Drinking Water from Forests and Grasslands

A Synthesis of the Scientific Literature

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Cover photo: Hendersonville Reservoir Dam, Pisgah National Forest, North Carolina. Photo by Bill Lea.

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Chapter 11

Forest Succession

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Introduction

The effects of forest management activities on water quality are generally of the greatest magnitude in the first several years after disturbance. However, during long-term succession and regrowth of forest ecosystems, changes in physical, chemical, and biological parameters of streams may occur.

Nutrients

Issues and Risks

After a forest disturbance such as harvesting or fire, nutrient levels in streams may be elevated during early successional stages until the forest matures (see chapter 10). Nitrate concentrations can be elevated for a few to many years depending upon whether the watershed is nitrogen limited or saturated (see chapter 3 for discussion of nitrogen saturation).

Findings from Studies

Changes in stream inorganic chemistry and sediment yield were observed over a 20-year period after clearcutting by cable logging of a 146-acre [58-hectare (ha)] Southern Appalachian watershed (Swank and others, in press). Stream nutrient concentrations and fluxes showed small increases after harvest, and responses were largest the third year after treatment. Nitrate-nitrogen ($\text{NO}_3^-$) was an exception. The initial increase in nitrate was from 0.1 milligrams (mg) per liter to 0.8 mg per liter (fig. 11.1) and increased net nitrogen export of 1.16 pounds per acre [1.3 kilograms (kg) per hectare] the third year after harvest. However, later in succession (15 to 20 years), nitrate concentrations exceeded values observed the first several years after clearcutting. This response is partially attributed to reduction in nitrate uptake due to vegetation mortality, changes in species composition, and nitrogen release from decomposition of woody plants.

Other long-term research in eastern forested watersheds (Edwards and Helvey 1991, Swank and Vose 1997) shows that as forests mature, less nitrogen is retained in the watershed and stream nitrate concentrations increase. These long-term studies support findings of shorter-term stream chemistry surveys. A survey of streamwater chemistry in 57 watersheds along successional and elevational gradients was conducted in the White Mountains of New Hampshire (Vitousek 1977). Differences in successional status among watersheds were found to be important in controlling nutrient and potassium concentrations. Streams draining old-aged forests had higher concentrations of nitrate, potassium, and other solutes than did streams draining intermediate-aged forests at the same elevation. Spruce-fir (Picea spp.-Abies spp.) watersheds with no record of logging had streamwater nitrate concentrations of about 3 mg per liter, while spruce-fir watersheds logged 30 years previously had nitrate concentrations <0.5 mg per liter.

Another survey of 38 streams draining partially or entirely clearcut watersheds was conducted in New England—(Martin and others 1985) on northern hardwood sites in New Hampshire, Maine, and Vermont; in central hardwood forests in Connecticut; and in coniferous forests in Maine and Vermont. Streams draining watersheds that had been partially or entirely clearcut in the previous 2 years were selected. There were no apparent changes in stream nutrient concentrations from many of the ecosystems, and the largest concentration increases were for nitrate, calcium, and potassium in northern hardwoods of New Hampshire. Inorganic nitrogen (nitrate plus ammonium) increased to an average of 2 mg per liter (Martin and others 1985). However, elevated solute concentrations appear to be short-lived even in streams draining successional northern hardwood forests in New Hampshire (Hornbeck and others 1987). Moreover, early stream chemistry changes after clearcutting were considered insufficient to cause concern for public water supplies or for downstream nutrient loading (Martin and others 1985).

In the Pacific Northwest, forest-successional stage is not always a good predictor of nitrate concentration in streamwater. For example, at the H.J. Andrews Experimental Forest in Oregon, forest harvest increased annual nitrate...
concentration from predisturbance levels of 0.001 mg per liter to 0.036 mg per liter (Martin and Harr 1989), but nitrate concentration returned to predisturbance levels within 6 years. Further, a 20-year postdisturbance record from a pair of treated and untreated watersheds at the experimental forest suggests that nitrate concentrations in streamwater remain very low in both watersheds once the clearcut watershed recovers from the immediate effects of disturbance. At the H.J. Andrews Experimental Forest, the ecosystem is highly nitrogen-limited, and vegetation imprint on nitrogen fluxes may be overridden by rapid immobilization of any available nitrogen by soil microbiota.

An extensive synoptic water-quality assessment was conducted on numerous streams in the Great Smoky Mountain National Park in the Southern Appalachian Mountains (Flum and Nodvin 1995, Silsbee and Larson 1982). Concentrations of nitrate in streams draining watersheds that had been logged prior to park establishment were significantly lower (one-half) than the nitrate concentrations in unlogged watersheds at similar elevations.

The magnitude of stream nitrate concentrations associated with long-term forest succession depends on a number of factors, such as levels of atmospheric nitrogen deposition, the type and rapidity of forest regrowth, soil microbial activity, and soil physiochemical reactions. Stream nitrate levels rarely exceed 5 mg per liter and are below current drinking water standards. The nitrate, however, may contribute to stream acidification, particularly during spring snowmelt when nitrate concentrations peak in the Northeastern United States (Murdock and Stoddard 1992).

Reliability and Limitations of Findings

Existing evidence for changes in stream chemistry with forest succession is based upon well-established programs of long-term research and is quite reliable. However, findings are limited in scope to select forest ecosystems in the United States.

