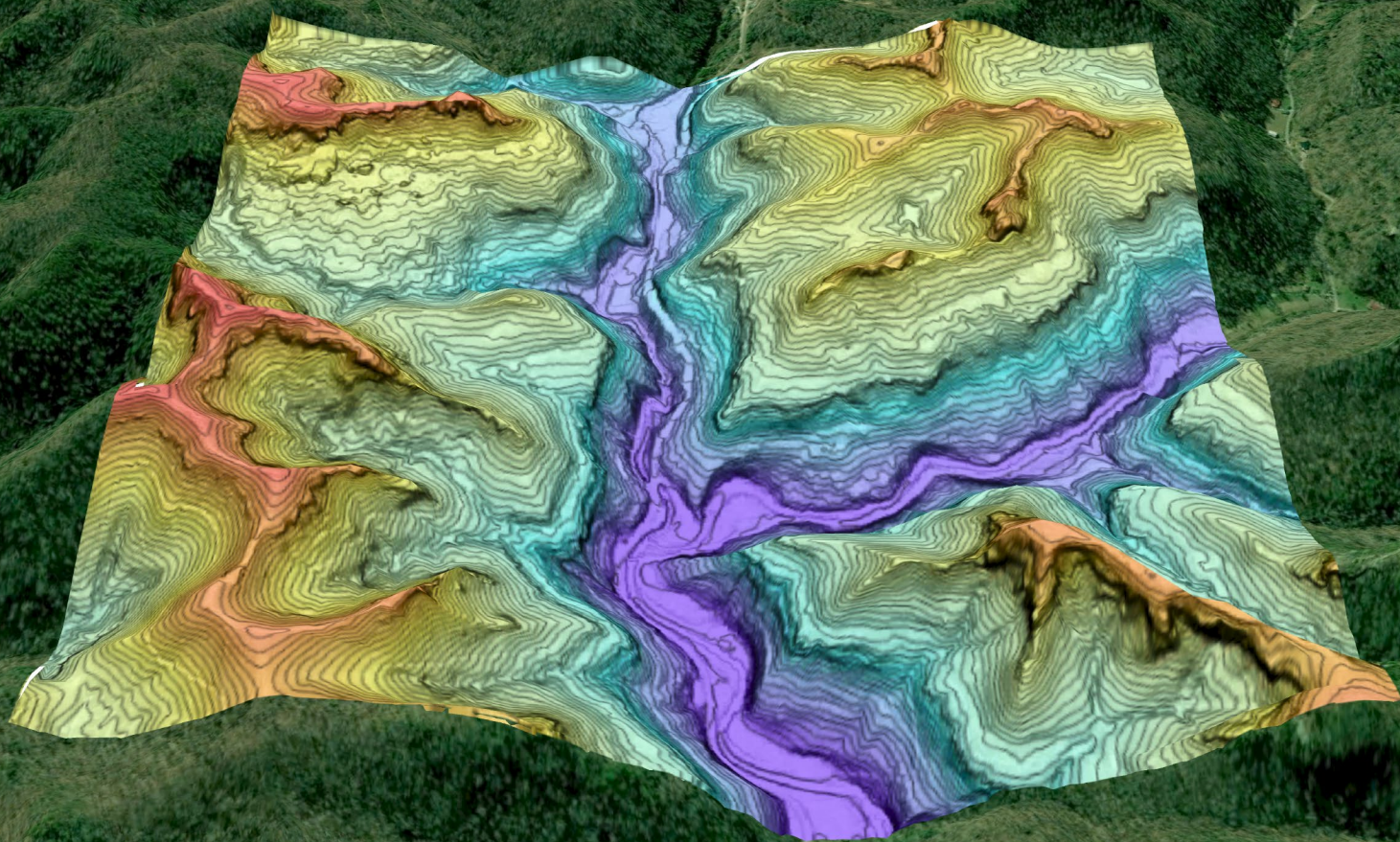


Kentucky Geological Survey

2017-2018 Annual Report



Kentucky Geological Survey

2017-2018 Annual Report

On the cover

The cover image shows a 5,000 by 5,000 foot tile from the KyFromAbove statewide airborne LiDAR digital elevation model draped over less-detailed pre-LiDAR topography and National Agriculture Imagery Program aerial photographs of an area centered around the confluence of the South Fork of the Red River and Stump Cave Branch near Bear Hollow in Powell County. View is toward the south. Virtual deforestation calculations remove trees from the LiDAR data to create an exceptionally accurate bare earth DEM, which allows geologists to discern landscape details even in heavily forested areas. The LiDAR image combines rainbow hues to represent elevation above sea level, a reversed gray-scale slope-angle map to help delineate geologic details such as landslide scars and individual rockfall blocks from the ridge-forming Corbin Sandstone, and topographic contours to further accentuate geomorphological subtleties. KGS geologists routinely take advantage of our Digital Earth Analysis Lab—KGS DEAL—to use LiDAR data in their research. Kentucky’s statewide LiDAR DEM, which was released in early 2018 after several years of data acquisition and processing, comprises about 46 billion laser-accurate ground-surface elevation measurements across the commonwealth. The DEM and related elevation products are available free of charge from kyfromabove.ky.gov. Read more about how KGS uses LiDAR on pages 22–23.

Earth Resources— Our Common Wealth

Mission

The Kentucky Geological Survey is a state-supported research center and public resource within the University of Kentucky. Our mission is to support sustainable prosperity of the commonwealth, the vitality of its flagship university, and the welfare of its people. We do this by conducting research and providing unbiased information about geologic resources, environmental issues, and natural hazards affecting Kentucky.

Vision

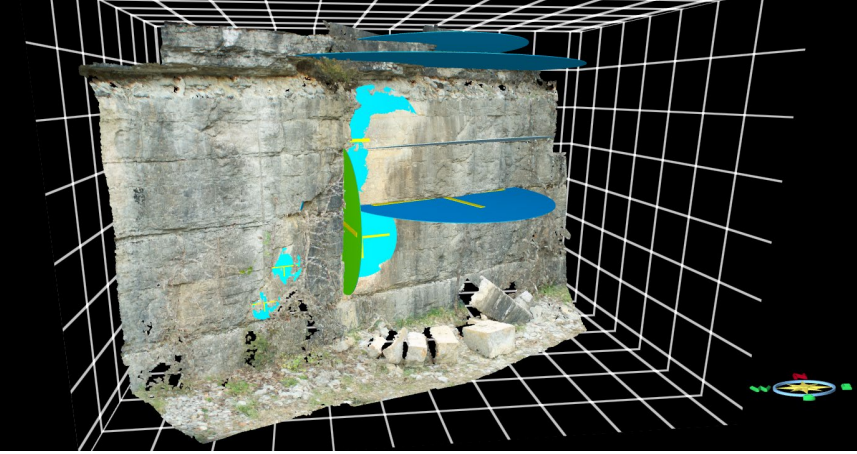
To be the primary source of geologic information about and for Kentucky.

Contents

1	From the Director
3	Water Resources
11	Energy and Minerals
20	KGS DEAL
22	Geologic Mapping
24	Outreach and Professional Engagement
27	GeoHealth
29	Geologic Hazards
34	Geologic Information Management
38	Well Sample and Core Library
39	Western Kentucky Office
40	Publications for 2017-2018
43	Kentucky Geological Survey Staff, Fiscal Year 2017-2018
44	Research Projects, Fiscal Year 2017-2018

From the Director

What would William Williams Mather—descendant of a Puritan minister, artillery instructor, inventor, and professor, who performed the first geological reconnaissance of Kentucky in 1838—have thought of smartphones that can locate a geologist



Three-dimensional digital outcrop model of Camp Nelson Limestone.

within a few feet in the field, connect to an internet map service to display an airborne LiDAR hillshade rendering of the area, measure and plot the orientations of structural features, and document an outcrop with high-resolution digital color photographs?

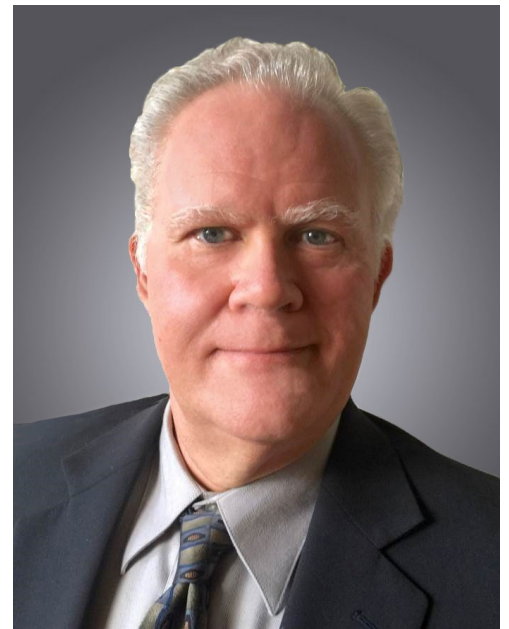
For that matter, what would he have thought of a plain old un-smart phone?

Kentucky and the world have changed tremendously since Mather set out 180 years ago to evaluate the commonwealth's natural resources. Even then, he was a bit behind the curve. Coal had been discovered in Kentucky in 1750, and the first commercial coal mine began operation in 1820 near Paradise, Muhlenberg County. Commercial amounts of oil had been inadvertently discovered and produced from a brine well near Burkesville, Cumberland County, in 1829. Responding to the concerns of influential Kentuckians, Sen. Cyrus Wingate and Rep. James Morehead introduced motions in the Kentucky legislature that authorized Gov. James Clark to retain the services of an expert to undertake a geological reconnaissance of the commonwealth. Even in those early days, it was clear that scientific understanding of our natural resources was essential for the prosperity of Kentucky and its people.

One hundred eighty years after Mather began his work in Kentucky—and 70 years after KGS became a part of the University of Kentucky by an act of the state legislature in 1948—we remain as committed as ever to fulfilling both our legislative mandate and the university's land-grant mission by performing a continuing geological study of the state, with an emphasis on the practical well-being of its people. But we do it differently than William Mather did.

One of our most important jobs is to serve as the repository for information about Kentucky's geology. That includes data obtained from oil, gas, and water wells; mineral exploration drillholes; and geotechnical borings in the form of rock cores, drill cuttings, lithologic logs, and chemical analyses. Most of that information is already online through our internet map service, but KGS is taking steps to make the service even more useful. We've embarked on a pilot program to photograph core so that visitors to our website will eventually be able to view high-resolution digital photographs of cores before traveling to our library to examine the cores in person, allowing them to make the best use of their time. We've also added a high-resolution multidirectional hillshade image layer, developed from Kentucky's now-complete statewide airborne LiDAR coverage, to our internet map service to help visualize details of local topography and geology across the state.

In addition to our interactive map services, digital versions of almost all of our maps, publications, and georeferenced data are already freely available online, providing a tremendous resource to other state agencies



from emergency management to transportation; engineering and planning firms laying the groundwork for continued economic growth; grassroots citizen and environmental groups; students and teachers; and anyone else interested in the Bluegrass State. If you need an old or obscure KGS publication that is not yet online, in most cases we will be able to scan and post it. There are sometimes copyright restrictions on papers published in peer-reviewed journals, but KGS authors are almost always able to provide copies to individuals upon request.

KGS scientists also conduct research and collect new data to improve the lives of Kentuckians. For several years now, we've been monitoring microseismicity in eastern Kentucky to better understand the potential effects of fluid injection should large-scale hydraulic fracturing ever become common in Kentucky, working with colleagues in the UK College of Agriculture, Food and Environment to help study edge-of-field water quality to improve farming practices, performing chemical analyses for our colleagues in the UK Department of Mining Engineering to help evaluate the feasibility of extracting critically important rare earth elements from coal, collaborating with the UK College of Nursing's BREATHE program to understand geologic controls on indoor radon gas (radon is the second leading cause of lung cancer), and making surficial geologic maps useful for engineering and planning studies in Kentucky's most rapidly developing areas.

When the state disaster mitigation plan needed updating, KGS was there to provide the latest and best information available about Kentucky's susceptibility to geologic hazards such as earthquakes, landslides, and sinkholes. Our new Digital Earth Analysis Lab—KGS DEAL—supports development of new solutions using Kentucky's statewide airborne LiDAR data, which currently give us about 460 billion laser-accurate measurements to help us understand the geology and topography of Kentucky.

We are continually improving the ways we communicate the things we know, from placing increased emphasis on publication of peer-reviewed papers in scientific journals—the gold standard of scientific publication—to exploring evolving technologies such as GIS-based Story Maps to create interactive online documents and using message-box strategies to identify the essential pieces of information we want to communicate and sharpen the messages to our audiences. We've used a graphical scale indicating the degree of complexity of each report published by KGS for some time now, and during the past year have started including a succinct statement of benefit to Kentucky, written in everyday language—no scientific jargon allowed! It's our job to explain clearly and unambiguously what we do and why our work matters to Kentucky.

Please take some time to read our 2017-2018 annual report and let us know how we're doing.

