

# Water, Energy, and Biogeochemical Budgets

## A Watershed Research Program

The U.S. Geological Survey (USGS) initiated the Water, Energy, and Biogeochemical Budgets (WEBB) program in 1991 to investigate processes, including the effect of atmospheric and climatic variables, that control water, energy, and biogeochemical fluxes over a range of temporal and spatial scales (Lins, 1994). Five research field sites were selected: Loch Vale Watershed, Luquillo Experimental Forest, Panola Mountain Watershed, Sleepers River Watershed, and Trout Lake Watershed. Site selection was based in part on the existence of long-term data sets on which the WEBB program could build, and in part to be geographically and ecologically diverse and represent a range of hydrologic and climatic conditions.

**W**atershed research provides vital understanding needed to guide decisions related to water resources and environmental quality. The USGS investigates watersheds at several scales that include the largest river-basins in the nation with data gathered through the National Stream Quality Accounting Network (NASQAN), mid-sized watersheds like the Potomac River Basin or Sacramento River Basin in the National Water Quality Assessment Program (NAWQA), and small watersheds like those in the Hydrologic Benchmark Network (HBN) Program, and the Watershed Ecosystem Studies Program and the WEBB Program (see map on last page). Information and results are shared within and between these programs.

In the WEBB Program, long-term field studies are used to explore temporal and spatial scaling issues. They provide a basis for determining decadal-scale trends in water and environmental quality that are related to atmospheric deposition, regional and global climate variations, changes in atmospheric composition, anthropogenic

disturbances, and non-point source pollution. Efforts at the sites include installation of instrumentation and collection of long-term data for key environmental variables and fluxes. The first phase of the WEBB Program focused on understanding processes at the individual watersheds.



The network of lakes in the Trout Lake Watershed, Wisconsin, are interconnected by ground water. Four of the seven lakes in the study area are seepage lakes, with no surface-water inlets or outlets.

The next phase of research will compare and contrast process understanding in these small watersheds and describe processes in larger watersheds so that water, energy, and biogeochemical budgets can be predicted over a wide range of spatial and temporal scales. The three areas that have

been identified for increased research efforts are: (1) to understand the effect of the geologic and physiographic framework, land use, landscape characteristics, and climatic setting of a watershed on the generation of streamflow or fluctuations of lake levels by using appropriate modeling techniques, (2) to increase our understanding of temporal and climatic factors that affect solute input, export, and retention, and (3) to estimate the impacts of land-use change on ero-

sion and water/soil resource degradation by developing sediment budgets and comparing carbon inventories and fluxes. Challenges for the coming decade in small watershed investigations will be to improve understanding of the effect of human influences on natural systems and to provide information for the restoration of damaged watersheds.

### Watershed Sites in the WEBB Program

**Loch Vale Watershed in Colorado** is an alpine/subalpine watershed that is typical of ecosystems in the Rocky Mountains. Lying within Rocky Mountain National Park and administered by the National Park Service, the watershed has been part of the interagency National Acid Precipitation Assessment Program (NAPAP) and is a United Nations Educational, Scientific, and Cultural Organization (UNESCO) designated International Biosphere Reserve.

Water cascades down a tributary of the Mameyes River, Puerto Rico. Runoff in the WEBB watersheds in the Luquillo Mountains averaged from 49 to 82 percent of precipitation inputs during the 1990s.





Loch Vale Watershed in Colorado, is an alpine/subalpine watershed that is typical of ecosystems in the Rocky Mountains. Melting of the snowpack is a major hydrologic event each year.

**Luquillo Experimental Forest in eastern Puerto Rico** is a tropical rainforest. It is administered by the U.S. Forest Service and is supported by the National Science Foundation (NSF) as a Long-Term Ecological Research (LTER) site and is an UNESCO-designated International Biosphere Reserve. WEBB research is also conducted in the nearby Río Grande de Loíza drainage basin, an urban and agriculturally developed watershed.

**Panola Mountain Watershed in Georgia** is a forested watershed previously under cultivation which is located south-east of Atlanta in the Georgia Piedmont. It is in the Georgia Department of Natural Resources Panola Mountain State Conservation Park, and has been part of NAPAP.

