Acid Rain: Progress and Problems

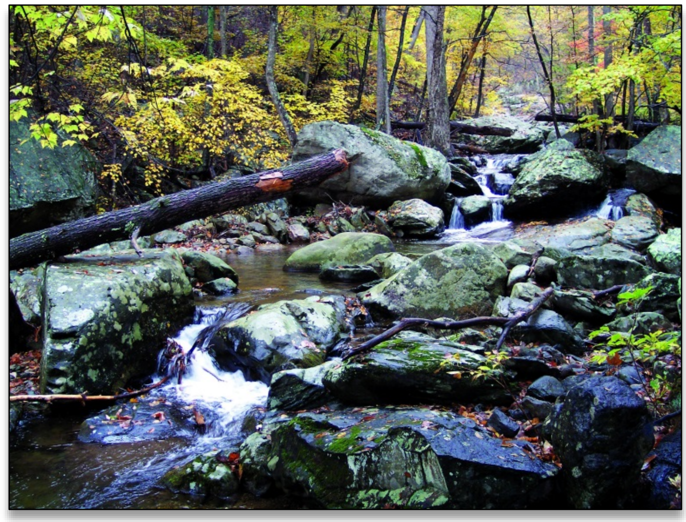
Background

The world renowned vistas of Shenandoah National Park attract visitors from around the country and around the globe. Their days are filled with adventure and wonder as they explore landscapes that have stunning vistas, dancing streams, and among the highest diversity of plants in the country. Brook trout and thirty seven other species of fish call these mountains home, along with the insects and other animals upon which they feed. However, air pollution threatens many of these valuable but vulnerable resources. Damage has already occurred in many aquatic ecosystems within the park due to acidic precipitation, and despite significant reductions in air pollution reaching the park, many areas remain at risk.

The primary threat to park ecosystems from air pollution is the acidification of streams. Acidification occurs when sulfur and nitric oxides produced primarily from fossil fuel burning and especially from coal, react in the air to form acid compounds, and then deposit on sensitive landscapes. The park's location downwind from industrial facilities, along with its position on ridgetops has led to high levels of acid rain over many decades. The short and long-term stresses of acidification were recognized as far back as the 1970's and led the park, in collaboration with scientists from the University of Virginia, to develop an innovative aquatic physical and biota monitoring program. The park now has over three decades worth of data on water quality and aquatic biota, such as brook trout, which can be used to evaluate the conditions and trends of park resources. By compiling these studies into one database, the U. S. Geological Survey (USGS) completed a comprehensive study (Jastram et al., 2013) that is now shedding light on acidification effects to park waterways.

Impacts from Acidification

The USGS study found that acid rain has harmed water quality, aquatic insects (macroinvertebrates) and fish populations within the park by decreasing the pH of the water, which leads to a lower diversity of species and number of individuals within each species. Acidification occurs when the ability of a stream to buffer or neutralize acids is overwhelmed by inputs of acid. In streamwater this is often assessed by measuring its acid neutralizing capacity (ANC) and its pH. ANC is the ability of a stream to neutralize a strong acid; pH is an indicator of how acidic or basic the water is. Streams with a low ANC (from 0-50 microequivalents per liter) are considered to be potentially sensitive to acidification because they are able to neutralize only small amounts of acids. This level of ANC is associated with reduced overall fitness in most fish and loss of biodiversity due to the disappearance of acid-sensitive fish species



Many watersheds in Shenandoah NP are sensitive to acid deposition.

and some common invertebrate species. Buffering is accomplished by base cations such as calcium, magnesium, or potassium, whose positive charge counteracts the negatively charged acid compounds of sulfate and nitrate. Thus, streams with low amounts of base cations have a low ANC and are at higher risk of acidification. When base cation levels get low enough in soils, aluminum, which at certain levels is toxic to plants, aquatic insects and fish, can be released from the soils. The aluminum interferes with the ability of plants to grow roots and the ability of insects and fish to breathe.

Although natural ecosystems are very complex, the health of park waters depends mainly on just three things: the amount and severity of acidic deposition, the type of bedrock, and the age of soils. Shenandoah NP receives both nitrate and sulfate from deposition, however, measurements in the park tell us that sulfate is primarily responsible for acidification of park surface waters. Past deposition of acid rain has acidified some streams in the park and left others relatively unchanged. Reductions in eastern U.S. emissions have been achieved, but deposition to the park is still at levels that impact many park ecosystems. The extent to which ecosystems are affected by current deposition, and their prognosis for recovery, depends on the remaining two factors. The first is geology, which supplies the base cations available for buffering.

