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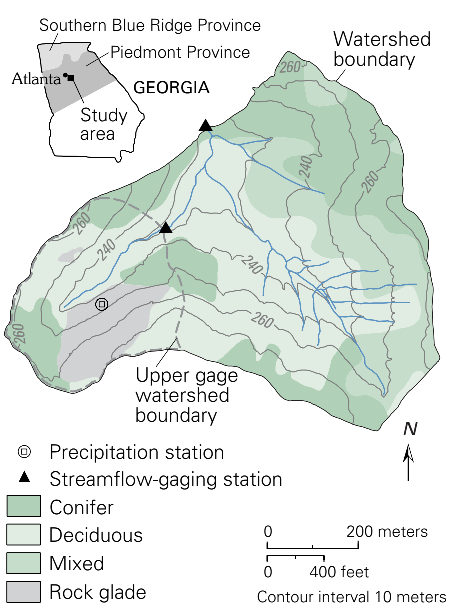
Panola Mountain, Georgia

A Water, Energy, and Biogeochemical Budgets Program Site

The Panola Mountain Research Watershed (PMRW) is a 41-hectare forested watershed in the southern Piedmont physiographic province near Atlanta, Georgia. The watershed contains a naturally regenerated second-growth forest on abandoned agricultural land, typical of the Piedmont. Research at PMRW has focused on how streamflow is generated, and in particular, on how water and solutes move from hillslopes to the stream. The research shows that streamflow and solute concentrations of precipitation, throughfall, soil water and streamwater change rapidly during rainstorms. Furthermore, these variations are strongly associated with the soil-moisture conditions, the soil type and thickness, and the rainfall intensity, all of which effect the chemical interactions and mixing of water traveling along hydrological pathways over and through the bedrock and soils.

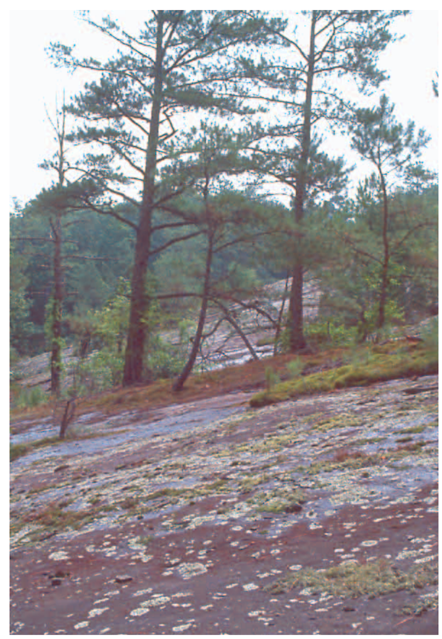
The Panola Mountain Research Watershed (PMRW) is about 25 kilometers southeast of Atlanta, and within the Georgia Department of Natural Resources Panola Mountain State Conservation Park, Stockbridge, Georgia. The PMRW is underlain predominantly by Panola Granite, which has a granodiorite composition that is interspersed with pods of hornblende biotite gneiss of the Clairmont Formation. The soils typically are from 0.6 to 1.2 meters thick and are underlain by a variable thickness of saprolite. The regolith ranges in depth from 0 to 5 meters over the Panola Granite and from 3 to 20 meters over the Clairmont Formation. The maximum altitude in the watershed is 279 meters above sea level, and the relief is 55 meters. The watershed is 93 percent forested, and the remaining 7 percent consists primarily of bedrock outcrop, which is covered with extensive lichen and moss communities and some small islands of shrubs and trees.

Location of stream-gaging stations and precipitation-quality stations at the Panola Mountain Research Watershed, Stockbridge, Georgia.



The forests in this part of the Piedmont Province were first settled and extensively cleared in the early 1800s. Subsistence farming was replaced with cotton production after 1893, which resulted in extensive gullying and erosion of topsoil. The forest consists of about equal amounts of deciduous, coniferous, and mixed coniferous/deciduous vegetation stands. The deciduous species are dominated by mockernut hickory, pignut hickory, northern red oak, white oak, and tulip poplar. The coniferous species include loblolly pine and shortleaf pine. The deciduous and mixed forest stands are present in areas abandoned in the early 1900s, whereas a smaller coniferous stand is in an area that was farmed as recently as the early 1960s. The oldest trees in the deciduous forest are about 120 years old and in the coniferous forest about 60 years old.

