Hydrologic Effects of Deforesting Two Mountain Watersheds in West Virginia

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Abstract. The upper half of one watershed and the lower half of another were deforested and maintained barren from 1965 to 1967. Forest on the remaining halves was cut in 1968. Water yield increases from both watersheds averaged almost 6 inches during the half deforested stage and rose to over 10 inches after complete deforestation. The duration of the flows greatly increased on both watersheds. Other hydrologic effects (instantaneous peak flows, stream temperature, specific conductance, and turbidity) were greater on the lower half deforested watershed. These results show again that forest cutting causes substantial increases in streamflow, but, more important, they provide some landmark values on hydrologic effects of complete deforestation.

To observe the quantity, regimen, and quality of streamflow from deforested watersheds and to compare hydrologic effects of deforesting upper and lower slopes, the upper half of one watershed and the lower half of another were cleared and maintained free of regrowth. Three years later, the remaining forested halves of the watersheds were also cleared. A third watershed was retained as a forested control throughout the experiment.

Most watershed experiments show that forest cutting increases annual streamflow in rough proportion to the amount of vegetation removed [*Hibbert,* 1967]. Because careful forest cutting seldom affects infiltration rates, these streamflow increases are rarely accompanied by increased overland flow [*Hoover,* 1962]. Increased streamflows are attributed to decreased evaporative losses [*Lull and Reinhart,* 1967] and, in mild climates, they tend to occur during the growing season [*Hibbert,* 1967]. The few analyses published [*Johnson and Meginnis,* 1960; *Reinhart et al.,* 1963; *Rothacker,* 1965] show that the harvesting of timber considerably augments the normally low flows of late summer and early fall but, outside the snowpack region, has little effect on peak flows of late winter or early spring. It is a common, but unnecessary, consequence of the harvesting of timber that water draining from the cutover land is turbid and that this turbidity originates primarily on poorly designed forest roads [*Packer,* 1967]. Ordinarily all of these hydrologic effects are maximized by clear-cutting in which the greatest volume per acre of forest growth is harvested.

THE EXPERIMENTAL WATERSHEDS, THEIR INSTRUMENTATION AND THEIR TREATMENT

The experiments were conducted on the Fernow Experimental Forest near Parsons, West Virginia. The Forest is in the Allegheny mountain section of the Appalachian plateau. The predominant soil is Calvin silt loam [*U.S. Department of Agriculture,* 1967] underlain with fractured sandstone and shale, and the elevation of the forest is about 2500 feet. Although precipitation is well distributed during most years, high evaporative losses usually reduce the flow in small forest streams to very low levels by late summer. Potential evapotranspiration was estimated to be 22 inches per year [*Patric and Goswami,* 1968]. The growing season is defined as May through October and the dormant season is defined as November through April. Soil moisture usually is completely recharged early in the dormant season. Table 1 lists other determinants of hydrologic behavior specific to individual experimental watersheds. These are not adjoining watersheds but are separated from each other by a few hundred yards of forest land.

Precipitation on these watersheds is sampled in a total of eight standard gages and two recording gages, and streamflow is measured in 120° V notch weirs. Details of watershed calibration and hydrologic data analysis are in *Reinhart et al.* [1963]. Stream temperatures were measured continuously at weir sites on Taylor temperature recorders, and specific conductivity from water samples was measured weekly with a microhmmeter. Turbidity was measured weekly, during peak flow, and during storms of special interest with a Hach turbidimeter, and stream *p*H was measured weekly with a Hellige *p*H field kit and with a Leeds and Northrup electric *p*H meter. Moisture in the upper 3 feet of soil was measured with a Troxler neutron probe; access tubes for the probe were installed 75 feet either side of midcontour lines that separated the forested from the deforested portions of both watersheds [*Troendle,* 1970].

After a 7-year period of calibration, the watersheds were divided as closely as possible in half during 1964; the upper half (29.3 acres) of watershed 7 and the lower half (27.0 acres) of watershed 6 were deforested in three stages. The three stages involved (1) the removal of saw logs, (2) the removal of pulpwood, and (3) the cutting of all remaining vegetation over 1-inch in diameter. The deforested halves were maintained free of most vegetation by intensive ground spraying, usually with 2, 4, 5-T, which was applied twice during each summer [*Reinhart,* 1965; *Patric and Campbell,* 1969, 1970]. (Our paper reports research involving herbicides. It does not contain recommendations for their use nor does it imply that the uses discussed here have been registered. All uses of herbicides must be registered by appropriate state and/or federal agencies before they can be recommended.)

