

Fifty Years of Watershed Research on the Fernow Experimental Forest, WV: Effects of Forest Management and Air Pollution in Hardwood Forests

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Abstract

In 1951, stream gaging was begun on five small headwater catchments on the Fernow Experimental Forest in West Virginia, to study the effects of forest management activities, particularly timber harvesting, on water yield and quality. Results from these watersheds, and others gaged more recently, have shown that annual water yields increase in proportion to the basal area cut, and that conversion of hardwood stands to conifers significantly decreases water yield. Accelerated nutrient leaching did not occur after heavy cutting, but did follow when herbiciding sustained barren conditions after clearcutting. Results from Fernow studies have shown that sediment increases in in-stream exports are minor and short-lived and mostly from roads when best management practices (BMPs) are conscientiously employed. Research on forest access roads and BMPs has provided important management guidelines for forest landowners. More recently work has focused on air pollution effects on hardwood forests. Ongoing research is evaluating the role of forest management on channel stability, nutrient cycling in polluted environments, and the interaction of forest management and air pollution on forest ecosystems.

Keywords: Fernow Experimental Forest, timber harvesting, water yield, nutrient cycling, sediment, watershed studies

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Introduction/Description

The Fernow Experimental Forest (FEF) was established to conduct research in forest and watershed management in the central and northern Appalachians and to provide relevant information to forest landowners. The 1868-ha FEF is located south of Parsons, West Virginia (Figure 1). The Elklick watershed, which later became the bulk of the FEF, was initially logged between 1903 and 1911 during the railroad-logging era (Trimble 1977). Most of the watershed was not farmed and the forest was allowed to regenerate naturally after logging. The federal government purchased the land in 1915 and dedicated it to forest and watershed research in 1934. The Elklick basin was selected because of its good soil, excellent young regrowth, ready access to many wood-using plants, and was considered to be representative of more than 5 million ha of mountainous forestland in West Virginia and adjacent states. Chestnut blight in the 1930s was the next major disturbance, and resulted in a 25 percent reduction in standing volume on the experimental forest. Closed during World War II, silviculture and watershed research began again in 1948 and have continued to date without interruption.

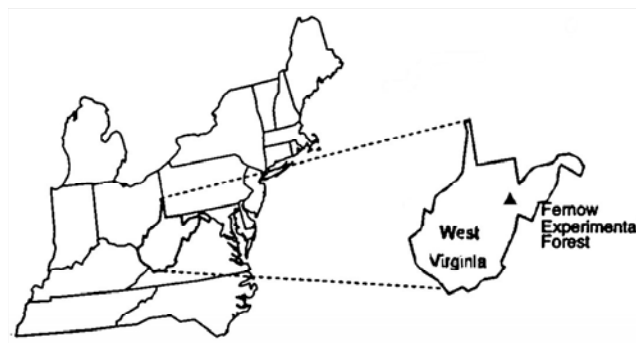


Figure 1. Location of Fernow Experimental Forest, WV.

The FEF is located in the Allegheny Mountains Section of the Central Appalachian Broadleaf Forest, and vegetation is classified as mixed mesophytic. Characteristic species include northern red oak (*Quercus rubra*), yellow-poplar (*Liriodendron tulipifera*), black cherry (*Prunus serotina*), sugar maple (*Acer saccharum*), sweet birch (*Betula lenta*), red maple (*A. rubrum*), and American beech (*Fagus grandifolia*). The mountainous topography has elevations ranging from 530 to 1115 m above sea level, with slopes of 20-50 percent common. Annual precipitation averages about 1480 mm and is distributed throughout the year. The growing season is May through October with an average total frost-free period of 145 days. Snow is common, but snowpacks generally last no more than a few weeks. Mean annual temperature is 9.2°C but temperatures reach -20°C during most winters. Large rainfall events normally are associated with hurricanes.

Soils are moderately deep and well-drained, formed in material weathered from interbedded shale, siltstone and sandstone. Soils average 1 m depth, and contain considerable stones and large gravels.