**Sleepers River Watershed in north-eastern Vermont** is mostly hardwood forest with the remaining land primarily pasture for dairy farming. Research in the watershed was begun by the Department of Agriculture's Agricultural Research Service in 1959 and now is conducted jointly by the USGS and the U.S. Army Cold Regions Research and Engineering Laboratory (CRREL). The site also has been used as a comparison site to the Hubbard Brook LTER site.

**Trout Lake Watershed in north-central Wisconsin** is in a forested upland area that is characterized by a moderately dense distribution of lakes, which is typical of the low-relief, glaciated terrain occurring over much of the upper Midwest and southern Canada. The watershed is supported by NSF as the North Temperate Lakes LTER, which is operated through the University of Wisconsin's Center for Limnology.

## Major Research Topics

The WEBB watersheds have different physiographic settings, hydrologic pro-

cesses, atmospheric inputs, and weathering reactions. The focus of research in the individual watersheds reflects these differences. Major research efforts include:

### Flowpath Studies

Research efforts focus on identifying and delineating the sources and flowpaths of ground water and surface water and on studying their interactions. TOPMODEL, which is a computer model based on surface topography, has been used to help understand water flow at Sleepers River (Wolock, 1995) and at Panola Mountain where bedrock topography was found to also be important (Freer and others, 1997). The knowledge of how water moves through the system provides a framework for investigating the biological and geochemical influences on water chemistry. In the Trout Lake watershed, for example, deuterium, oxygen-18, and strontium isotopes have been used to differentiate ground water recharged by lake seepage from ground



At Sleepers River, Vermont, nearly half of the annual streamflow occurs in the six weeks of spring snowmelt.

water that has been recharged by precipitation that infiltrates the inter-lake uplands (Bullen and others, 1996). It also was determined that dissolved organic carbon, carbon dioxide, and methane are generated as ground water flows through the hyporheic zone and discharges into a stream in the watershed (Schindler and Krabbenhoft, 1998).

### Climatic Gradients

The five WEBB sites represent watersheds along a continuum of annual precipitation and temperature—from Luquillo in the tropics, where conditions are warm and wet, to the alpine Loch Vale site in Colorado. The variety of conditions (tropical, subtropical, temperate, subalpine, alpine) provide a gradient in which to study and contrast processes, such as weathering and sediment transport, within and across watersheds. For example, three independently collected sets of data from the Luquillo watershed in Puerto Rico indicate that possible changes in precipitation, temperature, and vegetation during the past several hundred thousand years have not significantly impacted the weathering rates of silicate rocks. Furthermore, the rate was found to be an order of magnitude faster than the global average (White and others, 1998).

### Mass Budgets

A mass balance approach is being used to characterize and understand the processes that control the distribution and transport of sediment and solutes in and through the watersheds. This approach is helping scientists and managers understand landscape-scale processing of (1) solutes from weathering, (2) pollutants that are components of atmospheric deposition, and (3) sediment from erosion and landscape disturbance. Measurements of inorganic nitrogen fluxes made at Loch Vale, Colorado, for example, showed that the annual export of nitrogen from the watershed is not directly related to atmospheric deposition and suggests that biogeochemical cycling controls the release of nitrogen even in areas where soil and vegetation are sparse (Campbell and others, 2000).

### Environmental Change

Research investigations have been used to reconstruct background environmental



The Panola Mountain Watershed in Georgia is 93 percent forested. The remaining 7 percent is rock outcrop, as shown here, covered with lichen and moss with islands of shrubs and trees.

Individual fact sheets describe in detail the research being done in each watershed:

- Walker, J.F., and Bullen, T.D., 2000, Trout Lake, Wisconsin—A Water, Energy, and Biogeochemical Budgets Program Site: U.S. Geological Survey Fact Sheet-161-99.
- Peters, N.E., Hooper, R.P., Huntington, T.G., and Aulenbach, B.T., 2000, Panola Mountain, Georgia—A Water, Energy, and Biogeochemical Budgets Program Site: U.S. Geological Survey Fact Sheet-162-99.
- Larsen, M.C., and Stallard, R.F., 2000, Luquillo Mountains, Puerto Rico—A Water, Energy, and Biogeochemical Budgets Program Site: U.S. Geological Survey Fact Sheet-163-99.
- Clow, D.W., Campbell, D.H., Mast, M.A., Striegl, R.G., Wickland, K.P., and Ingersoll, G.P., 2000, Loch Vale, Colorado—A Water, Energy, and Biogeochemical Budgets Program Site: U.S. Geological Survey Fact Sheet-164-99.
- Shanley, J.B., 2000, Sleepers River, Vermont—A Water, Energy, and Biogeochemical Budgets Program Site: U.S. Geological Survey Fact Sheet-166-99.