Air temperature averages 16° Celsius. Precipitation is dominated by rainfall (greater than 98 percent), is distributed uniformly throughout the year, and



Lichen- and moss-covered bedrock outcrop with vegetation islands of shrubs and trees.

THE WEBB PROGRAM

The Water, Energy, and Biogeochemical Budgets (WEBB) Program was started in 1991 at five small watersheds in the United States to examine water, energy, and biogeochemical fluxes and to determine the effects of atmospheric deposition, climatic variables, and human influences on watershed processes. The five sites are at Loch Vale, Colorado; Luquillo Experimental Forest, Puerto Rico; Panola Mountain, Georgia; Sleepers River, Vermont; and Trout Lake, Wisconsin. These sites are supported, in part, by other programs in the USGS, other Federal and State Agencies, and Universities.

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Gullys developed prior to reforestation. Some gullys are still actively eroding during major storms.

averages about 1,200 millimeters annually. However, annual precipitation and runoff varied markedly from 1986 to 1999. Annual precipitation ranged from 750 to 1650 millimeters. The annual runoff transported from the watershed in streamflow, averaged 33 percent of the precipitation and ranged from 18 to 50 percent.

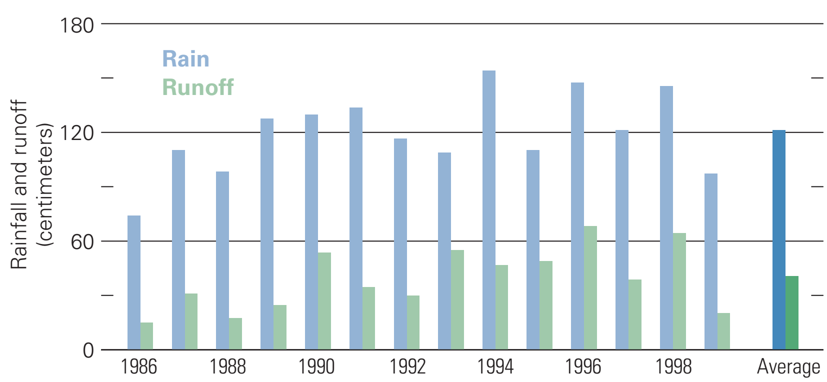
Atmospheric Deposition

Atmospheric deposition and aboveground cycling of major elements were evaluated in adjacent deciduous and coniferous forests at PMRW (Cappellato and others, 1999). Precipitation samples were collected in a wetfall/dryfall collector, which exposes a plastic sampling bucket only during rainstorms. During water years (WY: October through September) 1986 through 1999, weekly precipitation samples were collected. For some periods, samples were collected sequentially during rainstorms, and event samples were collected for entire rainstorms. Atmospheric deposition is acidic with pH averaging 4.4 from WY1986 to WY1999 for samples collected on a weekly basis. Precipitation is dominated by sulfuric and nitric acids with sulfuric acid contributing twice as much acidity as nitric acid. Some event and sequential samples were the most acidic with the lowest pH in the low 3s, but for some rainstorms, the pH was almost neutral with the highest pH in the high 6s. The precipitation at PMRW is less acidic than that in the northeastern United States, where pH averages between 4.0 and 4.2.

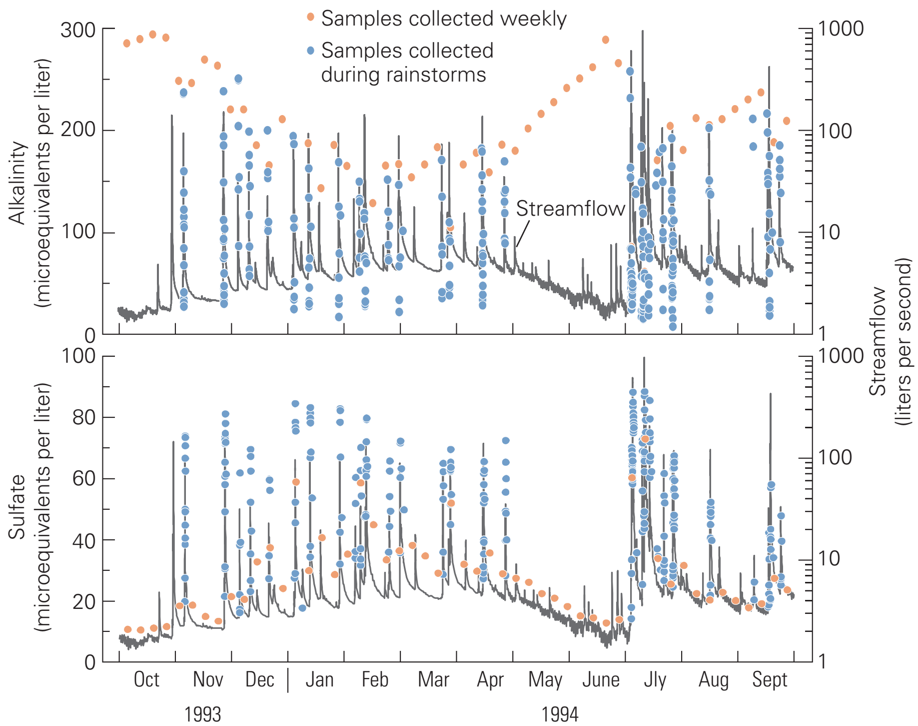
> Precipitation at the Panola site is acidic but it is less acidic than the northeastern United States. Dry deposition (particles, aerosols, and gases) accounts for about half of the total atmospheric deposition for most elements.