William C. Haneberg
Director and State Geologist

Water Resources

During 2017-2018, KGS hydrogeologists worked on ground- and surface-water characterization projects started in the previous year and began several exciting new projects in collaboration with the U.S. Department of Agriculture's Natural Resource Conservation Service, the Kentucky Division of Water, and the UK College of Agriculture, Food and Environment. **Ben Tobin** joined KGS on June 11, 2018, providing internationally recognized expertise in karst hydrogeology, speleology, and water-tracing techniques. Tobin previously worked for the National Park Service at Grand Canyon National Park. KGS also hired a recent UK graduate, **Adam Nolte**, as a geological technician.



Steve Webb measures discharge in the outlet channel of Head of Rough Spring, near Cecilia.

Collaborative aquifer characterization

In the fall of 2017, KGS began a new collaborative project with the Kentucky Division of Water, funded by the U.S. Geological Survey's Water-Use Data and Research Program, to identify and characterize aquifers used for public and industrial water supplies. The project will help improve the Division of Water's program to manage Kentucky's groundwater and the Division's permit processing by creating a new digital hydrogeologic framework of major Kentucky aquifers; the aquifers will be designated by identification codes used in the USGS National Water Information System database. Existing data, including water-well construction logs, oil and gas well records, geophysical logs, and other digital geologic mapping data presently archived by KGS, will be compiled and synthesized. KGS geologists **Chuck Taylor**, **Bart Davidson**, **Glynn Beck**, **Tom Sparks**, and **John Hickman** are working on the project, which is funded through June 2019.



Steve Webb calibrates a data sonde to monitor changes in temperature, pH, specific conductance, and turbidity of water pumped from Head of Rough Spring to the Hardin County Water District No. 1 treatment plant near Cecilia.

Head-of-Rough Spring discharge monitoring

Working in collaboration with the Hardin County Water District No. 1, **Chuck Taylor** and **Steve Webb** are collecting discharge measurements and water-quality data at a monitoring station at Head-of-Rough Spring near Cecilia. Monitoring equipment set up in December 2016 continuously tracks changes in water level, temperature, specific conductance, pH, and turbidity. These data, along with periodic spring discharge (flow) measurements

and analysis of water samples collected for total suspended solids concentration, provide information for the water district to improve its management of the spring as a public water source. The project is funded through June 30, 2018, by a grant from the Kentucky Division of Water's Source Water Protection Assistance Program, but monitoring will continue at least through the end of 2018.

Green River karst spring investigations

An investigation of the hydrogeology of the karst spring at The Homeplace on Green River farm, near Campbellsville, is funded through December 2018 by a Natural Resource Conservation Service Conservation Innovation Grant. KGS installed a data sonde capable of measuring multiple water-quality parameters in the spring of 2018. The sonde continuously monitors changes in pH, specific conductance, temperature, and turbidity. Discharge is monitored at a first installed in the fall of 2016. In June 2018, **Ben Tobin**, **Chuck Taylor**, **Steve Webb**, and **Adam Nolte** began making preparations for dye-tracer tests, which will delineate subsurface groundwater flow paths and basin boundaries, as well as identify sinkholes that contribute stormwater runoff to the spring. The dye tracing will continue through the remainder of 2018. These data will help characterize the spring's hydrology in anticipation of a future water-quality sampling project to develop and demonstrate edge-of-field monitoring techniques for water quality and soil-health assessments in sinkhole-dominated crop fields.



Chuck Taylor installs a data sonde in water flowing out of a cave spring at The Homeplace on Green River.



Ben Tobin (right) and **Adam Nolte** prepare to flush a fluorescent tracer dye into the partly blocked swallet (throat) of a sinkhole at The Homeplace on Green River.

Green River watershed nutrient and sediment loss

Glynn Beck is monitoring nutrient and sediment loss from active row-crop fields in the lower Green River watershed in a multiyear collaboration with Brad Lee and Dwayne Edwards of the UK College of Agriculture, Food and Environment. This edge-of-field project, which should run through 2028, is funded in part by the Kentucky Soybean Board and through an Environmental Quality Incentives Program contract from the Natural Resource Conservation Service. Beck and his collaborators identified

six suitable watersheds, ranging in size from 3.5 to 11.5 acres, in late 2017. In March and April 2018, they installed a flume, automated sampler, and ultrasonic flow meter in each watershed outlet. Nutrient and sediment sampling should begin in July 2018. The project will determine the nutrient and sediment loss from active row-crop fields under different nitrogen-application methods. Collaborator Mark Akland of the UK Department of Plant and Soil Sciences is conducting field work for the project.

Collaborative wetland monitoring

Glynn Beck is collaborating with Brad Lee and Dwayne Edwards of the UK College of Agriculture, Food and Environment on a multiyear project to monitor nutrient and sediment runoff from retired row-crop fields that have been converted or are being converted to wetlands. This project, which should run through 2023, is funded through the Wetland Reserve Program administered by the Natural Resource Conservation Service. Six wetland watersheds, ranging in size from 1.5 to 13 acres and located in western Kentucky, have been selected and will be instrumented with a flume, automated sampler, and ultrasonic flow meter by the end of August 2018. The project will assess the nutrient and sediment runoff from wetlands that are in various stages of agricultural or land-use management (for example, soybean field converted to trees, tree and dense vegetation, or mature forest). Leighia Eggett, a recent hire in the UK Department of Plant and Soil Sciences, who is stationed at the Natural Resource Conservation Service office in Mayfield, will perform the field work for this project.



Example of an edge-of-field monitoring station, which includes a flume, wing walls, solar panel, and instrument enclosure containing an automated sampler, flow-meter base station, and 12-volt battery.

Soil-moisture requirements for pivot irrigation

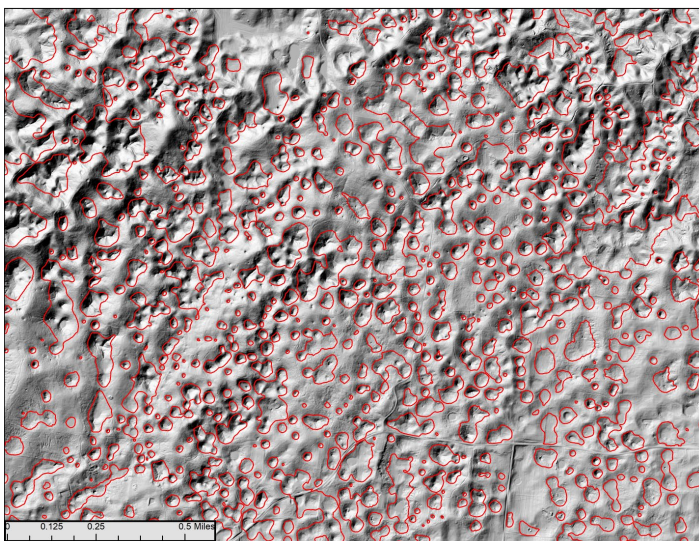
Glynn Beck collaborated with Brad Lee and other researchers from the UK College of Agriculture, Food and Environment to monitor soil moisture in a fragipan (impermeable zone) soil under pivot irrigation in Hickman County. Soil-moisture data collected from a corn field indicate that depth of the fragipan and landscape position influence soil-moisture capacity. In addition to soil-moisture data, groundwater elevation data are collected prior to, during, and after the growing season by a transducer installed in the production water well. A flow meter records the volume of groundwater used to irrigate the corn crop. Transducer data indicate that the local

groundwater elevation dropped during irrigation (July-August 2017), plateaued for several months after irrigation stopped (August-December 2017), and fully recovered to pre-irrigation levels by April 2018. Flow-meter data indicate that 8.2 million gallons of groundwater were used to irrigate approximately 105 acres in July and August 2017. The results will be published in a bulletin by the UK Cooperative Extension Service. The project is funded in part through a Conservation Innovation Grant from the Natural Resource Conservation Service and a Kentucky Water Resources Research Institute 104B Program Student Enhancement Grant.

Princeton Research and Education Center groundwater availability

A project funded in part by the University of Kentucky College of Agriculture, Food and Environment will drill wells and test aquifers in a follow-up investigation of groundwater availability at the University of Kentucky Research and Education Center at Princeton. In 2017, Glynn Beck and other KGS hydrogeologists collected fracture-trace, electrical-resistivity, and dye-tracer test data to help identify the best potential locations for new irrigation wells in a 255-acre row-crop field recently purchased as part of the new UK Grain and Forage Center of Excellence. In January 2018, four test holes ranging in depth from

80 to 160 feet below ground surface were drilled to determine whether the local limestone aquifer is capable of supplying the groundwater needed for planned pivot irrigation research. Beck and the other researchers determined that groundwater availability was severely restricted at the site: three of the test holes were dry and one produced only minimal amounts of groundwater (approximately 5 gallons per minute). Because the groundwater supply there was inadequate, the Center is investigating other potential water sources.



This LiDAR-derived image shows outlines of sinkholes in part of Hardin County.

LiDAR-based sinkhole mapping

Work to create a digital map of sinkhole locations in Kentucky, which began in 2014, continues, and is utilizing the now-complete LiDAR coverage for Kentucky. More information on this project is on page 20.

In a separate but related effort, Junfeng Zhu and Chuck Taylor revised existing maps showing sinkhole locations and information about sinkhole occurrence and other karst-related hazards for the update of the state's hazard mitigation plan (for more information, see page 32).

Drinking water corrosiveness

Junfeng Zhu, collaborating with UK Department of Earth and Environmental Sciences professor Alan Fryar and graduate students Amanda Sherman and Jason Merrick, completed a study of the quality of the Lexington-Fayette County public water supply, with an emphasis on water corrosiveness. This study was in response to the highly publicized water crisis in Flint, Mich., and was supported by the U.S. Geological Survey through the Kentucky Water Resources Research Institute at UK. The project team collected and analyzed 24 tap-water and source-water samples from throughout Lexington in spring and fall 2017. Results indicated that corrosiveness was

generally low, but can increase significantly during icy or snowy winters when large amounts of road salt are applied. Correlation analysis suggested that metal concentrations increase with pipe distance and also are influenced by pipe materials. A model was developed to locate potential areas of concern for metals leaching into Lexington's water distribution system. The final report was submitted to the Institute in May 2018. Sherman made presentations about the project at the 2017 Geological Society of America annual meeting and the 2018 Kentucky Water Resources Research Institute's annual symposium.

KGS assists Division of Water with groundwater sampling

The Kentucky Division of Water is responsible for sampling water quality at about 60 sites, including both wells and springs, across Kentucky as part of the Kentucky Interagency Groundwater

Monitoring Network (www.uky.edu/KGS/water/gnet). Most samples are collected quarterly or twice a year by Division personnel on 12 different sampling runs across the state. KGS geologists Bart Davidson and Richard Smath assist the Division by sampling at three sites: McConnell Spring and Russell Cave Spring in Fayette County, and Royal Spring in Scott County. The Environmental Services Branch Laboratory in Frankfort analyzes the samples, and the resulting groundwater-quality data are uploaded into the Kentucky Groundwater Data Repository.



Bart Davidson (left) and **Richard Smath** (above) gather water samples as part of the state Division of Water's annual sampling of about 60 wells and springs across the state.

Paducah Gaseous Diffusion Plant groundwater model review

Working with Steve Hampson from the Kentucky Research Consortium for Energy and the Environment and Lindell Ormsbee and Kelly Pennell from the Kentucky Water Resources Research Institute, Junfeng Zhu reviewed the groundwater flow model for the Paducah Gaseous Diffusion Plant. The current model is a recent update of a model used as a tool to remediate groundwater that was contami-

nated by decades of uranium enrichment at the plant. The review was to ensure that the model properly represents the groundwater flow system at the site. The modeling project, supported by the U.S. Department of Energy, began in September 2017 and finished in March 2018 when the report was submitted to the Department of Energy.

KGS fulfills legislative mandates

KGS is legislatively mandated to serve as the state's official repository for groundwater information (KRS 151.035) and oversee establishment of a long-term groundwater-monitoring network (KRS 151.625).

The Kentucky Groundwater Data Repository contains well-construction and water-quality sampling data for more than 105,000 sites across Kentucky, including more than 43,000 domestic wells, 1,300 public wells, 875 industrial wells, 4,400 agricultural wells, 35,400 monitoring wells, and more than 5,300 springs. Thousands of analytical results are available for many of these wells and springs. Since the Repository's inception in 1990, data have been compiled from more than 15 agencies, including KGS. The largest annual contributions come from the Kentucky Division of Water, and data compiled by the Division's Well Drillers Certification Pro-

gram and the Kentucky Interagency Groundwater Monitoring Network are uploaded to the Repository approximately once every quarter. Scanned copies of water-well drillers' logs are uploaded approximately every six months. All available Repository data for wells and springs are publicly accessible at www.uky.edu/KGS/water/research/gwreposit.htm and can be searched, downloaded, and displayed online using various base maps. Users can generate comprehensive hydrologic site assessments for multiple purposes, such as groundwater resource exploration, environmental monitoring and remediation, land-use development, recreation, and agricultural planning.