conditions. For example, data from the WEBB program, the Hydrologic Benchmark Network, and other relatively undisturbed watersheds are being used to establish a background level for nutrient fluxes. The data will provide a reference for comparisons of nutrient fluxes from urban and agricultural watersheds. Understanding background conditions and natural variability allows early warning of environmental change and comparisons between near pristine and human-impacted watersheds. Such a comparison is being made in Puerto Rico. Resulting data indicate that landslides are most likely to occur on hillslopes that were anthropogenically modified, face the east-northeast, and exceed 12 degrees in gradient and 350 meters in elevation, whereas bedrock geology and soil order seem less important in the determination of landslide frequency (Larsen and Torres-Sánchez, 1998).

### Collaborative Research

Studies at the WEBB sites have benefited from the infrastructure and long-term data support provided by other agencies, as noted in the descriptions of the five sites, and from a strong collaborative research relationship with scientists from other Federal and State agencies

and from over twenty universities. Students and volunteers have helped collect, process, and archive data and samples, and university faculty and graduate students have helped to advance our scientific understanding of important biogeochemical and hydrological processes and budgets by conducting research and publishing their results. Since the beginning of the program in 1991, 50 students have completed their theses or dissertations from work as a result of interactions with WEBB investigators and an equal number of university faculty advisors have collaborated with USGS scientists. The collaborative research efforts at the sites are exemplified by a compilation of seven papers on Loch Vale that were written by 20 investigators from eight institutions and were recently published in *Water Resources Research* (Baron and Williams, 2000). Cooperative efforts will continue to be fostered at all five sites and collaborations with scientists from other agencies and universities to enhance understanding of watershed systems will continue

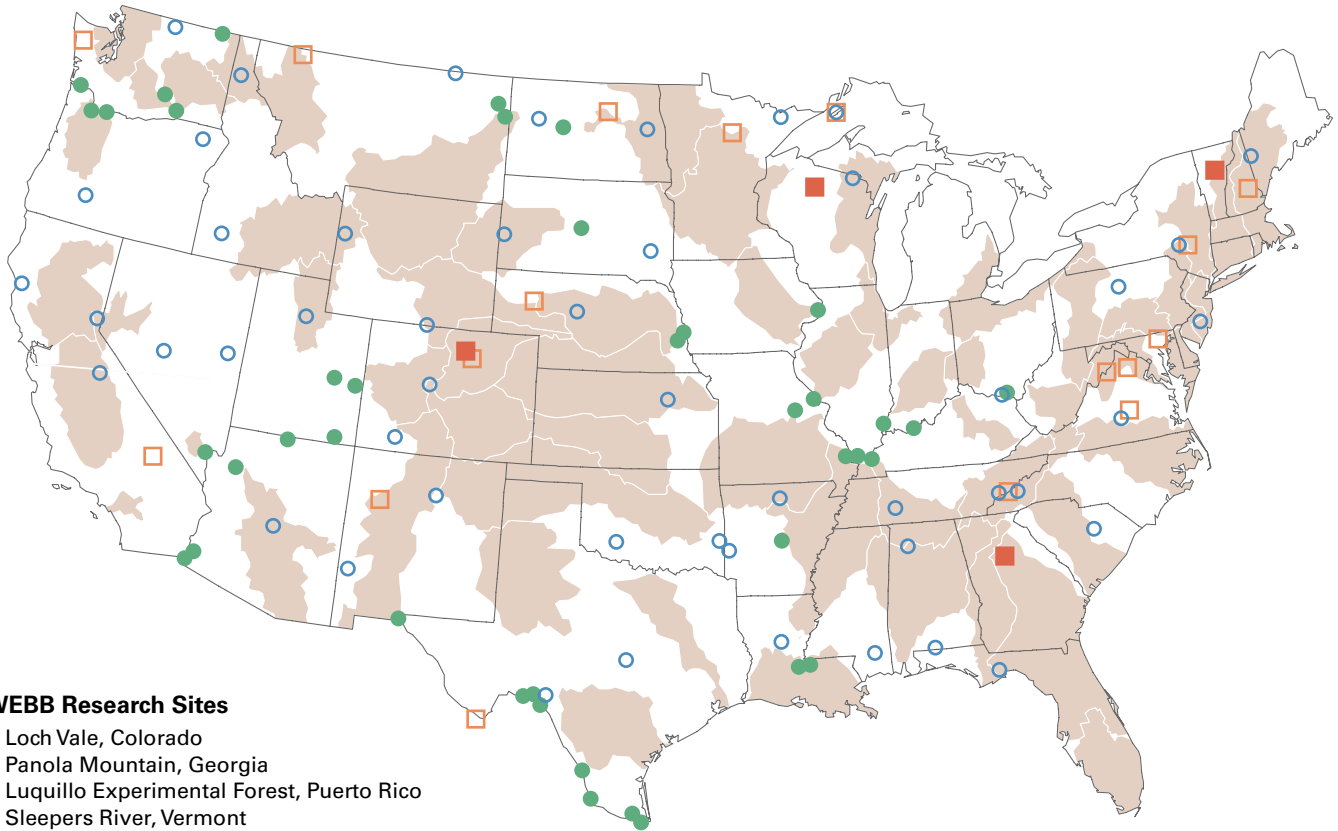
—Mary Jo Baedecker and  
Linda C. Friedman

