# PATTERNS OF NITRATE LOSS FROM A CHRONOSEQUENCE OF CLEAR-CUT WATERSHEDS

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**Abstract.** Three clear-cuts at the Hubbard Brook Experimental Forest (NH) have resulted in a chronosequence of forest watersheds in close proximity. Following clear-cutting, the stands, now 12, 21, 27, and 78 years old, have different species composition, nutrient capital, and biogeochemistry. In this study, we compared seasonal patterns of $NO_3^-$ in streamwater, changes in N capital, and N retention in watersheds of differing stand age. All of the watersheds showed elevated losses of $NO_3^-$, $H^+$ and nutrient cations ($Ca^{2+}$, $Mg^{2+}$, $K^+$) during the first few years following clear-cutting. Increased retention of N occurred during vegetation regrowth compared to the reference watershed (W6). Nitrate concentrations were low during the summer growing season, increased in the late fall and peaked in March during spring snowmelt. Concentrations of $NO_3^-$ were lower in the regrowing watersheds than in W6 during all months. In W6, there was considerable year-to-year variability in N retention, which was not initially observed in the manipulated watersheds. However, two cut watersheds exhibited higher export of $NO_3^-$ in 1989 and 1990, corresponding to a 10-year high value in annual $NO_3^-$ loss in W6. These results demonstrate the importance of land use and cutting history in assessments of N saturation and loss from forest watersheds.

Key words: nitrogen saturation, acidic deposition, clearcutting, nitrate, base cations, alkalinity

## 1. Introduction

There is considerable interest in patterns of nitrogen (N) leaching from forest watersheds because of concerns about the effect of elevated atmospheric deposition of N and conditions of N saturation. Many studies have examined watershed export of dissolved inorganic N ($DIN = NH_4^+ + NO_3^-$), relative to atmospheric inputs. However, assessments have been limited by an understanding of the role of disturbance (e.g. land-use history, stand age) in influencing patterns of N export.

Three clear-cutting experiments at the Hubbard Brook Experimental Forest (HBEF) in New Hampshire have resulted in a chronosequence of forest watersheds in close proximity (Likens et al., 1970; Likens and Bormann, 1974; Hornbeck et al., 1987). Four experimental watersheds had similar species composition prior to cutting and similar history of atmospheric deposition. Following cutting, the stands (now 12, 21, 27, and 78 years old) have different species composition, nutrient capital, and biogeochemistry. In this study, we compared seasonal patterns of $NO_3^-$ in stream water, changes in N capital, and N retention in watersheds of differing stand age.

These data demonstrate both the year-to-year variability of N loss in stream water, and the magnitude of loss that can occur with severe disturbance. These data, therefore, may be helpful in evaluating the N saturation hypothesis at sites with moderate inputs of N deposition. In addition, the seasonal patterns of N loss help identify some of the factors that control N export from forest watersheds.

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## 2. Site Description

The HBEF in the White Mountains of New Hampshire is a northern hardwood forest representative of much of the northeastern U.S. in stand age and disturbance history. Mean total inorganic N deposition was estimated as 620 mol/ha-yr, representing bulk wet deposition of 490 mol/ha-yr (for the period 1964-1991; Butler and Likens, 1991; Likens, 1992; Likens and Bormann, 1995) and dry deposition of 130 mol/ha-yr (for the year 1989; Lovett, unpublished data). The site is described in detail elsewhere (Likens et al., 1977; Bormann and Likens, 1979; Likens et al., 1994) and has been studied extensively since 1963. Watershed 6 (W6), the reference watershed, was logged intensively 1910-17. W2 was clear-cut in 1965-66, herbicide was applied during the summers of 1966, 1967 and 1968 to prevent regrowth of vegetation. Regrowth began in 1969. W4 was cut in 25-m wide strips along the elevational contour. Every third strip was harvested in 1970. The remaining strips were harvested in 1972 and 1974. Regrowth began in 1971, 1973 and 1975. W5 was whole-tree harvested in 1983-84.

