

## APPALACHIAN PLATEAUS GROUNDWATER AVAILABILITY

The U.S. Geological Survey's Groundwater Resources Program is conducting an assessment of groundwater availability throughout the United States to gain a better understanding of the status of the Nation's groundwater resources and how changes in land use, water use, and climate may affect those resources. The goal of this National assessment is to improve our ability to forecast water availability for future economic and environmental uses. Assessments will be completed for the Nation's principal aquifer systems to help characterize how much water is currently available, how water availability is changing, and how much water we can expect to have in the future (Reilly and others, 2008).

### Why a regional groundwater study?

Appalachian Plateaus aquifers occupy approximately 86,000 mi<sup>2</sup> in portions of Alabama, Kentucky, Maryland, Ohio, Pennsylvania, Tennessee, Virginia, and West Virginia (fig. 1). Appalachian Plateaus aquifers are comprised of alternating sequences of fractured sandstone, siltstone, shale, limestone, and coal in Permian-, Pennsylvanian-, and Mississippian-age rock formations. Erosion of the rock formations has produced the characteristic steep hills, rugged topography, and deeply incised valleys that are home to approximately 2.2 million rural residents withdrawing a total of 156 million gallons per day (Mgal/d) of potable water from domestic wells and 1.8 million residents receiving 289 Mgal/d of groundwater from public supplies (Kenny and others, 2009). The remaining 8.1 million residents rely on 1.2 billion gallons per day (Bgal/d) of surface water for potable water supply, which, in many cases depends on groundwater contributions as base flow to streams.

Groundwater withdrawals from Appalachian Plateaus aquifers are small when compared to the billions of gallons withdrawn daily from more prolific aquifers of the United States (Reilly and others, 2008). As a result, few studies have focused on groundwater availability in Appalachian Plateaus aquifers at regional-scales consistent with (1) Appalachian Basin energy resource assessments (ie. Kirschbaum and others, 2012), or (2) State and Federal regulatory frameworks.

The Appalachian Plateaus Groundwater Availability study is intended to provide the foundational groundwater-related datasets for other Federal and State water-resource investigations to assess drinking-water resources, aquatic ecosystems, and continued energy resource development in the region. A better understanding of groundwater availability in the Appalachian Plateaus thus plays a central role in sustained economic development of the region.



Active groundwater flow in Appalachian Plateaus aquifers occurs within a few hundred feet of the land surface where a local framework of stress-relief fracture and bedding-plane permeability is constrained near valley walls and under valley bottoms. Springs in valley walls discharge from stress-relief fractures at sandstone outcrops. Photo by USGS hydrologist Mark Kozar

### What is groundwater availability?

The concept of groundwater availability is more than just how much water can be pumped from any given aquifer. Groundwater availability is a function of many factors, including the quantity and quality of water and the laws, regulations, economics, and environmental factors that control its use.

The primary objective of the Appalachian Plateaus groundwater availability study is to identify spatial and temporal changes in the overall water budget by more fully determining the natural and human processes that control how water enters, moves through, and leaves the groundwater system.

## Major components of the study

### • Establishing a regional hydrogeologic framework

A hydrogeologic framework of the Plateaus aquifers inclusive of stress-relief fractures, regional structures, vast areas of underground coal workings, and areas of extensive karst development is needed to evaluate regional heterogeneities in context of regional water budgets and flow patterns. A regional hydrogeologic framework can be directly inferred from published geologic cross sections, isopach maps, coal-mine mapping efforts, and digital datasets from the National Coal Resources Data System (<http://ncrdspublic.er.usgs.gov/nflap/>).

The Appalachian Plateaus groundwater availability study will incorporate surficial mapping with these sources of subsurface data in the development of a three-dimensional model of bedrock aquifers.

