, reached higher surface temperatures than organic materials such as bark and needles. Pumice, which is a common component of this Forest's soil, also was comparatively warm due to poor heat transmission and lower specific heat (amount of heat to warm a unit volume, compared to water). Dense, light-colored materials such as concrete (used to simulate a barren, rocky surface) showed little temperature change with similar exposure.

Nocturnal heat loss created the response shown in Figure 11.

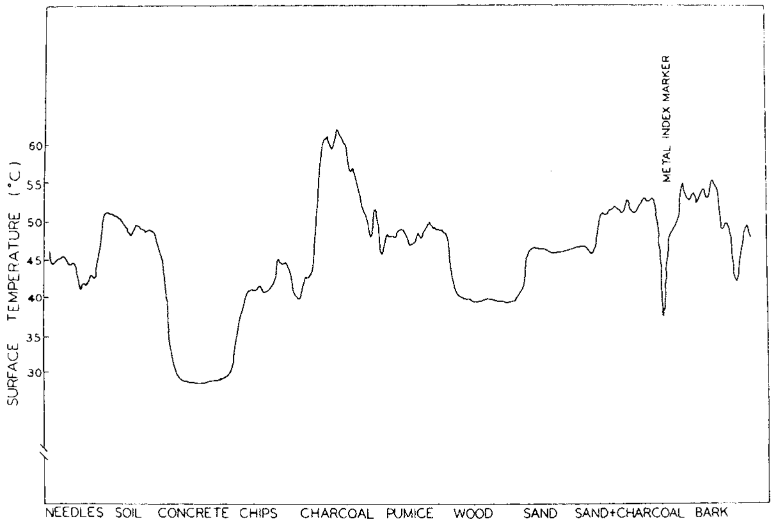

Fig. 10. Surface temperature on samples of various materials during midday heating in June.

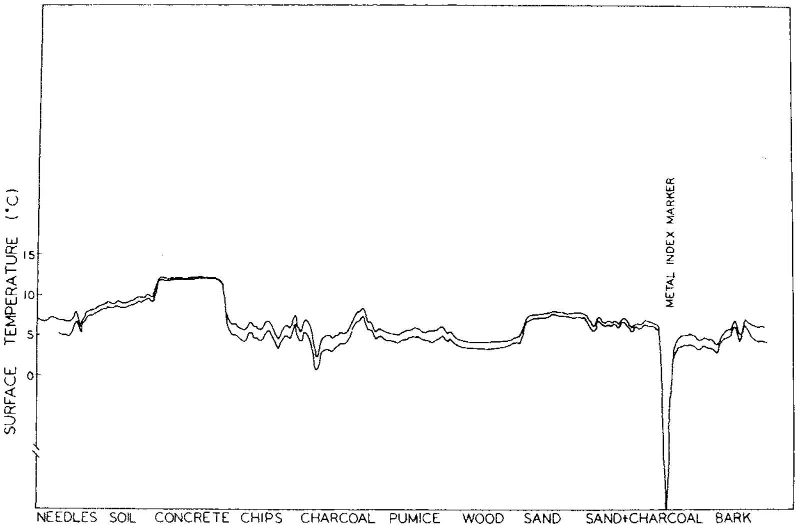

Fig. 11. Temperature record during nocturnal cooling in June. Second (lower) trace indicates rapid cooling over the 90-second rotation time.

Concrete had the highest surface temperature; organic materials, the lowest. Sites with surfaces high in organic materials can be expected to show temperature excesses during heating and cooling.

Even low shade from grasses, forbs, and shrubs modifies the environment near the ground and affects the site's potential for seed or seedling survival. On typical exposures on the Forest, a series of soil surface temperature measurements and corresponding cover amounts were taken in the summer of 1972. Figure 12 details the results. Presented are what we call "data groupings"—outlines that encompass all measurements for each exposure and disturbance class examined. Measurements were made at 0.6-m (1.6-ft) intervals on a 24-m (78.5-ft) transect.