## 3. Methods

For this analysis, we used data collected at the HBEF since 1963 (Likens et al., 1994; Likens and Bormann, 1995); the sampling and analytical methods are described in detail elsewhere (see Likens et al., 1994). To evaluate seasonal patterns, volume-weighted mean monthly concentrations of $NO_3^-$ in stream water were calculated for the

**Table 1**

Forest Cutting History

| | **Watershed 2** | **Watershed 4** | **Watershed 5** | **Watershed 6** |
|---|---|---|---|---|
| **Treatment** | Clear-cut | Strip cut | Whole-tree harvest | Logged |
| **Dates of Treatment** | 1965-68 | 1970-74 | 1983-84 | 1910-1917 |
| **Regrowth** | 1969 | 1975 | 1984 | 1918 |
| **Stand Age** | 27 years | 21 years | 12 years | 78 years |
| **POST-TREATMENT NITROGEN BUDGET** | | | | |
| **Years** | 1965-74 | 1970-79 | 1983-92 | 1983-92 |
| **Input Flux** | | | | |
| Bulk deposition | 4,495[1] | 4,070[1] | 4,210[1] | 4,291[1] |
| Herbicide | 171[2] | - | - | - |
| **Output Flux** | | | | |
| Stream loss | 36,006[1] | 4,205[1] | 4,815[1] | 994[1] |
| Biomass removal | - | 5,290[3] | 9,855[4] | |
| **Net Output Flux of Nitrogen** | 31,340 | 5,425 | 10,460 | -3,297 |

1. Data from Likens et al., 1977; Butler and Likens, 1991; Likens and Bormann, 1995. 2. Data from Likens et al., 1970. 3. Data from Hornbeck et al., 1987. 4. Data from Siccama, pers. comm.

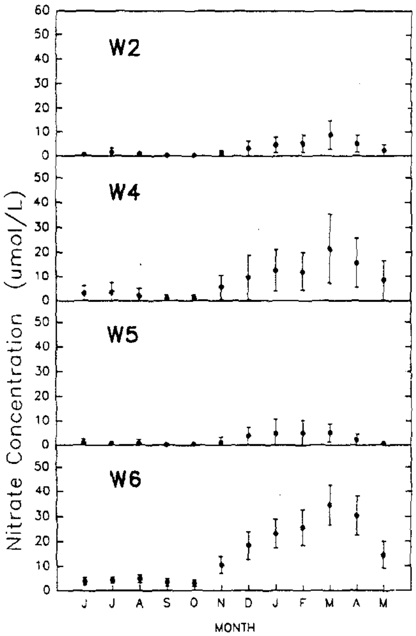


**Figure 1 Volume-weighted mean nitrate concentration in stream water by month for experimental watersheds at the HBEF**
W2 mean was calculated for years 1972-92 (n=20); W4 mean was calculated for years 1978-92 (n=14); W5 mean was calculated for years 1987-92 (n=5); W6 mean was calculated for years 1964-92 (n=28).Error bars represent the 95% confidence interval.

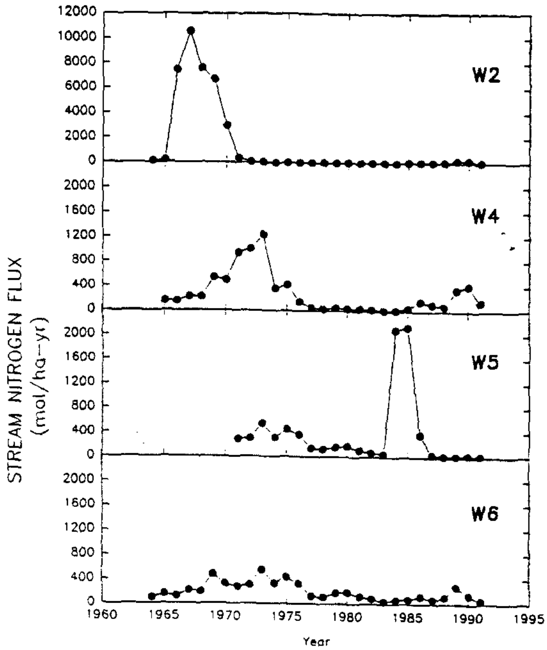


**Figure 2 Annual dissolved inorganic nitrogen (nitrate+ammonium) output flux in stream water for experimental watersheds at the HBEF**

