Nedavia Bethlahmy
U.S. Forest Service, retired
Seattle, Washington 98105

Exposure, Clearcutting, and Burning Affect Soil Moisture Levels

Abstract

The water content of soils increases when a forest is clearcut and the slash is burned. The amount of increase depends on the exposure of the site. These conclusions are based on a new interpretation and reanalysis of the 13-year soil moisture phase of the Wagon Wheel Gap experiment.

The Wagon Wheel Gap experiment in Colorado (1) was the first controlled watershed management experiment. Its specific goal was to determine "the effects of the forest destruction upon the time and amount of streamflow" in the central Rocky Mountains. The 15-year experiment was conducted on two areas (A—unlogged, B—clearcut and burned after a preliminary calibration period), and resulted in a published report that provides a wealth of data.

One phase of the study was an investigation of soil moisture levels before and after logging. Upon completion of the experiment, the investigators noted that "the natural variation of soil texture at the different stations will account for the entirely different moisture content . . ." and "Because of these soil variations station to station comparisons are not permissible." Bates and Henry (1) concluded that "No definite conclusion can be drawn" on the effect of forest removal on soil moisture levels; but they also qualified this conclusion by noting that "if the forest removal did decrease the summer drain upon the soil moisture, the difference must have been very slight."

I have reanalyzed the soil moisture data tabulated in the final Wagon Wheel Gap report (1) and concluded that logging and burning substantially altered soil moisture levels. This conclusion is consistent with the results of more recent investigations (2, 3, and 4).

A New Interpretation

The Wagon Wheel Gap report provides soil moisture data for the summer months (June-September) of 1914-1926. The data, collected weekly, are tabulated by soil depth (one, two, and three feet), by plots (north and south slopes of areas A and B), month, year, and period: pre-denudation (1914-1919) and post-denudation (1920-1926). Although the designations pre- and post-denudation are correct, they are nevertheless misleading with respect to the soil moisture study.

A close study of the report reveals the following sequence of events. At the beginning of the experiment (1913) the investigators excavated four soil pits in areas A and B, cleared the pits of rocks, and then (to facilitate later sampling with an auger) refilled them with native, rock-free soil. Six years later (summer 1919) they clearcut area B and piled the slash in windrows spaced 30 feet apart, and the following year (September 1920), they burned the slash. In effect, the soil moisture phase of the experiment consisted of two treatments: An initial treatment that eliminated all root activity in all four plots, and a second treatment (six years later) imposed on only the two plots in area B. Ostensibly, the second treatment reinforced the first by again eliminating root activity. As a consequence of these treatments, we should expect two results:

(1) Soil moisture levels at all plots should decrease gradually during the first six years because roots of plants surrounding the soil pits should gradually invade the root-free soil and extract water for transpiration;

(2) During the second period (the "post-denudation" period) soil moisture levels in the unlogged areas should continue their downward trend because of the continued proliferation of roots; but in the logged and burned areas the downward trend should be interrupted.

Soil Moisture as a Time Series

If the above reasoning is correct, and the entire elapsed time of the experiment is considered as a simple time series, then the slope of the soil moisture line should be negative (*i.e.,* downward with the passage of time) for the unlogged plots (area A); but in the logged plots (area B) the slope should be less negative or even positive if the soils are exposed to additional sources of water. These conclusions should be apparent only if approximately equal amounts of precipitation characterized the two periods.

Thus, the first question to be answered is whether precipitation levels were approximately equal in both watersheds during the two periods. Analysis by Student's "t" test (5) of summer precipitation data for the 13 years for which soil moisture data are available reveals no significant difference between either areas or periods:

	Area A	Area B	"t"
	Summer precipitation (inches)		
Pre-denudation period	2.15	2.19	0.09
Post-denudation period	2.02	1.98	0.11
"t"	0.39	0.59	

On the other hand, despite the equality of measured precipitation, large differences are apparent among the soil moisture regression coefficients for the 13-year time series —differences that reflect the effects of both exposure and treatment. Regression coefficients for the linear trend of soil moisture over time for the four plots are tabulated below. Each of the listed coefficients is the average of 12 coefficients (four months, three depths) which characterize a 13-year soil moisture trend. The regression coefficients reveal that for the June-September months at Wagon Wheel Gap, soils on south slopes lose water at a slower rate than on north slopes, and also that the two treatments on area B (in contrast to only one on A) resulted in a significant gain in soil moisture—*i.e.,* less negative slopes. (** represents the 1-percent level of significance.)

