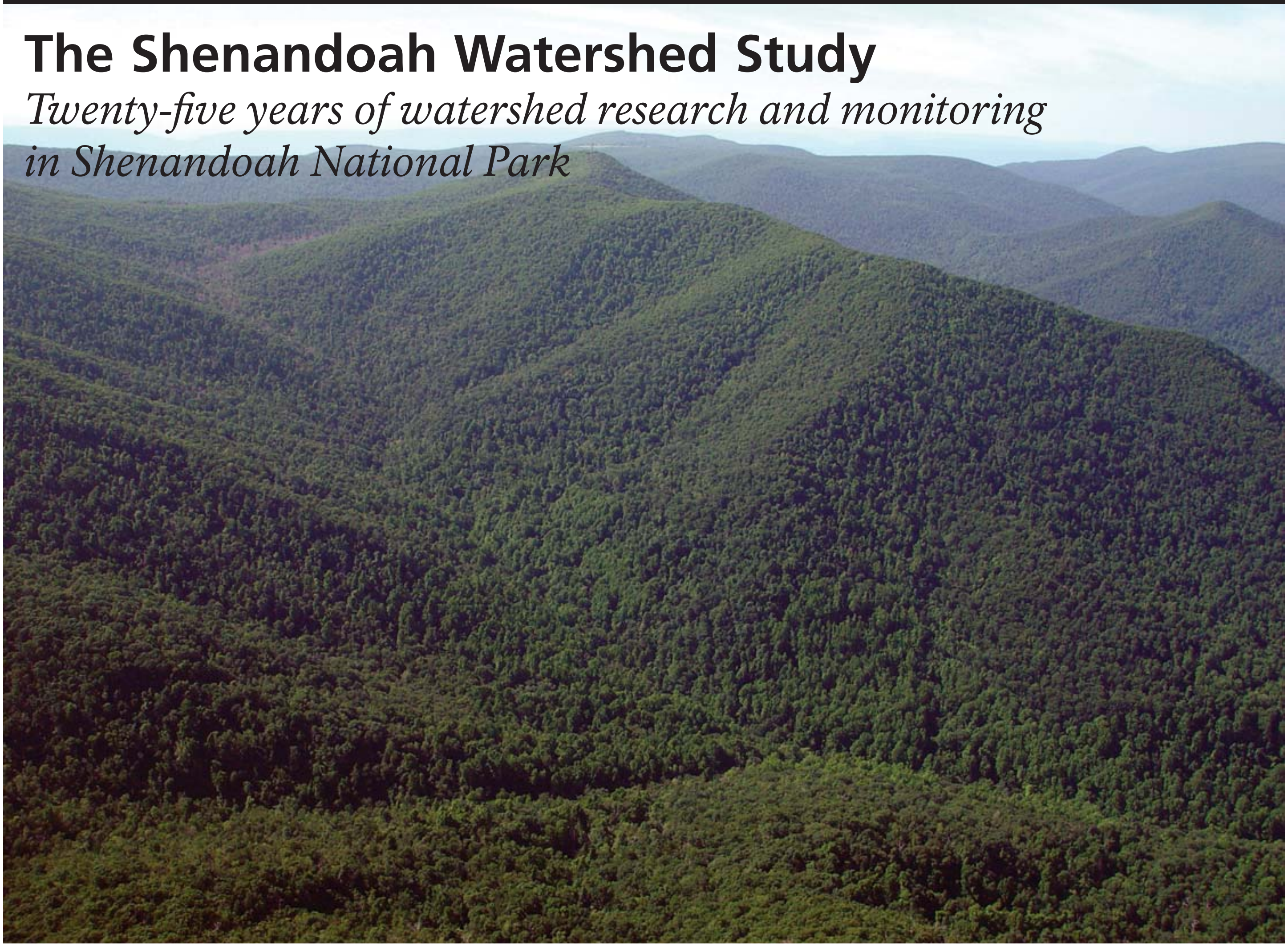
National Park Service
U.S. Department of the Interior

Northeast Region
Shenandoah National Park

The Shenandoah Watershed Study

Twenty-five years of watershed research and monitoring in Shenandoah National Park



The Staunton River watershed is one of the intensively studied watersheds in Shenandoah National Park. The Shenandoah Watershed Study program focuses on small watersheds as the ecological unit for study of biogeochemical status and change in the park and in the surrounding central Appalachian Mountains region.