During 2017-2018, KGS hydrogeologists collected groundwater-level data as part of an ongoing effort to rebuild a statewide groundwater observation network. Water levels were continuously recorded using automated water-level logging equipment at 10 observation wells in Caldwell, Calloway, Edmonson, Henderson, Hickman, Marshall, and Scott Counties. Sites for other potential observation wells are being sought in parts of the state where information on groundwater availability is critically needed by groundwater users and water-resource managers. KGS is currently developing a new webpage to display water-level hydrographs for the observation network wells and enable public access to the data.

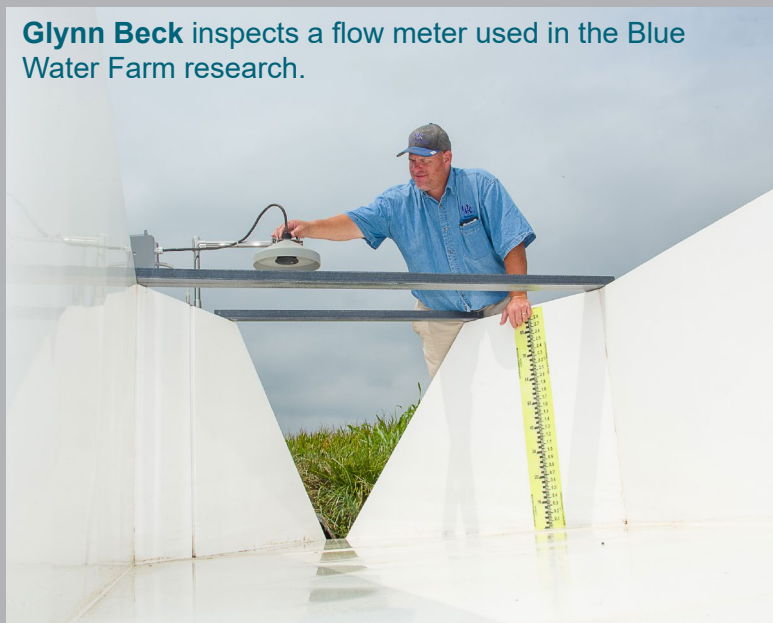
The screenshot shows the 'Water Well & Spring Records Database' search page. The header includes the KGS logo and navigation links. The main content area has a 'Select A Search Method:' dropdown menu with options: 'Search Entire Database (use the search limits below)', 'Search by Quadrangle', 'Search by County', 'ADVANCED: Radius Search (dialing coordinates)', and 'ADVANCED: Radius Search (decimal degree coordinates)'. Below this is a 'Select One or More COUNTIES to search:' section with a list of counties: ADAMS, ALLEN, ANDERSON, BELLARD, and BARREN. A note indicates to hold the 'ctrl' key for multiple selections. There are checkboxes for 'Limit wells & springs to the Kentucky Groundwater Monitoring Network' and 'Return only wells/springs with water-quality data available'. A 'Search Limit for Water Wells Only:' section contains input fields for 'Driller Last Name', 'First Name', 'Driller Certification Number', 'Owner Last Name', and 'First Name'. The page footer shows the time as 9:06 AM on 8/14/2018.

KGS and UK Agriculture faculty collaborate on Blue Water Farms research

Poultry, corn, and soybeans are important agricultural commodities in Kentucky. Sustainable production of these commodities depends on maintaining soil health and local and regional surface-water and groundwater quality. During the fiscal year, KGS hydrogeologist **Glynn Beck** and College of Agriculture, Food and Environment faculty **Brad Lee** and **Dwayne Edwards** initiated a research collaboration called the Blue Water Farms project. The project, funded by the Natural Resource Conservation Service and the Kentucky Soybean Promotion Board, is part of national agricultural research being conducted in 11 states. It promotes voluntary partnerships between agricultural producers and scientists to evaluate best management practices being implemented to improve soil health and nutrient management on agricultural fields, and reduce non-point-source impairments to water-quality.

At present, the KGS-College of Agriculture collaboration is evaluating nutrient best management practices, including applying poultry litter and establishing cover crops in corn and soybean rotations in the Lower Green River watershed. This long-term research project benefits from a close working relationship with cooperating Kentucky agricultural producers, who have allowed monitoring equipment to be installed on their farms. Data obtained from this project are proprietary, but will be used to model nutrient and sediment retention under differing management practices and to educate agricultural producers on conservation practices that are economically viable and also protect Kentucky's water resources.

Glynn Beck inspects a flow meter used in the Blue Water Farm research.



KGS laboratory support

The KGS analytical laboratory supports the research of KGS geologists, faculty and graduate students from the University of Kentucky, and students from other Kentucky universities by providing analytical expertise, as well as training on and access to analytical instruments. During the fiscal year, the laboratory analyzed water, mineral, coal, and biological samples from across the state for 14 ongoing projects.

Water-quality monitoring projects in Hardin County, at Cane Run, and at the Kentucky National Guard's Harold L. Disney Training Center, near Barbourville, send samples to the KGS lab. The lab also provides analysis for Kentucky Watershed Watch, and has done so since 1998. Many Kentucky River samples were analyzed for nutrient and metals in fall 2017. The UK Mining Engineering Department and Center for Applied Energy Research also supply

KGS laboratory (continued)

samples for a project to quantify rare earth elements in coal ash and refuse. The lab also analyzed biological samples for several researchers in the UK College of Medicine.

New instrumentation and enhancements this fiscal year will greatly enhance our ability to meet the analytical needs of our research scientists. A portable, field-capable gas chromatograph will enable KGS scientists to analyze volatile hydrocarbons, gases, and other types of organic compounds occurring in both gas and water samples. A new radiation tube was installed on the X-ray diffractometer that we share with other departments at UK; the diffractometer is housed in our laboratory and maintained by KGS.

More than 20 different researchers used the diffractometer this year.

Lab personnel train students from several Kentucky universities on how to use scientific equipment and instrumentation. For example, students from Morehead State University learned about sample preparation, X-ray fluorescence, and X-ray diffraction; students from Western Kentucky University were trained in X-ray fluorescence techniques and used the X-ray fluorometer; and several students from the UK Department of Earth and Environmental Sciences were trained to use our carbon analyzers.

Awards and recognitions

- Section Head **Chuck Taylor** is an appointed member of the Kentucky Agriculture Water Quality Authority.
- Taylor and **Glynn Beck** are members of the Kentucky Agricultural Science and Monitoring Committee.
- **Bart Davidson** is an appointed member of the Kentucky Water Well Certification Board.
- **Junfeng Zhu** is an associate editor of *Groundwater*, the journal of the National Ground Water Association.
- **Ben Tobin** is treasurer of the Karst Division of the Geological Society of America.

Energy and Minerals

Fossil fuels research

Berea Sandstone findings available

In addition to a final report made available to the public in May 2017, results from the petroleum system analysis of the Berea Sandstone were presented at a theme session, “Devonian-Mississippian Petroleum Systems,” at the 2017 annual meeting of the Eastern Section of the American Association of Petro-



KGS and the Geological Society of Kentucky sponsored an October 2017 core workshop and field trip on the Berea Sandstone.

leum Geologists in Morgantown, W.Va. The session, co-chaired by **Marty Parris** (also a speaker), included five talks on the Berea study by **Cortland Eble**, **Steve Greb**, **Dave Harris**, and **Paul Hackley** of the U.S. Geological Survey. The project team is writing manuscripts for the *AAPG Bulletin*; pending editorial review, they will be published in 2019.

Oil and gas potential of the Rogersville Shale

Research to determine the unconventional oil and gas potential of the Cambrian Rogersville Shale in eastern Kentucky continued in 2017-2018. Previous work by the Rome Trough Consortium in 2002 identified the Rogersville Shale (Conasauga Group) as a mature hydrocarbon source rock; its total organic carbon content is up to 4 weight-percent. Six wells have now been drilled to test the Rogersville in Kentucky and West Virginia. In 2018, the logging and completion data from two of these new wells (the Bruin Exploration No. 1H Walbridge Holdings in Lawrence County, Ky., and the Cabot Oil & Gas No. 50 Amherst Industries in Putnam County, W.Va.) were released, although the data from the remaining wells will be confidential until 2019 or 2020. KGS researchers are using these additional data to refine their interpretations of the thickness, depth, and lithologic character of the Rogersville Shale, as well as the rest of the Middle–Upper Cambrian Conasauga Group rocks.

John Hickman and **Dave Harris** have been evaluating the social and economic

impacts of resource development prior to any significant drilling in the Rogersville. Anticipating possible funding opportunities for emerging shale resources in the future, they and other KGS petroleum geologists are continuing research on the Rogersville to support interest in the play from exploration geologists working in both local and national energy companies. KGS has become the predominant source of public information on the Rogersville Shale.



Dave Harris shows Rogersville Shale cores at the AAPG–Eastern Section annual meeting in Morgantown, W.Va.

Oil and gas workgroup proposals passed by legislature

The Kentucky Legislature mandated an oil and gas workgroup (Kentucky House Bill 563) in its 2016 Regular Session. **Brandon Nuttall** was appointed to the group by Energy and Environment Cabinet Secretary **Charles Snively**. Consensus regulations proposed by the workgroup are now in effect for disposal and management of technologically enhanced naturally occurring radioactive material waste in landfills, rock cuttings at drill sites, and oil-field pipe materials. In 2018, the workgroup proposed Senate Bill 249 (passed by the General Assembly), which updated hearing processes of the Division of Oil and Gas, especially hearings involving pooling of adjacent leases for deep well drilling, enhanced recovery projects, and sequestration of carbon dioxide. Regulations to implement the new statutes are being developed.

KGS provides data for National Coal and Energy Minerals Resource Data System

This national cooperative program between the U.S. Geological Survey and state geological surveys provides funding to collect and assimilate data on coal and organic shales. Examples of the data are coal-quality analyses (proximate, ultimate), stratigraphic records (borehole descriptions, correlations), and resource estimates. The state-level data are included in a series of national databases. **Steve Greb** and **Cortland Eble** manage the Kentucky portion of this cooperative program. **Ethan Davis** worked on the project for part of the year, helping to prepare coal samples for a variety of analyses. This multiyear project ended in 2017, however, because the program was cut from the U.S. Geological Survey's budget.

Eastern and Western Kentucky Coal Field research continues

Steve Greb and **Cortland Eble** continued research on coal-bearing Pennsylvanian strata in both the Eastern and Western Kentucky Coal Fields. Although our state's coal production has declined in recent years, the national and international geological community remains interested in data about past mining, the state's general geology, and Kentucky's outstanding outcrops. Researchers from around the world have come to Kentucky to study our extraordinary roadcuts and highwalls, and to collect data for their research. Depositional facies between coals are of particular interest to oil and gas researchers, because they can provide two- and three-dimensional

exposures of a variety of coastal-deltaic reservoirs for comparison with downhole data from other areas. This year, Greb and Eble measured several new outcrops from newly constructed roadcuts, sampled coal and carbonaceous shales for analysis, and updated the KGS coal information website. Research on exposures in eastern Kentucky, created by new road construction in the vicinity of Jackson, provided the framework for a paper by Eble and Greb published in the journal *Palynology*. Eble and Greb also wrote a paper based on coal and shale samples provided by Alliance Resource Partners LLC that was published in the *International Journal of Coal Geology*.

Staff award

- **Steve Greb** was presented the Distinguished Achievement in Geoscience Award by the Geological Society of Kentucky at the KGS annual seminar in May 2018.

Energy and the environment

Carbon-storage potential and the Kentucky Energy Independence and Incentives Act

Steve Greb and Dave Harris are finishing work on cores from the KGS No. 1 Hanson Aggregates well in Carter County, drilled to a depth of 4,835 feet in 2013 to assess the geologic carbon storage potential of northeastern Kentucky.

