Forest Sci., Vol. 29, No. 3, 1983, pp. 545–558

Plant Succession and Hydrologic Recovery on a Deforested and Herbicided Watershed

J. N. Kochenderfer
G. W. Wendel

Abstract. The recovery of a 60-acre watershed that had been maintained nearly barren of vegetation for several years with herbicides was monitored. Increases in water yield returned rapidly to pretreatment levels. Aboveground biomass increased as the woody vegetation became dominant, averaging 14.7 ovendry tons/acre at the end of 10 growing seasons. There was a close relationship between biomass, height, percent ground cover, and increases in growing-season streamflow. Specific conductance of streamflow increased from a pretreatment level of 19 μmho/cm to 57 μmho/cm when the treatment was terminated. As the vegetation regrew, specific conductance decreased to about 24 μmho/cm 10 years later. Considering the drastic treatment of this watershed, the area has become well stocked with 3,800 stems/acre of commercial tree species. Forest Sci. 29:545–558.

Additional key words. Biomass, water yields, specific conductance, ground cover, tree reproduction.

Several studies have reported the effects of devegetation on the water and nutrient balances of forest ecosystems (Bormann and others 1968, Swank and Douglass 1975) but there are few data on species composition, stem numbers, aboveground biomass production, and growth rate of revegetation. A gaged watershed on the Fernow Experimental Forest near Parsons, West Virginia, received heavy applications of herbicide which killed virtually all of the vegetation. This afforded an excellent opportunity to record biomass accumulation and plant succession, and the effects of hydrologic recovery, during revegetation of this area after treatment ended.

Study Area

The 60-acre watershed 7 on the Fernow Experimental Forest is in the unglaciated Allegheny Plateau, a section of the Allegheny Mountains characterized by steep slopes and narrow valleys. Elevation of the study area is about 2,500 feet above sea level. The predominant soil is Calvin silt loam underlain with fractured sandstone and shale of the Hampshire formation (Losche and Beverage 1967). Annual precipitation, averaging 57 inches, is evenly distributed between the dormant and growing seasons.

This watershed was first logged between 1905 and 1910. Chestnut trees killed by the blight were salvaged in the 1930's. By 1960, watershed 7 was well stocked with mixed hardwoods; more than 100 sugar maple (*Acer saccharum* Marsh.) trees, 24 inches dbh and larger, and numerous large shagbark hickory (*Carya ovata* (Mill.) K. Koch.) and red oak (*Quercus rubra* L.) comprised a stand averaging over 13,000 board feet per acre. Most of the larger trees on the watershed were

The authors are research foresters at the Northeastern Forest Experiment Station Timber and Watershed Laboratory, P.O. Box 445, Parsons, West Virginia 26278. Manuscript received 31 March 1982.

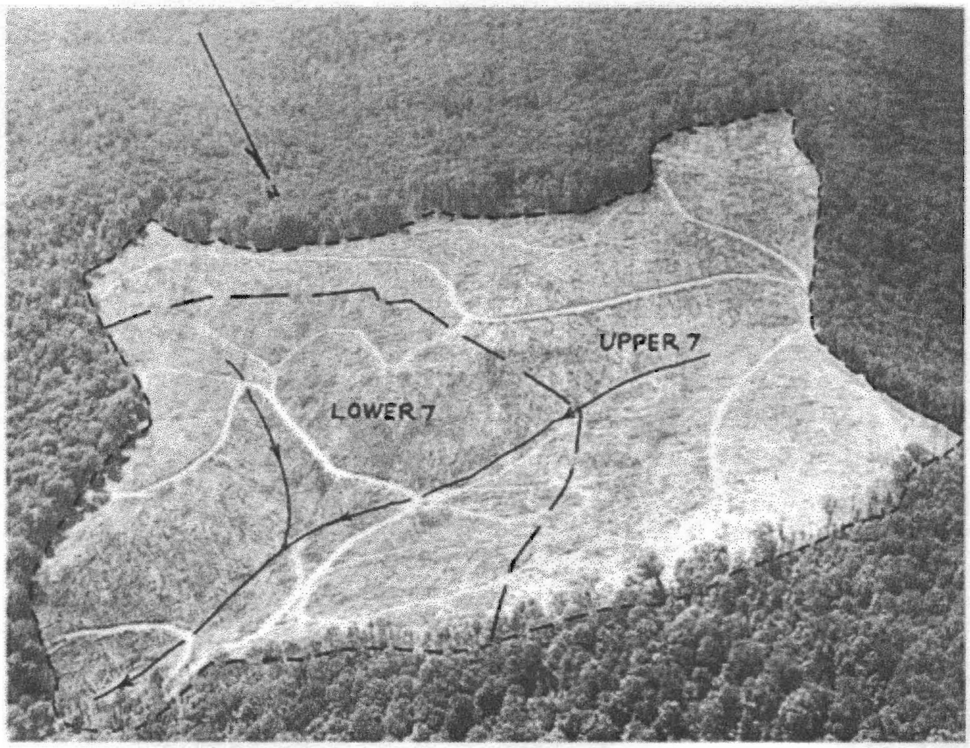

FIGURE 1. Watershed 7 divided along the contour.

residuals left from the early logging. Average oak site index on the watershed is 75.