The Shenandoah Watershed Study (SWAS) program is the longest continuously conducted watershed research and monitoring program in the National Park System. The SWAS program was begun in 1979 as a cooperative undertaking of Shenandoah National Park and the Department of Environmental Sciences at the University of Virginia. The initial focus of SWAS was the harmful effects of acidic deposition from the atmosphere on the park's sensitive streams. Over time the SWAS program has evolved to address additional issues that challenge watershed ecosystems in the park, including the legacy of past land use, the impact of forest defoliation by the gypsy moth, and the depletion of nutrients in watershed soils. However, despite recent reductions in air pollution emissions, the effects of acidic deposition remain a primary concern. In common with other areas in the southern Appalachian region, streams in Shenandoah National Park have shown limited evidence for recovery.

Over the past 25 years the design of the SWAS monitoring program has evolved to reflect increased understanding of biogeochemical processes in Shenandoah National Park watersheds. The current program seeks a balance between efficient use of available funding and effective detection and understanding of change.

The SWAS program has developed a monitoring framework that accounts for variation in basic ecosystem properties among park watersheds
SWAS monitoring is stratified based on differences in the watershed properties that determine biogeochemical conditions and stressor-response relationships. The successful SWAS strategy of distributing hydrochemical monitoring efforts within the context of a lithologic classification scheme has gained acceptance as a model for watershed monitoring in other national parks and forests.

SWAS hydrochemical monitoring captures change that occurs over a range of time scales
Stream water sampling at quarterly, weekly, and hourly frequencies allows identification and understanding of both chronic and episodic change in stream water composition. With continuing long-term data collection, misinterpretation due to transient changes can be avoided.

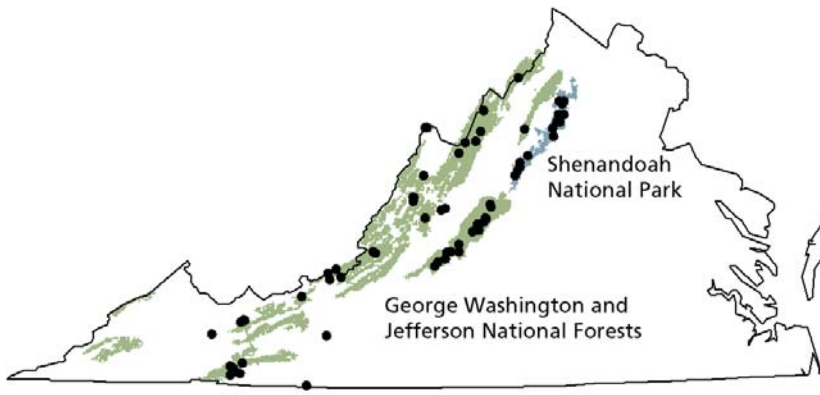
The SWAS program supports other ecosystem monitoring in Shenandoah National Park
Hydrochemical information from the SWAS program provides a framework for the Inventory and Monitoring Program (I&M) in Shenandoah National Park. Water-related I&M work is supported in terms of both monitoring design and data interpretation (e.g., fish and benthic macroinvertebrate monitoring programs).

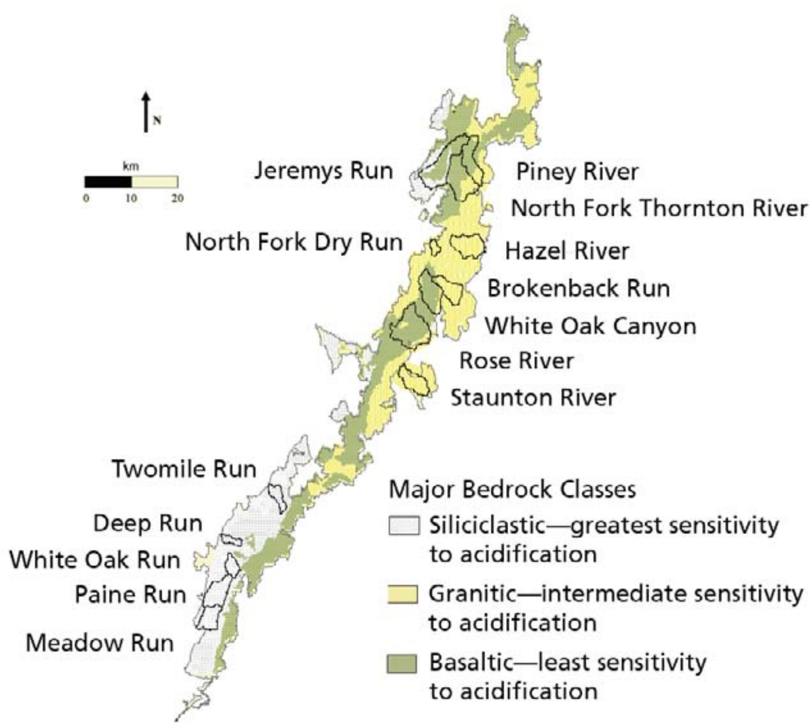
Coordination with regional-scale monitoring improves the reliability of change detection
SWAS data collection within Shenandoah National Park is coordinated with the Virginia Trout Stream Sensitivity Study (VTSSS). The increased statistical power associated with regional-scale analysis has allowed identification of biologically important trends that are obscured on less extensive scales by variation due to lithology, forest disturbance, and other local factors.

