Prepared in cooperation with the National Park Service

Acid Rain in Shenandoah National Park, Virginia

The pH scale is a measure of how acidic (low pH) or alkaline (high pH) a solution is. Rainwater is considered normal at 5.6 pH units. Shenandoah National Park rain typically is 10 times more acidic than normal rain.

Visitors to Shenandoah National Park (SNP) enjoy the animal and plant life and the scenery but may not realize how vulnerable these features are to various threats, such as invasion of exotic plants and insects, improper use of park resources by humans, and air and water pollution. The National Park Service strives to protect natural resources from such threats to ensure that the resources will be available for enjoyment now and in the future. Because SNP has limited influence over the air pollution that envelops the region, acidic deposition—commonly known as acid rain—is one of the more challenging threats facing park managers. With the help of U.S. Geological Survey (USGS) scientists, park managers can understand how acid rain interacts with ground- and surface-water resources, which enables them to explain why reductions in air pollution can help preserve park resources. Such understanding also provides essential insight into ecosystem processes, as managers strive to unravel and resolve other environmental problems that are interrelated to acid rain.

Even though reductions in emissions of acid-forming compounds mandated by the Clean Air Act and Amendments have occurred since 1990, acid rain continues to fall in the eastern United States, including SNP. The combination of acid rain (currently about 4.6 pH units) falling onto an environment that has little inherent ability to neutralize the acidic input and decades of exposure to acid rain have resulted in a fragile environment. When the effects of acid rain are combined with stressors, such as forest defoliation caused by the gypsy moth or coniferous tree demise caused by the hemlock woolly adelgid, significant environmental problems can develop, and park resources become threatened.

Understanding pH and Acid-Neutralizing Capacity

The severity of acid rain and acidic streamwater is measured by the pH scale—a quantitative measure of how acidic (low pH) or alkaline (high pH) a solution is (fig. 1). A neutral solution, which is neither acidic nor alkaline, has a pH of 7 units. The pH scale is logarithmic, which means that each whole-number change indicates a 10-fold change in acidity or alkalinity. For example, a pH of 4 is 10 times more acidic than a pH of 5. Rainwater is considered normal at 5.6 pH units; therefore, rain with a pH of 4.6, which typically occurs in SNP, is about 10 times more acidic than normal rain.

Acid-neutralizing capacity (ANC)—the ability of a solution to neutralize acidic inputs—is a quantitative measure associated with pH (fig. 1). In general, water with a high ANC (for example, 500 units[1]) also has a high pH and is good at neutralizing acidic inputs. In contrast, water with a low ANC (for example, 25 units) has a low pH and is a poor neutralizer. Stream animals and plants (the biota) can be sensitive to and negatively affected by changes in ANC, particularly when it decreases to near zero units, which can cause the biota to suffer "acid shock." Research on fish indicates that many species are sensitive at ANC values less than 50 units.

[1] ANC concentration typically is expressed in microequivalents per liter. "Unit" is used here for simplifying purposes.

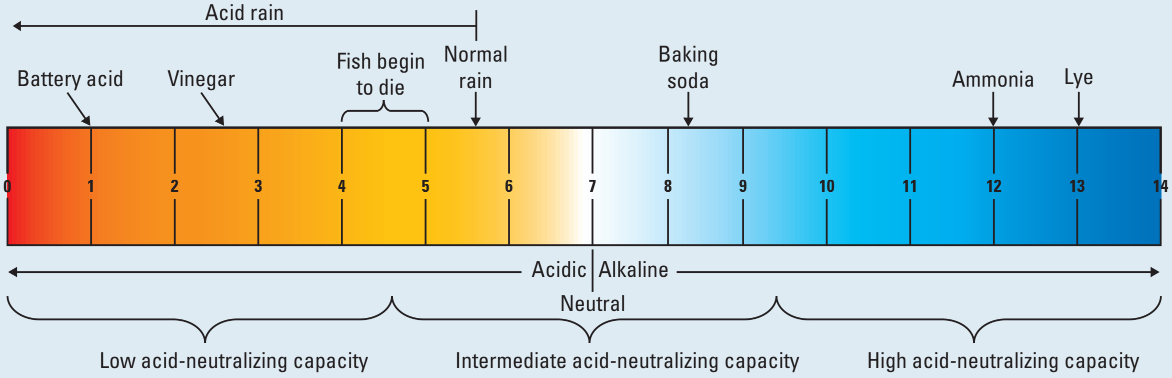

Figure 1. Relations of common solutions and acid-neutralizing capacity to the pH scale.