Rick Bowersox and co-authors Steve Greb and Dave Harris have completed three reports on this well. First is an operational review of the well, in press as a KGS Information Circular. The others are journal articles on CO₂ storage capacity of the

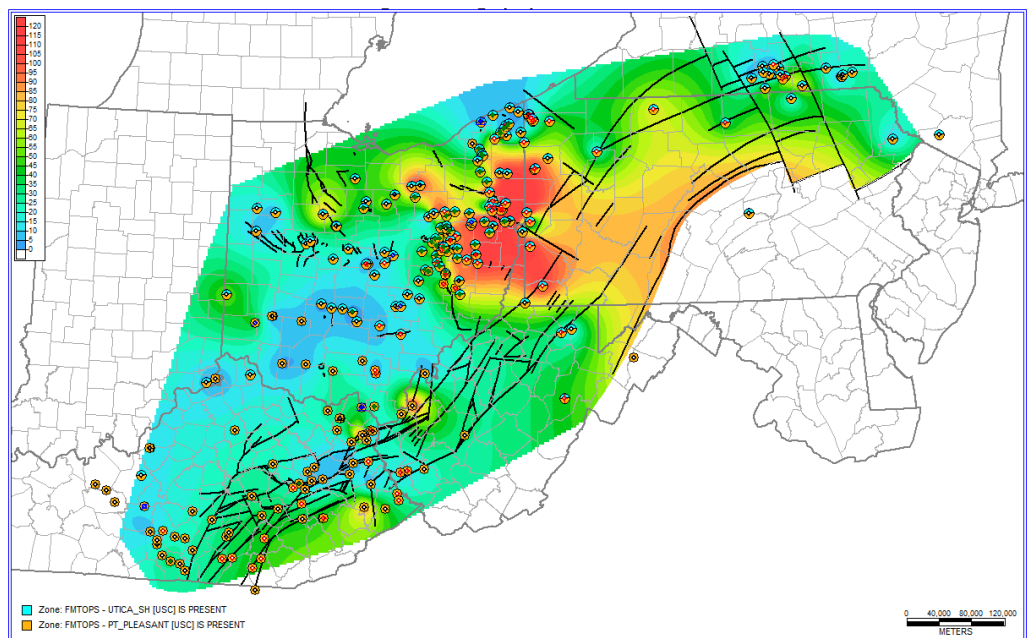
Maryville sand–Basal sand section, to be published in *Environmental Geosciences*, and another manuscript on the Rose Run Sandstone. Bowersox is writing the final analytical report on the Carter County project, which should be completed in mid-2018. Although there are currently no plans to store CO₂ in the deep subsurface in Kentucky, all of our research indicates that CO₂ could be confined in the deep subsurface and remain there indefinitely, making these formations potential storage options.

Regional carbon storage assessment

KGS participates in the Midwest Regional Carbon Sequestration Partnership, funded by the U.S. Department of Energy and managed by Battelle Memorial Institute. The partnership was established to assess the technical potential, economic viability, and public acceptability of carbon storage in the region. It is one of seven regional Department of Energy carbon-storage partnerships in the United States. Brandon Nuttall, Tom Sparks, and Steve Greb are working on phase III of the project, assessing the potential for carbon storage and enhanced gas recovery in organic-rich Devonian shales in the region, and compiling cross sections.

For the enhanced gas recovery project, total organic carbon content, density, and maturity data were compiled by research partners and are being analyzed for the Marcellus and Utica Shales in the eastern United States. KGS researchers are proposing new models for estimating total organic carbon using wireline log data for the Ordovician Utica Shale, and these models are being used to compile a new series of maps and storage assessments. We are collaborating with researchers from other states to make a series of cross sections that display the subsurface geology of the region relative to carbon-storage potential (showing potential reservoirs and confining intervals), from Precambrian basement to the surface. Information about the regional partnership and a list of the partnership's publications can be found at www.mrcsp.org.

Thickness of rocks with organic carbon content greater than or equal to 1.5 percent in the Ordovician Point Pleasant–Trenton Limestone interval. These organic-rich calcareous shales have potential for storing injected CO₂.



Environmental impacts of abandoned wells

Methane emissions associated with oil and gas activities have received national attention as the boom in natural-gas production from unconventional reservoirs has dramatically changed the energy portfolio in the U.S. Natural gas emits less carbon dioxide than coal, and therefore can be a transition fuel to a less carbon-intensive economy. Methane, the main component of natural gas, is itself a potent greenhouse gas, however, and emissions from oil and gas operations threaten to undermine some of the environmental benefit of natural gas. Methane emissions associated with active operations have attracted the most interest from researchers, but abandoned oil and gas wells—wells not properly decommissioned—are also potential sources of emissions, and have received little attention. The number of abandoned wells nationwide is significant (more than a million), and in Kentucky the number exceeds 14,000. The influence

of abandoned wells on the methane budget is largely unknown, and therefore is an understudied environmental challenge. Because the potential impact of abandoned wells can be both local (groundwater contamination) and global (greenhouse gas contribution), **Marty Parris, Brandon Nuttall, Jason Dortch, and Tom Sparks**, along with **Kelly Pennell** of the UK Department of Civil Engineering, are interested in the topic. They hope to find funding to (1) develop a hazard profile for potential leakage from abandoned wells, which can then be transformed into a hazard potential map, (2) measure the methane seepage or flow and soil-gas geochemistry at a subset of abandoned wells that fall into different hazard categories, and (3) estimate chemical flux from abandoned wells in different hazard categories using numerical models that describe vapor transport.



Underground brine-disposal and enhanced-recovery wells

Environmental concerns about wastewater disposal wells have received attention from the media and the public. In wastewater disposal, brines brought to the surface with oil and gas production are reinjected into the same or other porous underground formations. This practice helps protect underground drinking-water sources. The U.S. Environmental Protection Agency previously regulated all Class II underground injection wells in Kentucky under its Underground Injection Control Program, but the Commonwealth of Kentucky assumed primacy on Jan. 27, 2017. The Kentucky Department of Natural Resources–Division of Oil and Gas is now responsible for the regulation of Class II injection wells in Kentucky.

After **Tom Sparks** compiled a database of all Class II wells in Kentucky, a new KGS internet map service was developed to display the data and linked to the petroleum map service on the KGS Oil and Gas Data webpage. The database was developed with the original 100 brine-disposal wells whose locations are shown on “Class I Waste-Disposal Wells and Class

II Brine-Injection Wells in Kentucky” (KGS Map and Chart 204, series 12, published in 2013), as well as an additional 2,900 enhanced oil-recovery injection wells. Since 2014, the map service has been continually updated as brine-injection disposal wells are permitted or new EPA documents have been obtained.

In 2017, the Division of Oil and Gas received more than 100 boxes of legacy data related to the Kentucky UIC well inventory (annual reports of injection, mechanical integrity tests, etc.) from the EPA. Division personnel have nearly completed the process of scanning and tagging the records. The wells will be indexed by Kentucky permit and UIC permit numbers and should eventually be matched to the KGS Oil and Gas Records Database. In the future, these data will be served through the KGS petroleum map service and will be made publicly available. These new data will help with microseismicity monitoring, as monthly injection volumes and pressures will be available to compare with seismic records.

Portable gas chromatograph

The intersection of energy development and environmental concerns has fostered new collaborations within and outside of KGS (see “Environmental Impacts of Abandoned Wells,” page 14). Chemical characterization—especially of organic compounds—is an important part of these collaborations, and our recent acquisition of a gas chromatograph will fill an important analytical gap. The new chromatograph is versatile and capable of analyzing gas, water, and soil samples. It is equipped with a thermal conductivity detector, flame ionization detector, and dry electrolytic conductivity detector. It is also equipped with an automated purge-and-trap collector for analysis of volatile organic compounds according to EPA methods. The entire system is compact and robust enough that it can be used in the field, with a generator as a power source. **Jason Backus** and **Marty Parris** are developing a method to use the chromatograph, and hope to have the instrument in use by late summer of 2018. The chromatograph was purchased with a grant

from the UK Vice President of Research’s Office. Collaborators using the new instrument include the departments of Agriculture (**Rebecca McCulley**), Civil Engineering (**Kelly Pennell**), and Earth and Environmental Sciences (**Alan Fryar**).



Regional stress map of Kentucky

Efficient planning and execution of directional drilling and hydraulic fracturing programs for oil and gas wells require an understanding of the current subsurface state of stress. Furthermore, indications of past stress states can help elucidate the history of geologic deformation. In an effort to provide the public with a map-based assessment of the principal stress field across Kentucky, **John Hickman** is compiling direct and indirect stress data from numerous sources in a GIS project. In addition to the few scattered data points in and around Kentucky published by the World Stress Map Project (www.world-stress-map.org), measurements of coal-vein azimuths from both surface and subsurface mines, strikes and

dips of joints from the original U.S. Geological Survey 1:24,000-scale geologic mapping project in Kentucky, recent sandstone fracture data from KGS geologic mapper **Steve Martin**, and subsurface drilling-induced fracture data from oil and gas well logs have been combined into a single geographic framework. Hickman used the data set's 5,765 data points to analyze stress-direction data by geologic age, dominant lithology type, and depositional basin or region to look for areal trends. Future work will incorporate recent first-motion data from earthquakes provided by the Kentucky Seismic and Strong-Motion Network and the Eastern Kentucky Microseismic Monitoring project (see page 29).

Precambrian geology of southeastern Laurentia

Using published zircon geochronology work, **Rick Bowersox** and **John Hickman** are studying the Precambrian geology and tectonic history of Kentucky and surrounding states. They have compiled and analyzed geologic descriptions, gravity and aeromagnetic surveys, and logging data from wells penetrating Precambrian rocks in Kentucky, Indiana, Illinois, Ohio, and Tennessee. Earlier this year, Bowersox provided **Dave Moecher** of the UK Department of Earth and Environmental Sciences with core samples from a well in Hancock County, Ky., to be used in new zircon geochronology work on the Precambrian Middle Run Sandstone. Bowersox and Hickman are helping Moecher investigate (1) the nature of the Grenville Front (a continental suture, boundary fault, or just the westward limit of past metamorphism), (2) whether the Middle Run is a rift-basin deposit that predates the Grenville or a foreland basin deposit of the Grenville Orogeny, and (3) whether the East Continent Gravity High in central Kentucky is a remnant of the Midcontinent Rift Volcanic Suite, a Grenville feature, or something else. The answers to these questions will help us understand the tectonic

history of the Midcontinent region during the Precambrian Era. This research will help define the distribution of Kentucky's energy and mineral resources and their exploration and development. It will also be important for assessing the potential for oil and gas production and wastewater injection to induce seismicity, as has happened in Oklahoma and Kansas.

After identifying the need for updated interpretations of the Grenville Orogeny and its effect on Kentucky basement using modern data and theories, Hickman and Bowersox proposed a technical theme session for the 2018 Geological Society of America annual meeting in Indianapolis: "Different Roads to Rodinia: Re-Analysis of the Geochronology and Tectonic Evolution of Precambrian Sedimentary and Crystalline Basement Terranes in Southeastern Laurentia." Hickman will participate in an EarthScope workshop funded by the National Science Foundation, which will allow him to develop and discuss new interpretations of the creation of the Grenville Front through Ohio, Kentucky, and Tennessee with other earth scientists. The workshop will be held at Northwestern University July 25–28, 2018.

Cortland Eble receives Cady Award from Geological Society of America

In October 2017, Cortland Eble received the prestigious Cady Award at the Geological Society of America annual meeting in Seattle. **Jim Hower** of the UK Center for Applied Energy Research nominated Eble and presented the award (right). The award, named for respected coal researcher Gilbert H. Cady, is given to scientists who have made outstanding contributions to the study of coal and associated rocks, including their economic implications. Eble has been at the Survey since 1990, analyzing coal beds and organic-rich petroleum source rocks, as well as studying coalbed methane. He is also a palynologist, studying fossil spores and plant pollen in coal. He oversees a coal-quality database available through the KGS website.



Kentucky 3-D geologic database being assembled

John Hickman is working with **Drew Andrews** and **Doug Curl** on a new database referred to as 3DKY. This project will result in a searchable, relational database of point (well-based), line (two-dimensional profile), and areal (map-based) geologic data that retain the location coordinates of those data in three-dimensional space. They will also design queries to extract formation depths from the database to predict horizon depths at any location in the commonwealth. To help guide the design direction and capabilities of this project, KGS organized open discussions with GIS and digital mapping professionals who attended the 2018 Digital Mapping Techniques meeting at UK.

In 2017-18, Hickman filled in near-surface structure-contour data missing from 1:24,000-scale

geologic quadrangle maps, using data from oil, gas, and domestic water wells, and new high-resolution LiDAR-based topography data. These data will allow the project team to make dip and azimuth maps and produce subsurface structure maps. In addition, Hickman mapped the base geologic architecture and lithostratigraphic framework for the data model and is developing a regional three-dimensional fault model that can be used to separate regions of differing structural history. As a limited test of potential, Hickman is using the data to help identify the specific aquifers penetrated by high-output water wells in Kentucky.

Staff awards

- A paper by **Marty Parris**, **Paul Hackley** (of the USGS), **Steve Greb**, and **Cortland Eble**, “Molecular and Isotopic Composition of Associated and Nonassociated Gases and Evolution of Gas in the Berea Sandstone, Eastern Kentucky,” was awarded the Eastern Section of the American Association of Petroleum Geologists’ A.I. Levorsen Memorial Award for best oral paper during the Eastern Section annual meeting in September 2017 in Morgantown, W.Va.
- Also at that meeting, a poster by **Rick Bowersox**, **Steve Greb**, and **Dave Harris**, “Porosity and CO₂ Storage Capacity of the Maryville–Basal Sandstone Section in the Kentucky Geological Survey 1 Hanson Aggregates Stratigraphic Research Well, Carter County, Kentucky,” won the Best Poster Award presented by the Section’s Division of Environmental Geosciences.

Mineral resources

Rare earth elements in coal and coal-combustion byproducts

Cortland Eble, Ethan Davis, and Jason Backus, along with researchers from the UK Department of Mining Engineering and the Center for Applied Energy Research, are testing for economic concentrations of rare earth elements in Kentucky coal, coal-preparation refuse, and coal-fired power-plant byproducts. Rare earth elements are the lanthanide series elements (lanthanum through lutetium on the periodic table) plus scandium and yttrium—collectively known as REE+Sc+Y. The U.S. Department of Energy provided phase II funding to UK for this research in March 2017; the goal is to set up and operate a mobile unit to extract rare earth elements at an active coal mine and preparation plant in Kentucky.