recovery period following clear-cutting in the manipulated watersheds. The recovery period was defined as the period following elevated stream losses of $NO_3^-$, generally initiated three years after regrowth began. For the reference watershed (W6), volume-weighted mean $NO_3^-$ concentrations were calculated for the period 1964-1992. Annual input and annual and monthly output of DIN were calculated. Nitrogen retention was calculated by subtracting DIN loss in stream water from DIN atmospheric input and dividing by DIN input.

## 4. Results

Seasonal patterns in $NO_3^-$ loss were observed in all four watersheds (Figure 1). Nitrate concentrations were low during the summer growing season, increased in the late fall and peaked in March during spring snowmelt. Nitrogen efflux from the ecosystem followed the same seasonal pattern (e.g. Likens, 1992). Concentrations of $NO_3^-$ in stream water were lower in the regrowing watersheds than in the reference watershed (W6) during all months. Nitrate concentrations were lowest in W2 and W5, and intermediate in W4 during the recovery period relative to W6 (Figure 1).

For several years immediately following clear-cutting, annual DIN loss was high in all treated watersheds (Figure 2; Table 1). Drainage losses of DIN from W2 associated with the disturbance, far exceeded losses from either W4 or W5. Annual atmospheric input of DIN typically exceeded annual drainage losses of DIN in W6. Annual atmospheric inputs of DIN always exceeded annual losses during the recovery period in the cut watersheds. Annual losses of DIN from W2 during the early years of the recovery period were lower than losses from W4 and W5; all were lower than losses from W6 (Figure 2). Note that in recent years, stream losses of DIN in W2 and notably in W4 have increased, and W4 exceeded W6. Increases in DIN loss were synchronized in time between watersheds. For example, when higher losses occurred in W6 in 1989, higher losses also occurred in W2 and W4 that year (Figure 2). Patterns of monthly $NO_3^-$ loss were also synchronized between W6 and W2, W4 and W5. During the summer of 1990, elevated losses of $NO_3^-$ were observed during the growing season in W2 and W4 and slightly in W6.

Retention of atmospheric deposition of DIN was very different in each of the four watersheds with time and with disturbance (Figure 3). Nitrogen was strongly retained in young, regrowing stands early during the recovery period, but has decreased in recent years. Nitrogen retention in W6 has varied considerably from year to year. Note that retention of DIN was particularly low in the early 1970's, corresponding to a period of elevated N loss in stream water (Likens et al., 1977).

## 5. Discussion

The experimental clear-cuts of three watersheds (W2, W4, and W5) at the HBEF have produced a chronosequence. Coincident with elevated losses of $NO_3^-$, all of the cut watersheds showed elevated losses of $H^+$, Al and nutrient cations ($Ca^{2+}$, $Mg^{2+}$, $K^+$) during the first few years following disturbance (Likens et al., 1970; Bormann and Likens, 1974; Hornbeck et al., 1987). Increased retention of DIN occurred during vegetation regrowth, coinciding with increased pH, increased concentrations of base cations and decreased concentrations of Al compared to the reference watershed (Likens et al., 1978; Nodvin et al., 1988). As a result, there has been an increase in alkalinity during the regrowth period following clearcutting.

The seasonal pattern in loss of DIN demonstrates the significance of forest biota in regulating N losses from these watersheds. In W6, during the growing season when plant uptake of N was high, losses of DIN were minimized. During snowmelt, losses of $NO_3^-$ peaked. During the first year after cutting in W2, Likens et al. (1970) observed that the increase in $NO_3^-$ loss did not begin during spring snowmelt, but rather was initiated during the summer growing season, when nitrifier populations had increased (Smith et al., 1968).

