MUNICIPAL WATERSHED MANAGEMENT

Symposium Proceedings

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F. BRYAN CLARK, STATION DIRECTOR

FOREWORD

SINCE THE BEGINNING of time, forests and streamflow have been interrelated. Although this relationship has not always been completely understood, it was accepted about the turn of the century that forests generally exert a beneficial influence on streamflow. This concept was based on the fact that forests provide a protective cover on the soil surface, thereby allowing rainfall to infiltrate into the soil rather than flowing over the surface and eroding the soil. History has provided sufficient evidence that, where man has carelessly removed the forest and has denuded the land, devastation occurred. Fertile top soil was lost by erosion; springs ceased to flow; streams dried up; and damaging floods occurred. In some instances, the total result was the demise of the civilization.

Increasing population and improved technology have placed new values on the forest and water resources, particularly in highly urbanized regions. For instance, in the densely populated Northeast, the primary source of most of the surface water is streamflow from forested watersheds. In this area there are more than 2 million acres of land under the control of municipalities, private water companies, and state and federal agencies for management as either water-source areas or protection lands for municipal water supplies. Continuing urbanization has increased water demands and has necessitated that these watersheds be managed for maximum water production, while at the same time there are mounting public pressures to utilize these areas for recreation.

During the past 30 years, forest-watershed-management research has produced a wealth of information about water-yield augmentation and water-quality protection. The purpose of this Symposium was to bring together some of the research and management information that would be useful to municipal watershed administrators in formulating land-management policies.

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The program was conducted in cooperation with the American Water Works Association, the New England Water Works Association, and the Pennsylvania Department of Environmental Resources.

A report on the Symposium held 11-12 September 1973 at The Pennsylvania State University, University Park, Pennsylvania, and 19-20 September 1973 at The University of New Hampshire, Durham, New Hampshire.

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Program Committee

The Symposium was organized and conducted as one of the activities of the Working Group on Municipal Watershed Management of the Pinchot Institute Consortium for Environmental Forestry Studies. Members of the planning committee were:

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Raymond O. Benton, Northeastern Area State and Private Forestry
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E. L. Shafer, Jr., Northeastern Forest Experiment Station

—**WILLIAM E. SOPPER**
EDWARD S. CORBETT
Symposium Co-Chairmen

William E. Sopper is Professor of Forest Hydrology, School of Forest Resources, The Pennsylvania State University, University Park, Pa. 16082.
Edward S. Corbett is Principal Hydrologist, Northeastern Forest Experiment Station, Forest Service, USDA, Pennington, New Jersey 08534.

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EFFECTS OF MANAGEMENT PRACTICES ON WATER QUALITY AND QUANTITY: FERNOW EXPERIMENTAL FOREST, W. VIRGINIA

by JAMES N. KOCHENDERFER *and* GERALD M. AUBERTIN, *Research Forester and Research Soil Scientist, USDA Forest Service, Northeastern Forest Experiment Station, Timber and Watershed Laboratory, Parsons, West Virginia.*

ABSTRACT. Results of 22 years of forest hydrology research on the Fernow Experimental Forest are reviewed. Forest influences were measured on quantity and timing of streamflow and on parameters of water quality such as turbidity, temperature, specific conductance, pH, alkalinity, and nutrient concentrations. These results indicate that it is currently not practical to manage forest land for both sustained increased water yield and merchantable timber products, and that forest land can be managed for a variety of uses without impairing water quality if these uses are regulated intelligently.

THE FERNOW Experimental Forest, near Parsons, West Virginia, was established in 1934 for forest research and the demonstration of its results. Containing 3,640 acres and representing the major hardwood types found in the central Appalachians, the Forest is located in the unglaciated Allegheny Plateau region of north-central West Virginia. This section of the Allegheny mountains is characterized by steep mountains and narrow valleys. The average elevation of the study area is about 2,500 feet above sea level. The predominant soil is Calvin silt loam *(Losche and Beverage 1967)* underlain with fractured sandstone and shale of the Hampshire (formerly Catskill) formation. Soil depth is normally less than 5 feet.