Three years after the original treatment, the second half of each watershed was cleared and the land was maintained barren. Most of the stream channel, especially on watershed 6, is in the lower half of the watershed.

A carefully designed forest road system was installed to insure that effects of deforestation on water quality would be only minimally confounded by overland flows originating on these roads. *Hornbeck* [1967] has described the road system that thus far meets these needs. Roads were located nearly on contours and, where possible, well clear of streams. Timber and pulpwood harvest, herbicide spraying, and all other operations were conducted from these roads. About 18% of each deforested area was used for roads, skid trails, or log landings. Although travel routes were carefully drained, they could not, of course, be planted with grass, a common method of erosion control on logging roads.

TABLE 1. Some Characteristics of the Experimental Watersheds before Deforestation, Fernow Experimental Forest, Parsons, West Virginia

Characteristic	Watershed 4 Control	Watershed 6 Barren	Watershed 7 Barren
Size, acres	96.0	54.1	58.6
Precipitation, in./yr	56.9	56.7	57.4
Streamflow,* in./yr	23.6	19.4	30.4
Aspect, overall	southeast	southeast	east
Predominant tree species	red and chestnut oaks, sugar maple	white and chestnut oaks	red oak and sugar maple
Volume per acre, ft^3	2320	2650	2800
Basal area per acre, ft^2	106	114	115

* Note considerable discrepancies of precipitation minus streamflow (often equated to evapotranspiration). These discrepancies probably are caused by leakage into fissured shale and sandstone bedrock underlying these watersheds.

RESULTS

Substantial increases in seasonal and annual streamflow followed the deforesting of the halves of the watersheds (Table 2). Tabulated increases were measured at the weir; therefore when these figures are doubled the increases actually produced on the deforested half of the watersheds are defined. Thus the lower half deforested treatment (watershed 6) averaged 7.5 inches of increased flow for the growing seasons, 3.6 inches for dormant seasons, and 11.1 inches for the full year. The upper half deforested treatment (watershed 7), after initial complete deforestation, averaged 7.6 inches of increased flow for growing seasons, 4.2 inches for dormant seasons, and 11.8 inches for the full year. When both watersheds were fully deforested, the average increases were 8.0, 2.1, and 10.1 inches for the growing season, the dormant season, and the full year, respectively.

The duration of streamflow increased on each experimental watershed following both half and full deforestation (Figure 1). This increase occurred even with the less than average 41.6 inches of rainfall during the years 1965–1966 and 47.9 inches during 1968–1969. Flows of 1 cfsm (cubic feet per second per square mile) or less increased significantly on both watersheds during every year of treatment. Changes in the duration of flows 5 cfsm or higher were not significant. Before deforestation, both streams dried up one or more months during each summer. While the watersheds were half deforested, flows in both streams never were less than 0.05 cfsm, and while the watersheds were fully deforested, the flows in both streams were never less than 0.3 cfsm.

Regression analysis showed no significant differences in instantaneous peak flows during the dormant season after both watersheds were deforested. However, on watershed 6, most of the area along the stream had been deforested since 1965, and soil moisture remained at high levels. Here, instantaneous peak flows during the growing season were four times greater than those on the control watershed. On watershed 7, growing season increases in peak flows averaged 5 cfsm per storm through 1968, but these were not significant.

Stream temperatures during the dormant season were unchanged by any forest cutting. After deforesting the lower half of watershed 6, the mean daily stream temperature increased by 4°F during the growing season, an increase that was unchanged by complete deforestation. After deforesting the upper half of watershed 7, the stream temperature was not affected because most of the channel remained under forest. The complete deforestation of watershed 7 raised the mean daily stream temperature by 2°F during the growing season. Maximum stream temperatures recorded (65°, 80°, and 71°F on watersheds 4, 6, and 7, respectively) were on August 23, 1968. The air temperature at the Parsons climatic station reached

TABLE 2. Streamflow Increases at Watersheds 6 and 7 after Two-Stage Deforestation, Fernow Experimental Forest, Parsons, West Virginia, in Area Inches

Year	Annual Precipitation on Control Watershed 4	Watershed 6		Watershed 7	
		Growing Season	Dormant Season	Growing Season	Dormant Season
1964–1965	54.90	1.2	0.8 (cut)	3.6*	2.5*
1965–1966	43.16	3.1*	3.4*	2.9*	2.8*
1966–1967	50.11	4.2*	1.4*	4.9*	1.0* (cut)
1967–1968	50.72	3.9*	0.6 (cut)	8.6*	1.3*
1968–1969	51.11	7.9*	2.3*	7.5*	2.8*

The year is based on a May 1 through April 30 hydrologic year.