The paired watershed technique was used to determine changes in water yields. After a 7-year calibration period, treatment began in 1963. To better define water yields from different parts of the watershed it was divided along the contour (Fig. 1) into upper and lower halves (Patric and Reinhart 1971) and treated as shown in Table 1.

Most of the herbicide was applied with a powered backpack mistblower. Mistblowing usually started when the vegetation began to green in the spring and continued all summer. Because the species composition on parts of the watershed changed during the treatment period, several herbicides were used to maintain a nearly barren condition. The herbicides used on watershed 7 during the 7-year period are listed in Table 2. The most commonly used herbicide on the watershed was 2-4-5-T. When treatment ended in 1969, plant succession and hydrologic changes were monitored during the revegetation process.

TABLE 1. Summary of watershed 7 treatments.

Treatment	Upper 7	Lower 7
Stems 1-inch and larger basal sprayed with herbicide	Oct–Nov 1963	Oct–Dec 1966
Cut sawtimber	Nov 1963–Mar 1964	Oct 1966–Mar 1967
Maintained barren of vegetation by mistblowing	Summers 1964, 1965, 1966, 1967, 1968, 1969	Summers 1967, 1968, 1969

TABLE 2. Summary of herbicides used on watershed 7 between 1963 and 1969.

Herbicide	Amount used
2-4-5-T	914 lb acid
2-4-D	512 lb acid
Brushkiller 155	
2,3,6-TBA	100 lb acid
2,4-D	100 lb acid
2,4-DP	75 lb acid
Dalapon	150 lb 74 percent active ingredients
Atrazine 80W	100 lb
Simazine 80W	50 lb
Amitrole	48 lb 90 percent active ingredients
Banvel pellets	55 lb 10 percent active ingredients
Banvel K	
dicamba	12.5 lb acid
2,4-D amine	25.0 lb acid
Banvel	24 lb acid of dicamba (6 gal)

Data Collection

Aboveground biomass and successional trend data were measured on milacre and 1/100 acre plots during the course of the study (Table 3). Beginning in 1976, the number of these plots was reduced to 26 and plot size was increased to 1/100 acre because the vegetation had increased in size. No sample plots were measured in 1975 or 1977. The watershed was stratified by upper and lower halves and sampled accordingly. All sample plots were referenced to 25 randomly located soil moisture access tubes which had been established for an earlier study. Biomass plots were laid out on randomly selected azimuths (without replacement) each year samples were taken. The 180° azimuth was reserved for 75 permanent milacre successional trend data plots and the 75 temporary sampling measurement plots.

Aboveground biomass was separated into three classes for weight determinations: (1) herbaceous (herbs, ferns, and grasses), (2) semiwoody (blackberry, greenbrier, grape), (3) woody. Ovendry weight of each component was determined.

Percent ground cover, species that covered at least 5 percent of plot area, average vegetation height, and number of stems by tree species, shrubs, grapevines, and debris or open area coverage were recorded. Plot boundaries were projected vertically so that all vegetation covering the plots, regardless of origin was included in the ground cover and biomass determinations. In 1978, tree reproduction by species, number, size, crown class, and stem quality of all stems larger than 1-inch dbh were tallied.

Streamflow was calculated from a continuous record of water depth through a 120° V-notch weir at the mouth of the watershed. Specific conductance of stream water was determined from weekly samples collected at the mouth of the watershed. Comparative water data also were determined for the control watershed.

Results

Water Yield and Dry-Matter Production.—The relationship between aboveground biomass and increases in water yield during the growing season (May 1 through October 31) is shown in Figure 2. This type of die-away curve normally would be expected to show a decrease in streamflow back to pretreatment levels as the vegetation regrew. After 5 years of regrowth, growing-season water yield was not