### • Computing Estimates of Hydrologic Budget

Precipitation falling on the Plateaus is ultimately consumed by evapotranspiration, groundwater recharge, and runoff to streams. Direct runoff to streams accounts for 17 to 20 percent of annual precipitation in the Appalachian Plateaus (Zurawski, 1978). Evapotranspiration accounts for an estimated



Recharge occurs primarily in topographically high areas (ridges) and flows laterally and downward through shallow fractures in the bedrock. Aquifers discharge to local streams and rivers where aquatic ecosystems within the Plateaus rely on sustained base flow from groundwater. Photograph by Gary Hartley, National Park Service



Fracture pathways seated in valley bottoms serve as routes of groundwater flow where regional joints sets (as shown above) and stress-relief fracturing are superimposed on the hydrostratigraphic framework. Photo by USGS hydrologist Mark Kozar.

21 in/yr (Mohamoud, 2004) to 29 in/yr (Zuwarksi, 1978). Long-term historic recharge to Appalachian Plateaus aquifers typically ranges from 6 to 18 in/yr (Reese and Risser, 2010; Dumouchelle and Schiefer, 2002; Zurawski, 1978). Recharge to Appalachian Plateau aquifers is approximated by base flow because most streams in the Appalachian Plateaus are gaining streams, the water table is relatively shallow, and losses of groundwater from riparian evapotranspiration and consumptive withdrawals are considered to be small.

Recharge, evapotranspiration, and runoff during 1980-2010 will be estimated by the Soil-Water-Balance (SWB) method (Westenbroek and others, 2010), which is based on a modified version of the Thornthwaite-Mather equations and can be discretized at sub-watershed scales.

### • Defining the Largest Flow System of Relevance

Groundwater flow in Appalachian Plateaus aquifers is characterized by short flow paths, typically extending no more than tens of miles. Groundwater flow is controlled both by the regional dip of bedrock, local topography, and distal hydrologic boundaries coincident with large river valleys (Carswell and Bennett, 1963). A refined conceptual model of the groundwater-flow system in the Appalachian Plateaus will further the understanding of a locally driven groundwater-flow system in the context of hydrostratigraphy developed at the regional scale.



## Previous Work

Regional assessments of groundwater resources in the Tennessee River (Zurawski, 1978) and Ohio River Basins (Bloyd, 1974) were undertaken to show the need for management of groundwater resources in regional water-supply planning. These assessments described groundwater occurrence, water budgets, and development potential of aquifers in the Plateaus and adjacent physiographic provinces.

Seaber and others (1988) described the dominant geologic controls on groundwater flow in the Plateaus, including Zurawski's (1978) conceptual model of the Cumberland Plateau in Tennessee and Wyrick and Borchers (1981) model of stress-relief fracturing in southern West Virginia.

## Coal Hydrology

The USGS Coal Hydrology Program in the late 1970s and early 1980s provided a broad characterization of the hydrology and energy production in the Plateaus as it related to coal extraction in 23 areas of the eastern coal province.

In the following two decades, numerous studies focused on local-scale issues related to stress-relief fracture and mining-related hydrology (i.e. Donovan and Fletcher, 1999; Hawkins and others, 1996). Regional geologic constraints, conceptual models, and hydrostratigraphy of the Plateaus by physiographic province were synthesized by Trapp and Horn (1997) and Lloyd and Lyke (1995).

