The Effects of Acidic Deposition in the Southern Appalachian Mountains

United States Department of Agriculture

Forest Service Air Program

Contact: Claire O'Dea

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What is Acidic Deposition?

Fossil fuel burning emits air pollution in the form of sulfur dioxide (SO_2) and nitrogen oxides (NO_x), while agricultural activities are the primary source of ammonia released to the atmosphere. These emissions lead to the acidic deposition of sulfuric acids, nitric acids, and ammonium to ecosystems. In sensitive ecosystems, these acid compounds can acidify soil and surface waters, affecting nutrient cycling and impacting the ecosystem services provided by forests.

Acidic deposition occurs as wet deposition (rain and snow), dry deposition (gases and particles), and cloud and fog deposition. Wet deposition forms when NO_x and SO_2 are converted to nitric acid (HNO_3) and sulfuric acid (H_2SO_4), or when ammonia is converted into ammonium. Dry deposition can be converted into acids when deposited chemicals meet water (Figure 1).

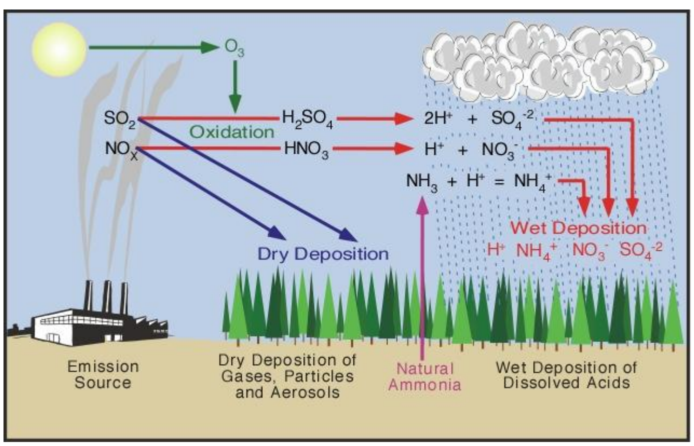

Figure 1: Nitrogen oxides and sulfur dioxide released into the atmosphere fall to the ground as acid deposition.[1]

Acidic Deposition Impacts to Nutrient Cycling

Soils maintain baseline concentrations of essential nutrients including calcium (Ca^{2+}), magnesium (Mg^{2+}), and potassium (K^+). These base cations originate from bedrock weathering and the deposition of windblown dust. Soils in the southern Appalachian Mountains can be inherently low in base cations due to the slow breakdown of parent rock material[2]. Base cations are withdrawn from the soil and used for vegetation growth; they are later returned to the soil during the decomposition of falling leaves and woody material.

In the southern Appalachians, sulfuric acid has the largest effect on nutrient cycling, since nitric acid and ammonium byproducts are used by forest vegetation to support growth. As sulfuric acid is deposited from the atmosphere into the soil, each molecule separates into two hydrogen ions (H^+) and a negatively charged sulfate molecule. In order to maintain an ionic balance, an equivalent amount of positively charged base cations adhere to the negatively charged sulfates and move into the soil water solution, acidifying the remaining soil and fundamentally altering soil processes. In addition, aluminum begins to dissolve from previously insoluble minerals and Al^{3+} enters the soil water solution when the soil pH falls below 4.5.

Once in soil water solution the H^+, Al^{3+}, and base cations travel until they reach a surface water body. This can result in acidification of streams and lakes. Surface waters surrounded by limestone-rich soil and bedrock can buffer the acidity in the soil solution, minimizing surface water acidification (with its increasing Al^{3+} content) (Figure 2).

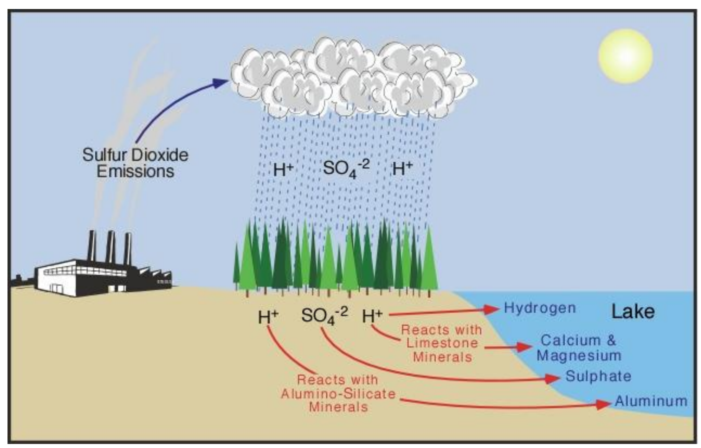

Figure 2: Surface water acidification begins with acid deposition to adjacent terrestrial areas.[1]