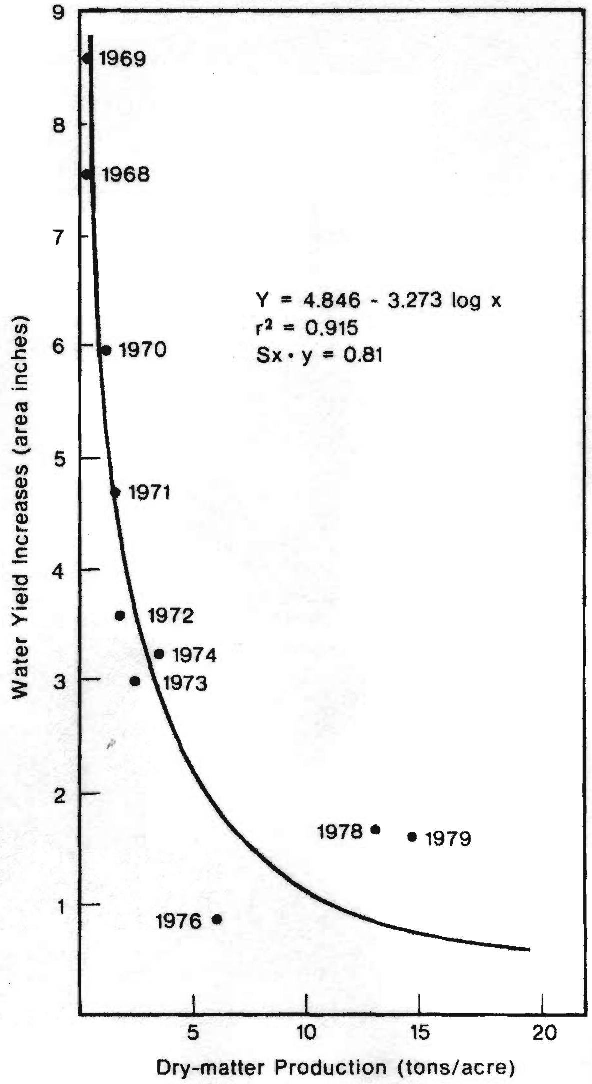

FIGURE 2. Increases in growing-season water yield as a function of dry-matter production: No biomass data were collected in 1975 and 1977.

significantly different from the pretreatment data at the 0.05 level. Increases in water yield remained insignificant for 3 growing seasons, 1975, 1976, and 1977. In 1978 and 1979, there were slight but significant increases in growing-season water yield.

Average height of regrowing vegetation was inversely related to increases in growing-season water yield (Fig. 3). Because average height of the vegetation can be easily obtained, this parameter might be used to estimate yield. Some of the reductions in water yield on the Coweeta North Carolina watersheds were also attributed to increases in vegetation height (Douglass 1967).

Figure 4 shows the increases in aboveground biomass on watershed 7. Although an attempt was made to maintain a barren condition on the watershed, we estimate that aboveground biomass averaged about 0.1 ton/acre during the treatment period. Aboveground biomass continued to increase as the woody vegetation became

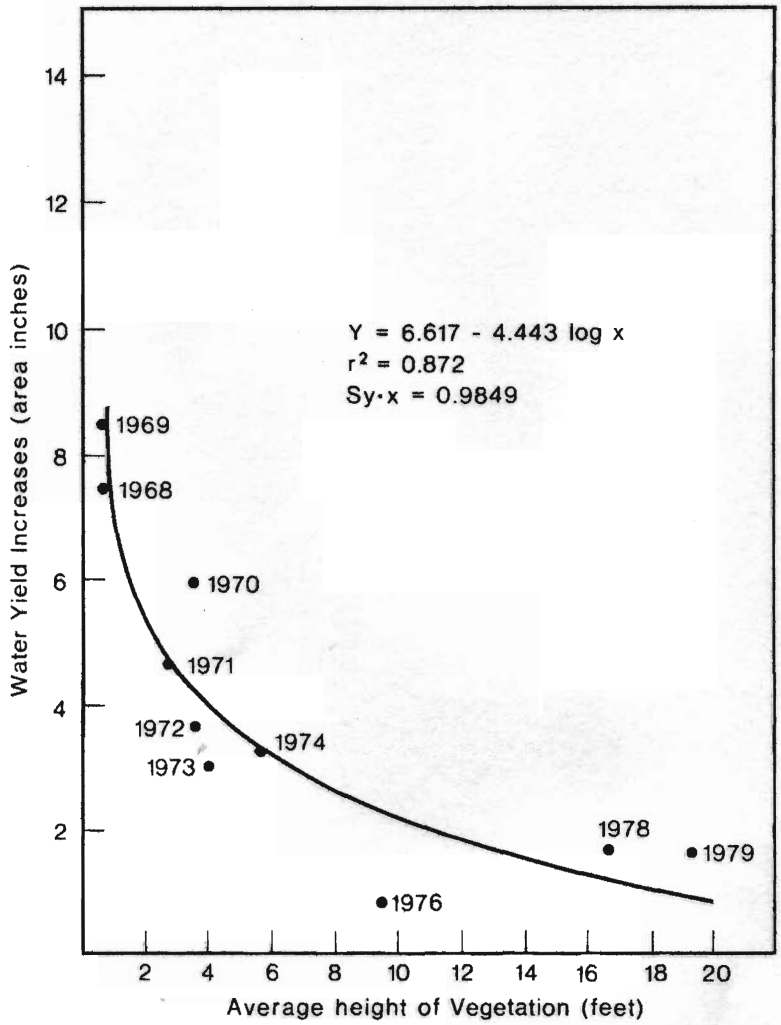

FIGURE 3. Increases in growing-season water yield as a function of average vegetation height.

more dominant. Of the 14.7 tons of ovendry material per acre produced during the 10-year period, 77 percent was produced in the last 3 years.

As expected, there is a strong relationship between aboveground biomass and average height of vegetation (Fig. 5). However, few data are available from other research stations to compare this relationship in other areas or forest types. Also, there was a strong relationship between percent ground cover and growing-season water yield (Fig. 6). The curve illustrates the rapid decrease in streamflow as vegetation quickly covered the soil surface. Although the longevity of these two relationships remains to be determined, of primary importance is the fact that evapotranspiration from the 10-year-old stand of vegetation is approximately the same as that from the 60- to 100-year-old hardwood stand before harvesting.

