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## Chapter 5: Acid Deposition

### *Question 5: To what extent are resources in the Highlands being affected by acid deposition?*

Sulfur dioxide ( $\text{SO}_2$ ) and nitrogen oxides ( $\text{NO}_x$ ) present in the atmosphere can react with water, oxygen, and oxidants (such as ozone) to form mild solutions of sulfuric acid and nitric acid (U.S. EPA 1998a). These acidic solutions are often found in rainwater, snow, fog, and other forms of precipitation. When precipitation containing these acidic compounds falls to the earth, the acidic compounds are deposited on the earth's surface (acid deposition or wet deposition), and the precipitation carrying the acidic compounds is referred to as "acid rain." Scientists have discovered that air pollution from the burning of fossil fuels is the major cause of acid rain. Acidic compounds in the atmosphere and the deposition of acidic compounds on the earth's surface can disrupt forest and aquatic ecosystem functions, impair visibility, and create human health problems.

Chapter 1 provides a regional perspective on sources and amounts of nitrogen (fig. 1.6) and sulfur compounds (fig. 1.12) emitted into the atmosphere. It is worth restating that 28 percent of nitrogen oxide ( $\text{NO}_x$ ) emissions in the Assessment area and nearby are from industrial fuel combustion sources, 22 percent are from vehicles (internal combustion engines), and 20 percent are from electric utilities (fig. 1.5). As figure 1.11 shows, sulfur dioxide ( $\text{SO}_2$ ) is primarily produced from electric power generation (72 percent), with all other industry sources producing 15 percent (U.S. EPA 1996).

Since the mid- to late 1970's, emissions of  $\text{SO}_2$  and  $\text{NO}_x$  have decreased and leveled off, respectively, in contrast to the upward trends in emissions of these gases experienced from the early 1950's to the mid-1970's (fig. 1.17). Vehicle miles traveled have doubled since 1970, but

exhaust emissions have only slightly increased (U.S. EPA 1996) because of better fuel economy and more efficient engines. Since 1996, this same strategy has been applied to selected nonroad categories (e.g., small engines such as lawn mowers and outboard motors). The Environmental Protection Agency (EPA) (1996) expects significant emission reductions after the year 2000. Sulfur emissions have also been reduced per unit of production. From 1970 to 1995,  $\text{SO}_2$  emissions from electric utilities decreased about 31 percent (U.S. EPA 1996). Implementation of the Clean Air Act amendments of 1990 should reduce  $\text{SO}_2$  emissions by 10 million tons and  $\text{NO}_x$  by 2 million tons by the year 2000 (U.S. EPA 1996).

The impact of acid deposition on forest and aquatic ecosystems has been the subject of much research and debate. The 1980 to 1990 National Acid Precipitation Assessment Program (NAPAP) provided indepth research on these impacts (see Baker and others 1991). As NAPAP and others have reported, the potential harmful effects of acidic deposition include: (1) leaching of nutrients from plant foliage and the soil by hydrogen, sulfate, or nitrate ions (Lee and Webber 1982); (2) alteration of beneficial micro-organisms in the forest floor and upper soil horizons, including damage to symbiotic nitrogen-fixing organisms (Francis 1982); (3) acid-induced mobility and toxicity of aluminum in the soil solution leading to toxic levels of aluminum in streamflow and water bodies (Steiner and others 1980; Ulrich and others 1980; Johnson and others 1981); (4) increased susceptibility of trees and plants to environmental stresses, including drought (Johnson and others 1981; Lee and Webber 1982); (5) delayed frost hardiness leading to vegetation damage (DeHayes 1992); and (6) acidification of aquatic ecosystems (Herlihy and others 1996). Impacts may thus affect entire ecosystems including vegetation, soil, and the receiving watercourse.

## Key Findings

1. Atmospheric wet acid loadings are less than the loadings observed in the Southern Appalachian region. Nitrate and sulfate loadings are expected to decrease in the future based on expected decreases in emissions of sulfur dioxide and nitrogen oxides (see Chapter 1).
2. Most surface waters within the Assessment area do not appear to be adversely impacted by the previous and present rate of acid deposition.
3. The low acid neutralizing capacity headwater areas of the Ouachita Mountains make them most at risk while the limestone areas of the Ozark Plateau are least at risk.