So far, approximately 500 samples from coal preparation plants have been evaluated. Research will identify specific grades of material in preparation plants that contain the highest amounts of REE+Sc+Y. After that task is completed, the researchers will determine the most cost-effective way to separate and concentrate REE+Sc+Y.

DOE is also funding a second UK project to evaluate the REE+Sc+Y potential of western Kentucky coal beds. More than 400 samples from the KGS Well Sample and Core Library, exploration drill cores, and active coal mines have been collected and tested for REE+Sc+Y. The goal is to identify coal beds that contain more than 300 parts per million of REE+Sc+Y. Results thus far indicate that one coal in particular, the Baker coal, consistently meets or exceeds this threshold. Other coals are also being evaluated.

The role of KGS in both projects is to identify and collect samples, crush the samples, convert the coal to ash in a muffle furnace, and then dissolve the ash using strong mineral acids (hydrofluoric, nitric, and hydrochloric). The dissolved ash is then tested for REE+Sc+Y using inductively coupled argon plasma optical emission spectroscopy.

DOE has recently funded a third UK project to compare methods of testing for rare earth elements used by different laboratories across the United States. KGS will collect and test Appalachian coal samples from Pennsylvania, Kentucky, and Alabama, and then distribute representative splits of the collected materials to other participating laboratories. This project is a collaborative effort with the University of North Dakota.

Since the late 1980s, nearly all of the rare earth elements used in the United States have been imported from China. These projects are part of an aggressive effort to boost domestic production.



Ethan Davis prepares to analyze samples for rare earth elements.

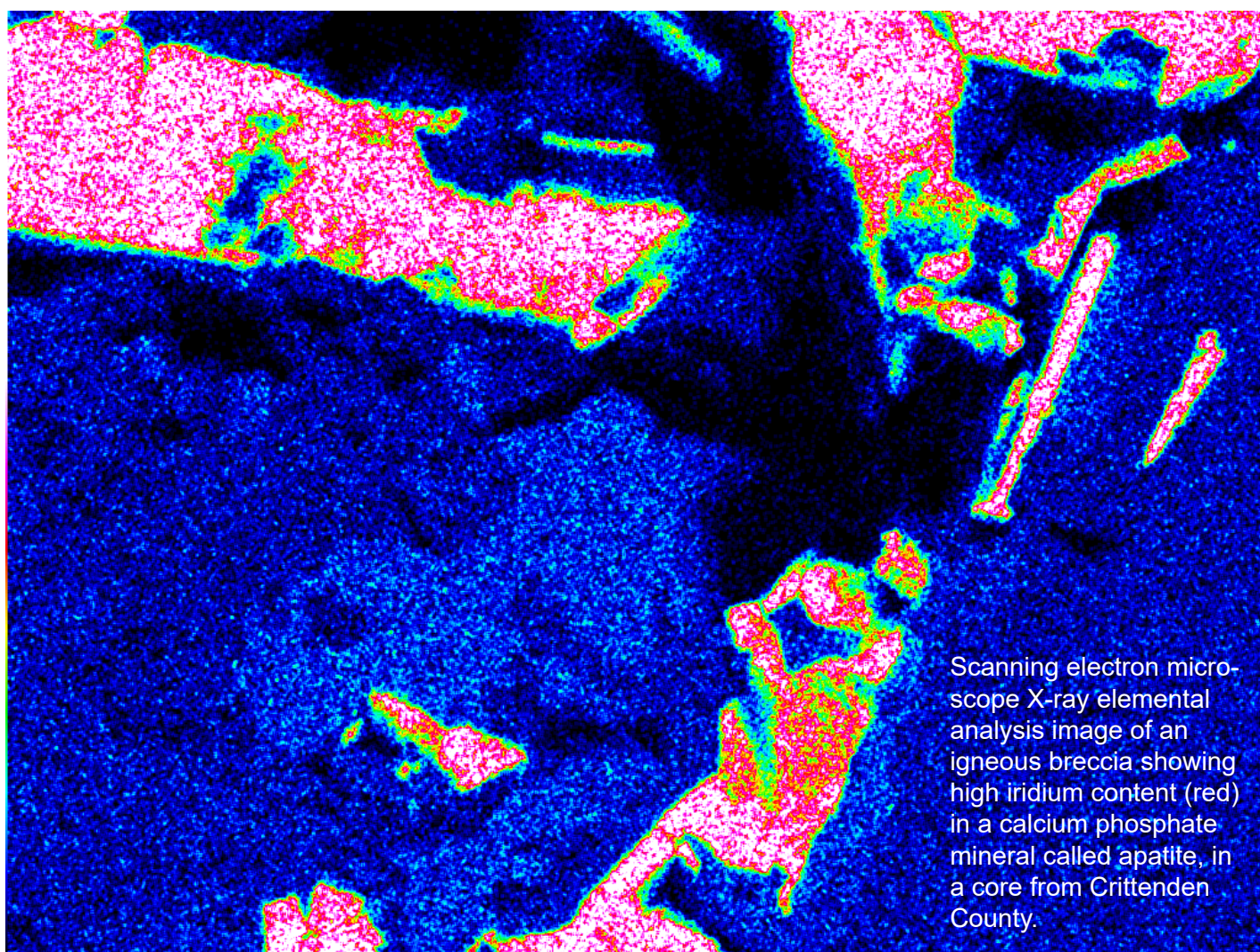
KGS searches for rare minerals in the Western Kentucky Fluorspar District

Warren Anderson and Jason Backus are investigating the occurrence of rare minerals in igneous rocks in the Western Kentucky Fluorspar District. Preliminary mineralogic and petrologic analysis indicates that the depositional process may have concentrated rare earth elements there.

These igneous dikes contain rare minerals such as astrophyllite, schorlomite, niobium rutile, villiamite, natrite, wüstite, fluoro-tetraferriphlogopite, and several fluorides; they are considered “pathfinder minerals” that can suggest the occurrence of a

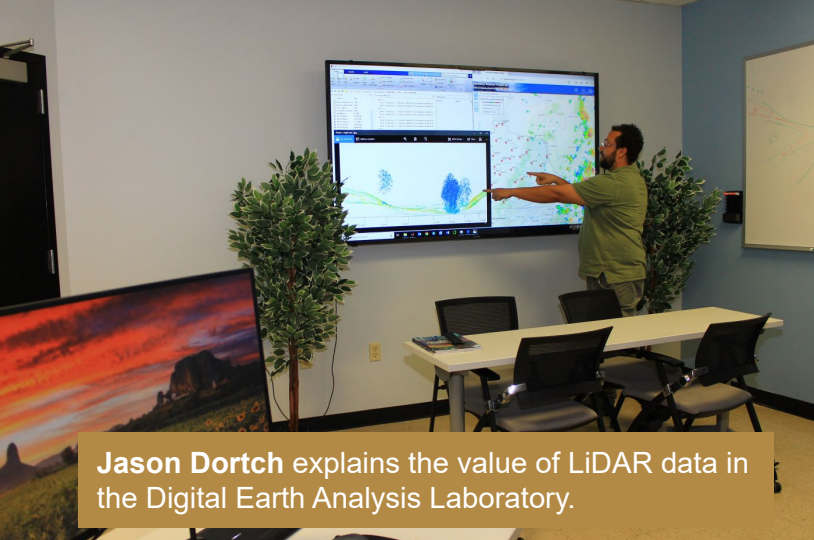
REE-bearing rock called carbonatite. Anderson and Backus will also examine other elements and minerals of strategic importance, including cobalt, iridium, molybdenum, chromite, and various titanium minerals.

Rare earth elements are critical for electronics, magnets, green energy applications, and military use, including smart weapons systems. Reducing the United States’s dependence on foreign sources of REEs (particularly China) has national security implications.



Scanning electron microscope X-ray elemental analysis image of an igneous breccia showing high iridium content (red) in a calcium phosphate mineral called apatite, in a core from Crittenden County.

KGS DEAL



Jason Dortch explains the value of LiDAR data in the Digital Earth Analysis Laboratory.

New laboratory created to develop the use of LiDAR data

KGS established the Digital Earth Analysis Laboratory—known as KGS DEAL—in 2017 to help make the Survey a leader in LiDAR (light detection and ranging) solutions for geologic, engineering, and environmental problems in Kentucky.

LiDAR is a type of laser scanning that can be performed using airplanes, helicopters, automobiles, and, increasingly, even high-end drones; it has revolutionized many aspects of geology during the past 20 years. One of the attractions of LiDAR is that trees and brush can be mathematically removed to create exceptionally detailed three-dimensional topographic maps, shaded-relief images, and digital elevation models, even for heavily forested areas. Geologists have come to value LiDAR because it provides information about geologic features such as landslides, faults, sinkholes, floodplains and flood deposits, and disturbed lands at a level of detail never before possible. Foresters, civil engineers, soil scientists, hydrologists, emergency managers, and even archaeologists have quickly found LiDAR to be indispensable in their work.

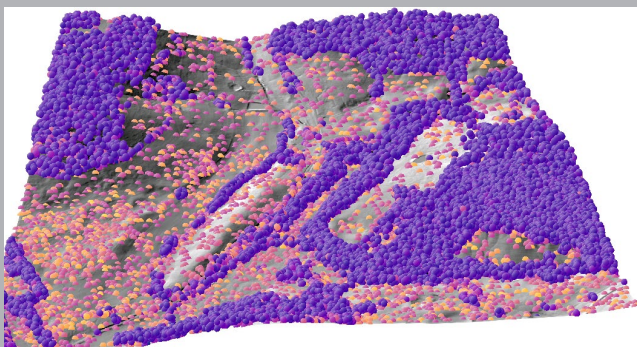
The practical benefits of a statewide digital elevation data set are many. Kentucky's Division of Geographic Information embarked on a multiyear program known as KYAPED—Kentucky Aerial Photography and Elevation Data—in 2010. The final installment of statewide airborne LiDAR coverage was released early in 2018. KGS geologists have been using LiDAR data for projects around the commonwealth as they have become available.

Jason Dortch joined KGS in January 2018 as a post-doctoral fellow, a first for KGS, to manage KGS DEAL and work with other KGS scientists to identify new LiDAR applications beneficial to the commonwealth. KGS DEAL has three high-speed computer workstations, specialized software, a dedicated LiDAR data server that facilitates accessing the 14 terabytes of Kentucky statewide data, and an 80-inch touchscreen monitor for group collaboration. Dortch is currently using convolutional neural networks to determine whether a machine-learning approach can help to locate previously unknown abandoned oil and gas wells, which could pose environmental and safety hazards; he is also working with other KGS scientists to more accurately map modern and ancient floodplain deposits along the Ohio and Licking River Valleys.

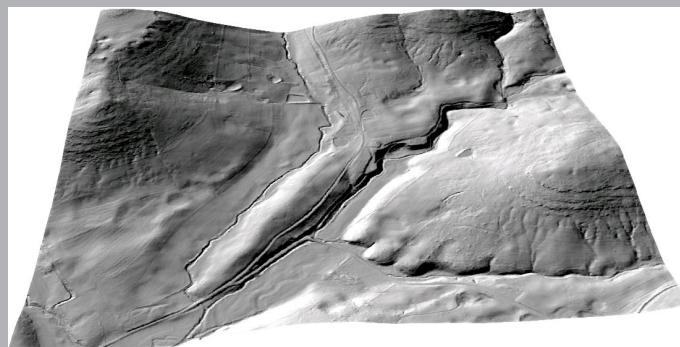
KGS hydrogeologist **Junfeng Zhu** started using LiDAR data to map Kentucky's many sinkholes in 2014. He and geological technician **Adam Nolte** mapped three more counties—Bourbon, Hardin, and Madison—which added 17,500 more sinkhole locations to the sinkhole database during the past year, bringing the total number of counties mapped to 10. The results are available on the KGS internet map service. The sinkhole mapping team is turning to machine-learning techniques to help automate and expedite the process.