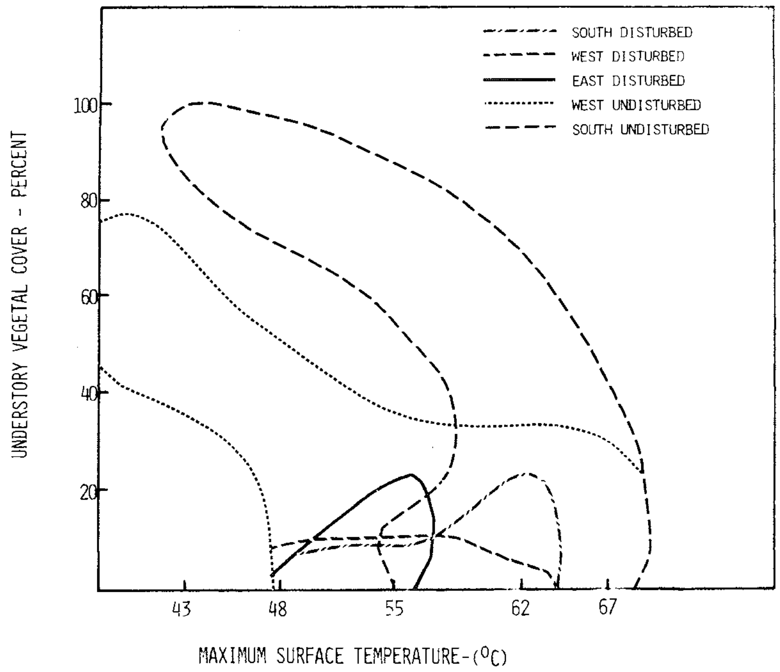

Fig. 12. Relationship between maximum surface temperatures and understory vegetal cover for sites on the Entiat Experimental Forest. Outlines encompass data points for each combination.

Data are tightly grouped on disturbed sites with east, west, or south exposures, and variability of the surface temperatures is small due to the low and fairly constant amounts of shade and the exposure of light-colored subsoil. Within the undisturbed conditions, the rapidly responding undergrowth and a wider range of soil surface materials broaden the grouping. Presence of more charred plant remains and low density needle and dry grass litter produces the higher surface temperatures.

Temperature measurements have been made with increasing intensity since the 1970 fire. As a parallel to the study of water temperatures, a detailed measurement network for air temperature has been installed. Data from the 17 recording sites are being analyzed for a comparison of unburned and burned conditions within and outside the watershed complex. Results of this study are not available.

SUMMARY

WATER YIELD

Streamflow increased strikingly after the vegetation was destroyed by wildfire. Snowmelt runoff started earlier and runoff peaks were higher after the fire compared with the calibration period. The future objective will be to document water yield trends as the watersheds are reoccupied by vegetation.

WATER CHEMISTRY

No effects of fire or fire followed by erosion control fertilization were detected on quality of water for municipal uses. Even though concentration and total losses of constituents (primarily nitrate-N) increased considerably, there has been no adverse effect on the future productivity of these ecosystems because the soil is still able to conserve applied nutrients.

STREAM, AIR, AND SOIL TEMPERATURE

Stream temperature increased after the channels were exposed to direct sunlight, but temperature remained within the range recommended for trout. Suspected air temperature changes could not be documented because prefire data are limited. Several more seasons will be required before an adequate test of temperature trends can be made. Surface temperature response is more likely representative of the extreme conditions that were experienced throughout the watershed early in the postfire period. High surface temperatures caused by exposure of charred plant remains can be expected to become more moderate as the residual plant community occupies the site and as more hardy pioneers occupy the harsher sites. Several favorable seasons with optimum water supply and moderate temperatures may be required to accomplish the process. Somewhat surprising, the disturbance due to logging may be beneficial in reduction of excessive surface temperature conditions. Excessive disruption of the site with soil and nutrient loss, however, cannot be recommended.

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