## Data Sources and Methods of Analysis

Because nitrate and sulfate depositions over a region are related to precipitation patterns, it was necessary to assess the spatial variations in precipitation over the Assessment area at a sufficient resolution to account for major elevation changes. The deposition model of Lynch and others (1997), used in this Assessment for generating nitrate and sulfate deposition maps, incorporates precipitation patterns that account for the changes in topographic variations observed in the Assessment area. The coordinates, elevations, and monthly precipitation records from the National Oceanic and Atmospheric Administration's (NOAA) precipitation monitoring sites in the States within and adjacent to the Assessment area constitute the precipitation-volume data set used to develop the deposition model. Lynch and others (1997) obtained precipitation concentration data for sulfates and nitrates from weekly rainfall samples collected at monitoring sites within and adjacent to the Assessment area.

The deposition model uses a statistical method that includes: (1) the precipitation observed at monitoring sites, (2) elevation, and (3) a set of variables representing both slope and aspect. The derived regression equations from each 0.1-degree block are then applied to corresponding digital elevation data to produce a grid of precipitation estimates. The current model compares the predicted and observed quarterly and annual precipitation volumes at approximately 1,500 validation sites scattered over the

Assessment area. The average annual estimation error is consistently near 3.0 inches (in.) for each year from 1991 through 1993 (Lynch and others 1997).

The NOAA data set comprises the only precipitation values that cover the Assessment area at a site density sufficient for deposition modeling. A major limitation on the accuracy of the model's precipitation calculations is the imprecise coordinates of the NOAA precipitation sites. NOAA coordinates for the location of a rain gauge are reported at a resolution no finer than 1 minute of a degree of latitude or longitude. This level of uncertainty impedes the modeling of localized—but important—geographic influences on precipitation. The modifications that Lynch and others (1997) made to the model overcame the imprecision of the coordinates and estimated more precise coordinates of each NOAA precipitation monitoring station.

Because precipitation varies year to year, the amount of deposition also varies. Deposition rates, therefore, are modeled values, not measured values; they should be considered relative rather than absolute values and used with caution. Actual values determined at the site of concern will be needed to document any influence on the local ecosystem.

## Patterns and Trends

Figures 5.1 and 5.2 indicate that the southwestern part of the Assessment area has the highest sulfate and nitrate deposition. Figure 5.2 shows that sulfate deposition exceeds 20 pounds per acre (lbs/ac) in the high elevation and high precipitation areas of the southwest portion of the Ouachita range. An EPA finding suggests this pattern could be a result of sulfur dioxide emissions from coal-burning industries in Louisiana and Texas (OK WRB 1990). The other area receiving high sulfates but not high nitrate deposition is the northeastern portion of the Assessment area, including the Potosi-Fredericktown District and the eastern half of the Salem District of the Mark Twain National Forest.

Figure 5.3 shows the average modeled sulfate and nitrate deposition within the Assessment area from 1983 to 1995. Compared to the Southern Appalachians, the annual sulfate deposition in the Ozark-Ouachita Highlands is moderate—15 lbs/ac in the Highlands compared to 20 to 25 lbs/ac for the Southern Appalachians. The