## Karst in the Appalachian Plateaus

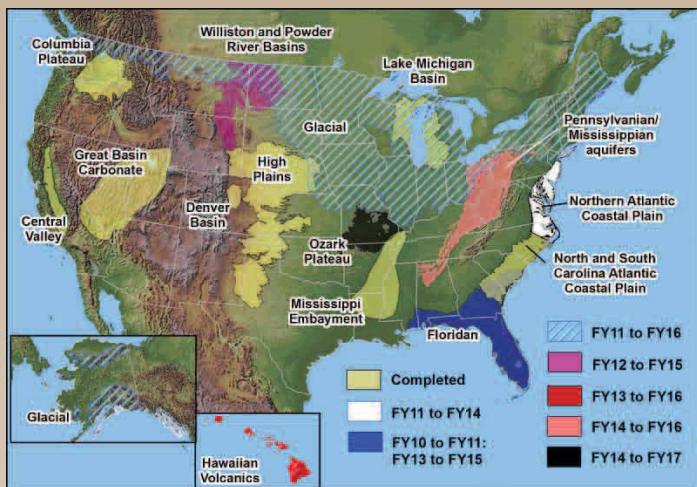
Mississippian-age aquifers consist of sandstone, limestone, and fractured chert. Limestone content increases to the south where in Kentucky, Virginia, and West Virginia, the Greenbrier Limestone and Slade Formation discharge 1,000 gal/m or more to springs. Large spring discharges from the Mississippian-age carbonate aquifers along the sides of major incised valleys such as the Sequatchie Valley in Tennessee yield as much as 4,000 gal/m from the Bangor and Tuscumbia Limestones (Miller, 1990).

Dissolution of Mississippian-age aquifers has resulted in the development of locally permeable karst features (Seaber and others, 1988). Caves, sinkholes, and sinking streams are prevalent in the extensive Mississippian-age karst aquifers of southeastern West Virginia and eastern Kentucky. In West Virginia alone, there are over 3,000 documented caves in Mississippian-age units (Dasher, 2012). Cave passages tend to be constrained by stress-relief fracturing within valley walls in "Cumberland Style" karst, indicating



Figure 1. Location of Permian-age, Pennsylvanian-age, and Mississippian-age aquifers of the Appalachian Plateaus, eastern United States.

coincident groundwater and surface-water drainages on the Cumberland Plateau (Simpson and Florea, 2009; Sasowsky and White, 1994; Crawford, 1984). Simpson and Florea (2009) have noted several exceptions where cave passages follow fracture swarms associated with regional structures, effectively routing groundwater through ridges and between adjacent valleys.



Map of U.S. Geological Survey (USGS) Groundwater Resources Program regional scale groundwater study areas. Explanation indicates the fiscal years during which the studies are planned to occur. (Updated January 2013).

## How is study information used?

Groundwater is among the Nation's most important natural resources. It provides half our drinking water and is essential to the vitality of agriculture and industry, as well as to the health of rivers, wetlands, and estuaries throughout the country. Large-scale development of groundwater resources with accompanying declines in groundwater levels and other effects of pumping has led to concerns about the future availability of groundwater to meet domestic, agricultural, industrial, and environmental needs. The challenges in determining groundwater availability are many.

The USGS Groundwater Resources Program is undertaking a series of regional groundwater availability studies to improve our understanding of groundwater availability in major aquifers across the Nation.

## References

Bloyd, R.W., Jr., 1974, Summary appraisals of the nation's ground-water resources-Ohio region: U.S. Geological Survey Professional Paper 813-A, 41 p.

Carswell, L.D., and Bennett, G.D., 1963, Geology and hydrology of the Neshannock Quadrangle, Mercer and Lawrence Counties, Pa: Pa Topographic and Geologic Survey, Ground Water Report W15, 90 p.

Crawford, N.C., 1984, Karst landform development along the Cumberland Plateau escarpment of Tennessee, in LeFleur, R.G., ed., Groundwater as a geomorphic agent: Boston, Allen and Unwin, Inc., p. 294-338.

Dasher, G., 2012, The caves and karst of West Virginia: West Virginia Speological Survey Bulletin No. 19, 263 p.

Donovan, J.J., and Fletcher, J., 1999, Hydrogeological and geochemical response to mine flooding in the Pittsburgh coal basin, southern Monongahela River basin: Project WV-132 Report to the U.S. Environmental Protection Agency, 47p.

Dumouchelle, D.H., and Schiefer, M.C., 2002, Use of streamflow records and basin characteristics to estimate ground-water recharge rates in Ohio: Ohio Department of Natural Resources, Division of Water, Bulletin 46, 45 p.

