Synthesis of Thirty Years of Surface Water Quality and Aquatic Biota Data in Shenandoah National Park: Collaboration between the US Geological Survey and the National Park Service

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The eastern United States has been the recipient of acidic atmospheric deposition (hereinafter, "acid rain") for many decades. Deleterious effects of acid rain on natural resources have been well documented for surface water (e.g., Likens et al. 1996; Stoddard et al. 2001), soils (Bailey et al. 2005), forest health (Long et al. 2009), and habitat suitability for stream biota (Baker et al. 1993). Shenandoah National Park (SNP) is located in northern and central Virginia and consists of a long, narrow strip of land straddling the Blue Ridge Mountains (Figure 1). The park's elevated topography and location downwind of the Ohio River valley, where many acidic emissions to the atmosphere are generated (NSTC 2005), have made it a target for acid rain. Characterizing the link between air quality and water quality as related to acid rain, contaminants, soil conditions, and forest health is a high priority for research and monitoring in SNP. The US Geological Survey (USGS) and SNP have had a long history of collaboration on documenting acid rain effects on the park's natural resources, starting in 1985 and continuing to the present (Lynch and Dise 1985; Rice et al. 2001, 2004, 2005, 2007; Deviney et al. 2006, 2012; Jastram et al. 2013).

Acidification is both a chronic and an acute stressor that triggered the need for water quality monitoring and research in the late 1970s. Shenandoah National Park natural resource managers showed abundant foresight by implementing an aquatic biota monitoring program well before the park became a National Park Service prototype inventory and monitoring park in the early 1990s (Davis et al. 1995). As a result of these early and continued monitoring efforts, a combined record of over three decades of data on water quality and biota in SNP cold-water riverine systems exists.

Water resource data-collection efforts in SNP have been conducted by many different groups to satisfy a wide range of objectives. The majority of the data, however, were collected

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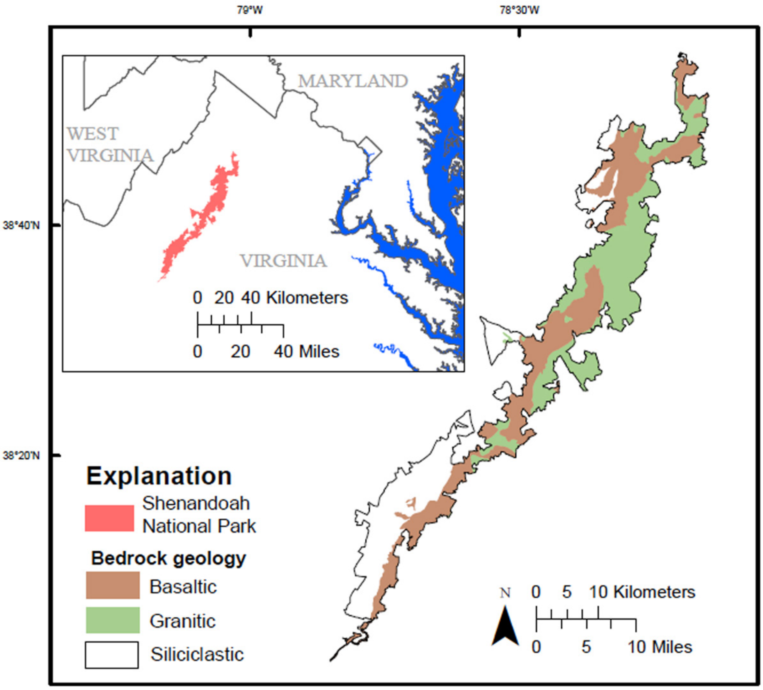

Figure 1. Map showing location of Shenandoah National Park in Virginia and simplified geology of the park.