Total atmospheric deposition to the watershed is derived primarily from wet deposition, which consists of rainfall and some snowfall, and dry deposition, which consists of particles, aerosols and gases. Dry deposition is an equally important source of chemical elements to the watershed and generally contributes more than 40 percent of the total annual atmospheric deposition (Cappellato and others, 1993). Fifty-five percent of the dry sulfur (S) deposition is sulfur dioxide (Cappellato and others, 1998). The source of chloride (Cl), which is a mobile and conservative solute, is from the atmosphere; a comparison of Cl transported in streamwater from the watershed to that deposited to the watershed in rainfall from WY1986 through WY1997 indicates that dry deposition contributes more than 50 percent of the Cl input to the watershed (Peters and Ratcliffe, 1998). The dry S deposition to the watershed is similar to regional estimates indicating that the 70-kilometer proximity to several local fossil-fuel emission sources does not impact dry deposition at the PMRW.

Annual below-canopy fluxes (throughfall plus streamflow) for most constituents except nitrogen are higher in the



Precipitation varied by a factor of two whereas runoff varied by more than a factor of four at the PMRW during the period from water year 1986 to 1999.



Streamwater sulfate and alkalinity, the acid neutralizing capacity, varied more during stormflow than during the period of weekly sampling.

deciduous forest than in the coniferous forest. The high below-canopy flux in the deciduous forest is attributed to leaching from the canopy and greater dry deposition than in the coniferous forest. Furthermore, total S deposition to the forest floor by throughfall, streamflow and litterfall was at least two times higher than the annual S requirement needed for forest growth. Although S deposition exceeds the forest growth requirement, more than 85 percent of the total atmospheric S deposition was retained by the watershed (Cappellato and others, 1998). Sulfur retention at the PMRW is primarily due to sulfate adsorption by iron oxides and hydroxides in the watershed soils (Shanley, 1992). The S mobility varies with the timing of rainfall and soil wetness conditions (Huntington and others, 1994). The S content in white oak and loblolly pine boles has increased more than 200 percent since the middle of the 1970s, possibly reflecting increases in fossil-fuel emissions (Cappellato and others, 1998).

Hydrological Processes

One objective of the WEBB study is to improve the understanding of hydrological processes, particularly those that control streamflow generation and the evolution of water quality along hydrologic pathways. An evaluation of short-term hydrologic measurements, solute concentrations and temperature variations (Peters and Ratcliffe, 1998) show that water and solutes can be rapidly transported through the soil. Also, laboratory experiments including the use of tracers on large nearly undisturbed soil cores show that preferential flow occurs in the soils, and that water and solute transport is faster from more clay-rich ridge-top soils than from hillslope soils.

Detailed measurements of hydrologic and chemical characteristics from a 20- by 40-meter hillslope plot were evaluated to identify hydrologic pathways and the changing chemical and isotopic compositions of soil water and ground water. Where the slope of the bedrock and surface topography are distinctly different, that is not parallel, the bedrock surface has a considerable influence on local hydraulic gradients and therefore, on the dominant flowpath directions (Freer and others, 1997). Flow indices for bedrock and topographic slopes are poor indicators of downslope water flux under dry conditions. Consequently, initial pre-storm soil-moisture distribution and upslope contributing area are difficult to predict, especially in a soil having significant macropore development. Also, the side of the plot that had the shallowest soil, that is the bedrock surface with the highest elevation, also delivered the most water. This water also had the lowest solute concentrations (Burns and others, 1998). The high flow and presumably rapid delivery of water causes soil water, which typically has high solute concentrations produced from mineral weathering, to be diluted.