Hawkins, J.W., Brady, K.B.C., Barnes, S., and Rose, A.W., 1996, Shallow ground water flow in unmined regions of the northern Appalachian Plateau: Part 1. Physical characteristics: Annual Meeting of the American Society for Surface Mining and Reclamation, May 18-23, Knoxville, TN, p. 42-51.

Kenny, J.F., Barber, N.L., Hutson, S.S., Linsey, K.S., Lovelace, J.K., and Maupin, M.A., 2009, Estimated use of water in the United States in 2005: U.S. Geological Survey Circular 1344, 52 p.

Kirschbaum, M.A., Schenk, C.J., Cook, T.A., Ryder, R.T., Charpentier, R.R., Klett, T.R., Gaswirth, S.B., Tennyson, M.E., and Whidden, K.J., 2012, Assessment of undiscovered oil and gas resources of the Ordovician Utica Shale of the Appalachian Basin Province, 2012: U.S. Geological Survey Fact Sheet 2012-3116, 6 p.

Lloyd, O.B., and Lyke, W.L., 1995, Groundwater Atlas of the United States, Chapter K: Illinois, Indiana, Kentucky, Ohio, Tennessee, U.S. Geological Survey HA 730-K.

Miller, J.A., 1990, Groundwater Atlas of the United States, Chapter G: Alabama, Florida, Georgia, and South Carolina, U.S. Geological Survey HA 730-G.

Mohamoud, Y., 2004, Comparison of hydrologic responses at different watershed scales: EPA Report EPA/600/R-04/103, 74p.

Reese, S.O., and Risser, D. W., 2010, Summary of groundwater-recharge estimates for Pennsylvania: Pennsylvania Geological Survey 4th Series, Water Resource Report 70, 27p.

Reilly, T.E., Dennehy, K.F., Alley, W.M., and Cunningham, W.L., 2008, Ground-water availability in the United States: U.S. Geological Survey Circular 1323, 70 p.

Sasowsky, I.D. and White, W.B., 1994, The role of stress release fracturing in the development of cavernous porosity in carbonate aquifers: Water Resources Research, v. 30, no. 12, p. 3523-3530.

Seaber, P.R., Brahana, J.V., and Hollyday, E.F., 1988, Region 20-Appalachian Plateaus and Valley and Ridge, in Back, William, Rosenshein, J.S., and Seaber, P.R., eds., Hydrogeology: Geological Society of America, The Geology of North America, v. 0-2, p. 189-200.

Simpson, L.C., and Florea, L.J., 2009, The Cumberland Plateau of Kentucky: Caves and Karst of America, 2009, p. 70-79.

Trapp, H., and Horn, M.A., 1997, Groundwater Atlas of the United States, Chapter L: Delaware, Maryland, New Jersey, North Carolina, Pennsylvania, Virginia, and West Virginia: U.S. Geological Survey HA 730-L.

Westenbroek, S.M., Kelson, V.A., Dripps, W.R., Hunt, R.J., and Bradbury, K.R., 2010, SWB—Am modified Thornthwaite-Mather Soil-Water-Balance code for estimating groundwater recharge: US Geological Survey Techniques and Methods 6—A31, 60 p.

Wyrick, G.G., and Borchers, J.W., 1981, Hydrologic effects of stress relief fracturing in an Appalachian valley: U.S. Geological Survey Water-Supply Paper 2177, 51 p.

Zurawski, A., 1978, Summary appraisals of the Nation's ground-water resources-Tennessee region: U.S. Geological Survey Professional Paper 813-L, 35 p.

## For more info:

For more information:

Visit the project Web site at:

<http://va.water.usgs.gov/appalachianplateaus/main.html>

Or contact Kurt J. McCoy

U.S. Geological Survey Virginia Water Science Center  
804-261-2656

[kjmccoy@usgs.gov](mailto:kjmccoy@usgs.gov)