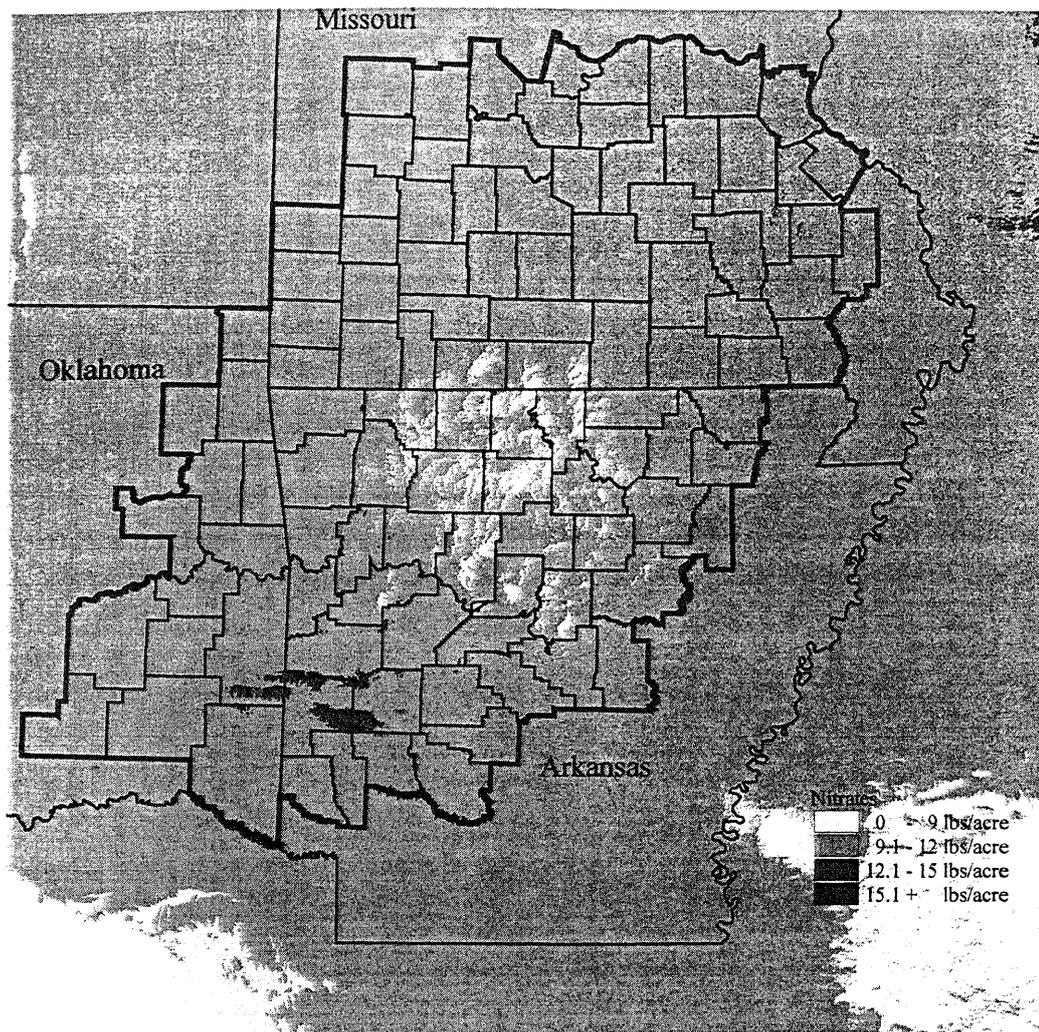


Figure 5.1—The period average for nitrate deposition (lbs/ac) in the Assessment area from 1983 through 1995 (Lynch and others 1997).

average annual nitrate deposition in the Assessment area is 10 lbs/ac compared to 15 to 20 lbs/ac in the Southern Appalachians (SAMAB 1996).

During the NAPAP era (1980 to 1990), there was an effort to look for evidence that acidic deposition was affecting surface waters within the Assessment area. Between 1984 and 1986, the EPA conducted one of the largest limnological reconnaissance projects ever undertaken—the National Surface Water Survey (NSWS)—the results of which are available from the EPA. The NAPAP and NSWS used the acid neutralizing capacity (ANC) to rate streams and lakes. This survey found that a relatively high percentage of streams with ANC equal to or greater than 200 existed in the interior Southeast region, which includes the Assessment area, while no lakes or streams in this region had ANC values less than

or equal to zero (Baker and others 1991). However, this same report indicated that the Ozark-Ouachita area had 19 percent of the streams with ANC greater than zero and less than or equal to 50 (Baker and others 1991). These poorly buffered systems can be considered at risk for acidification.

Within the Assessment area, the headwater sections of the Ouachita Mountains in Arkansas contain very little limestone bedrock, while the Ozark Plateau area in Missouri contains large areas of limestone and karst topography (irregular limestone with sinks, underground streams, and caverns). These geological differences suggest that the Ouachita Mountain headwaters are likely to be more at risk for acidification than streams in the Ozark Plateau.