Several years ago, KGS landslide researcher **Matt Crawford** developed a LiDAR-based method to locate landslides in Kenton and Campbell Counties, where steep slopes and weak shale bedrock cause chronic slope-stability problems. LiDAR also helps to confirm the location and type of landslides listed in KGS's statewide landslide inventory. Like the sinkhole maps, the landslide inventory is available as a layer in our internet map service. Visiting Kent State University graduate student **Hannah Chapella** made good use of LiDAR to more accurately map

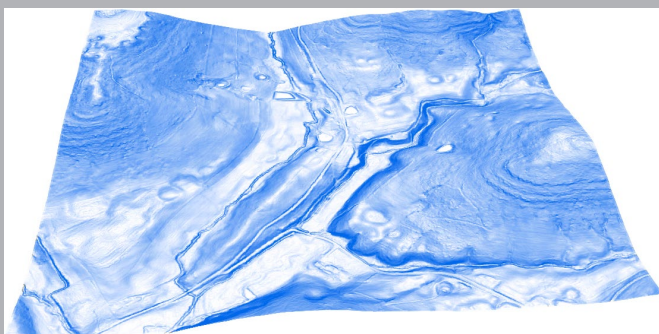
Types of LiDAR images



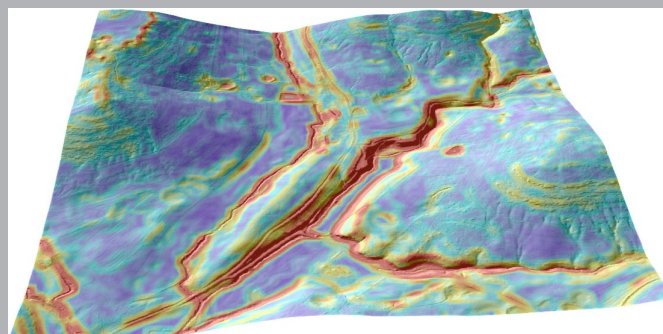
LiDAR-derived topographic surface superimposed with 3-D points representing nonground (mostly vegetation) returns colored by laser return intensity. Purple dots indicate low-intensity returns characteristic of forested areas whereas pink and yellow dots indicate high-intensity returns characteristic of nonforested areas such as fields or pastures.



Hillshade image of the bare earth LiDAR digital elevation model with simulated illumination from the northwest (upper left), useful for general landscape visualization and geologic interpretation.



Slope-shade image of the bare earth LiDAR digital elevation model with darkness proportional to slope angle, useful for delineating features such as landslides, sinkholes, areas of active erosion, and disturbed land.



LiDAR-derived hillshade image draped with colors representing the degree of topographic roughness, which can be used to identify features such as bedrock outcrops, landslides, land-use differences, and land disturbances. Blue and green indicate smooth areas whereas orange and red indicate rough areas.

Data source: KyFromAbove LiDAR 5,000-foot tile N188E268, Clinton County.

landslides in the Prestonsburg area during the summer of 2017. She also used LiDAR images, bedrock and soil information, and slope steepness to develop a landslide-susceptibility model using PISA-m, a

physics-based, probabilistic slope-stability computer program written by Bill Haneberg before he joined KGS.



FY 2017-2018 mapping provided our first encounter with an exposure of till—material that was directly deposited by glacial ice—in northern Kentucky. It was found in a creek valley in western Boone County.

Geologic mappers use new technology for surficial mapping

KGS produced maps for areas that citizens groups, through the Kentucky Geologic Mapping Advisory Committee, determined to be high priority and developed critical derivative maps and applications. We have expanded our use of LiDAR data and collaborated with other KGS researchers on integrative projects. We have also adopted a more efficient team-based mapping approach and helped to develop a comprehensive three-dimensional data system for the Survey.

Geologic mappers continued surficial mapping of 7.5-minute quadrangles in northern Kentucky. With funding from the U.S. Geological Survey's STATEMAP program, KGS mapped the Rising Sun, Patriot, Covington, and Newport quadrangles, and Kentucky portion of the Lawrenceburg, Ind., quadrangle. This completed surficial mapping in northern Kentucky and will allow us to start compiling maps for Boone, Kenton, and Campbell Counties.

Matt Massey expanded his role as the field mapping manager and took a new team approach to the work, assigning each mapper geologic domains instead of specific quadrangles. Rather than having to examine and interpret all of the features of an

Geologic Mapping

entire quadrangle, the mappers now focus on geologic themes and improve their expertise in particular features. They made full use of a spatial database engine that allows digital mapping data to be simultaneously edited by multiple users and coordinate their efforts.

Mapping was enhanced by LiDAR data, grain-size and geochronology laboratory analysis, and data gathered from outside sources. **Max Hammond** used a LiDAR-derived relative elevation model to establish relationships between widely separated outwash terraces along the Ohio River. **Massey** used LiDAR data to compile histograms of elevations of different terraces to identify and correlate sets of terraces on the Licking River.

KGS hosted the 2018 Digital Mapping Techniques national conference on the UK campus, attended by more than 70 cartographers, GIS professionals, and other geoscientists from around the country. Workshop sessions were held May 20–23 at the Don and Cathy Jacobs Science Building. At a “digital open house” during the conference, KGS staff gave presentations on their use of new mapping technologies, digital field data-collection methods, and



Steve Martin examines materials in a creek bed during a field review for the northern Kentucky mapping project.

the capabilities of the Survey's online map service. The annual conference has provided a networking opportunity for sharing techniques, outcomes, and lessons learned for 22 years.

William Andrews worked with structural geologist **John Hickman** to establish the intended structure and function of a planned three-dimensional database for Kentucky.

Emily Morris began working as the Survey's cartographic data manager on Jan. 2, 2018. She studied spatial analysis in public health, and had previously worked with environmental consulting com-

panies, collecting GIS field data, designing maps, and conducting GIS analysis. At KGS, she has worked on the surficial mapping products funded by STATE-MAP and data compilation and management.

Geologic mappers participated in the annual conference of the Kentucky Association of Mitigation Managers, the Kentucky GIS Conference, the Geological Society of America annual meeting in Seattle, GSA Southeastern and Northeastern Section meetings, and the Geologic Mapping Forum in Minneapolis.

Longtime KGS cartographer **Terry Hounshell** retired in October 2017. During his 28-year career at the Survey, he created numerous maps and illustrations. "His meticulous attention to detail was evident in every map he produced or assisted with," KGS hydrogeologist **Bart Davidson** said of Hounshell. "He had a wonderful eye for choosing colors that made maps pleasant to look at." KGS staff recalled that Hounshell would drop what he was doing on many occasions to help find a particular base map or provide advice on a GIS project.

Hounshell received cartographic training with the U.S. Geological Survey for a year after his high school graduation. He later worked with the Lexington-Fayette Urban County Government, managing cartographic projects, and as a consultant to the Winchester/Clark County Planning Commission, providing mapping services.



Outreach and Professional Engagement

Fifty-seventh annual KGS seminar

The 2018 KGS annual seminar focused on geoscience communication and featured speakers from KGS and several other UK and outside organizations. More than 140 people attended the May 18

seminar at the Well Sample and Core Library. Representatives of the Kentucky Water Resources Research Institute and the UK Colleges of Nursing and Public Health made presentations. Keynote speakers were **Lauren Cagle** from the UK Department of Writing, Rhetoric and Digital Studies and **Aileen Buckley** of the mapping and spatial software company Esri.



Aileen Buckley

Iain Stewart delivers lecture at UK

Scottish geoscientist **Iain Stewart**, director of the Sustainable Earth Institute at Plymouth University in England, delivered “Between a Rock and a Hard Place: Communicating Contested Geoscience to the Public.” The Jan. 17, 2018, event attracted 50 people to the UK campus. Stewart, a professor of geoscience communication, has worked with BBC Science to host a number of television documentaries. His visit to campus was a stop on his James B. Thompson Jr. Distinguished International Lecture tour sponsored by the Geological Society of America. It was also a part of KGS’s **Donald C. Haney** Lecture Series, named for the former state geologist and director of KGS from 1978 to 1999, who died in 2014.



Iain Stewart

Berea Sandstone core workshop



On Oct. 6, 2017, KGS and two professional geological societies organized a short course and field trip to acquaint geologists with the Berea petroleum reservoir, located in parts of eastern Kentucky. Steve Greb and Dave Harris led the short course, “Black Shale, Bedford-Berea Interval,” at the Well Sample and Core Library. The final report on the Berea Sandstone Petroleum System Consortium research project had been released earlier in 2017.

Core Library display at downtown Lexington Public Library

In November 2017, staff of our Well Sample and Core Library set up displays in glass cases on three floors of the main public library in downtown Lexington. Cores of various geologic age were available for the public to view in the library’s Kentucky Room through January 2018. Maps, books, compasses, and other geologic gear were displayed elsewhere in the building.



Earth Science Week open house

KGS opened its doors to the public the evening of Oct. 11, 2017, for its annual Earth Science Week open house. Students of all ages, families, and teachers browsed interactive displays on earth science topics set up by KGS and other organizations. On the sidewalk in front of the building, the Indiana Geological and Water Survey set up its popular Quake Cottage, which gives visitors an idea what various magnitudes of earthquakes might feel like. Behind the building, Pete Idstein of the UK Department of Earth and Environmental Sciences was cheered and applauded during several demonstrations of a simulated volcano eruption.



GeoHealth

Geology and epidemiology short course held

KGS worked with several University of Kentucky departments to organize a short course, “Geospatial Approaches to Epidemiology,” in January 2018, attended by 32 people. The three-day course covered data sources, data challenges, and basic GIS operations that support integration of epidemiologic, geologic, and topographic information. The course concluded by correlating epidemiological data with geologic and geomorphic attributes. **Bethany Overfield**, **Bill Haneberg**, **Matt Crawford**, and **Doug Curl** teamed up with **Jay Christian** of the UK Department of Epidemiology to teach the course.

“As we’ve focused more of our KGS research efforts on the intersection of public health and geology,



Bethany Overfield speaks at an April 2018 meeting of the Kentucky Center for Smoke Free Policy.

we’ve had the opportunity to collaborate with folks from backgrounds very dissimilar to ours,” Overfield says. “This has been a tremendous learning opportunity. In an effort to come together to tackle common research goals, we wanted to bring researchers doing GIS work from the medical field and geosciences together for this short course.”



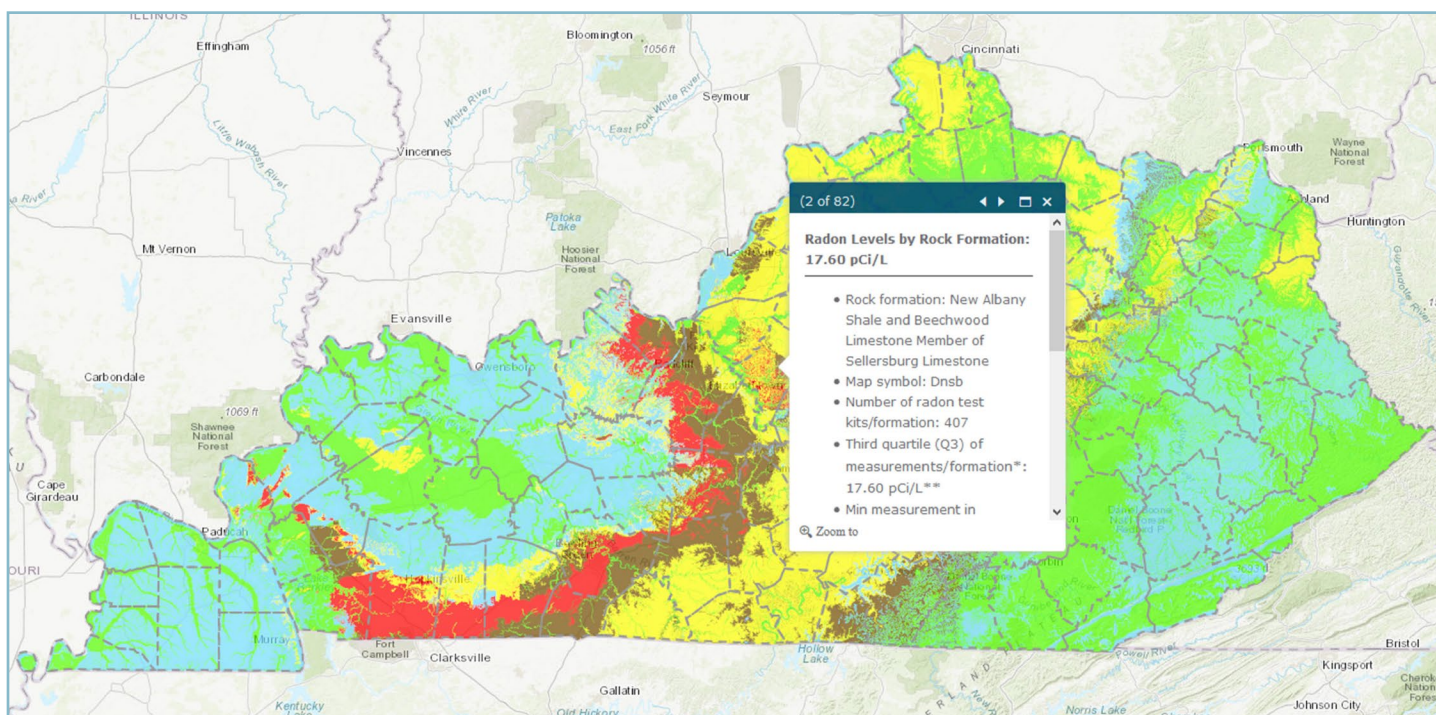
Jay Christian of the UK Department of Epidemiology leads a section of the epidemiology short course.