Research Results: Timber Harvesting

Effects on water yields

The earliest watershed studies on the FEF evaluated the effects of timber harvesting on streamflow and water yield. Five forested watersheds were gaged in 1951, then after a 6-year calibration period, four cutting treatments ranging from clearcutting to intensive selection were applied (Table 1). Other

watersheds have been gaged during the last 50 years, and treatments applied, as the questions of interest to landowners and scientists evolved over time. Summaries of these studies (Reinhart et al. 1963, Kochenderfer et al. 1990, Hornbeck et al. 1993) have concluded that (1) removing significant amounts of timber increased annual water yield from a watershed, (2) the increases were related to the intensity of harvest and the basal area removed from the stand, with the largest increases coming from clearcut watersheds, and (3) generally, at least 25% of the basal area of a stand must be removed before a change in annual water yield can be detected. Greater flow increases during the growing season suggest reduced losses of soil moisture to transpiration after cutting trees. Even the increases from clearcuts were relatively short-lived, and annual water yields from harvested watersheds, with a few notable exceptions, returned to predicted flows within 5-10 years after treatment. This return to predicted levels coincides with crown closure of the stands for most of the watersheds. Use of herbicides on FEF6 and FEF7 to control regrowth significantly prolonged increases in annual flow relative to the watersheds that were only clearcut with no vegetation control (FEF3). Continuing reductions in annual water yield on FEF6 are attributed to the greater interception and transpiration by the planted conifer (*Picea abies*) stand compared to the original hardwood stand (Helvey 1967). Annual streamflow reductions have averaged 23% for the past six years on FEF6, with most of the significant decreases during the dormant season. Changes in seasonal water yield probably reflect the severity of treatment as well as vigor of regrowth.

Table 1. Experimental Watersheds on the FEF.

WS & area (ha)	Treatment	Date
WS1, 29.9	Clearcut to 6 in. dbh	1957/58
	Urea application	1971
WS2, 15.4	Six 17 in. diameter limit cuts	1958-1996
WS3, 34.4	Two intensive selection cuts	1958- 1963
	Clearcut, all but buffer strip	1969/70
	Aerial application of fertilizer	1989-present
WS4, 38.9	Reference	Activated 1951
WS5, 36.4	Six single-tree selection cuts	1958-1998
WS6, 22.3	Lower and upper watershed clearcut and herbicided	1964-1969
	Planted with Norway spruce	1973
	Aerial herbicide applications	1975,1980
WS7, 24.3	Upper and lower watershed cut and herbicided	1963-1969
WS10, 15.2	Control	Activated 1984
WS13, 14.2	Control	Activated 1988

Growing season water yield increases due to harvesting were longer-lived for FEF6 than FEF7 because other vegetative regrowth (competing hardwoods) was controlled with aerial herbicide applications in 1975 and 1980 to release planted Norway spruce (Wendel and Kochenderfer 1984), while the rapid decline in growing season water yield increases on FEF3 was attributed to luxuriant vegetative regrowth (Aubertin and Patric 1974). Vegetation was set back to an earlier successional stage on FEF7 by the herbicide treatments (Kochenderfer and Wendel 1983). Because of the repeated herbicide treatments, stump sprouts were nearly eliminated on FEF7, and most regeneration originated from seeds. Semiwoody herbaceous vegetation (mainly *Rubus* spp.) and grasses remained dominant for 5 years after the cessation of herbicide treatments. On FEF3, woody vegetation comprised of seedlings and seedling and stump sprouts developed very rapidly. This deeper-rooted vegetation had better access to soil water, resulting in greater transpiration during the growing season than on FEF7.

Tree species composition after harvesting also can affect annual water yields. For example, lower than predicted growing season yields on FEF3 in the late 1980s-2002, may be due to the large increase in black cherry (from 5 % prior to cutting to 50% of basal area 20 years after cutting). Black cherry consistently transpires at the highest rate per unit of leaf surface area found in hardwoods (Kochenderfer and Lee 1973). It is also interesting to note that during the ten-year time period (1989-1999) that coincided with a fertilization treatment on FEF3, growing season flows were consistently less than predicted. Patric and Smith (1978) suggested that fertilization decreased throughfall and temporarily increased interception, partly through the mechanism of increased leaf area. These data provide some support for this hypothesis.