Certain ecosystems are more susceptible to the effects of acid deposition; parent material geology, elevation, and forest overstory can all be used to identify potentially sensitive ecosystems. Soils developed from sandstone rocks are inherently low in base cations, leaving these areas vulnerable to acidic deposition. High elevation areas (above 2500 feet) are vulnerable due to increased acidic cloud deposition and decreased soil depth to buffer acid inputs. Finally, the breakdown of needles naturally acidifies forest soils, increasing the vulnerability of conifer forests. These characteristics have been used by USDA Forest Service staff to identify areas vulnerable to the effects of acidic deposition.

Acid Deposition Impacts to Soil Health

When base cations are removed from the soil by acidic deposition at a rate faster than they can be replenished by slow mineral weathering or deposition from windblown dust, this results in the reduced availability of Ca^{2+}, Mg^{2+}, and K^{+} in the soils of acid-sensitive forest ecosystems. This reduced availability hinders the capacity for sensitive soils to recover from acidic deposition and compromises the health and continued growth of the plants dependent on these nutrients.

Soil base saturation is highly correlated with base cation availability, and can therefore be used to identify sensitive terrestrial ecosystems (ecosystems likely to experience the effects of acid deposition). Base cation availability is generally not limited when soil base saturation is above 20%, and availability is severely limited and forest mortality effects are likely when soil base saturation is below 5%. In between these saturation rates, base cation availability is limited and forest growth reductions and mortality risks from various stressors increase[3].

Acid deposition can also lead to an increase in H^{+} ions in the soil, resulting in decreased soil pH and increased mobilization of aluminum in soils, affecting the soil water solution. Because of the strong positive charge, Al^{3+} enters plant roots more easily than other bases, thus displacing other nutrients during uptake, resulting in a nutrient deficiency. This deficiency is compounded by the toxic effect of Al^{3+} on fine roots, further reducing the potential uptake of nutrients and water by plants.

The accumulation of sulfur in the soil can also be detrimental. Soils in the southeast are known to retain sulfates; these sulfates can result in continued stream acidification, even after deposition has been reduced. Recovery of streams has been slow and will not be complete until the sulfur that has accumulated in the soil has been released[3].

Acid Deposition Impacts to Stream Health

Stream acidification is accompanied by decreasing pH levels (increased H^{+} ions), increasing aluminum concentrations, and decreasing acid-neutralizing capacity (ANC). ANC is a measure of a water body's ability to neutralize acidic inputs. ANC is calculated as the difference in concentrations (μeq/L) between the sum of the base cations (Ca, Mg, Na, K) and the sum of the acid anions (SO_4, NO_3, and Cl). A reduction in stream ANC further reduces the stream's ability to buffer against additional acids entering the system. Decreases in pH and increases in Al^{3+} result in reduced diversity and abundance of aquatic species (fish, plankton, and invertebrates). High acidity and Al^{3+} disrupt the salt and water balance in fish blood, rupturing red blood cells and increasing blood viscosity, resulting in heart attack and suffocation.

ANC is highly correlated with pH, and is the most commonly used indicator of stream health for the protection of streams from acidification. The protection of aquatic biota is generally based on maintaining surface water ANC at an acceptable level (0, 20, 50, or 100 μeq/L in various European and North American applications)[4, 5]. Fish species and aquatic macroinvertebrate community diversity and richness are likely unaffected when average ANC is > 100 μeq/L, while lethal effects on brook trout populations and complete extirpation of fish populations and macroinvertebrate communities are expected when average ANC is < 0 μeq/L. In between these ANC levels, macroinvertebrate communities begin to decline, followed by fish species richness reductions at ANC levels between 50-100 μeq/L, and eventually lethal and sub-lethal effects on brook trout populations and marked declines in aquatic insect families begin at ANC levels between 0-50 μeq/L[4]. Numerous water samples have been collected in the southern Appalachians (Figure 3), and the greatest number of chronically acidic streams (ANC <0) are found in George Washington and Jefferson National Forests.