as part of three efforts: (1) the Shenandoah Watershed Study (SWAS), a partnership led by the University of Virginia (http://people.virginia.edu/~swas/POST/scripts/overview.php), has monitored water quality in SNP since 1979; (2) SNP's Vital Signs Program (Olson et al. 2010), formerly known as the Long Term Ecological Monitoring Program, with independent efforts in fish monitoring (starting in 1982) and macroinvertebrates (starting in 1986); and (3) the Springs and Headwater Streams Study, conducted from 2007 to 2010 (Snyder et al. 2013), which identified the physical, chemical, and biological characteristics of headwater streams and small springs in SNP. Although the objectives of these efforts differed, the common element that unites the three is SNP water resources; therefore, some of the same water quality parameters were collected for each effort. For example, all three efforts measured water temperature, pH, and specific conductance for each sample, in addition to the collection of other data specific to the effort's objectives.

Inconsistent overlap among the three data-collection efforts described above resulted in spatially and temporally disparate data. Combination of disparate datasets containing common characteristics can result in a unified database that often supports broad and powerful data analyses. Starting in 2010, USGS and SNP undertook a study to combine the three datasets into a comprehensive water resources database. The objective of the study was to integrate, analyze, and interpret the data in the three datasets in order to provide SNP natural resource managers with information about current water resource monitoring gaps, trends in conditions, adequacy of the monitoring programs, and relations between aquatic fauna and streamwater chemistry.

The combined database, created in the NPSTORET framework, contains nearly 1.3 million measurements of stream habitat characteristics, approximately 442,000 measurements of water quality characteristics, and over 438,000 measurements of biological taxa, including fish and aquatic macroinvertebrates. The data were collected across 673 sites over a period of more than 30 years. After compilation, the database was used to support evaluations of spatial patterns and temporal trends in the available data, and characterization of those data to better understand interrelations among water quality, aquatic macroinvertebrates, fish, and the landscape. Highlights of the results are reported here, and full results of the study can be found in Jastram et al. (2013).

The geology of SNP is easily simplified into three major bedrock types, which include basaltic, granitic, and siliciclastic (Figure 1). Each bedrock type represents about one-third of the area within the park. Streams with watersheds underlain by these bedrock types differ in their ability to neutralize acidic inputs, as measured by the acid-neutralizing capacity (ANC) of the water. This strong geologic control on streamwater chemistry was noted long ago for the Blue Ridge Mountains of Maryland (Bricker and Rice 1989) and within SNP in particular (Cosby et al. 2006; Deviney et al. 2006; Rice et al. 2007). Because geology serves as a master variable with regard to streamwater chemistry, many of the results of the study can be summarized on the basis of the three bedrock types. Results of the assessment can be reported as both status and trend. Status of a particular metric generally reflects a spatial pattern on the landscape, here defined largely by geology, whereas trend reflects change in a metric over time. The results summarized here (Table 1) on the basis of bedrock type are broad generalizations and many details have been omitted; for such details, the reader is referred to Jastram et al. (2013).

Assessment of the status of the basaltic watersheds, which are the best buffered against acid rain, indicates relatively good measures of water quality as well as healthy communities of macroinvertebrates. These watershed types also have moderately high measures of fish species richness (most fish species found in the park are native) and brook trout abundance. Similarly, the granitic watersheds, which are intermediate between basaltic and siliciclastic in their ability to neutralize acidic inputs, also have relatively good water quality, the highest aquatic macroinvertebrate metrics, and intermediate measures of fish species richness and brook trout abundance. In contrast, the siliciclastic watersheds, which have the lowest ability to buffer against acid rain, have the lowest streamwater quality, the lowest measures of healthy community of aquatic macroinvertebrates, the lowest fish species richness, and relatively low measures of brook trout abundance. It is important to note that these quality designations are relative to comparisons within the park boundary; therefore, a designation of "degraded" for within-park resources may actually reflect "high quality" when compared with streams located outside of SNP.