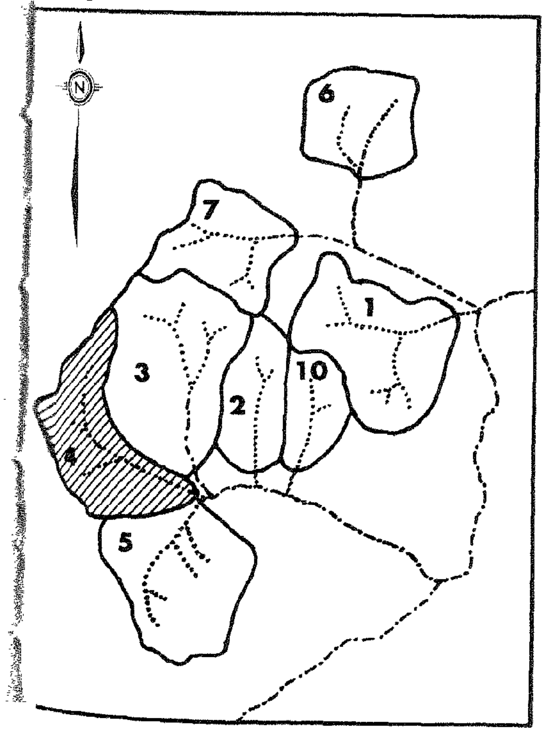
Timber stands on the watersheds before treatment were 40 to 50 years old, with many scattered older residuals. Vegetation on the watersheds fits into Core's *(1966) mixed hardwood forests* floristic province. Common tree species on the better sites are yellow-poplar *(Liriodendron tulipifera* L.), sugar maple *(Acer saccharum* Marsh.), black cherry *(Prunus serotina* Ehrh.), white ash *(Fraxinus americana* L.), basswood *(Tilia americana* L.), and red oak *(Quercus rubra* L.). The dominant tree species on the poorer sites are various species of oak *(Quercus* spp.), hickory *(Carya* spp.), sourwood *(Oxydendrum arboreum* (L.) DC.), and sassafras *(Sassafras albidum* (Nutt.) Nees.). Sawtimber volumes varied from 7,000 to 13,000 board feet per acre.

The growing season extends from 1 May through 31 October, the dormant season from 1 November through 30 April. Annual precipitation is evenly distributed between the dormant and growing seasons, averaging 56 inches on the control watershed for a 21-year period. Annual runoff from the control watershed for the same period of record averaged 24 inches, 6 inches during the growing season and 18 inches during the dormant season. Potential evapotranspiration on the Fernow Forest was estimated to be 22 inches per year *(Patric and Goswami 1968)*.

THE STUDIES

We have eight gaged watersheds on the Fernow Forest (fig. 1), ranging in size from 38 to 96 acres. Collection of streamflow and climatic data began on watersheds 1 to 5 in 1951, on watersheds 6 and 7 in 1957. Stream discharge, turbidity, pH, alkalinity, specific conductance, and temperature data were collected from each watershed for a period of 6 years. Data obtained during this calibration period were used as a base for evaluating changes due to treatment.

Figure 1.—Location of the watersheds on the Fernow Experimental Forest, Parsons, West Virginia.



After calibration, one of the original five watersheds (No. 4) was retained as an untreated control, and the others underwent different cutting treatments. These treatments and their hydrologic effects have been described by Reinhart et al. *(1963)*. Watersheds 6 and 7 were treated in 1963; results of this experiment have been presented by Patric and Reinhart *(1971)*. Water-quality studies were expanded in 1969 to include measurements of calcium, magnesium, potassium, sodium, phosphate, nitrate-N, ammonium-N, sulfate, iron, manganese, zinc, and copper. A summary of the watershed treatments is presented in table 1.

Stream discharge is measured with 120° V-notch weirs. Precipitation is measured in a network of 4 recording gages and 14 standard 8-inch rain gages. Water temperatures are measured with both recorders and maximum-minimum thermometers. Water samples are obtained weekly by grab sampling, with some additional sampling during storm periods.

WATER QUALITY

Of the many water-quality parameters studied, the best known and most easily obtained are turbidity, temperature, specific conductance, pH, and alkalinity.