> Recent increases in the sulfur content of white oak and loblolly pine boles correlates with increases in fossil-fuel emissions.

Streamwater Chemistry

A computer-based system was developed at PMRW to sample streamwaters for examining the short-term variations in the chemical composition of streamwater and investigating related processes (Peters, 1994). The concentrations of most major solutes, for example sulfate and alkalinity, vary markedly during storms. Decreases in alkalinity, which is a measure of the acid-neutralizing capacity of streamwater, and concurrent increases in sulfate concentrations are much greater during single storm events than would be expected from fixed-interval weekly sampling. These short-term variations in solute concentrations, which typically are not observed from traditional fixed-time interval sampling, affect interpretations of hydrological processes and computations of solute transport.

The chemical composition of runoff from the bedrock outcrop in the headwaters is considerably different than that from streamwater at the basin outlet. Runoff from the bedrock outcrop typically is more acidic than precipitation, particularly at the beginning of a storm, reflecting the additional acidifying potential from the washoff of acidic dry deposition that accumulated on the outcrop before the storm. By subtracting the mass of sulfate in rainfall from that transported in runoff from the outcrop, another estimate was made for the contribution of dry S deposition. The amount of dry S deposition to the bedrock outcrop was slightly lower (30 percent) than that for the forest canopy. The lower estimate of dry S deposition to the bedrock outcrop compared to the forest is consistent with the difference in surface area. The lichens and mosses on the outcrop are not as effective as the forest canopy in filtering out the atmospheric S. However, causes for the streamwater chemical variations at the basin outlet are more difficult to identify.

> The soils and the forest may be important sinks for carbon in the Southeastern United States.

One hypothesis to explain the variability in the chemical composition of the streamwater is that streamwater is a mixture of ephemeral hillslope ground water, near-surface soil water, and older ground water in the surficial aquifer. The chemical composition of hillslope soil waters generally is different than either ground water or streamwater (Hooper and others, 1990; Burns and others, 1998; Peters and Ratcliffe, 1998). Furthermore, the chemical concentrations of most solutes in streamwater are extremely low, and the concentrations in streamwater are negatively correlated with discharge (Peters, 1994). A simple mixing of ground water with rainfall (or throughfall, which includes enrichment owing to the washoff of dry deposition) can explain most of the variation in the sodium, chloride and silica concentrations of streamwater (Peters and Ratcliffe, 1998).

Although concentration for most solutes in streamwater is negatively correlated with discharge, the relationship between concentration and streamflow may vary depending on the prevailing climatic conditions (Huntington and others, 1994). Varying the sequence of flood flows and drought conditions can alter the relative contribution of water and solutes from hydrologic pathways to streamflow, and consequently, alter the mixture of these waters, which compose streamwater. Climate, therefore, may affect the relation between the chemical composition of streamwater and streamflow.

Carbon Cycling

An analysis of carbon (C) sources including the carbon stored in the soils and the forest, and transported in streamwater at PMRW indicates that the forest is an important C sink (Huntington, 1995). Furthermore, soil respiration, which liberates carbon dioxide (CO_2) to the atmosphere, is controlled by the available C, and the temperature and moisture content of the soil, which vary seasonally. An empirical soil respiration model was developed as a function of soil moisture and temperature during the non-growing season. During the growing season when the soil was dry, soil respiration CO_2 flux was higher from an irrigated plot than from a dry control plot. Soil respiration is similar at coniferous and deciduous forest plots. Biomass C accumulation and soil respiration are much larger than C transport in streamwater.

—Norman E. Peters, Richard P. Hooper, Thomas G. Huntington and Brent T. Aulenbach

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COLLABORATORS

The research at PMRW has been conducted as a collaborative effort among the USGS; the National Oceanic and Atmospheric Administration (NOAA); the U.S. Department of Agriculture; the National Science Foundation; the Georgia Department of Natural Resources; several universities, including the University of Georgia, Georgia Institute of Technology, the University of Cincinnati, Emory University, Oregon State University, the State University of New York at Syracuse, the University of Vermont; and several international institutions, including the University of Bristol, Lancaster University, Newcastle University, and the Institute of Hydrology in the United Kingdom; the Czech Geological Survey, the Potsdam Institute for Climate Impact Research in Germany, and the University of Western Australia.

For more information about the Panola Mountain Research Watershed WEBB study visit:

http://wwwga.usgs.gov/projects/ga103.html

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