Restoration and Recovery

Restoring acidified soils and surface waters requires further reductions in acid loading, especially from sulfur dioxide emissions. In some areas reductions in acidic deposition will reduce the rate of base cation leaching enough that weathering of the parent bedrock will be sufficient to allow ecosystem recovery and improvement in forest-provided ecosystem services. There are areas in the southern Appalachians where the damage is so severe that acidic deposition reductions alone will not be sufficient for ecosystem recovery[6]. Soil liming in these severely impacted areas could be considered to replace previously leached base cations[3]. Replacement of the base cations are likely to have long-term (10 or more years) benefits in improving both vegetation and aquatic health.

References

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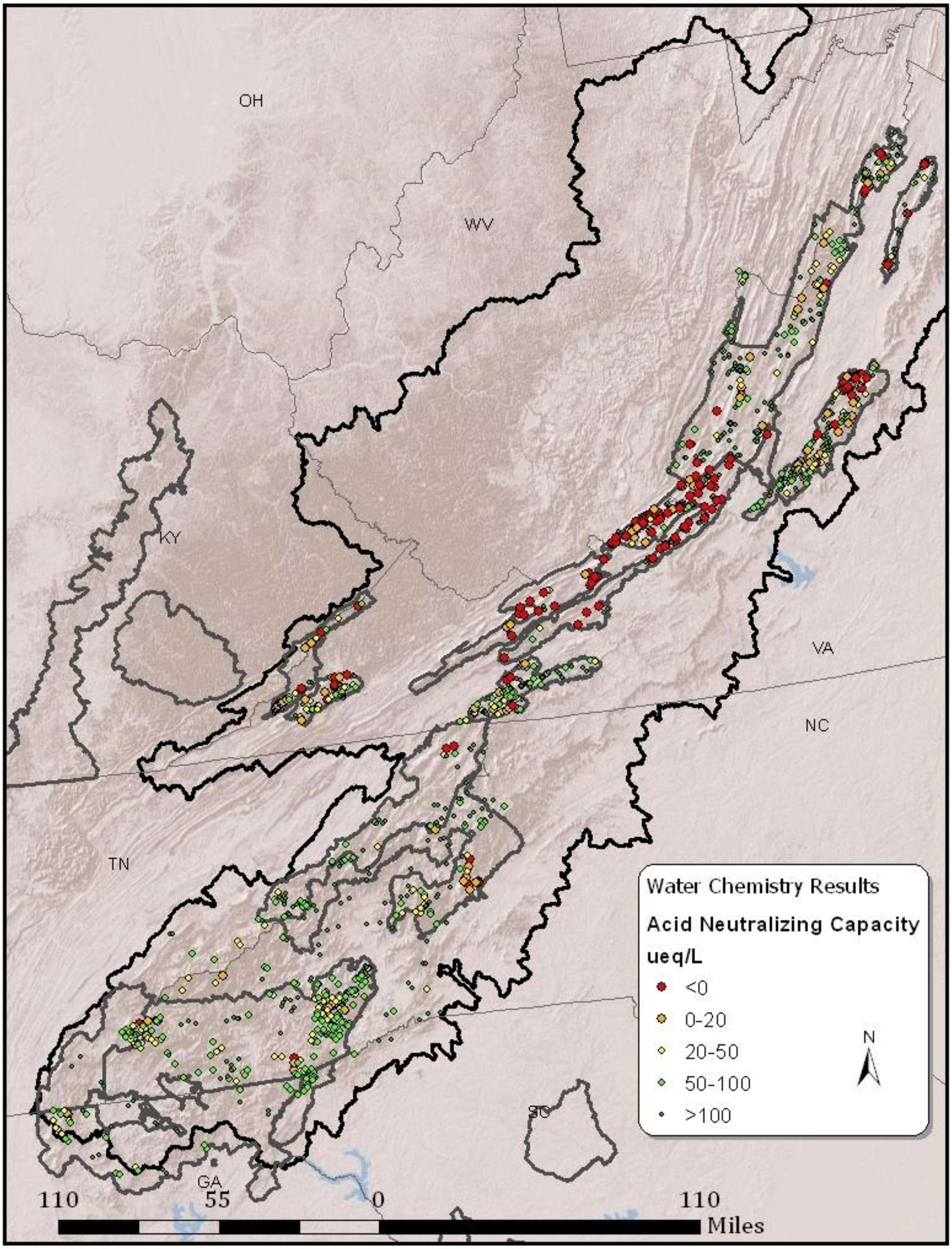

Figure 3: Acid neutralizing capacity stream chemistry results for the Southern Appalachian region.[5]