Turbidity

Bare soil exposed by road-building and to a much less extent by log landings, has long been recognized as the major source of stream sediment associated with logging operations. Turbid

Table 1.—Summary of treatments on Fernow watersheds

Watershed number and size (acres)	Type of treatment	Treatment date	Basal area[1] cut	Original sawtimber volume[2]	Sawtimber cut
			Percent[4]	*Bd. ft./acre*	*Percent*[4]
1 (74)	Clearcut to about 6 inches dbh except for culls.[3]	5/57–6/58	74	9,926	86
	Applied 500 lbs/acre of 45% urea.	5/71	—	—	—
2 (38)	17-inch diameter limit cut, entire watershed.	6/58–8/58	32	7,145	59
	17-inch diameter limit cut, 27 acres of watershed; in both cuts, culls larger than 17 inches were cut.	9/72–10/72	12	—	—
3 (85)	Intensive selection cut including cull treatment in trees above 5 inches dbh.	10/58–2/59	13	8,300	20
	Same treatment.	9/63–10/63	8	7,848	12
	0.4-acre patch cuttings totaling 5.6 acres; everything cut down to 5 inches; 1- to 5-inch stems basal sprayed with herbicide.	7/68–8/68	6	8,435	6
	Clearcut to 1-inch dbh.	7/69–5/70	91	7,928	91
5 (90)	Extensive selection cut, including cull treatment in trees larger than 11 inches dbh.	8/58–11/58	20	11,993	31
	Same treatment.	2/68–6/68	14	13,020	19
6 (54)	Lower half (27 acres) of watershed clearcut.	3/64–10/64	51	10,948	51
	Maintained barren with herbicides.	5/65–10/69			
	Upper half (27 acres) of watershed clearcut.	10/67–2/68	49	11,224	49
	Maintained barren with herbicides.	5/68–10/69			
	Entire watershed maintained barren with herbicides.	2/68–10/69	100	—	100
7 (59)	Upper half (29.5 acres) of watershed clearcut.	11/63–3/64	49	13,758	51
	Maintained barren with herbicides.	5/64–10/69			
	Lower half (29.5 acres) of watershed clearcut.	10/66–3/67	51	13,193	49
	Maintained barren with herbicides.	5/67–10/69			
	Entire watershed maintained barren with herbicides.	2/68–10/69	100	—	100

[1] Basal area as used in this report refers to the total basal area in trees 1 inch in diameter and larger.

[2] Trees 11 inches dbh and larger.

[3] No care was exercised on the road system.

[4] Based on the total basal area and sawtimber volume on the entire watershed.

ity, an optical index of sediment suspended in water, is often interpreted as an index to water quality that is closely related to logging activity. Careless logging caused very turbid water; but logging on carefully located, constructed, and maintained road systems caused only minor increases in turbidity (table 2).

Watershed 1 (commercially clearcut) produced a maximum of 56,000 turbidity units, measured while logging was in process. Turbidity levels were high during and immediately after logging,

Table 2.—Turbidity values for selected Fernow watersheds

Period	Average turbidity non-stormflow	Range in turbidities, including stormflow
	In Jackson turbidity units	
Commercial clearcut (watershed 1):		
During logging operation	490	0–56,000
First year after logging	38	0–5,000
Second year after logging	2	0–170
Silvicultural clearcut (watershed 3):		
During logging operation	6	0–90
First year after logging	5	0–35
Second year after logging	2	0–23
Undisturbed control (watershed 4):		
5/59–11/72	2	0–25

but decreased rapidly after disturbance ended. By contrast, watershed 3 was logged with a carefully planned and maintained road system, and it produced only minor increases in turbidity.

Temperature

Stream temperatures were raised by some of the cutting practices used on the Fernow Forest. Average maximum stream temperature on watershed 1 increased about 8°F during the first growing season after cutting. Temperatures returned to pre-cutting levels within 5 years after cutting. Deforesting and herbiciding the lower halves of watersheds 6 and 7 also substantially increased growing-season stream temperatures, but deforesting and herbiciding the upper halves had no appreciable affect. There was, of course, no channel exposed to direct insolation on the deforested upper halves.