Shenandoah National Park Streams

Shenandoah National Park streams start near the top of a mountain, usually as a spring or seep on a hillface. As the water flows downhill, the stream increases in size as more tributaries and ground water contribute to the streamflow. Such streams are called “headwater streams.” Because these streams begin with little water, contributions of acid rain can make the streamwater more acidic. During storms, acid rain quickly reaches headwater streams and can decrease the ANC and pH of the stream temporarily. As the pulse of acidic water flows downstream, the streamwater recovers to the pre-storm ANC and pH values.

Although the acidity of rain is spatially uniform across SNP, streamwater ANC and pH values vary substantially across the park. These differences are related to the underlying geology (bedrock type) and topography (steepness of the slope) of the watersheds. The three main bedrock types in SNP are basaltic, granitic, and siliciclastic. Basaltic rocks are the best of the three bedrock types at neutralizing acidic inputs, siliciclastic rocks are poor, and granitic rocks are intermediate. Each of the three bedrock types underlies approximately one-third of SNP.

Shenandoah National Park has 231 headwater streams in which ANC and pH decrease to various degrees, depending on the geology and topography. In general, the steeper the slope, the more quickly acid rain reaches the stream with less chance of being neutralized along the way. Therefore, a small stream near the crest of a mountain, on a steep slope, and underlain by siliciclastic bedrock, is likely to have some of the most acidic water in SNP (fig. 2). Such streamwater does not support a diverse population of aquatic biota. Conversely, a large stream with a gentle slope and underlain by basaltic bedrock will have near-neutral water and, consequently, a diverse population of aquatic biota (fig. 2).

Acid Rain Facts

- Acid rain is caused by combustion of fossil fuels (gas, oil, coal) and to a much lesser extent by natural processes (volcanic emissions, forest fires).
- Combustion emits sulfur dioxide and nitrogen oxides (the two major contributors to acid rain) into the atmosphere; these oxides can travel hundreds of miles from the source of emission.
- Sulfur dioxide and nitrogen oxides convert to sulfuric and nitric acids in the atmosphere; the acids are deposited to the earth by wet deposition (rain, snow, fog) and dry deposition (dry particles, gases), collectively referred to as “acidic deposition.”
- Some of the largest emissions in the United States originate in the Ohio River Valley and are carried downwind through the atmosphere toward Shenandoah National Park.
- The Clean Air Act, designed to reduce emissions, was passed in 1970, amended in 1990, and amended again in 1995.
- In Shenandoah National Park, the annual average pH values of precipitation for the following periods were: 4.53 for 1981–1990; 4.59 for 1991–1995; 4.62 for 1996–2005. These pH values suggest incremental improvements in response to the Clean Air Act amendments.
- Rain tends to be most acidic during the summer; longer periods between storms allow acids to build up in the atmosphere before being “rained out.”
- Individual pH values of rain well below 4.0 have been measured in Shenandoah National Park.

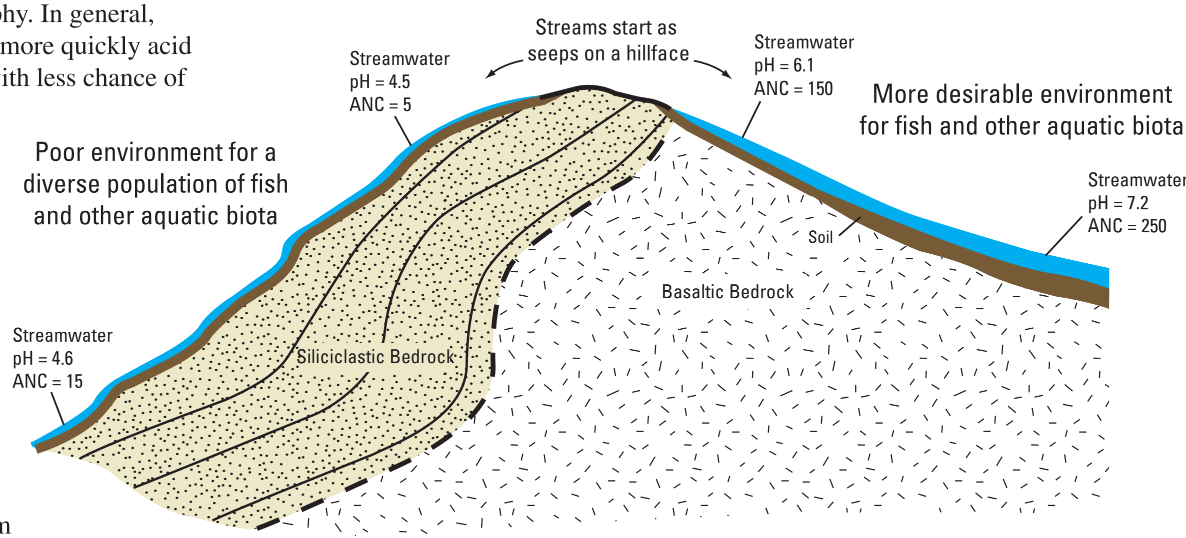

Figure 2. Two stream systems with different characteristics that result in differences in water quality. Whether or not the aquatic biota will be diversified is strongly controlled by the geology and topography.