Specific conductance of stream water for the treated and control watersheds for a 20-year period are shown in Figure 7. Specific conductance is an index of total dissolved solids in water and does not indicate the chemical constituents involved. However, when specific conductance is monitored over time, it can be used to infer chemical changes in the water.

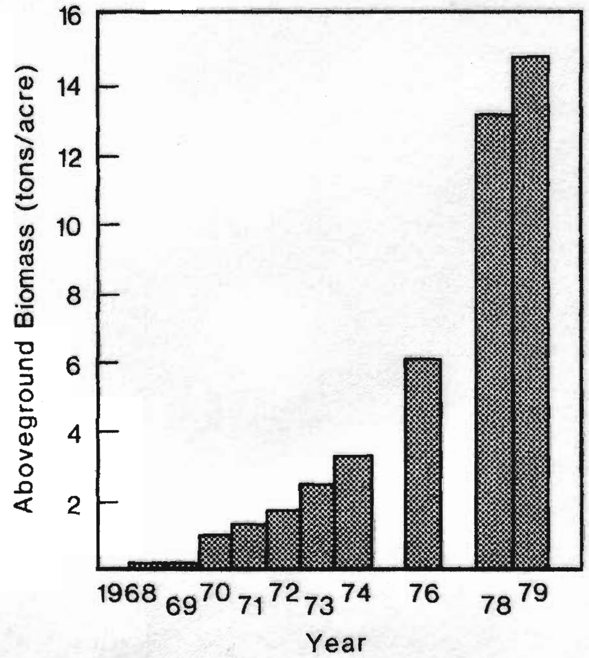

FIGURE 4. Total aboveground biomass by year.

Specific conductance of the control watershed stream water averaged 17 μmho/cm with very little variation during the 20-year period of record. Specific conductance of flow from the treated watershed was highly correlated with vegetation control; the average was about 19 μmho/cm during the calibration period, increasing to 57 μmho/cm in 1969, the last year of treatment, then decreasing to about 24 μmho/cm (near pretreatment levels) 10 years later when water use by the new stand was only slightly less than during the calibration period (Fig. 7).

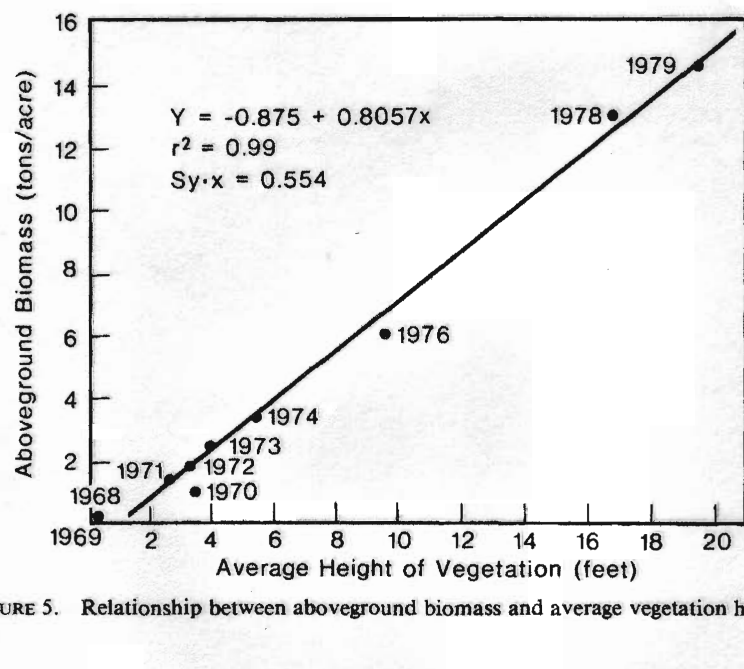

FIGURE 5. Relationship between aboveground biomass and average vegetation height.

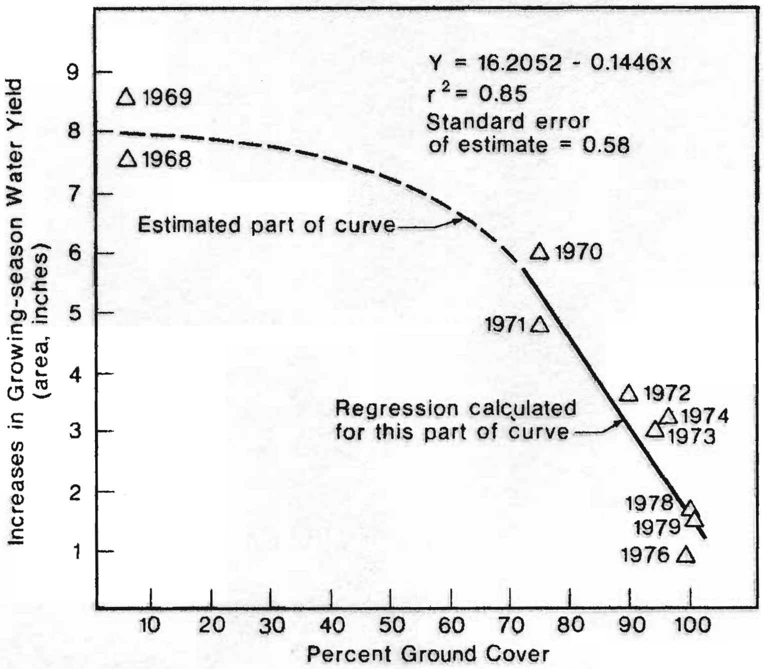

FIGURE 6. Relationship between percent ground cover and increases in growing-season water yield.