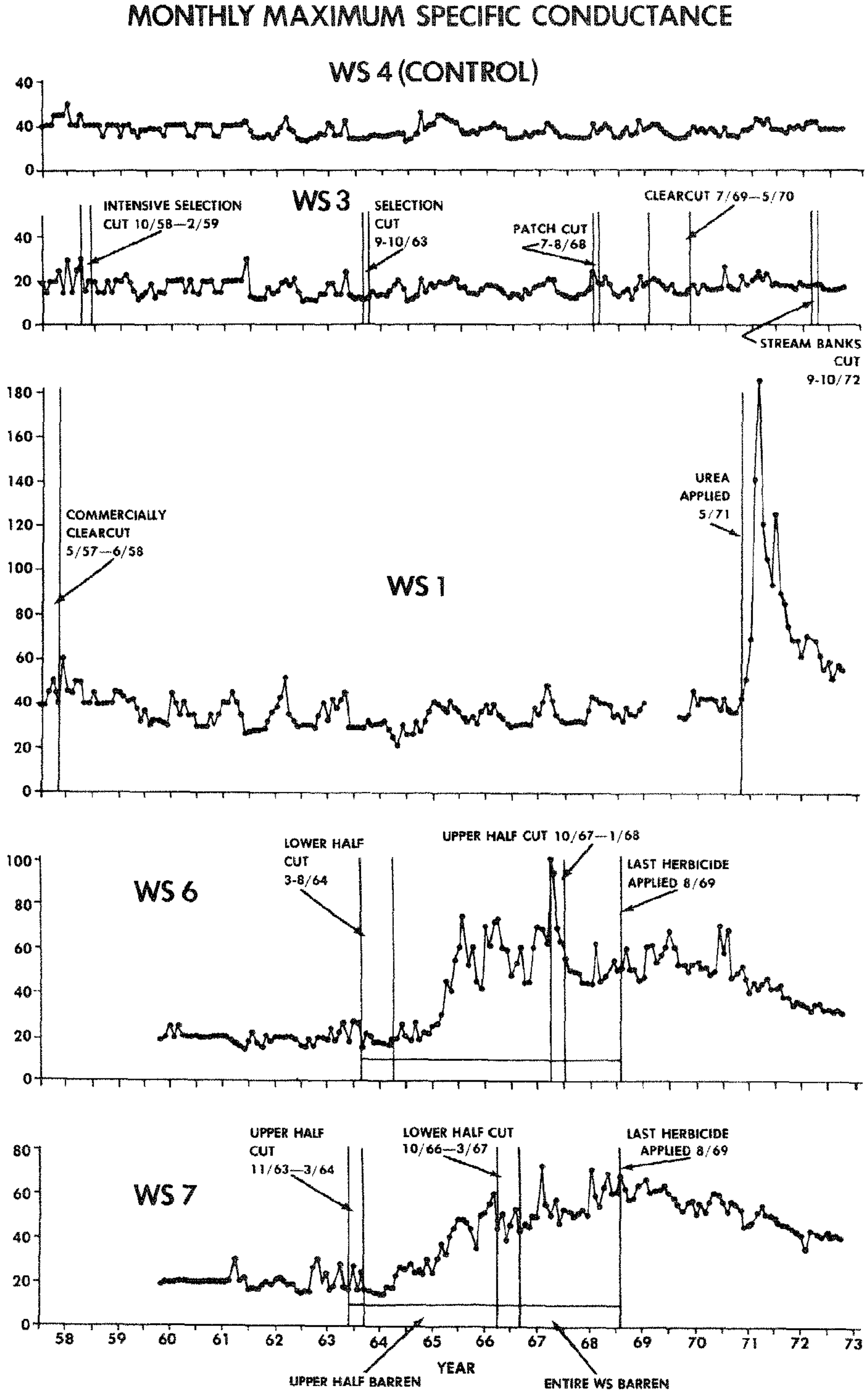
Maximum growing-season stream temperatures for watershed 6 averaged about 10°F higher than those on the control watershed, while watershed 7 averaged about 4°F higher. The marked difference between the results of deforesting and herbiciding the lower halves of watersheds 6 and 7 reflect orientation and the harvesting techniques employed. In south-facing watershed 6, the trees were felled in such a manner that a minimum of slash covered the stream channel area. In east-facing watershed 7, the reverse was true: the stream was partly covered by a large amount of slash that shaded the channel. By contrast, watershed 3 — with two selection cuttings, a patch cutting, and a complete clearcutting of all but the channel area — showed little or no influence of cutting on stream temperature. This reflects the importance of leaving uncut trees to shade the stream channel if maintenance of cool water is an objective of forest management.

Specific Conductance

Specific conductance indicates, within rather wide limits, the concentration of ionized substances in water. These values give no indication of which ionized substances are present, but any increase or decrease in their concentration will cause corresponding changes in conductivity. Thus specific conductivity can be used to infer chemical changes in the water.