Nitrogen retention in W6 was both lower and more variable than in the cut

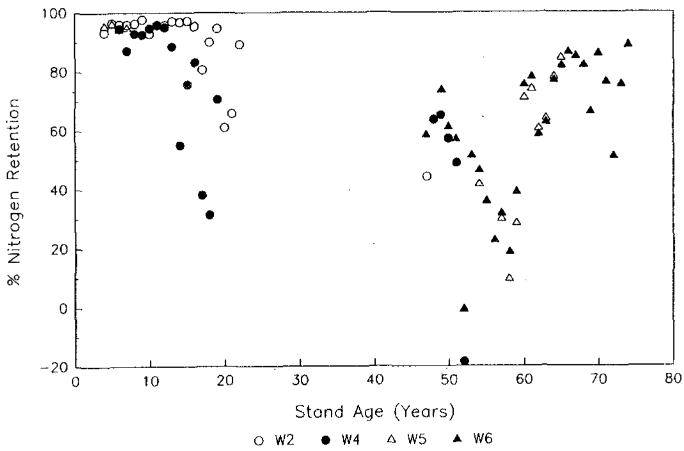


**Figure 3 Percent dissolved inorganic nitrogen deposition retained in experimental watersheds at the HBEF**

watersheds during the early years of regrowth. In W4, N retention decreased sooner following the clear-cut than in W2. Low N retention suggests that biotic demand for N was less than N available. A pattern of increasing N loss has been used as an indicator of N saturation (Aber et al., 1989; Stoddard,1994). While absolute $NO_3^-$ concentrations in stream water were different in the four watersheds, seasonal patterns of $NO_3^-$ concentrations have been similar since 1989. The similarity between watersheds with different land-use histories suggests that large-scale factors, such as input of N deposition and climatic patterns, can influence N loss patterns.

Watershed retention of DIN (Figure 3) can also be used to assess year-to-year variability. Despite the large variability, there were distinct patterns in the N retention. It has been suggested that W6 has reached N saturation, because of the low levels of N retention observed in the early 1970's (years 50-56)(Agren and Bosatta, 1988). In fact, the higher levels of N retention following the years of elevated N loss illustrate that while W6 may exhibit moderate N leaching, the watershed cannot be considered to be at N saturation over the long-term.

In recent years (1989-91), two of the cut watersheds (W2 and W4) exhibited higher losses of $NO_3^-$ corresponding to a 10-year high value in 1989 in annual $NO_3^-$ loss in W6. For the cut watersheds, the fluxes were elevated during the entire year, but most notably in 1990, concentrations of $NO_3^-$ were high during the growing season for the first time since disturbance. Note that $NO_3^-$ concentration in stream water was higher in W4 than in W6 both during the growing season and during snowmelt in 1989 and 1990. Loss of N during the growing season can be considered a more advanced stage in the progression toward N saturation (Stoddard, 1994).

There are several reasons that W4 may have had higher losses of $NO_3^-$ during the growing season than W2. First, losses of N were greater from clear-cutting of W2, even though vegetation was removed from W4 and not from W2 (Table 1). Therefore, the depletion of N capital was greater in W2 than in W4. This disturbance history undoubtedly contributed to stronger retention of N in W2. Second, the timing of increased loss in W2 and W4 (1990) has coincided with a decline 20 years after disturbance in the dominance of pin cherry (*Prunus pensylvanica*), a species in post-disturbance sites which is characterized by high uptake of N (Bormann and Likens, 1979). Finally, the higher losses of N at the HBEF during the most recent years of record were also synchronized with high drainage losses of N from other sites in the northeastern US (Mitchell et al., in prep.). These results suggest that land-use history, year-to-year variability and climatic patterns may be important factors in assessments of N saturation, determination of critical atmospheric loads, and acidification of landscapes.

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