On watershed 6 the lower half was deforested between March 24 and August 31, 1964, and the upper half was deforested between October 16, 1967, and January 31, 1968.

On watershed 7 the upper half was deforested during the dormant season in 1963, and the lower half was deforested between October 17, 1966, and March 3, 1967.

* Significant at 0.05 level.

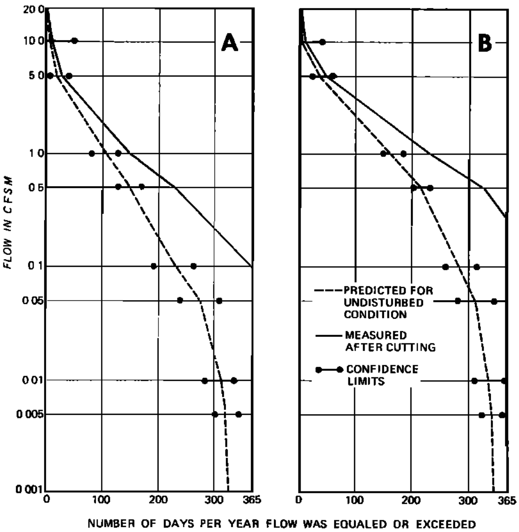

Fig. 1. Effect on flow duration of two-stage deforestation in watershed 7. (*a*) Half deforested, 1965. (*b*) Fully deforested, 1968.

89°F, and was almost as high on several preceding sunny days.

Specific conductance, the most accurate and objective water quality test used, is a quick indicator of ionic concentration in water. Before deforestation, specific conductance varied little among streams draining the experimental watersheds. Although specific conductance remained nearly constant in the stream that drained the watershed maintained in forest (Table 3), it almost tripled in streams that drained both deforested watersheds. As might be expected, the highest values of specific conductance usually were observed on watershed 6 where the channel area was devegetated the longest.

Deforestation also increased maximum turbidities (Table 4). These data evidence that road construction and (or) deforestation increased soil and organic matter in storm flow draining from the treated watersheds. Although turbidity of storm flow did increase, the maximums were not high enough to cause serious concern. Nonstorm flows, constituting over 90% of water yield from all three watersheds, never contained more than 5 ppm of turbidity, the level acceptable for drinking water [*U.S. Public Health Service,* 1962].

Other water quality observations provided inconclusive results. Measurements of *p*H ranged from 5.2 to 6.6 and was usually about 5.6–5.9. Our *p*H data seemed to be related more closely to the method of measurement than to watershed treatment. Water samples also were taken to evaluate herbicide contamination. During 1965, three panelists could not detect the taste or odor of herbicides in water samples from streams draining the treated watersheds. (The panel did single out lab-prepared samples containing as little as 0.5 ppm of herbicide mix.)

By 1967, only traces of forest litter remained on initially deforested halves of both treated watersheds, but organic matter remained high in the A_1 soil horizon. Under these soil conditions, ring infiltrometer tests showed infiltration rates about the same as those observed on the forested watershed. All infiltration rates far

TABLE 3. Specific Conductance in Micromhos in Streams before and after Deforesting Watersheds, Fernow Experimental Forest, Parsons, West Virginia

Item	Watershed 4 Forested	Watershed 7 Upper Half Deforested	Watershed 6 Lower Half Deforested
Before deforestation (average of 3 years)	16 ± 3*	19 ± 3	19 ± 2
After deforestation			
First year	14 ± 1	18 ± 4	19 ± 2
Second year	17 ± 3	25 ± 4	23 ± 7
Third year	16 ± 2	40 ± 9	53 ± 18
Fourth year	15 ± 2	46 ± 7†	57 ± 17†

The calculations are based on calendar years.

* Mean and one standard deviation.

† Fully deforested.

TABLE 4. Maximum Observed Turbidity in Parts per Million in Streams before and after Deforestation, Fernow Experimental Forest, Parsons, West Virginia

Item	Watershed 4 Forested	Watershed 7 Upper Half Deforested	Watershed 6 Lower Half Deforested
Before treatment	6	16	29
After treatment			
First year	8	42	83
Second year	4	25	40
Third year	25	38	55
Fourth year	7	130*	55*

* Fully deforested.

exceeded maximum rainfall intensities [*Hershfield,* 1961].