The data show that, on the Fernow Forest, a watershed can be clearcut without producing major increases in the stream's specific conductance (fig. 2, WS 3). Under less carefully controlled clearcutting conditions, the resultant increase in conductivity was short-lived

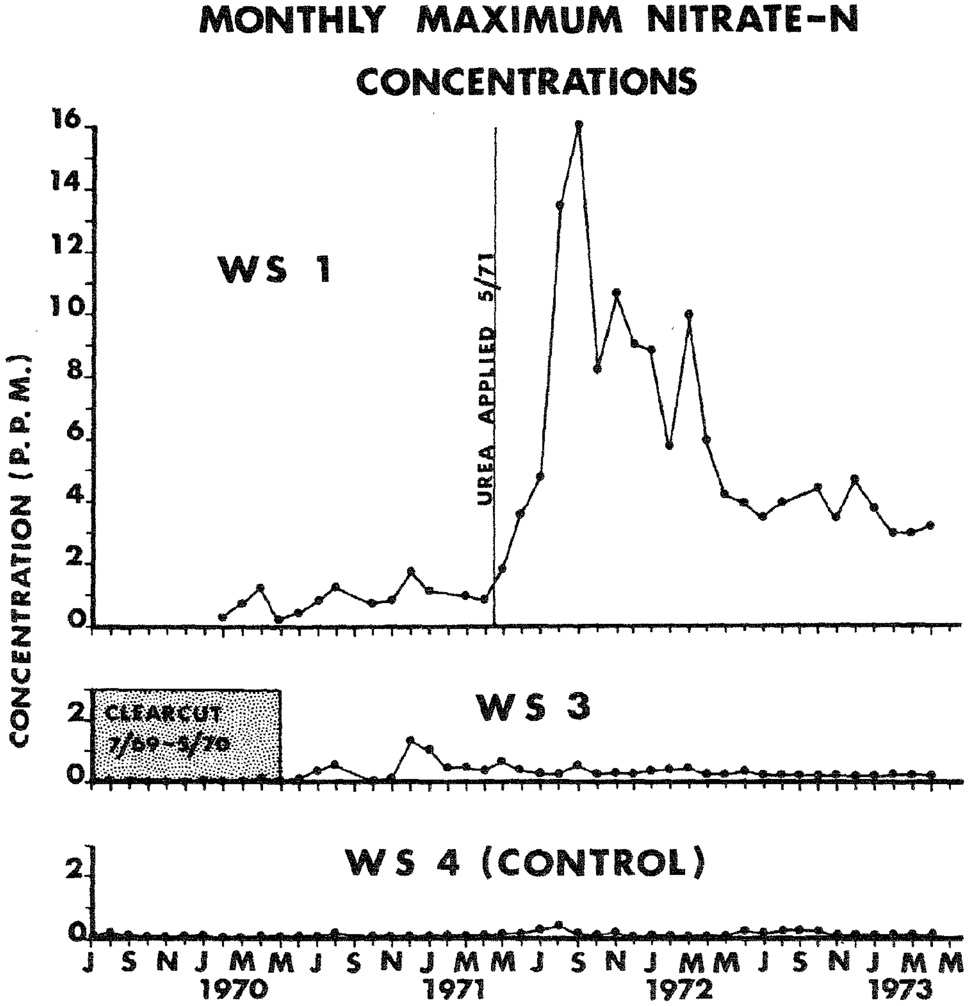
Figure 2.—Monthly maximum specific conductance for selected watersheds, Fernow Experimental Forest, Parsons, West Virginia.



and returned to pre-cutting level as the watershed revegetated (fig. 2, WS 1). Only when we prevented natural regrowth did the streams' specific conductance increase markedly (fig. 2, WS 6 and WS 7). Regrowth and declining specific conductance followed termination of herbicide applications. The major difference between the clearcut and the deforested and herbicided watersheds was prevention of natural revegetation on the latter.

Applying 230 pounds of nitrogen per acre in the form of urea to watershed 1 markedly increased that stream's specific conductance (fig. 2, WS 1). Immediately after application, the specific conductance began to increase, reaching a maximum approximately 6 times higher than normal 4 months after application. Decline has since been steady, and the specific conductance now is approximately 1.5 times the pre-fertilization level.