Ground Cover.—Species that accounted for an average of 1 percent of the ground cover on the watershed in any one year were grouped by cover type (Table 4). In 1970, the year after treatment ended, fireweed was the dominant ground cover on the watershed. Blackberry was dominant from 1971 through 1976. Sweet birch made up the largest single component of ground cover after 1976 and staghorn sumac formed the second largest component. The amount of sumac peaked in 1978 and we expect it to continue to decrease as it becomes shaded out by other vegetation. Perhaps the most dramatic change in vegetation was the decrease in fireweed from 22 percent in 1970 to about 2 percent in 1971, and its complete disappearance in 1972. The average percent of ground covered by woody vegetation increased from 4 percent in 1970 to 85 percent in 1979. Semiwoody vegetation (blackberry) increased from 11 percent in 1970 to 38 percent in 1974 and then decreased to 10 percent in 1979. We expect blackberry to continue to decrease

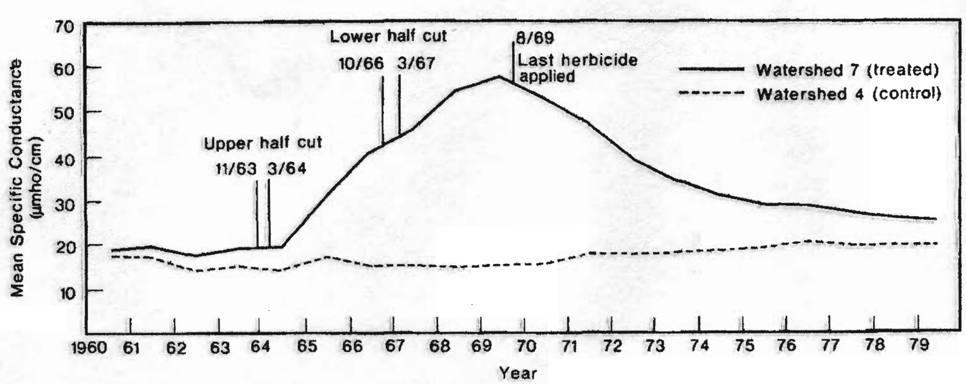

FIGURE 7. Mean specific conductance by water year (May 1–April 30).

TABLE 3. Sampling scheme for plant succession and aboveground biomass on watershed 7.

Date	Number of plots annually	Plot size (acre)	Type of plot	Data collected	Plot distribution
1970, '71, '72, '73, '74	100	1/1,000	Destructive	Aboveground biomass, percent ground cover by species, average vegetation height.	4 plots on random azimuth at 1-chain intervals from each access tube.
1976, '78, '79	26	1/100	Destructive	Same as above	1 plot on random azimuth at 1-chain intervals from each access tube.
1970, '71, '72, '73, '74, '76, '78, '79	75	1/1,000	Permanent	Same as above, except no biomass measurements. Also, number of tree stems, shrubs, and grapevines.	3 plots on 180° azimuth from each access tube at ½-chain intervals.
1978	75	1/100	Temporary	Cruise: tree reproduction >1.0 inch dbh, species, quality, dominance, numbers.	3 plots at 180° azimuth from each access tube at 1-chain intervals.

TABLE 4. Percent ground cover, by species.