Due to the magnitude of ecosystem change that confronts Shenandoah National Park, an understanding of the processes and factors that govern biogeochemical conditions in park watersheds is critical for informed resource management.

(Below) Distribution of SWAS and VTSSS study watersheds in the western Virginia mountains.

(Bottom) Distribution of SWAS study watersheds in Shenandoah National Park in relation to bedrock type and sensitivity to effects of acidic deposition.





Important SWAS findings

Stream water acidification is a continuing problem in western Virginia's forested mountain watersheds
Despite recent decreases in acidic deposition and evidence for recovery in other regions, chronic stream acidification continues on a regional basis in western Virginia.

Regional model forecasts indicate that current air pollution reduction programs will be insufficient to achieve recovery and prevent further stream acidification
Reductions in acidic deposition anticipated from implementation of the Clean Air Act amendments of 1990 will not achieve recovery from stream acidification in the western Virginia region. This projected lack of recovery can be attributed to depletion of calcium and other basic materials in watershed soils.

Stream-water acidification may have stabilized in Shenandoah National Park
Recent trend analysis provides evidence for decreasing acidity levels in park streams, although the degree of recovery is small in relation both to the magnitude of historic acidification and to recovery observed in other regions. It also appears that the observed recovery is not the result of changes in acidic deposition. Instead, the observed decrease in acidity appears to be related to forest defoliation by the gypsy moth.

Sulfur deposition drives the acidification process in Shenandoah National Park watersheds
Western Virginia consistently receives among the highest levels of sulfur deposition in the United States, and atmospherically derived sulfate has become the major dissolved ion in many of the region's mountain streams. Despite this increase, the impact of acidic deposition has been partly delayed by retention of sulfate in watershed soils. The impact will increase as soil retention capacity is exhausted.

Geology accounts for much of the variation in watershed response to acidic deposition
The acid neutralizing capacity of western Virginia mountain streams is closely related to watershed bedrock type. Stream acidification effects are most pronounced for watersheds associated with base-poor sandstone and quartzite (siliciclastic) bedrock, which include one-third to one-half of the watersheds in Virginia that support native brook trout. Stream acidification has not been as severe in watersheds associated with other bedrock types, such as basalt and limestone.

The depletion of base material (e.g., calcium and magnesium) in watershed soils is a long-term effect of acidic deposition and historic land use
The naturally low base supply in soils associated with base-poor bedrock has been further reduced by acidic deposition and past timber harvest. The loss of soil bases, which provide acid neutralization capacity and serve as forest nutrients, is essentially irreversible.

Forest disturbance can alter biogeochemical conditions and modify responses to atmospheric deposition
Dramatic changes in elemental cycling were observed in western Virginia watersheds during and following the episode of forest defoliation caused by the gypsy moth in the late 1980s and early 1990s. The export of nitrogen and base material in streams increased, potentially altering nutrient and base availability in watershed soils.

The integrity of fish communities in regional streams is related to bedrock type and stream water acid neutralizing capacity
Research in Shenandoah National Park has shown that less acidic streams have higher fish species diversity. In addition, less acidic streams have more successful fish reproduction and healthier fish than more acidic streams.

Chronic stream acidification continues on a regional basis in western Virginia.