Figure 3.—Monthly maximum nitrate-N concentrations for selected watersheds, Fernow Experimental Forest, Parsons, West Virginia.



pH and Alkalinity

Timber harvesting had little effect on pH and methyl orange alkalinity levels. The watershed 1 treatment increased the mean pH from about 6.1 to 6.4 and the alkalinity about 2 ppm *(Reinhart et al. 1963)*. The other treatments had even smaller effects.

Nutrients

Of the twelve nutrients studied, nitrate-N usually is considered most significant to water quality. Our limited data suggest that Fernow watersheds can be clearcut without appreciably increasing nitrate-N concentration in the streams (fig. 3, WS 3). Another study showed that fertilizing a watershed with urea can cause a marked increase in the stream's nitrate-N concentration (fig. 3, WS 1). Even so, this stream's nitrate-N concentration remained well below the U.S. Public Health's drinking-water limit of 10 ppm, in 811 of 829 samples analyzed during the first year after application.

Nitrate-N levels for watershed 7 have shown a steady decline from about 5 ppm, in January 1971 when determinations were begun, to the present level of about 2 ppm. Watershed 6 shows a similar trend but with corresponding concentrations between 0.5 and 1 ppm lower. Levels of other nutrients were little affected by clearcutting *(Aubertin and Patric 1972)*. However, after urea fertilization, the concentrations of calcium, magnesium, sodium, and potassium increased slightly *(Aubertin and Smith 1972)*.

WATER YIELD INCREASES

Amount

Equations developed during the calibration period *(Reinhart et al. 1963)* provided a means to demonstrate streamflow changes after forest cutting. Growing-season increases in water yield from the Fernow watersheds generally have been proportional to the severity of cutting (fig. 4). The lightest cutting that produced a statistically significant increase was on watershed 5. There, 20 percent of the basal area was cut; average timber volume removed was 3,690 board feet per acre. Ten years later, a similar cut on watershed 5 removed 13.7 percent of the basal area or 2,453 board feet per acre, but failed to produce a significant yield increase.

The effects of other variables such as tree size, species composition, and spatial arrangement of the cutting have not been tested on the Fernow watersheds. The largest yield increase occurred after watersheds 6 and 7 were deforested and treated with herbicides to prevent forest regrowth. We suspect that increased evapotranspiration after fertilization contributed to the rather large decrease in streamflow on watershed 1 during the 1972 growing season. This decrease will be examined more closely in the near future.