Information about the WEBB program is available on the internet:  
<http://water.usgs.gov/nrp/webb/>

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- Baron, J.S., and Williams, M.W., 2000, Preface to special section: recent Loch Vale watershed research: *Water Resources Research*, v. 36, no. 1, p. 11–12.
- Bullen, T.D., Krabbenhoft, D.P., and Kendall, C., 1996, Kinetic and mineralogic controls on the evolution of groundwater chemistry and <sup>87</sup>Sr/<sup>86</sup>Sr in a sandy silicate aquifer, northern Wisconsin, USA: *Geochimica et Cosmochimica Acta*, v. 60, no. 10, p. 1807–1821.
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- Wolock, D.M., 1995, Effects of subbasin size on topographic characteristics and simulated flow paths in Sleepers River watershed, Vermont: *Water Resources Research*, v. 31, p. 1989–1997.

# USGS Long-Term Watershed Research Sites



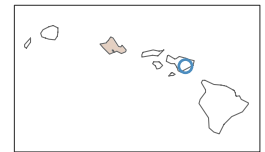
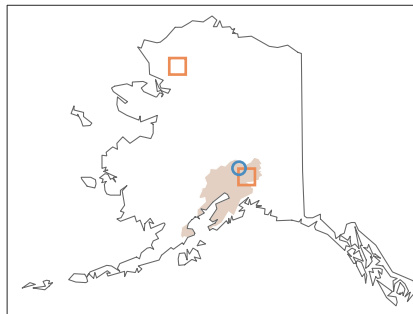
## ■ WEBB Research Sites

- Loch Vale, Colorado
- Panola Mountain, Georgia
- Luquillo Experimental Forest, Puerto Rico
- Sleepers River, Vermont
- Trout Lake, Wisconsin

## □ Other Small Watershed Research Sites

- Noatak National Preserve, Alaska\*
- Denali National Park, Alaska\*
- Sequoia and Kings Canyon National Parks, California\*
- Rocky Mountain National Park, Colorado\*
- Catoctin Mountains, Maryland
- Isle Royale National Park and Lake Superior Basin, Michigan\*
- Shingobee Headwaters Research Area, Minnesota
- Glacier National Park, Montana\*
- Crescent Lake, Nebraska
- Mirror Lake, New Hampshire
- Rio Puerco Basin, New Mexico
- Nerversink, New York
- Cottonwood Lake, North Dakota
- Great Smoky Mountains National Park, North Carolina and Tennessee\*
- Massanutten, Virginia
- Old Ridge Mountains, Virginia
- Shenandoah National Park, Virginia
- Big Bend National Park, Texas\*
- Olympic National Park, Washington\*

\*part of the Watershed Ecosystems Studies Program



## ● National Stream Quality Accounting Network (NASQAN) stations

Designed to monitor water quality of the Nation's largest rivers.

## ○ Hydrologic Benchmark Network (HBN) Sites

Designed to monitor water quality of selected underdeveloped watersheds. HBN stations are being operated on a rotational basis.

## ■ National Water Quality Assessment (NAWQA) Program study units

Designed to describe how the quality of the Nation's water resources changes with time and with natural and human influences.

For additional information about the WEBB Program, contact

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