Trends in ecosystem measures of health across the park were mixed. Air quality within the region generally has been improving since the Clean Air Act, passed in 1970, and the

Measure of stream condition	Basaltic	Granitic	Siliciclastic
Streamwater quality (ANC and sulfate)[1]	High	Intermediate	Low
20-year trend in streamwater quality (ANC and sulfate)[1]	Improving	Mixture of Improving and Degrading	Degrading
AM metrics	Intermediate	High	Low
20-year trend in AM metrics	Degrading	Degrading	Degrading
Fish mean species richness	Intermediate	Intermediate	Low
14-year trend in fish species richness	Improving	Improving	No trend
Mean abundance of adult (age 1+) brook trout	Intermediate	Intermediate	Low
14-year trend in adult (age 1+) brook trout	Mixture of Improving and Degrading	Improving	Improving

[1]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.

Table 1. Summary of status quality ranking and trend results of the ecosystem health assessment by Jastram et al. (2013) on the basis of bedrock type. The 20-year and 14-year trends mentioned in the table both ended in 2009. AM = aquatic macroinvertebrate; ANC = acid-neutralizing capacity.

Clean Air Act Amendments, passed in 1990, went into effect, causing a decrease in acid rain (Burns et al. 2011). As such, one might expect that water quality trends, and associated trends in aquatic ecosystem health, would respond accordingly across the park. Most often, however, an ecosystem's recovery path is not a simple reversal of the degradation path. Basaltic watersheds had improving streamwater quality, with associated improvement in fish species richness as well as improvements in some macroinvertebrate metrics, though the overall pattern indicated degrading conditions in macroinvertebrate communities in these watersheds. Trends in brook trout abundance in basaltic watersheds were mixed and largely site dependent. Streams draining granitic watersheds showed improving or degrading streamwater quality, overall degrading trends in macroinvertebrate health despite stability in some metrics, improvement in fish species richness, and predominantly improving trends in brook trout abundance. The siliciclastic watersheds showed continued degrading trends in streamwater quality, continued declines in already degraded macroinvertebrate communities, stable trends in fish species richness, and surprisingly, improving trends in brook trout abundance. In general, the trend data reflect a pattern whereby the ecological health of streams currently degraded by acid rain are continuing to degrade, whereas streams more resilient to the effects of acid rain are either stable or are showing improvements in water quality and aquatic ecosystem health.

Additional analyses of the combined data indicated that some changes to aquatic ecosystems were occurring parkwide and were independent of underlying geology. For example, an unexpected result of the analysis of the combined data was the finding that temperatures in numerous SNP streams are increasing and seem to be related to increases in air temperature. One stream, White Oak Run, with a 30-year record of temperature data, had a small but statistically significant increase in annual mean, median, and maximum water temperature for the period ending in 2009. Most sites had shorter periods of data collection, but many sites with water temperature data collected for more than 10 years showed increasing trends in annual mean, median, and maximum water temperature values. Many macroinvertebrate metrics that showed changes parkwide (i.e., independent of geology) indicated a parkwide decline in ecosystem condition, and the data suggest that this might be a result of increasing water temperatures. Although brook trout population growth was generally stable parkwide, it is possible that additional increases in water temperature will cause thresholds to be crossed that would negatively affect cold-water fish communities.

SNP is one of a very few national park units that has such an extensive and long-term set of environmental data. These data span over 30 years and cover almost 40% of the park's history. Long-term monitoring programs can be difficult to implement because their value must be recognized up-front and on a recurring basis, even when the data may not appear to be tremendously useful over short time frames. The successful collaboration between USGS and NPS resulted in an unprecedented ability to interpret this wealth of data, answering questions about status and spatial and temporal trends in streamwater quality, aquatic macroinvertebrate assemblages, fish species distributions and richness, and their interactions with environmental factors. In addition, the collaboration resulted in the creation of a master database for aquatic data collected in the park. As the database is kept current with new information, it will facilitate other broad analyses and similar synthesis and trends work in the future. Most notably, the collaboration and resulting analysis highlight the importance of long-term environmental monitoring, particularly in a national park, where natural resources are mandated to remain unimpaired for current and future generations.

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