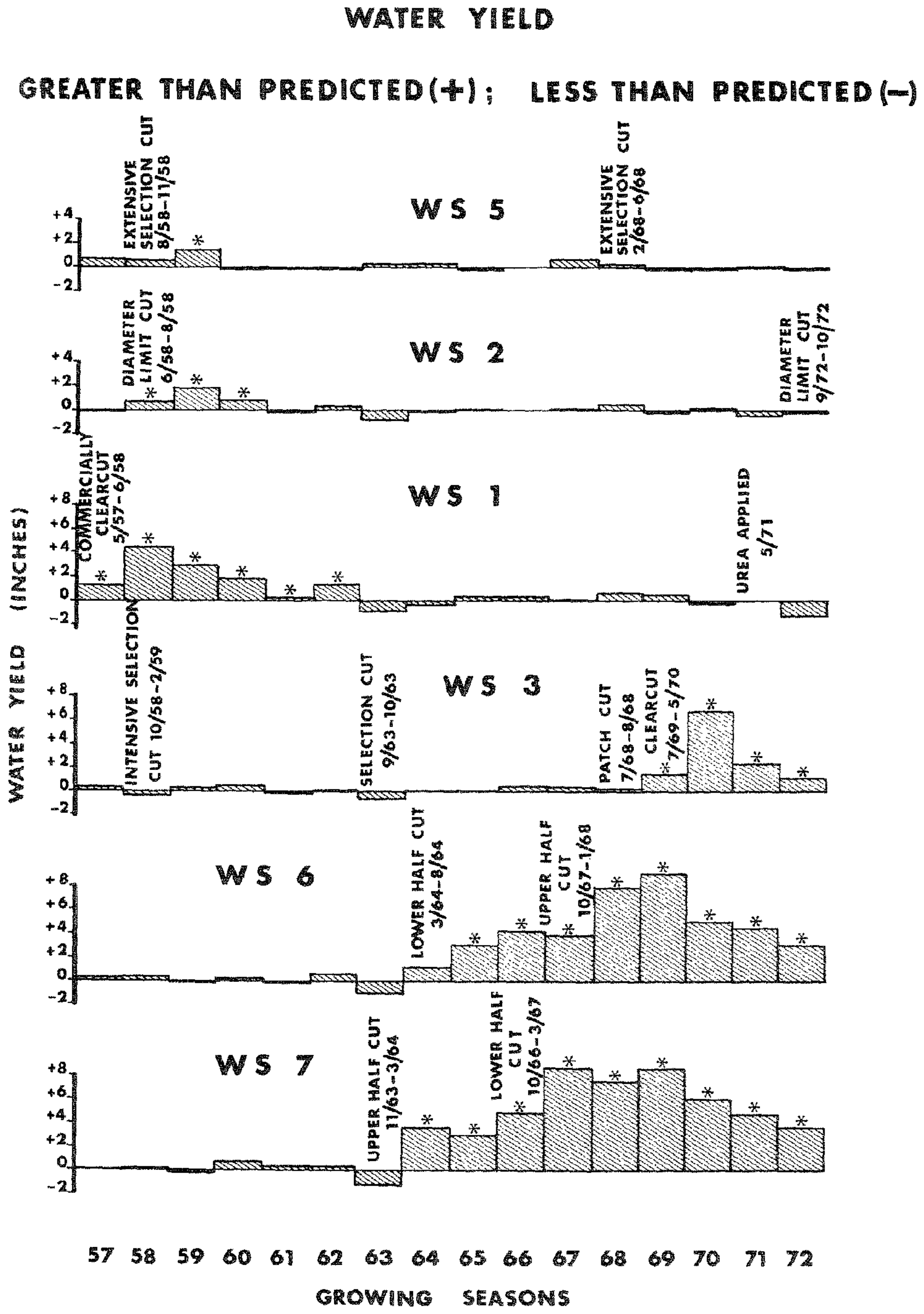
Timing

When a substantial part of the forest was cut early in the growing season, significant increases in water yield were obtained at that time, but the largest increases usually occurred during the first growing season after treatment. Largest increases always occurred from July to November. Dormant-season responses were variable, usually less than half of those obtained during the growing season. The most consistent and usually the largest dormant-season yield increases occurred in November and December.

Longevity

The duration of yield increases also varied with severity of cutting. Streamflow increases resulting from cutting on the Fernow Forest have returned rather rapidly to pre-treatment levels (fig. 4). Yield increases obtained by partial cutting (watersheds 2, 3, and 5) were never significant for more than 2 years.

Figure 4.—Effects of treatments on water yields. Deviation of water yields from amounts predicted for selected watersheds, Fernow Experimental Forest, Parsons, West Virginia.



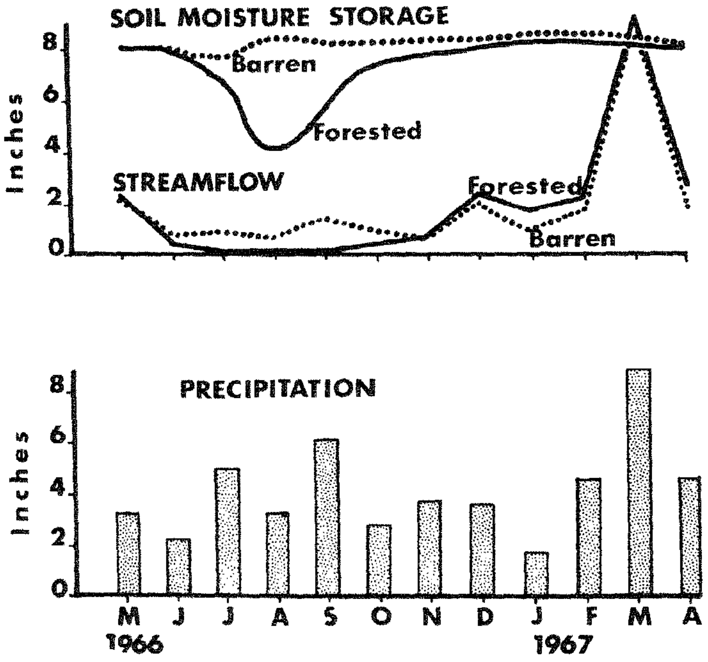
Yield increases after clearcutting lasted 6 years on watershed 1 and 5 years on watershed 3. Clearcutting with herbiciding (watersheds 6 and 7) produced the longest lasting increases. Three years of regrowth have reduced yield increases about two-thirds on watersheds 6 and 7, where revegetation has been slower. After three growing seasons, woody vegetation comprised only 15 percent of the ground cover, most of it of seed origin as opposed to other watersheds where regrowth was primarily of sprout origin. Regrowth from old root systems would at least initially be expected to better exploit soil moisture. The faster recovery of watershed 6 may relate to the fact that the upper half of this watershed was herbicided for only 2 years and that much of the vigorous regrowth there is of sprout origin.