DISCUSSION

This experiment shows again that forest cutting causes substantial streamflow increases. More important, complete devegetation shows that the maximum expected increase, under local conditions of climate and soil, is about 12 inches during the first year after complete deforestation compared with increases up to 16 inches in North Carolina [*Hibbert,* 1967] and 13 inches in New Hampshire [*Hornbeck et al.,* 1970] during the first year. Although these experiments show considerable variation, we can conclude that complete deforestation will substantially increase water yields throughout the Appalachian region.

One approach to predicting streamflow increases following forest cutting is to keep repeating the trials. To date, the literature contains only *Hibbert*'s [1967] account of a forest water yield experiment repeated on the same catchment. Our experiments caused similar streamflow increases from similar watersheds similarly treated. This study also further allays 'statistical doubts and arguments as to whether calibration of paired watersheds for acceptable periods of time could provide for subsequent climatic fluctuations' [*Pereira,* 1967].

This experiment also indicates that the location of treatments within watersheds has little effect on water yields in the humid east. This indication is not surprising because evapotranspiration on the Fernow Experimental Forest approaches potential rates most of the time (Reinhart, unpublished file report 4300, 1966). In drier regions, cutting riparian vegetation caused much larger streamflow increases than did cutting on less moist parts of experimental watersheds [*Bowie and Kam,* 1968; *Crouse,* 1961; *Rich,* 1965]. In the humid east, similar differentials can be expected in exceptionally dry years and could be important because streamflow increases are needed most during droughts.

Part of the value of this experiment is that it reinforces conclusions reached in earlier studies. This type of watershed experiment has been criticized as providing unrepresentative results with insufficient replication. *Hewlett et al.* [1969] have presented the case for gaged watershed research. Each new experiment, insofar as its results are compatible with earlier work, helps refute this criticism. Also, soil moisture and other correlative data obtained in conjunction with stream gaging records help to nullify another criticism, that this type of research is uninformative as to individual processes. As stated by *Hewlett et al.* [1969], simple curiosity and the need to explain experimental results must lead to supplemental investigation and to a better understanding of hydrologic processes.

Soil-moisture measurement has provided a better understanding of the results of this study. During the growing season, moisture loss from forested soil on the control watershed provided storage for up to 4 inches of rain [*Troendle,* 1970]. With evaporative losses minimized on deforested land, soil moisture remained near field capacity, which caused the rain to move quickly through the soil to the streams. Most forest hydrologists accept *Hewlett and Nutter*'s [1970] concept that mountain streams originate in moist soils near channels. Thus, with soil-moisture maintained at near maximum levels throughout deforested watersheds, much of the water normally evaporated as transpiration and interception became available for streamflow. These augmented flows mostly occurred during the growing season because greatest diversions from evaporation occur at that time.

Soil-moisture measurement also explains why increased instantaneous peak flows were restricted to the growing season. Again, lack of storage capacity caused the rain to move quickly through wet soils to streams on the deforested watersheds. This effect was most evident on watershed 6 where the entire channel area had been deforested since 1965. It was much less apparent on watershed 7 where much of the channel remained forested during the initial half-cut stage of treatment. During the dormant season, storm flows were little influenced by deforestation because rainfall far exceeded evapotranspiration, and soils on all watersheds remained near field capacity regardless of vegetative cover.

Certainly these watersheds will erode badly if barren conditions are maintained. Perhaps the most surprising fact about maintaining them barren for 5 years is that so little damage has occurred. The litter and smaller slash have disappeared from the soil surface. Although considerable rock now lies exposed on the soil surface, it is not an erosion pavement because little evidence exists of overland flow except on and immediately below hard-packed roads and trails. Slight erosion, high infiltration rates, and only minor reduction in water quality during storm flow are evidence that infiltration rates still exceed rainfall intensity over most of the experimental watersheds. Even though turbidity and specific conductance have trebled, no enduring damage was done to water quality. Tests showed the streamflow quality to be well within drinking water standards acceptable to the *U.S. Public Health Service* [1962] except during the heaviest storm flow (about 5% of the total water yield).

Experimental treatments like these should not be confused with clear-cutting, a silvicultural practice designed to harvest existing forest cover and to provide for immediate regeneration of a new stand. Persistent efforts to prevent immediate revegetation clearly distinguish this experimental watershed treatment from any acceptable silvicultural practice. Thus, the effects on timing and quality of streamflow observed during this study must not be interpreted as the results of clear-cutting.

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