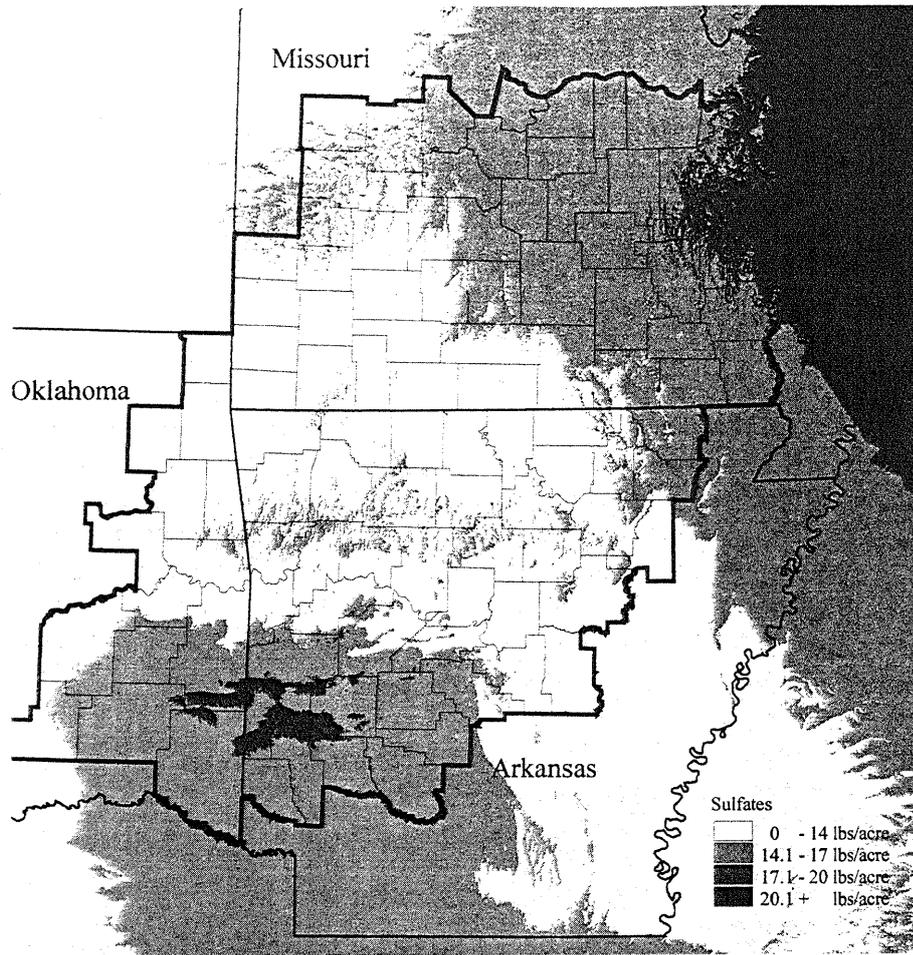


Figure 5.2—The period average for sulfate deposition (lbs/ac) in the Assessment area from 1983 through 1995 (Lynch and others 1997).

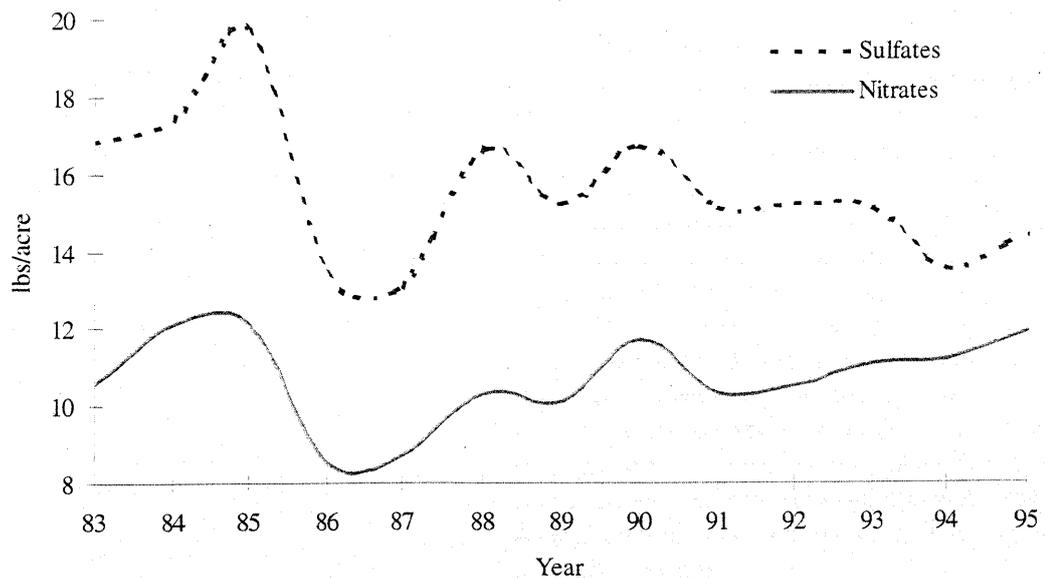


Figure 5.3—Variation in modeled mean sulfate and nitrate deposition within the Assessment area from 1983 through 1995 (Lynch and others 1997).