Shenandoah National Park Facts

- Consists of 308 square miles (nearly 200,000 acres)
- Straddles the crest of the Blue Ridge Mountains
- Stretches from Front Royal in the north to Rockfish Gap in the south, with Skyline Drive traversing the entire length
- Touches eight counties (Albemarle, Augusta, Greene, Madison, Page, Rappahannock, Rockingham, and Warren)
- Has 231 headwater streams
- Contains three main types of bedrock (basaltic, granitic, and siliciclastic)
- Has land-surface elevations that range from about 600 to 4,051 feet

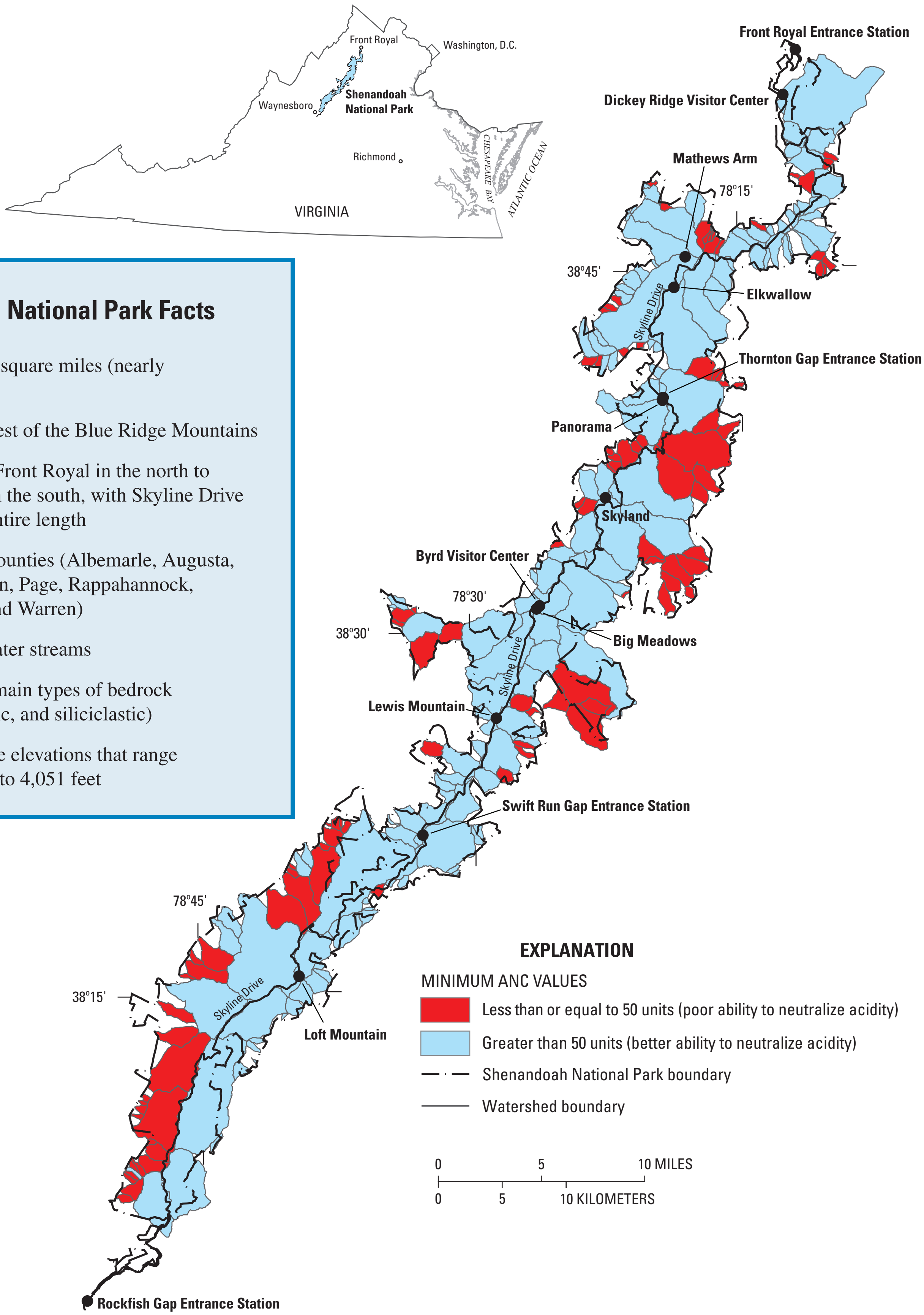

Figure 3. Predictions of Shenandoah National Park watersheds that are likely to have a minimum average acid-neutralizing capacity (ANC) less than or equal to 50 units (red) or greater than 50 units (blue) for 6 consecutive hours about once every 4 years. The watersheds shown in red have the greatest likelihood of losing native aquatic species because of extended periods of low ANC.