Species	1970	1971	1972	1973	1974	1976	1978	1979
Open space and debris cover	26	26	11	6	4	1	<1	<1
Woody								
Sweet birch (*Betula lenta* L.)	—	<1	<1	3	4	10	18	16
Staghorn sumac (*Rhus typhina* L.)	1	2	2	4	6	3	14	13
Black locust (*Robinia pseudoacacia* L.)	<1	<1	2	3	4	6	13	12
Sassafras (*sassafras albidum* (*Nutt.*) Nees)	<1	2	2	4	3	6	6	8
Yellow-poplar (*Liriodendron tulipifera* L.)	—	<1	—	<1	1	3	6	7
Sugar maple (*Acer saccharum* Marsh.)	—	<1	<1	<1	2	5	5	5
Hercules club (*Aralia spinosa* L.)	—	<1	<1	<1	1	2	5	5
Black cherry (*Prunus serotina* Ehrh.)	—	<1	<1	1	1	11	3	4
Red maple (*Acer rubrum* L.)	—	<1	—	<1	2	2	4	4
White ash (*Fraxinus americana* L.)	2	<1	<1	<1	1	3	2	3
Fire cherry (*Prunus pensylvanica* L.)	—	<1	1	1	<1	<1	2	2
Flowering dogwood (*Cornus florida* L.)	—	<1	<1	<1	1	2	1	1
Red oak (*Quercus rubra* L.)	—	—	—	<1	<1	<1	1	1
Blackgum (*Nyssa sylvatica* Marsh.)	—	<1	<1	<1	<1	1	<1	<1
Other woody	1	4	5	6	4	1	2	4
Semiwoody								
Blackberry (*Rubus* spp. L.)	11	17	31	31	37	28	9	7
Grape (*Vitis* L.)	<1	<1	<1	<1	<1	1	3	3
Other semiwoody	—	—	1	1	1	—	1	—
Grasses								
Deertongue (*Panicum boscii* Poir.)	2	2	1	1	1	<1	<1	—
Broomsedge (*Andropogon virginicus* L.)	1	4	3	3	2	<1	—	—
Other grasses, namely (*Panicum* spp., *Agrostis* spp.)	6	2	5	3	—	2	<1	—
Herbaceous								
Hay-scented fern (*Dennstaedtia punctilobula* (Michx.) Moore)	7	12	14	14	14	9	4	3
Fireweed (*Erechtites hieracifolia* L.)	22	2	—	—	—	—	—	—
Pokeweed (*Phytolacca americana* L.)	3	2	<1	<1	<1	<1	—	—
Sedge (*Carex* spp. L)	1	<1	1	<1	<1	—	—	—
Cinquefoil (*Potentilla simplex* Michx.)	<1	<1	2	3	1	<1	—	—
Whorled loosestrife (*Lysimachia quadrifolia* L.)	<1	2	2	3	<1	<1	—	—
Dotted St. John's-wort (*Hypericum punctatum* Lam.)	—	<1	2	<1	<1	<1	—	—
Climbing false buckwheat (*Polygonum scandens* L.)	6	2	<1	—	<1	<1	—	—
Elm-leaf goldenrod (*Solidago ulmifolia* Muhl.)	—	<1	<1	<1	1	—	<1	<1
Smartweed (*Polygonum persidaria* L.)	<1	1	—	—	—	—	—	—
Horseweed (*Erigeron canadensis* L.)	1	—	—	—	—	—	—	—
Moss	—	<1	1	2	1	1	<1	<1
Other herbaceous and miscellaneous	10	20	14	11	8	3	1	2
Total	100	100	100	100	100	100	100	100

as it is shaded by woody vegetation. Grasses and herbaceous vegetation show trends similar to blackberry but their competitors have decreased at a faster rate.

These vegetation changes are summarized in Figure 8. Blackberry, grasses, and herbaceous vegetation were largely eliminated by shading from the woody vegetation. The percentage of open space and debris-covered area decreased from 26 percent in 1970 and 1971 to less than 1 percent in 1978. Although much of the logging slash has not completely decomposed, it has been overtopped by living vegetation.

Tree Reproduction.—Considering the treatment of watershed 7, the area has be-

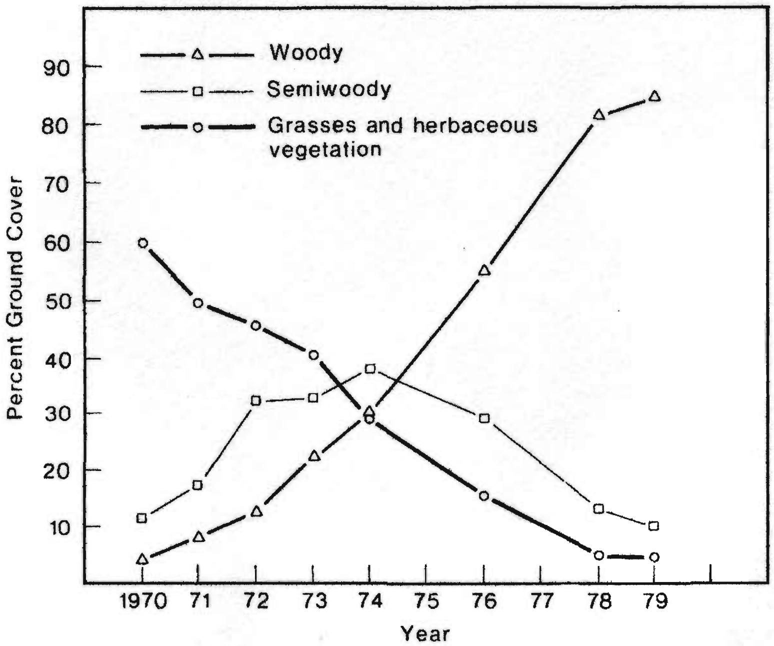

FIGURE 8. Ground cover trends for three broad vegetation classes.

come well stocked with tree reproduction. After 10 years, there are about 3,800 stems of commercial tree species per acre. The most abundant species is sweet birch, followed in order by sugar maple, yellow-poplar, red maple, and black cherry. Eighty-seven percent of the milacre plots examined were stocked with at least one commercial species. Sugar maple and yellow-poplar were the most widely distributed species with 35 percent of the milacre plots stocked. Red maple, sweet birch, and black cherry also were well distributed. Numbers of commercial species have decreased about 40 percent after peaking at about 6,360 in 1973, while stocking in milacre plots decreased from 97 percent in 1973 to 87 percent in 1979.