Effects on peak flows

Dormant season storm flows and peak flows draining the harvested watersheds differed little from those of the control watersheds, probably because similar evaporative losses from both sustained similar soil moisture levels. However, growing season peak flows were consistently greater on some clearcut watersheds where soil moisture was higher for a short period after cutting until vegetation regrowth. This effect was more pronounced for smaller storms. The number of runoff events that are large enough to constitute stormflow increased with clearcutting

(Bates 2000). Snowmelt storm flows peaked earlier on clearcut watersheds than the control watersheds, due to greater net radiation on the snow cover of clearcut watersheds. Except for snowmelt and overland flow from logging roads, there were no dramatic timing changes in the hydrographs after harvest, and subsurface flow is the main runoff production mechanism both before and after harvests.

Effects on sediment yields

Sediment exports in stream water prior to treatment and on the reference watersheds ranged from 6 to 25 kg ha⁻¹ yr⁻¹ (Patric 1980, Kochenderfer et al. 1987). Clearcutting using an unplanned road system and no BMPs increased sediment yields to over 3000 kg ha⁻¹ on FEF1 during logging (Kochenderfer and Hornbeck 1999) in 1957 and 1958, compared to only 97 kg ha⁻¹ in 1970 when BMPs were carefully applied to FEF3. On both watersheds, sediment yields decreased rapidly to 44 kg ha⁻¹ and 28 kg ha⁻¹ respectively in 5 years. Most sediment was produced during storm flows (Kochenderfer et al. 1987). For all of these studies, turbidity or suspended sediment returned to pre-treatment or reference levels within a few years. Overland flow seldom was observed, only occurring on or directly below steep roads (Patric 1973).

Effects on stream temperature

Clearcutting FEF1 and leaving no streamside vegetation raised stream temperature 4.5°C during the growing season, and decreased temperature 2°C during the dormant season (Reinhart et al. 1963). Temperatures returned to pretreatment levels within 3 years. By contrast, clearcutting FEF3 in 1969 had no effect on temperature when a 50-ft wide vegetated buffer strip was left along the channel. Removal of that buffer strip increased stream temperature about 4°C during the summer it was cut. Channel shading was sufficient after 5 years of regrowth to return temperatures to pre-clearcutting levels (Patric 1980).

Effects on stream chemistry

Stream water nitrate concentrations are of concern to forest managers because forests provide the source of most drinking water in the U.S., and because nitrate concentrations can be a very sensitive indicator of disturbance and change in plant and soil systems. Many studies on the FEF have shown that forest harvesting, including clearcutting has little effect on nitrate concentrations. Clearcutting on FEF3 (Figure

2) resulted in maximum concentrations that were well below safe drinking water standards. By contrast, forest fertilization on FEF1 with 500 kg ha⁻¹ of urea in 1971 resulted in increases of monthly maximum nitrate from 0-8 mg L⁻¹ to 70 mg L⁻¹. Devegetating

may poorly capture the variation of air quality in mountainous and rural areas.

Research on the FEF also has shown that nitrogen may be a more significant actor than sulfur relative to