Models and Predictions

Scientists studied streamwater data from five SNP streams and developed a specific mathematical model for each of the five watersheds based on mathematical relations among ANC decreases in each stream and the geologic and topographic characteristics of the watershed (Rice and others, 2005). The models for the five watersheds were transferred to the rest of the watersheds on the basis of known geology and topography in each watershed.

The models were designed to predict the **magnitude, frequency,** and **duration** of decreases in ANC in each of the 231 streams. The **magnitude** of a decrease in ANC is important because as water approaches zero units, fewer fish species are able to tolerate the increased acidity. The **frequency** of a decrease in ANC is important because the more often the ANC changes, the less time the aquatic biota has to recover between storm events. For example, during the spring when many fish spawn and other organisms reproduce, fish larvae and young fry are especially sensitive to acid shock. Two back-to-back events causing streamwater to have zero units ANC could destroy an entire population of aquatic organisms. The **duration** of a decrease in ANC is important because aquatic biota may be able to survive acid shock for a short time, but the longer the water remains acidic, fewer organisms will survive.

Predictions of annual minimum ANC values for specific durations that could occur on average once every 4 years for each of the 231 watersheds are summarized on maps of SNP. These predictions were made for 6-hour, 1-, 3-, and 7-day durations. The 6-hour duration map (fig. 3) indicates the watersheds that are predicted to have a minimum average ANC value less than or equal to 50 units (red) or greater than 50 units (blue) for 6 continuous hours during any 4-year period. During the 6 hours, ANC values may increase or decrease, but the average ANC value for the 6 hours will be lower than for any other 6-hour period. Stated another way, the map indicates the watersheds that are predicted to have a 25-percent chance in any single year to have a minimum ANC value less than or equal to 50 units for 6 continuous hours.

These results are of concern because they indicate a high probability for loss of native aquatic species in the park.

One-half of the SNP watersheds are predicted to have ANC values less than or equal to 50 units for 6 continuous hours approximately once every 4 years. This does not mean that the other half of the SNP watersheds will never have these same conditions, but the probability of having them in any given year is predicted to be less than 25 percent.

Fish Health Threatened

Of the 231 SNP watersheds, 52 are predicted to occasionally have 3-day periods when the average ANC value is less than zero units, and 34 of these will have *less than 2 years* between occurrences of this condition. These predictions indicate that within the next 40 to 100 years, these 34 watersheds will have *4 consecutive years* when this condition occurs at least once each year, assuming there is no change in the current (2007) acid rain conditions. The probability for these predictions to be accurate is greater than 90 percent. Several fish species, including native brook trout (the most acid-tolerant species in SNP), have maximum life spans less than 4 years. Less acid-tolerant species, such as rosy-sided dace, are even more vulnerable.

Brook trout in Shenandoah National Park

Karen C. Rice, Frank A. Deviney, Jr., and Gordon Olson

For additional details about the information presented here, refer to

Rice, K.C., Deviney, F.A., Jr., Hornberger, G.M., and Webb, J.R., 2005, Predicting the vulnerability of streams to episodic acidification and potential effects on aquatic biota in Shenandoah National Park, Virginia: U.S. Geological Survey Scientific Investigations Report 2005–5259, 51 p. (online at *http://pubs.water.usgs.gov/sir2005-5259/*).

Mission of USGS: The USGS serves the Nation by providing reliable scientific information to describe and understand the Earth; minimize loss of life and property from natural disasters; manage water, biological, energy, and mineral resources; and enhance and protect our quality of life.

Mission of NPS: The NPS preserves unimpaired the natural and cultural resources and values of the national park system for the enjoyment, education, and inspiration of this and future generations. The Park Service cooperates with partners to extend the benefits of natural and cultural resource conservation and outdoor recreation throughout this country and the world.

For information about Shenandoah National Park, see *http://www.nps.gov/shen/index.htm*

For information about water resources in Virginia, see *http://va.water.usgs.gov* or contact Mark Bennett, Director, U.S. Geological Survey Virginia Water Science Center, 1730 East Parham Rd., Richmond, VA 23228; 804-261-2643 (*dc_va@usgs.gov*).