Stormflow

The effects of heavy cutting on stormflow have been variable *(Reinhart 1963)*. Generally, growing-season peaks increased; dormant-season peaks were unaffected. Patric *(1973)* reported that instantaneous peak flows were increased during small storms when watersheds 6 and 7 were barren, but this peak effect was minor in large storms and in all storms during the dormant season.

Troendle *(1970a)* noted that timber-harvesting generally extended periods of high flow and shortened periods of low flow. The effects of treatment were greatest on low flows. Deforestation increased the duration of streamflow on watersheds 6 and 7. Streams draining these watersheds had dried up periodically when the watersheds were fully forested; during deforestation, flows

Figure 5.—Soil moisture-streamflow relationships. Upper, soil moisture and discharge from forested and barren watersheds. Lower, precipitation.



in both watersheds were never less than 0.3 cfsm *(Patric and Reinhart 1971)*.

Soil Moisture Influences

Soil-moisture depletion on the Fernow provides an insight into streamflow response to treatment. There was a close correlation between streamflow and moisture content in the upper 2 feet of soil *(Troendle 1970b)*. During the growing season, up to a 4-inch soil-moisture deficit has been recorded on forested areas on the Fernow Forest (fig. 5). Substantial reduction of water normally lost by transpiration and interception maintained soil moisture at higher levels during the growing season on barren or recently cut areas (fig. 5).

Streams draining the wetter soils on barren or recently cut watersheds are more responsive to precipitation than those draining the drier, forested areas. After soil became recharged, streamflow responses on treated and forested areas were similar except for small differences due to snowmelt. Soil-moisture measurements indicated that the relatively shallow soils on the Fernow Forest usually are recharged by January and remain so until May.

DISCUSSION

Perhaps the most important finding to emerge from the Fernow research is that timber-harvesting with well-planned, well-constructed, and well-maintained road systems simply does not damage water resources. The severity of cutting has little effect on water quality when enough trees are left to shade stream channels. Thus it is possible to produce potable water from forest land and also manage for other uses such as timber production, recreation, and wildlife habitat.

The relatively short-term effects of removing vegetation and the difficulty of controlling revegetation govern attempts to manage forest land for water. Experience on the Fernow Forest indicates that water-yield increases will not be maintained merely by periodically harvesting merchantable forest products. Increased water yield, resulting from the lightest cut that produced a significant increase of water yield on the Forest, lasted only 1 year. In other words, this cutting would have to be repeated annually to maintain the flow increase. Yet, silviculturally speaking, this heavy a cutting requires at least a 10-year cutting cycle even on the most productive sites. In the Appalachians, it requires at least 20 years for a tree to reach merchantable size. In many areas where there is no market for small products, 40 years would be a more realistic figure.

Economically, the difference between manipulating merchantable and unmerchantable vegetation is very great. No additional costs above those normally associated with harvesting forest products are incurred when it is silviculturally desirable to cut merchantable trees; under these circumstances, increased streamflow can be considered a free byproduct. Removal of unmerchantable trees to improve streamflow is an entirely different matter. The vigorous regrowth characteristic of the Appalachians is extremely difficult and costly to control. Aerial application of herbicides would seem to be the only practical way to maintain control of vegetation on areas large enough to appreciably influence water yields. The acceptance of this practice by a public that is concerned about environment is indeed highly questionable.

CONCLUSIONS

- Given current market values, it is not practical to manage forest land for both sustained water yield increases and merchantable timber products.
- Forest land can be managed for a variety of uses without impairing water quality if these uses are regulated intelligently.

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