Another test of acidification is the amount of nitrates and sulfates moving through a system. The consensus of NAPAP is that the streams in the Ozark-Ouachita Highlands are at equilibrium for sulfates and that 99 percent of the nitrates are being retained. Sulfate enrichment is occurring in some waters in the Ozark-Ouachita Highlands (Baker and others 1991).

Nix and Thornton (1987) confirmed the overall NAPAP and NSWS assessment that the higher elevation streams in the Ouachitas are vulnerable to acid deposition. Their major findings were that: (1) during storm events, ionic aluminum is released into surface waters; (2) 90 percent of nitrogen is being retained; (3) sulfates are near equilibrium; and (4) base cations are being exported at twice the rate of precipitation input. They concluded that headwater streams that have low ANC are potentially at risk with respect to acidic deposition.

Precipitation patterns strongly influence acid deposition. As explained in the "Data Sources and Methods" section of this chapter, elevation changes can impact precipitation amounts. The Ouachita Mountains in the southwestern part of the Assessment area can produce orographic lifting (the lifting of air when it flows over higher elevation terrain) of moist air moving northward from the Gulf of Mexico across the Gulf Coastal Plain. The Atmospheric Team expects this area will receive the greatest amount of deposition. Kress and others (1988) found that an average 400-foot increase in elevation from the Gulf Coastal Plain to the Ouachita Mountains in southeastern Oklahoma resulted in a 12-percent increase in average annual precipitation (60.2 to 67.6 in. in 1984 to 1985). They also found the average pH decreased with increased elevation of the station (4.67 at the Coastal Plain to 4.53 at the Ouachita Mountains). Total nitrate deposition increased from 3.2 to 3.5 lbs/ac, and total sulfate deposition increased from 28.3 to 32.7 lbs/ac as elevation increased.

## Implications and Opportunities

Acid deposition can pose a threat to forest and aquatic ecosystems—especially on poorly buffered, higher elevation watersheds. Acid deposition patterns in the Assessment area as a result of sulfate and nitrate in the atmosphere are affected by the emissions of  $\text{SO}_2$  and  $\text{NO}_x$  and the patterns of precipitation over the region. As noted in Chapter 1, emissions of  $\text{SO}_2$  from electrical utilities in the Assessment area are expected to decrease as the Clean Air Act Amendments of 1990 are fully implemented. Furthermore, the emissions of nitrogen oxides from fuel combustion at industrial sources in the Assessment area will likely be reduced in response to current efforts by the EPA. Future reductions in the emissions of sulfur dioxide and nitrogen oxides should lead to reduced atmospheric sulfate and nitrate concentrations, thereby reducing the potential for acid deposition episodes. However, future changes in precipitation patterns as a result of changes in regional climate and climate variability may also impact the amount of acid deposition over the Assessment area.

A comprehensive assessment of how acid deposition patterns might change over the Assessment area as a result of changing emissions of  $\text{SO}_2$  and  $\text{NO}_x$  and a changing climate (including precipitation patterns) will require the use of coupled, high-resolution atmospheric mesoscale and chemistry models that can generate plausible scenarios of acid deposition, e.g., the U.S. EPA (1998b) Regional Acid Deposition Model. The development of these future scenarios of acid deposition must take into account the complex atmospheric dynamics associated with the emission, transport, and diffusion of the chemical species involved in the formation of acid rain; the dynamics of cloud formation and precipitation occurrence over the region; surface-atmosphere interactions that influence the hydrologic cycle in the region; and the overriding chemical reactions that lead to the formation of sulfuric and nitric acid in the atmosphere. The acid deposition scenarios generated by coupled atmospheric mesoscale and chemistry models can provide vital information to natural resource managers as they develop management strategies for specific watersheds in the Assessment area known to be sensitive to potential acid deposition events.

# **Ozark-Ouachita Highlands Assessment:**

## **Air Quality**

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U.S. Department of Agriculture  
Forest Service  
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North Central Research Station  
U.S. Department of Agriculture  
Forest Service  
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Southern Region  
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This publication provides information about the atmospheric conditions in and near the national forests in the Ozark-Ouachita Highlands: the Mark Twain in Missouri, the Ouachita in Arkansas and Oklahoma, and the Ozark-St. Francis National Forests in Arkansas. This report includes information about particulate matter, visibility, ozone concentrations, and acid deposition in the Ozark-Ouachita Highlands Assessment area.

**Keywords:** Acid deposition, Clean Air Act, ozone, particulate matter, pollution, visibility.