Limited evidence indicates that stream nitrate concentrations for older hardwood forests of the southern and central Appalachian regions are higher than for younger successional forests. However, site-specific research shows that nitrate levels can vary substantially even during early succession (first 20 years), although the general applicability of findings is unknown. Assessments of nitrate levels in streams draining successional forests in New England show mixed responses and appear to be ecosystem specific. Very limited information on stream nitrate is available for successional forests in the Pacific Northwest. Current findings

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2 Personal communication, 1999. Kristin Vanderbilt, Graduate Student Oregon State University, Corvallis, OR.
indicate that elevated nitrate concentrations following clearcutting are short-lived and return to predisturbance levels early in succession.

**Research Needs**

1. Long-term assessments of stream chemistry changes associated with forest succession are lacking for most major forest ecosystems in the United States. From a public drinking water perspective, synoptic stream nutrient surveys across a range of forest types and stand ages with known disturbance histories would greatly enhance planning information for managers.

2. There is a large knowledge gap in nutrient concentration changes associated with storm runoff events. Such information is most important where water supplies are derived from forested headwaters with rapid streamflow responses to precipitation, e.g., watersheds with shallow soils, steep slopes, intense rainfall, and rapid snowmelt.

**Sediment**

**Issues and Risks**

Stream sediment may also exhibit long-term dynamics after forest disturbance. Logging roads associated with harvesting activities are frequently the major source of sediment to streams and are a potential legacy to consider when evaluating sources of sediment in drinking water (see chapters 3, 9).

**Findings from Studies**

A synthesis of long-term sediment yield responses following forest watershed disturbances is provided by Bunte and MacDonald (1999). Based on studies in Oregon and New Hampshire, they identify three kinds of potential responses in postdisturbance sediment yields:

1. Sediment yields remain high for a number of years after disturbance due to a large sediment pulse to the stream from a storm or other disturbance. That is, sediment from upstream storage areas or destabilized hillslopes and channels continues to be released;

2. Sediment yields decline below average annual yields after disturbance when sediment storage is depleted by a major sediment transport event; and

3. Sediment yields rapidly return to predisturbance conditions because excess material has moved through the system.

Recent findings in the Southern Appalachians provide an example of the first type of response where sediment yield remains high for a number of years during forest succession (Swank and others, in press). A cable-logged, clearcut watershed required only three contour access roads because logs could be yarded 1,000 feet (305 meters) with the cable system. Record storms (15 inches or 38 centimeters) in the last 2 weeks of May 1976, prior to grass establishment, eroded both unstable soil and hydrosed materials from the roads. Roads were the source of elevated sediment yield as illustrated by soil loss measured at a gaging station in the stream immediately below a road crossing in the middle of the catchment (fig. 11.2A). In those 2 weeks of May, sediment yield was nearly 55 tons [50 metric tonnes (Mg)] from 0.21 acre (0.085 ha) of road contributing area (roadbed, cut, and fill). In the ensuing period of road stabilization and minimum use (June to December 1976), soil loss was low but accelerated again briefly during the peak of logging activities (fig. 11.2A). In the next year, soil loss below the road declined to baseline levels.

The pattern of sediment yield at the base of the second-order stream (fig. 11.2B, gaging site) draining the watershed was different from the pattern of sediment loss from the roads. Following an initial pulse of sediment export from the watershed, sediment yield remained substantially elevated during and after logging. In the 3-year period between 1977–80, the cumulative increase in sediment yield was 240 tons (218 Mg) (fig. 11.2B). During the next 10 years, sediment yield declined with a cumulative increase in export of 240 tons (218 Mg). The rate of sediment yield over the 5- to 15-year period after disturbance was about 300 lb per acre per year (336 kg per hectare per year), or 50 percent above pretreatment levels. The long-term sediment yield data illustrate a lag or delay between pulsed sediment inputs to a stream and the routing of sediments through the stream channels. In the absence of significant additional sources of sediment to streams on the watershed, annual sediment yield at the base of the watershed was still substantially above predisturbance levels at least 15 years later. Thus, there appears to be a continual release of sediment from upstream storage that was primarily deposited from road crossings of streams during exceptionally severe storms.

**Reliability and Limitations of Findings**

Few studies have documented the long-term effects of management practices on sediment yield. As pointed out in chapter 10, increases in sediment yields from timber management activities are typically considered to be short-lived. However, unique conditions during management can lead to elevated stream sediment later in forest succession. The importance of this process is site-specific and requires
present land uses. It is important to consider successional impacts along with the cumulative impacts of other past and present land uses across the landscape when assessing impacts of land management on drinking water sources.

**Literature Cited**


that each stream be evaluated to assess the legacy of past management practices on current levels of stream sedimentation.

**Research Need**

Recommendations for future research related to this topic are given in chapter 10.

**Key Points**

In the long term, forest harvesting practices alone may have little deleterious impact on stream sediment and chemistry, which are of primary concern in drinking water. However, other past and present land uses affect present sediment and nitrate concentrations in streams. Sediment and nitrate yields associated with early successional development of forest may be in addition to yields from other past and

This report reviews the scientific literature about the potential of common forest and grassland management to introduce contaminants of concern to human health into public drinking water sources. Effects of managing water, urbanization, recreation, roads, timber, fire, pesticides, grazing, wildlife and fish habitat, and mineral, oil, and gas resources on public drinking water source quality are reviewed. Gaps in knowledge and research needs are indicated. Managers of national forests and grasslands and similar lands in other ownerships, environmental regulators, and citizens interested in drinking water may use this report for assessing contamination risks associated with land uses.

Keywords: Economics, nutrients, pathogens, sediments, source water assessments, toxic chemicals.