Radon research continues

Bethany Overfield continued her work with the UK College of Nursing's **BREATHE (Bridging Research Efforts and Advocacy Toward Healthy Environments)** team, completing geologic maps showing radon potential for each of Kentucky's counties. These maps were included on easy-to-read infographic sheets to show indoor radon-gas potential by rock type. Overfield also spoke to professional groups, including the International Radon Symposium in New Orleans and the UK Markey Cancer Center, about the radon research. She and **Bill Haneberg** also chaired the session "Origin, Transport, and Accumulation of Geogenic Carcinogens" at the American Geophysical Union 2017 fall meeting. A radon

information and research page was added to the KGS website; it includes a link to an interactive statewide radon-potential map that allows users to look up the radon potential in their neighborhoods.

Two new portable radon measurement instruments, funded in part by the UK Vice President for Research, give KGS the ability to monitor radon concentrations in real time. The radon detectors will allow KGS scientists to validate the information on which the radon-potential maps are based and help expand radon research to include soil and groundwater in addition to indoor radon gas.



The KGS radon webpage contains an interactive map of statewide radon potential.

Geologic Hazards

Kentucky Seismic and Strong-Motion Network

The Kentucky Seismic and Strong-Motion Network monitors seismic events across Kentucky. KGS shares real-time data with the neighboring seismic network operated by the University of Memphis and also with the Data Management Center at Incorporated Research Institutions for Seismology, for archiving and global usage. More than 230 gigabytes of data from the Kentucky network were downloaded from IRIS this fiscal year for use around the globe.

Recordings from networks operating in Kentucky and surrounding states are acquired in tandem with real-time data from the Kentucky Seismic and Strong-Motion Network and used to detect mine blasts and earthquakes in and around Kentucky, and larger events around the world. Thirty earthquakes were recorded in the state during the fiscal year, ranging in magnitude from 0.6 to 2.8. Eight of these events happened in the Mississippi Embayment and 22, including the largest, occurred in eastern Kentucky. Eleven of the earthquakes were reported as felt by local residents. The Dec. 17, 2017, magnitude-2.8 earthquake in Mason County was the largest earthquake in Kentucky this fiscal year, and was felt in northern Kentucky and southern Ohio.

Sixteen of the eastern Kentucky earthquakes were not reported by other agencies. KGS was able to detect and analyze these earthquakes because of a temporary network, the Eastern Kentucky Microseismic Monitoring Network, deployed beginning in June 2015 with state support, and in partnership with the UK Department of Earth and Environmental Sciences and private companies. By the end of the fiscal year, 15 of these temporary stations have operated in the Rome Trough of eastern Kentucky. The data arrive at KGS in real time using wireless communication for processing and archiving.

Andrew Holcomb, a former master's student of the Department of Earth and Environmental Sciences at UK, joined KGS this fiscal year and helped to maintain the seismic stations and analyze their recordings. Holcomb presented "Results from Monitoring Microseismicity in the Rome Trough, Eastern Kentucky" at the 2018 Eastern Section of the Seismological Society of America annual meeting, June 10–14, in Niagara Falls, Ontario, Canada. Seismic data recorded from the Kentucky Seismic and Strong-Motion Network, as well as from EarthScope USArray and OIINK (for Ozarks, Illinois, Indiana, Kentucky) stations, were utilized for research on deep earth structure. **Seth Carpenter** co-authored a paper, "Detailed Crustal Thickness Variations Beneath the Illinois Basin Area: Implications for Crustal Evolution of the Midcontinent," with researchers at Purdue University, Indiana University, and the University of Illinois that was published in the *Journal of Geophysical Research—Solid Earth*.



Strong-motion accelerograph installed near the Capital Plaza Tower (in the background) to monitor the tower's April demolition.

The March 11, 2018, implosion of the Capital Plaza Tower provided an unusual source of seismic energy for a ground-motion investigation in downtown Frankfort. KGS deployed instruments to record the shaking induced by the demolition, which revealed site effects, including basin resonance, in the alluvium underlying much of downtown Frankfort. Seth Carpenter, Mike Lynch, Brandon Nuttall, Zhenming Wang, and Andrew Holcomb described the monitoring and their observations in “Ground Motions Induced by the March 11, 2018, Implosion of the Capital Plaza Tower, Frankfort, Kentucky” (Report of Investigations 2, series 13, 2018). Ed Woolery, Zhenming Wang, and Seth Carpenter, as well as UK students, have collected additional data, including SH-wave soundings, for a detailed subsurface investigation of the soils overlying bedrock in the downtown Frankfort area.

Ground-motion amplification

Seismic data recorded from the Kentucky Seismic and Strong-Motion Network, as well as from other networks in the United States, China, and Japan, are being used for research on ground-motion amplification. Seth Carpenter, Zhenming Wang, Ed Woolery, and former visiting scholar Mianshui Rong published “Estimating Site Response With Recordings From Deep Boreholes and HVSr: Examples From the Mississippi Embayment of the Central U.S.” in the *Bulletin of the Seismological Society of America*. Rong, Wang, Carpenter, Woolery, and others also wrote “On the Amplitude Discrepancy of HVSr and Site Amplification From Strong-Motion Observations,” also published in the *Bulletin of the Seismological Society of America*.



KGS staff and students collect seismic data to study ground-motion site effect in Frankfort's downtown area.

Landslide research

Matt Crawford made several new entries to the landslide inventory database, bringing the total number of entries to 2,667 by the end of the fiscal year. The landslide locations come from state agencies, field investigations, published maps, LiDAR mapping, and reports from the public. Landslides are documented as point data that represent larger landslide deposits such as translational slides, slumps, debris flows, earth flows, and rockfalls. With likely thousands of unknown or unreported landslides, an inventory is a critical step in hazard assessment. In addition to the landslide-inventory point data, reports of more than 13,000 landslides and more than 60,000 areas susceptible to debris flows from “Landslide and Related Features Maps” published by the U.S. Geological Survey are included in the inventory. All of the landslide data can be viewed and queried in the KGS online Geologic Map Information Service. The service improves our understanding of landslide occurrence and provides information to assist land-use planners, transportation officials, emergency managers, and the public in their mitigation efforts.

Matt Crawford monitored three shallow colluvial landslides in Kenton, Lewis, and Pulaski Counties, collecting and analyzing data on hillslope moisture conditions, precipitation, landslide movement, and surface electrical-resistivity data. The data will be the basis of a framework that uses long-term field monitoring techniques to link hydrologic and

electrical-resistivity data to geotechnical properties of soil. Monitoring long-term hydrologic conditions in an active landslide allows relationships to be established across the slope and parameters that influence how water moves through the slope to be analyzed. Electrical-resistivity data can help identify specific landslide features in the subsurface, and determine hydrologic relationships and constitutive equations that can be used to assess shear strength in a slope. Much of the monitoring is in collaboration with the U.S. Geological Survey Landslide Hazards Program and with **Sebastian Bryson** of the University of Kentucky Department of Civil Engineering. Crawford and Bryson described their research in “Assessment of Active Landslides Using Field Electrical Measurements,” published in *Engineering Geology*. Another paper by Crawford and Bryson, “Using 2-D Electrical-Resistivity Imaging for Joint Geophysical and Geotechnical Characterization of Shallow Landslides,” has been accepted for publication in the *Journal of Applied Geophysics*.

KGS is helping the U.S. Geological Survey develop a national-scale landslide inventory. The USGS invited KGS, along with a few other state surveys, to help in the initial planning process, which included discussions about data standardization, quality, and delivery. In addition, Crawford worked with landslide researchers at NASA to embed the KGS landslide inventory into the NASA online Landslide



Landslide monitoring at the Roberts Bend landslide in Pulaski County.

Viewer. The viewer is part of a global catalog of landslide hazards around the world. Having the KGS inventory associated with this inventory shows the importance of regional and local government entities in hazard assessment.

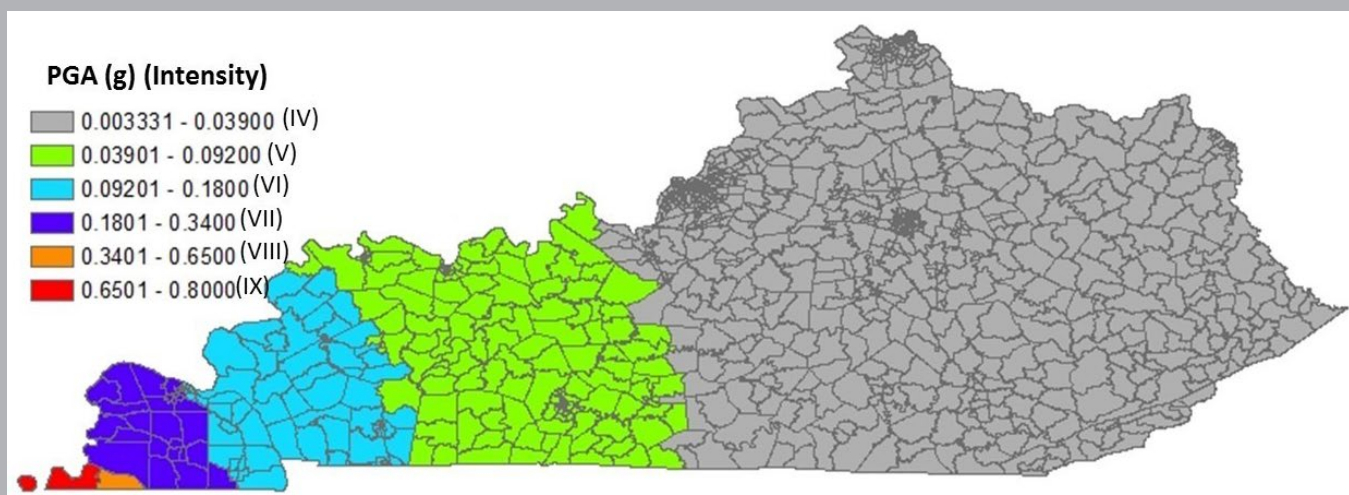
Matt Crawford submitted a proposal for a pre-disaster mitigation grant to the Federal Emergency Management Agency at the end of 2017. The proposed project will implement a multi-jurisdictional

plan for communities to address landslide hazards, reduce risk, and reduce loss and vulnerability to the built environment. Communities included in the grant are Pike, Martin, Johnson, Magoffin, and Floyd Counties in the Big Sandy Area Development District. The project will develop landslide susceptibility and risk analysis, and communicate mitigation and planning strategies.

KGS updates geohazard section of state mitigation plan

The Kentucky Division of Emergency Management asked KGS to update the geologic hazards section of the state's hazard mitigation plan, which is required by FEMA to establish eligibility for federal assistance after major natural disasters. All of the natural hazards affecting a state must be included in the assessment.

KGS staff worked to update previous assessments of the earthquake, landslide, karst/sinkhole, and mine-subsidence threats in the state. They used data such as landslide and sinkhole locations gathered by KGS, maps showing the extent of underground coal mines, and FEMA's HAZUS loss assessment tool in their work. They also developed new assessment methods for all four geologic hazards. A draft of the updated assessment was sent to the Division of Emergency Management in April 2018.



Peak ground acceleration on rock from a scenario earthquake of magnitude 7.5 in the central New Madrid Seismic Zone, created for the earthquake section of the geologic hazard assessment.

China exchange goes beyond earthquake research

This was the 14th year for the exchange program between KGS and the Lanzhou Institute of Seismology and other organizations in the China Earthquake Administration. **Lanmin Wang**, director and professor of the Key Lab of Loess Earthquake Engineering, a unit of the China Earthquake Administration, was invited as the UK Confucius Institute Distinguished Scholar Speaker to give lectures and conduct cooperative research on the UK campus Oct. 16–20, 2017.

KGS Director **Bill Haneberg** was a keynote speaker at the 7th Technical Conference in Eastern Asia on Geo-Natural Disasters, held in Chengdu, China, May 12–14, 2018, as part of the International Conference for the Decade Memory of the Wenchuan Earthquake. His presentation was “Effects of Pore-Water Pressure Uncertainty in Regional Models of Earthquake-Triggered Landslides—Insights From the 2015 M_w 7.8 Gorkha, Nepal, Earthquake.” Haneberg also visited the Wenchuan earthquake impact area.

Ed Woolery of the Department of Earth and Environmental Sciences at UK and KGS seismologist **Zhenming Wang** were both invited to attend and give presentations at the 8th International Conference on Environmental and Engineering Geophysics, June 10–13, 2018, in Hangzhou, China. Woolery served as one of six executive chairmen on the conference organizing committee. He and Wang also visited the Institute of Crustal Dynamics, a unit of the China Earthquake Administration, in Beijing during the trip.

Three visiting scholars, **Dongwang Tao** of the Institute of Engineering Mechanics in Harbin, **Tao Lu** of the Institute of Disaster Prevention in Yanjiao, and **Fajun Miao** of the Earthquake Administration of Jiangsu Province in Nanjing, came to UK to conduct research on seismic-network data analysis and strong ground motions. All three visiting scholars are supported by the China Scholarship Council.