(Left) Tree mortality because of repeated defoliation by the gypsy moth. Defoliation of study watersheds during the 1990s contributed to a transient pulse in nitrate concentrations, as well as alteration of sulfate and base-cation concentrations.

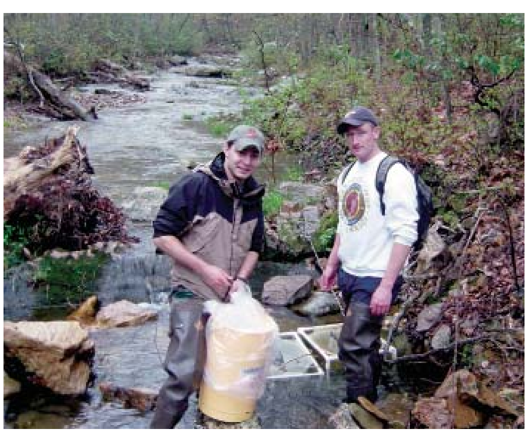
(Below) Most of the SWAS and VTSSS study streams support reproducing populations of native brook trout.

National Park Service
U.S. Department of the Interior

Shenandoah National Park
3655 U.S. Highway 211 East
Luray, VA 22835-9036

A University of Virginia student collects water samples for chemical analysis. Changes in stream-water composition indicate biogeochemical change occurring in the watershed.

Collecting cores from red oak trees for analysis of calcium and other base cations. Depletion of exchangeable base cations in soils is a problem with significant implications for the health of both streams and forests.



University of Virginia students conducting bio-assays on Meadow Run, an acidic stream in Shenandoah National Park, to determine the relative sensitivity of park fish.

Selected publications related to the Shenandoah Watershed Study

Cosby, B. J., P. F. Ryan, J. R. Webb, G. M. Hornberger, and J. N. Galloway. 1991. Mountains of western Virginia. Pages 297–318 in D. F. Charles, editor. Acid deposition and aquatic ecosystems: Regional case studies. Springer-Verlag, New York.

Bulger, A. J., J. R. Webb, and B. J. Cosby. 1998. Current and projected status of coldwater fish communities in the southeastern U.S. in the context of continued acid deposition. Trout Unlimited Coldwater Conservation Fund report, Arlington, Virginia. Available at wsrv.clas.virginia.edu/~swasftp/docs/Current-and-Projected-Status.pdf.

Stoddard, J. L., J. S. Kahl, F. A. Deviney, D. R. DeWalle, C. T. Driscoll, A. T. Herlihy, J. H. Kellogg, P. S. Murdoch, J. R. Webb, and K. E. Webster. 2003. Response of surface water chemistry to the Clean Air Act amendments of 1990. EPA/620/R-03/001. U.S. Environmental Protection Agency, Corvallis, Oregon. Available at www.epa.gov/ord/htm/CAAA-2002-report-2col-rev-4.pdf.

Sullivan, T. J., B. J. Cosby, J. A. Laurence, R. L. Dennis, K. Savig, J. R. Webb, A. J. Bulger, M. Scruggs, C. Gordon, J. Ray, E. H. Lee, W. E. Hogsett, H. Wayne, D. Miller, and J. S. Kern. 2003. Assessment of air quality and related values in Shenandoah National Park. Natural Resources Technical Report NPS/NERCHAL/NRTR-03/090. National Park Service, Philadelphia, Pennsylvania. Available at www.nps.gov/shen/air_quality.htm.

Sullivan, T. J., B. J. Cosby, A.T. Herlihy, J. R. Webb, A. J. Bulger, K. U. Snyder, P. Brewer, E. H. Gilbert, D. Moore. 2004. Regional model projections of future effects of sulfur and nitrogen deposition on streams in the southern Appalachian Mountains. Water Resources Research 40.

Webb, J. R., B. J. Cosby, F. A. Deviney, Jr., J. N. Galloway, S. W. Maben, and A. J. Bulger. 2004. Are brook trout streams in western Virginia and Shenandoah National Park recovering from acidification? Environmental Science and Technology 38.

For more information about the Shenandoah Watershed Study, visit swas.evsc.virginia.edu on the Internet, or contact:

SWAS Program Codirectors
- *Jim Galloway*
  jng@virginia.edu
- *Jack Cosby*
  B.J.Cosby@virginia.edu

or

SWAS Program Projects Coordinator
- *Rick Webb*
  rwebb@virginia.edu