	N-exposure	*S-exposure*	*"t"*
	Regression coefficients		
Area A	–0.69	–0.19	5.39**
Area B	–0.40	+0.27	10.13**
"t"	3.02**	7.47**	

Actual and Expected Soil Moisture Levels

A legitimate assumption is that during the six-year first phase of the experiment, the roots of plants surrounding the soil plots gradually encroached into the initially root-free soil. Another reasonable assumption is that root proliferation in the unlogged soil sites continued unabated during the second period. If these assumptions are correct then in the unlogged sites (area A) soil moisture content during the second period should be less than the amount predicted on the basis of soil moisture-precipitation regression equations developed for the first period. In contrast, in the logged sites (area B), root development should be less rapid during the second period, and more water should become available because of reduced interception of summer rains. During the second period, soil moisture conditions in the logged sites should differ considerably from those in the unlogged sites. This conclusion is corroborated in the following tabulation of differences between actual and predicted values (percent of dry weight) of soil moisture content during the post-denudation period. Predicted values are based on soil moisture-precipitation equations that characterized the pre-denudation period. Analysis by Student's "t" shows that the twice-treated B plots gained water relative to the once-treated A plots, and also that the second treatment was particularly effective on south slopes. (* and ** indicate the 5- and 1-percent levels of significance.)

	N-exposure	*S-exposure*	*"t"*
	(soil moisture change: actual %—predicted %)		
Area A	–1.86	–0.50	4.99**
Area B	–1.03	+1.22	10.71**
Student's "t"	2.55*	14.88**	

Covariance Analysis

Additional proof of the effect of clearcutting and burning on soil moisture levels can be obtained by covariance analysis—a technique used to analyze the relations between variables that are initially unlike.

The Wagon Wheel Gap experiment comprised two periods and four plots. I shall designate plots on north and south exposures in areas A and B as A_N, A_S, B_N, B_S. All plots were treated at the beginning of the experiment, but only two plots (B_N,B_S) were again treated at the beginning of the second period. The change in relation between any two plots during the two periods should depend on the effectiveness of the treatment imposed during the second period. Thus, if the second treatment affected soil moisture levels, then the relation that existed between B_S and A_S during the first period should change during the second; similarly, the relation between B_N and A_N should also change; moreover, if the effectiveness of the treatment depended on exposure, then the relation between B_N and B_S should also change between periods, but in the unlogged area the relation between A_N and A_S should remain constant. Statistical evidence for the change in relations induced by the clearcutting and burning treatment is shown in the following tabulation in which only the 5 percent (*) and 1 percent (**) levels of significance are indicated. Relations between A_N and A_S during the two periods remained constant and therefore are not listed. On the other hand, significant changes did occur in the relations between B_N and B_S. The tabulation shows that logging and burning altered soil moisture levels and that the magnitude of the effect depends on the exposure.

Soil depth	*Comparison*		
feet	B_N/B_S	B_S/A_S	B_N/A_N
		JUNE	
1	**	**	—
2	*	—	*
3	—		**
		JULY	
1	**	**	*
2	**	**	*
3	**	*	
		AUGUST	
1	*	*	—
2	*	*	—
3	**	**	—
		SEPTEMBER	
1	*	—	—
2	**	**	—
3	—	*	—

Effect of Exposure

Soil moisture is greatly influenced by exposure, particularly in mountainous terrain, where snow is a major component of annual precipitation. South slopes receive more solar radiation than north slopes; their soils are warmer, shallower, and are also exposed to drying conditions for longer periods of time. Bates and Henry's report (1) documents significant differences between north and south slopes at Wagon Wheel Gap: Snow disappears from south slopes about five to six weeks sooner; average soil tempearture at the 12-inch depth is about 8°F (4.4°C) warmer; and the average summer soil water content is about 7 percent (of dry weight) lower. On the other hand, soils on northerly exposures at Wagon Wheel Gap appear to have a greater water holding capacity, and they also lose more water during the summer months, presumably because of greater transpiration. Vegetation is more dense on north slopes, and also establishes itself more quickly after logging and burning.

Effect of Burning

The effect of burning on soil moisture cannot be evaluated precisely because the experiment was not designed for this purpose. Nevertheless, a qualitative evaluation can be made. In their report, Bates and Henry (1) indicated that the up-and-down-hill windrows of slash covered 20 percent of area B and burned so intensely that mineral soil was laid bare and aspen roots were killed: "The most striking feature of the fire scars was the complete absence of aspen sprouts for several years after the windrows were burned, in contrast to the prompt and general appearance of aspen sprouts elsewhere." It is logical to surmise that at Wagon Wheel Gap slash burning not only delayed the reappearance of aspen, but also delayed potential water losses from transpiration, and consequently raised the general level of soil moisture.

Summary and Conclusion

A reanalysis of the soil moisture data of the Wagon Wheel Gap experiment shows that the water content of soils increases after a forest is clearcut and the slash is burned. These results become evident when the soil moisture phase of the experiment is reinterpreted in light of the actual conduct of the experiment. Initially, soil pits were dug, rocks sifted out, and native soil returned to the pits. The experiment therefore consisted of two treatments: an initial one that temporarily stopped all root activity in all plots; and a second treatment imposed six years later on only two plots. The experiment should be viewed as one that allowed roots to proliferate for 13 years in an initially root-free area, but temporarily impeded their growth in another area after six years of unimpeded growth. One would expect soil moisture to diminish gradually in the first area (because of increased root activity and transpiration losses), but to diminish at an overall reduced rate in the second area. The data corroborate these expectations and also reveal substantial differences between the effects of the treatment on soils located on north and south exposures. In the Wagon Wheel Gap area slash burning is significantly related to soil moisture because it prevents the prompt regeneration of aspen sprouts.

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