Yellow-poplar and sassafras have shown the greatest decrease in numbers of the commercial species. Yellow-poplar decreased from 1,960 seedlings/acre in 1970 to 573 seedlings/acre in 1979. Sassafras decreased from 1,880 stems/acre in 1970 to 307 stems/acre in 1979. Sweet birch showed the greatest increase, from 240 stems/acre in 1970 to 1,613 stems/acre in 1972. That species decreased to 866 stems/acre in 1979. This is not surprising since sweet birch is a very strong competitor in its early life on many cutover sites (Wendel and Trimble 1968, Trimble 1972).

In addition to the commercial species present in 1979, there were 1,225 stems/acre of noncommercial woody species, the most common being wild grape, staghorn sumac, and devil's walking-stick. Wild grape has shown the greatest decrease but is still the most common; it decreased from 1,240 vines/acre in 1970 to 413 vines/acre in 1979. Overall, 48 percent of the 75 milacre plots were stocked with at least one noncommercial species. Grape stocking remained relatively constant at about 50 percent until 1976, then decreased to 32 percent in 1978 and 21 percent in 1979.

The 1979 tally showed that there were 973 stems/acre larger than 1.0 inch dbh. Of these, 379/acre were dominant or codominant, well-formed stems of seed or sprout origin (Table 5). Fewer sprouts were recorded on upper watershed 7 than on lower 7, probably because upper 7 was treated with herbicide over a longer

TABLE 5. Number per acre and stocking of well-formed, dominant and codominant tree reproduction larger than 1-inch dbh on watershed 7 at the end of 9 years.

Species	Upper 7		Lower 7		Total watershed 7	
	Number per acre	Percent stocked	Number per acre	Percent stocked	Number per acre	Percent stocked
Sweet birch	109	58	132	56	122	55
Black locust	21	21	24	22	23	22
Cucumber	3	3	—	—	1	1
Red maple	36	24	5	5	19	14
Yellow-poplar	58	3	81	41	70	38
Black cherry	15	12	34	24	26	19
Aspen	18	12	—	—	8	5
Hickory	6	2	—	—	3	3
White ash	55	12	17	5	34	8
Red oak	3	3	10	5	7	4
Blackgum	—	—	7	2	4	3
Sugar maple	—	—	37	10	20	5
Sassafras	—	—	76	22	42	12
Basswood	—	—	2	2	1	1
Total	324	88	425	88	379	88

period. Most of the sprouts were root sprouts from black locust and sassafras but some were white ash stump sprouts.

Discussion

The results of this study indicate that recovery of this watershed has been much faster (Figs. 9–10) than the 60 to 80 years predicted by Likens and others (1978) for a similarly treated watershed in New Hampshire. Actually, watershed 7 was more severely treated than its New Hampshire counterpart. No forest products were removed from the New Hampshire watershed, whereas all merchantable forest products above 5 inches dbh were removed from watershed 7. Also, half of watershed 7 was maintained barren for an additional 3 years.

Although we know little about the long-term effects of this treatment on site quality, biomass production is comparable to the annual dry-matter production of 1.2 tons of aboveground biomass reported by Young and others (1979) for immature, fully stocked, 15-year-old hardwood stands growing on good sites in Maine. We expected that biomass on our watershed would be quite low at this stage of succession since the stand originated primarily from seed, and because 15 percent of the watershed remains unoccupied by the heavier woody vegetation. As was pointed out, 77 percent of current biomass has been produced in the past 3 years. Therefore, we expect continued acceleration in biomass accumulation during the next few years. However, since we had no measurements of aboveground biomass productivity before treatment, we can only speculate on the effects of this drastic treatment on long-term site productivity.

The decline of streamflow during revegetation of several watersheds in the United States is well documented (Hibbert 1967, Bosch and Hewlett 1982). The unexplained departures of streamflow from a smooth recession line has been reported for other experimental watersheds (Swift and Swank 1981). These authors felt that climatic variation was the likely agent causing departure of streamflow increases from a smooth trend line. We were unable to explain these 1978–79 streamflow increases. A comparison of precipitation during the calibration period

FIGURE 9. Watershed 7 at the end of 1971 growing season after 2 years of regrowth.

and 1978–79 did not reveal any abnormalities which were not represented in the calibration period. Changes in vegetation composition or density also could influence streamflow. However, this is doubtful on the basis of this study since significant increases in streamflow recurred in 1978–79 when woody vegetation was predominant, occupying over 80 percent of the watershed. The rather rapid decrease of streamflow back to pretreatment levels is a reflection of vigorous regrowth on the watershed.

The high correlation between biomass, height, percent cover, and increases in growing-season streamflow reflects a close relationship between each of these parameters and evaporative potential of the vegetation. Aboveground biomass and percent ground cover were the best predictors of changes in water yield. The correlation with height was slightly less, but height is one of the easiest parameters to measure. Our observation of a strong correlation between height and aboveground biomass also was reported by Young (1973). In studies of more than 50 stands of different height and species composition, he reported an accumulation of about 0.8 ton of dry matter (exclusive of leaves) per linear foot of average stand height. This compares favorably with the 0.7 ton of ovendry aboveground biomass (exclusive of leaves) observed on watershed 7.