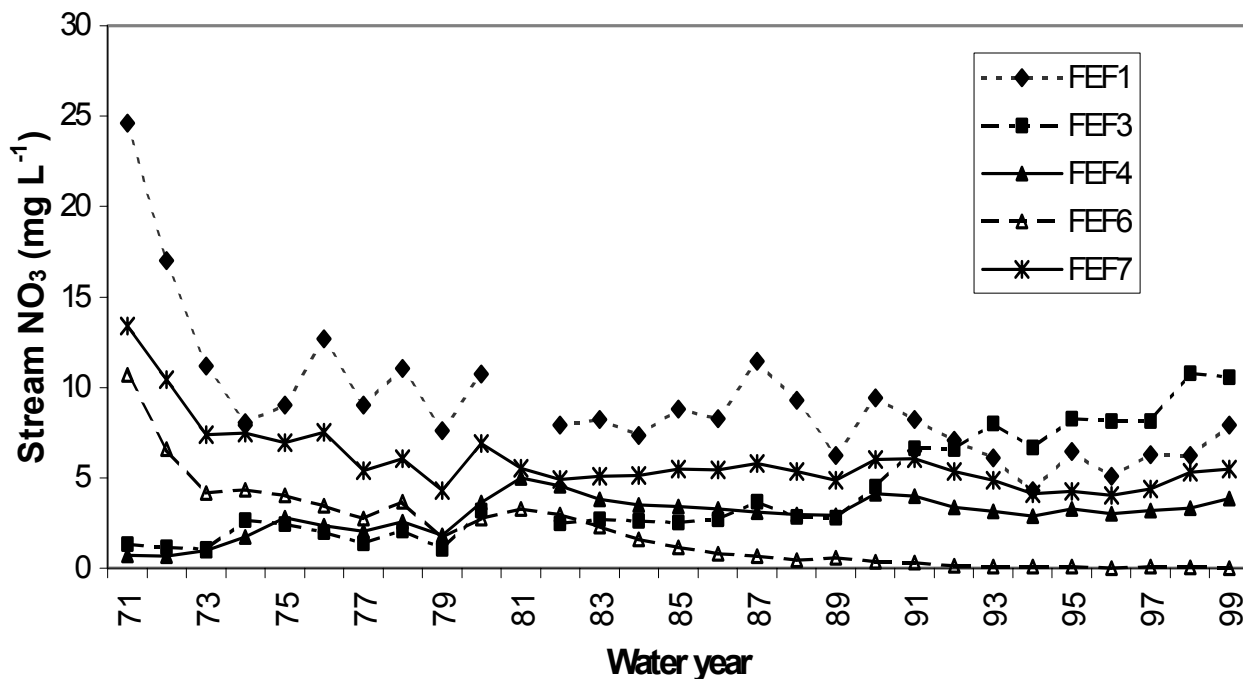


Figure 2. Levels of nitrate concentration at five sites, 1971-1999.

FEF6 and FEF7 with herbicides repeatedly for several years after clearcutting also caused substantial increases in nitrate concentrations. These results demonstrate the importance of vegetation in maintaining water quality through nutrient uptake and control of microclimate.

Research Results: Air Pollution

In recent years, scientists at FEF have been involved in monitoring air quality and evaluating the effects of air pollution on forest ecosystems. The first monitoring station in the nation-wide National Acid Deposition Program (NADP) came on-line in Parsons in 1978 as part of the research program at FEF. Data from this site showed that the central Appalachians receive some of the highest levels of nitrogen and sulfur deposition (i.e. acid rain) in the U.S., despite its rural location. Ozone monitoring at low and high elevation sites near the FEF, along with analysis of ozone concentrations throughout the central Appalachians, has shown that remote areas can have poor air quality due to long-distance transport of pollutants, and that existing monitoring networks

its effects on forest ecosystems (Adams et al. 2000). Increased nitrogen deposition can result in leaching of base cations, particularly calcium and magnesium, from the soil (Edwards et al. 2002), with significant concerns for sustainable forest health. Acidification of streams may result from high levels of nitrate and/or sulfate deposition. No significant decreases in tree growth or forest health have been detected on the FEF as a result of elevated nitrogen and sulfur deposition, however.

Summary

More than 50 years of watershed research at the Fernow Experimental Forest has provided important information about the effects of forest management on annual water yield, storm flows, sediment export, stream temperatures, and nutrient cycling. In addition, a much more thorough understanding of the use of water and nutrients by forest ecosystems in the central Appalachians has resulted. Research on air pollution effects on forests has informed national policy discussions. Scientists on the FEF continue to conduct relevant research on long-term species

composition trends in central Appalachian forests, the role and effects of fire, the integration of silvicultural activities for landscape level management for a variety of resources, including wildlife, water and forest productivity, and other important management and research questions. The research program at the FEF provides ample evidence of the utility and importance of long-term watershed research, and the need for well-designed experimental manipulations to address complex questions over the life of a forest.

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