Measure of Stream Condition	Basaltic	Granitic	Siliciclastic
Condition: Streamwater Quality (ANC and sulfate)	High	Intermediate	Low
Trend (20-years): Streamwater quality (ANC and sulfate)	Improving	Mixture of Improving and Degrading	Degrading
Condition: Aquatic Macroinvertebrate Metrics	Intermediate	High	Low
Trend (20-years): Aquatic Macroinvertebrate Metrics	Degrading	Degrading	Degrading
Condition: Fish species richness	Intermediate	Intermediate	Low
Trend (14-years): Fish species richness	Improving	Improving	No trend
Condition: Brook trout - Mean abundance of adults (age 1+)	Intermediate	Intermediate	Low
Trend (14-years): Brook trout - Adults (age 1+)	Mixture of Improving and Degrading	Improving	Improving

Streamwater quality was summarized by combining ANC and sulfate concentrations and trends
High/increasing ANC and low/decreasing sulfate indicate high ranking and/or improving trends; low /decreasing ANC and high/increasing sulfate indicate low ranking and/or degrading trends.

Adapted from Rice et al. 2014a

Because the base cations come almost exclusively from rock weathering, the composition of the underlying bedrock exerts a strong control on water chemistry. The park's geology can be simplified into three different bedrock types: granitic in the northern regions of the park, basaltic in the northern and central, and siliciclastic in the southern regions. These three bedrock types differ in the amount of base cations they can supply to a watershed. Basaltic rocks supply a large amount of cations that are able to effectively buffer acid inputs.

Watersheds underlain with granitic bedrock are intermediate in their ability to buffer while watersheds overlying siliciclastic bedrock have the lowest ability to neutralize deposited acids due to the low amount of base cations bound within the rock. Therefore, park streams on siliciclastic bedrock have been impacted more than others, and many types of fish and aquatic insects are negatively impacted in these waters.

The final important factor governing whether acidification will occur is the ability of the soil to hold on to incoming sulfate as it is deposited in precipitation. When sulfate enters the soil it can adsorb to (attach itself to) soil particles. Soils with a low adsorption capacity will have trouble holding on to newly deposited sulfate. It will quickly enter surface waters, possibly causing rapid and serious acidification when deposition levels are high, causing injury or death to fish and insects. Soils with a high sulfate adsorption capacity will hold on to deposited sulfate well, preventing it from entering surface waters all at once. However, these soils can build up high amounts of stored sulfate within the soil profile, and when the capacity of the soils to retain sulfate is reached, chronic or acute acidification can result. The soils of Shenandoah NP are older soils which tend to have higher sulfate adsorption capacity compared to other areas experiencing acid rain.

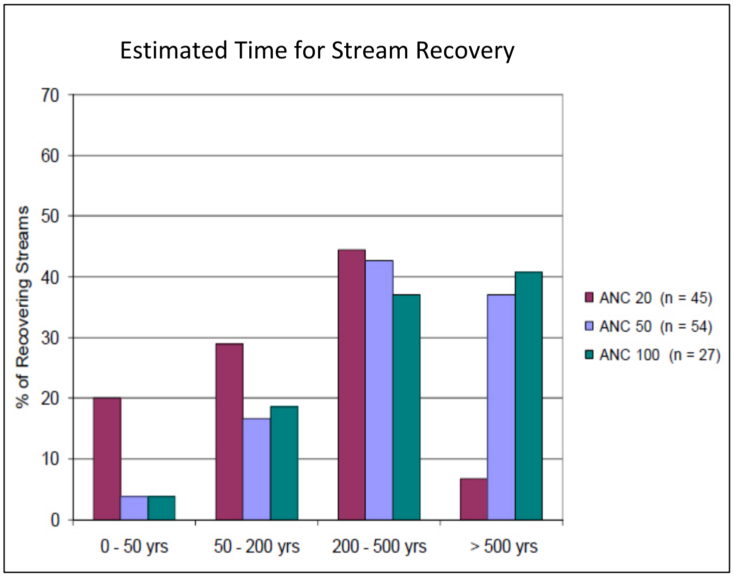
These three factors combine to explain most of the acidification currently experienced in Shenandoah NP. Watersheds underlain by basaltic bedrock have good water quality with improving ANC and sulfate levels, because this rock type supplies abundant base cations for neutralizing acids once acid rain deposition is lowered through emissions reductions. The variety of fish species, as well as brook trout abundance, are at moderately high levels, with species richness improving. The trend for brook trout abundance is both improving and degrading, depending on the site.