Nutrient export data per se are lacking in this study but specific conductance doubled during the treatment period, indicating that average concentration of dissolved solids in the streamflow increased while vegetative cover was minimal. Increases were considerably less than those reported by Likens and others (1978) for a similarly treated watershed in New Hampshire but greater than reported by Aubertin and Patric (1974), who found that conventional clearcutting of a watershed adjacent to watershed 7 had almost no influence on the concentration of dissolved solids of the stream draining the clearcut.

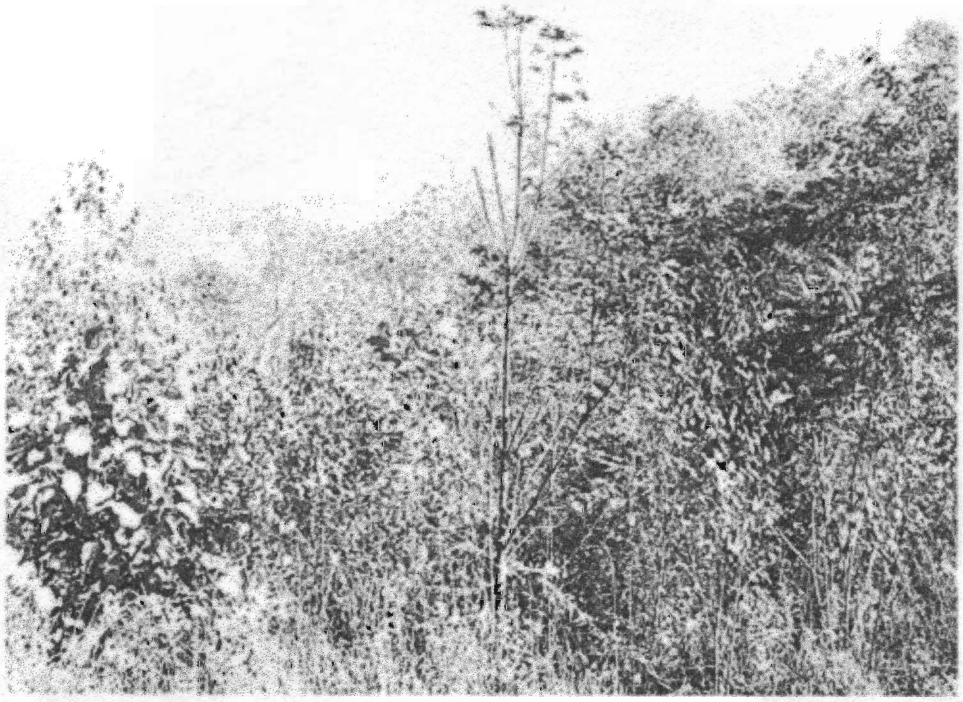

FIGURE 10. Watershed 7 at the end of the 1976 growing season after 7 years of regrowth.

Beginning in 1967, Troendle and others (1974) monitored the organic fraction of the forest floor on lower watershed 7. After 4 years, they concluded that the deterioration of the organic fraction was too slight to adversely influence soil stability, but they predicted increasing erosion if the treatment were continued for a longer period. The root mat remained intact throughout the experiment and erosion was minimal even though the litter layer disappeared. Had there been surface runoff and soil erosion, severe site degradation would probably have occurred.

The adverse effects of erosion on the same soil type as the treated watershed can be observed on a nearby gaged watershed which was cultivated for many years and then abandoned in 1930. Lima and others (1978) concluded that serious erosion had occurred during the cultivation period but was halted before 1945, and that streamflow increases had peaked 20 years before hydrologic observation began in 1958. Severe site degradation is still evident on large portions of the watershed, some of which remain in a grass stage of succession. This strengthens our argument that site quality was probably not seriously changed on watershed 7 because severe erosion did not occur although there were temporary changes in the physical and chemical properties of streamflow draining the watershed.

Plant succession on this watershed was similar to what would be expected for any severely disturbed area in the central Appalachians. Unlike conventional clearcuts, this area had fewer sprouts because the repeated herbicide treatments killed plant roots as well as the tops. Therefore, revegetation started mostly from the grass and herbaceous stages of succession. The watershed became occupied with a respectable hardwood stand much faster than we had expected. No residual effects of herbicide are evident in the vegetation currently occupying the watershed.

Conclusion

When herbicide treatment ended in the fall of 1969, the physical appearance of watershed 7 was one of complete desolation. In actual practice, treatment this drastic would never be administered to a forest ecosystem. However, the remarkable recovery of this watershed from intentional abuse indicates that forested ecosystems in the central Appalachians are not as fragile as some believe. These results should be interpreted not as an excuse to lessen environmental concerns but as a confirmation that the use of existing recommended management practices can produce many benefits from forested ecosystems with little harm other than temporary esthetic changes.

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