Granitic watersheds have a mixture of improving and degrading water quality, but all are of intermediate condition, between the conditions in basaltic and siliciclastic regions. These areas show the highest indicators of macroinvertebrate health in terms of the diversity of species and insect abundance. Fish species richness and brook trout abundance are both at intermediate levels and improving.

As expected, due to the very low supply of base cations, streams that drain siliciclastic watersheds display poor water quality (low pH and ANC and high sulfate levels), which continues to worsen. Macroinvertebrate health, fish species richness and brook trout abundance are all low, though surprisingly, brook trout abundance seems to be improving. Over all of the sites, irrespective of geology, macroinvertebrate health is in decline, even as emissions reductions occur to improve air quality in the area.

Going Forward

The Clean Air Act of 1970 and the Clean Air Act Amendments of 1990 have successfully reduced the amount of airborne sulfate being deposited in the park, though it still remains at elevated levels. While inputs of acid rain to the park have decreased, certain park watersheds still retain a high amount of sulfate due to their relatively good ability to retain it in soils. Models predict that over time this stored sulfur will gradually be released into streams as it is freed from the soil, especially if deposition continues to decline. This will provide surface waters with sulfate in addition to that which is deposited, so it is unlikely that streams with low levels of base cations will see improvement in their buffering ability until this store of sulfate in the soil is reduced. Recently though, net export of sulfur has been observed, indicating that sulfur storage has decreased. If this continues, ANC will stabilize or even increase, allowing streams to neutralize more of the acids, thereby reducing stresses on fish populations and the insects they eat.



Modeled estimates of time for stream recovery based on different ANC (deposition) targets. Sullivan et al., 2010

Brook trout are an iconic park species and have been impacted by acid rain.

Because the main control on whether acidification takes place in sensitive watersheds is the supply of base cations available for buffering, for recovery to occur, the supply of sulfur to streams must be lower than the supply of base cations. In areas underlain by siliciclastic bedrock, the amount of base cations available for neutralization has already been depleted and further acidification is likely even with significant reduction of acid inputs. Because weathering of rocks is a slow process and these rocks are inherently low in base cations to begin with, recovery will take substantially longer. In these siliciclastic regions, models have shown that when pollution levels are reduced to the point where adverse effects start to appear, recovery may still take hundreds of years. However, in basaltic and granitic areas, the abundant quantities of base cations have generally led to stable or improving water quality when acid deposition is reduced. These more naturally resilient regions show that improvements in air quality through reduced emissions can translate into improvements in stream health relatively quickly.

Emissions reductions are an important component to recovery but other stressors are influencing park streams such as vegetation inputs that add acidity and climate change. The uptake of base cations by vegetation for growth or organic matter production and decomposition will naturally acidify surface waters, especially in areas where re-forestation is taking place and vegetation is growing quickly. When this occurs it may partially counteract improvements. In addition, water temperature in many streams throughout the park has been found to be increasing, most likely due to climate change, and this may complicate the recovery of biota such as macroinvertebrates and brook trout that require cool-water environments.

Summary

Research that takes into account all of the complexity described here points to a general trend: streams that are currently degraded will continue to decline in quality, while streams that are more resilient will remain stable or even show signs of improvement. In central and northern areas of the park where watersheds are underlain by rock with abundant base cations, measures and effects of acidification such as water quality, fish species diversity and brook trout abundance are in good or intermediate condition and stable or improving. Watersheds with underlying siliciclastic rock which supply few base cations to neutralize acids continue to degrade. Net export of sulfur and decreased storage of sulfur (required precursors for recovery) have recently been observed, but because the soils of Shenandoah NP tend to be adept at holding on to deposited sulfate, it will take many decades for the already accumulated sulfur to exit the ecosystem.

Despite significant emissions reductions, acidic deposition continues to impact Shenandoah NP. New information gleaned by the USGS report and other research helps park managers to know where impacts to park streams are most pronounced, as well as which streams are more resilient to acid rain. This information will assist park managers to identify which streams will recover more quickly and which are not as naturally resilient but are still headed in the right direction. This will allow them to allocate recovery efforts and resources to watersheds where they will have the biggest payoff and be the most effective.

While some areas of the park will struggle to recover from acidification due to underlying bedrock and soil properties, this research reinforces the benefits of reductions in air pollution. Even in the most resilient regions of the park, recovery would not be possible without decreased acid deposition. Yet observations from the report that sensitive southern regions of the park are continuing to decline is a reminder that further emissions reductions are needed to ensure that all waters of the park recover and thrive.

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