Cortland Eble gave a series of lectures on coal geology and organic petrography at the China University of Mining and Technology in Beijing in September 2017. Eble also attended the International Conference on Coal Science and Technology, and served as a session chair. Starting in October 2018, **Xin Guo**, a Ph.D. student at China University of Mining and Technology, will spend a year studying coal with Eble at KGS.

Junfeng Zhu attended the 2017 International Forum on Groundwater and the Cross-Strait Symposium on Application of Hydrogeology, July 6–7, at Hefei University of Technology. Zhu talked about assessing risks to groundwater resources posed by unconventional development of shale oil and gas.



Lanmin Wang



Bill Haneberg



Cortland Eble



Junfeng Zhu

Geologic Information Management

Three-dimensional digital point-cloud model of the Whitfield stump.

KGS makes research data, maps and publications, database updates, and other information available to researchers and the general public. More than 20,000 files are accessible from our website's homepage, and **Rebecca Wang**, the lead developer of the website, is working with other KGS staff to update the content and design of the webpages. Wang collaborated with **Steve Greb** and **Jerry Weisenfluh** to develop a new KGS Coal Information website. The new site contains abundant information about coal, such as formation, rank, type, grade, analysis, and uses. As part of this website, a coal core-logging tutorial on the use of the three-digit "Ferm" code for core description was created, as well as educational pages about potential geologic obstacles and hazards. The new site is a gateway for hard-to-find coal information.

Greb and Wang also created a new webpage that provides information on upright fossil tree stumps. The new site not only educates the general

public about how fossil tree stumps form and their types and sizes, but also contains many photographs and information about how to locate such stumps that are on public display. One such stump is the Whitfield stump, originally found in Harlan County, Ky., and donated to UK in 1961. It was moved behind the Mining and Mineral Resources Building, where KGS is located, in 2017.

This year, KGS debuted a new version of its databases, maps, and publications search website, called "KY Geode" (kgs.uky.edu/kygeode). The site is still under development, and is running in parallel with the current version (kgs.uky.edu/kgsweb), but all of the data search services will soon be transitioned to the new version. KY Geode is more streamlined, allowing users to locate items with fewer clicks. It integrates the search results with the search parameters on the same page, works better with mobile devices, and incorporates a map view (for geographic data such as well locations) into the results. A redesigned Oil and Gas Well Search and Publications Search are the two services currently developed in the KY Geode format. KY Geode can also be used

as a one-stop shop for KGS data and maps, as all the current database search and map services are linked from KY Geode.

The KGS homepage continues to play an important role in delivering information, and in fiscal year 2017-2018 attracted close to

The screenshot displays the 'KY Geode' website interface. The top navigation bar includes the 'Kentucky Geological Survey' logo and the 'KY Geode' title with the subtitle 'free access to KGS data, maps, and publications'. A left sidebar contains a 'Home' link and a 'Publications*' link, followed by a dropdown menu for 'Oil and Gas' which is currently expanded to show 'Oil & Gas Records*'. Below this are links for 'Production Data', 'Petroleum Geology Map Service', 'Core & Sample Holdings', 'Permitted Wells Timeline Tool', 'Permitting Visualizations', 'Disposal & Injection Wells', 'Shapefile Download', and 'Gathering Line Map'. The main content area is titled 'Oil and Gas Wells Search' and features a 'Search' button. Below the search bar, there are several search criteria: 'County' (a dropdown menu currently set to 'None selected'), 'Quadrangle(s)' (a dropdown menu currently set to 'None selected'), 'Text entries' (a text input field with a note 'Use * char for wildcard searches (exact by default)'), 'Operator' (a text input field), 'Farm Name' (a text input field), 'Well Number' (a text input field), 'KGS Record Number' (a text input field), and 'Permit (Plot) Number' (a text input field). There are also links for 'About' and 'use an INDEX MAP to make selection'. On the right side of the search criteria, there are dropdown menus for 'Carter Coordinates' (set to 'Not Selected'), 'Completion Result(s)' (set to 'None selected'), 'Total Depth Stratigraphy' (set to 'None selected' with a link to 'About stratigraphic codes'), and 'Deepest Pay Stratigraphy' (set to 'None selected' with a link to 'About stratigraphic codes'). A checkbox for 'Exclude all terminated well permits' is also present.

1 million page views. Almost 235,000 users from 207 countries accessed information about KGS, Kentucky's resources, and geoscience education. Approximately 76 percent of the users were from the United States; others were from the Philippines, India, the United Kingdom, Canada, and Australia. About a quarter of domestic users are in Kentucky; the next most common groups of users are from California, Texas, Ohio, Georgia, and Illinois. Approximately 10 percent of visits to the KGS webpages were on mobile and tablet devices.

The most visited webpages were:

1. Identifying Unknown Fossils (by their shape)
2. KGS homepage
3. Methods Used in Identifying Minerals
4. What Is Coal?
5. Kentucky Seismic and Strong-Motion Network

The Survey's online services had more than 1.1 million hits during the fiscal year.

Since 2001, KGS has provided free online access to oil and gas records and data, water-well and springs data, coal data, publications, images, and other geologic data, now numbering more than 6.6 million records. More than 542,000 visits originating from 138 countries were made during the past fiscal year to the KGS database, maps, and publications search website (kgs.uky.edu/kgsweb). The great majority of visitors were from the United States (88 percent), followed by India, Canada, the United Kingdom, Germany, and Indonesia. Users from all 50 states and the District of Columbia visited the site; a little less than half were from Kentucky, followed by users from California, Ohio, Texas, Georgia, and Tennessee. Approximately 203,000 database searches were conducted by more than 86,000 users, of which almost 35,000 were unique users. Database searches increased 3.5 percent from last year, likely the result of an 8 percent increase in searches for oil and gas data. This is a turn-around from last year, which reported a 33 percent drop in searches for oil and gas data. Searches for water wells and springs data were down 33 percent to 8,250 searches.

KGS online map services were accessed close to 70,000 times, about a 5 percent increase from the pre-

vious fiscal year. There were nearly 7,400 tabular data downloads, which was about a 33 percent decrease from the 2016-2017 fiscal year, consistent with the decrease in water well and springs database searches. Nearly 816,000 files were downloaded from the website, including KGS publications and presentations, which was a decrease of 13 percent from the previous year. Oil and gas records, water wells and springs data, online publications, coordinate conversion services, and data from the geologic map server continue to be the most frequently downloaded data.

The most download publications were:

1. "The Geologic Story of Kentucky," by **Preston McGrain** (Special Publication 8, series 11)
2. "Earthquakes in Kentucky: Hazards, Mitigation, and Emergency Preparedness," by **Seth Carpenter, Zhenming Wang, and Mike Lynch** (Special Publication 17, series 12)
3. "Geology of the Mammoth Cave National Park Area," by **Ann Livesay and Preston McGrain** (Special Publication 7, series 10)
4. "Mineral and Fuel Resources Map of Kentucky," by **Warren Anderson and Garland Dever Jr.** (Map and Chart 26, series 12)
5. "Kentucky Landscapes Through Geologic Time," by **Dan Carey** (Map and Chart 200, series 12)

The most downloaded presentations from the KGS website were:

1. "Kentucky Coal and Coal Combustion By-products as Potential Sources of Rare Earth Elements," by **Cortland Eble**
2. "Introduction to KGS Interactive Web-Based Services," by **Brandon Nuttall and Doug Curl**
3. "New Unconventional Oil and Gas Plays: The Berea Sandstone and Rogersville Shale," by **Dave Harris**
4. "Regional Modeling of Class II Wastewater Injection Wells, Appalachian Basin," by **Tom Sparks**
5. "Assessing Baseline Groundwater Chemistry for the Berea Sandstone and Rogersville Shale Play Area, Eastern Kentucky," by **Junfeng Zhu**

Other activities

- **Mark Thompson** and **Mike Ellis** helped set up KGS DEAL (Digital Earth Analysis Lab) for examining and processing LiDAR data. This lab features three powerful workstations, a 10-terabyte file server for storing data, and an 80-inch, high-definition touchscreen linked to the workstations. The statewide 2.5-terabyte LiDAR point cloud and derived digital elevation model were also loaded onto the file server for local use. This important LiDAR data set will be a primary source of data for users to work with and was obtained through a partnership with the Kentucky Division of Geographic Information (Commonwealth Office of Technology). We plan to add another high-end workstation and connect to the University of Kentucky 40-gigabyte high-speed research network. Connection to this network will allow KGS DEAL users to share and collaborate across campus using very large data sets. (See more about KGS DEAL on pages 20–21.)
- Grant funding from the USGS National Geological and Geophysical Data Preservation Program supported two University of Southern Indiana students, **Holly Keimig** and **Jessica Mayes**, who scanned legacy oil and gas well documents from the KGS Western Kentucky Office for the 2017-2018 USGS National Data Preservation project. A student in the Lexington office, **John Piening** from the UK Department of Earth and Environmental Sciences, was also partially supported with this funding to add new data to our oil and gas databases, and scan and organize oil and gas well documents for archiving and web dissemination.
- The section also used funds from the Data Preservation Program to record, digitize, archive, and attribute various geochemical data sets and reports (mostly sampled from oil and gas wells) that have been collected by or submitted

to the Survey over the years. We will design a database architecture and data-input protocol for entering these data into an online database format. **John Hickman** is assisting in this project by identifying relevant lab records, helping with the classifications and standard units of measured analytes, and helping with the design of the data-entry form. The project database format has been finalized, and Piening began entering data in June 2018.

- **Liz Adams** and **Doug Curl** received funding from the National Geological and Geophysical Data Preservation Program to attend and present at a USGS data preservation workshop hosted by the Utah Geological Survey in September 2017.
- With a grant from the Watershed Watch Kentucky organization, **Doug Curl** worked with the Kentucky Division of Water and Kentucky River Watershed Watch to develop a pilot lake-sampling program in which volunteers use mobile devices to collect and submit water-quality information. Volunteers took basic lake-quality measurements (lake appearance, secchi disk measurements of clarity or turbidity) and photos



Participants in the Digital Mapping Techniques conference, hosted by KGS, are shown the capabilities of the new Digital Earth Analysis Laboratory.

approximately every two weeks in coordination with Landsat mission (USGS satellite imagery program) passes over Kentucky lakes. The focus for summer 2017 was Herrington Lake in central Kentucky and Lake Barkley and Kentucky Lake in western Kentucky. The survey app immediately adds the observations to the KGS database, and the results and photos can be viewed on an interactive map (kgs.uky.edu/wwky/lake). Volunteers and the public can see the trend of observations over time with this map service. These observations also provide data for researchers at the Division of Water to predict lake quality. The program will continue and expand with more volunteers and lakes during summer 2018.

- **Liz Adams** submitted a proposal for a Museums for America Collection Stewardship and Public Access grant from the Institute of Museum and

Library Services. Requested funding would pay for three student employees to work on a three-year project to photograph, catalog, and preserve 10,000 of the 120,000 core boxes housed at the KGS Well Sample and Core Library. A small portion of the requested funding will go toward purchasing new labeling and archiving equipment. If approved, this project will begin in October 2018.

- **Carrie Pulliam** manages the Oil and Gas Records Database. This year, KGS changed the way production data are managed and presented online. We now host the raw data collected by the Division of Oil and Gas. During this production-data change, more than 3,000 historic wells were added to the KGS database, making the online oil and gas database more robust and detailed for all users.



Carrie Pulliam keeps the online Oil and Gas Records Database up to date.



Example of photographed drill core. The image will be added to the KGS database.

The KGS Well Sample and Core Library provides cores and well cuttings from more than 25,000 locations in Kentucky for research and the development of resources, including oil and natural gas.

More than 10,539 feet of well cuttings and cores were examined during the fiscal year: 21 industry geologists examined 20 cores and seven sets of cuttings, and seven researchers were provided with 124 samples for geochemical and physical properties testing. The number of geologists visiting the library, along with requests for materials for research, was low because of the continued decline in the price of oil and gas, resulting in decreased drilling in Kentucky.

Library staff began photographing 23 deep cores. The photographs will be edited and added to the KGS database and made available for online examination. Liz Adams applied for a grant to photograph, catalog, and preserve 10,000 boxes of core at the facility. (See page 37 for more details.)

More information on the facility, including forms for core donations and requesting samples for testing, are available on the core library's webpage, www.uky.edu/KGS/core_library.

Well Sample and Core Library



Patrick Gooding examines a black shale core.



Ray Daniel and Ryan Pinkston photograph cores available at the Well Sample and Core Library.

Western Kentucky Office

Five KGS employees worked at the Western Kentucky Office during the 2017-2018 fiscal year: **Dave Williams**, **Glynn Beck**, **Amy Bleichroth-King**, **Holly Keimig**, and **Jessica Mayes**. **Mark Akland**, who was hired in July 2017 as a scientist in the University of Kentucky Department of Plant and Soil Sciences, was also stationed in the Western Kentucky Office.

Dave Williams oversaw the U.S. Geological Survey-funded National Data Preservation work, in which petroleum well records housed in the Henderson office were scanned by Keimig and Mayes. Funding for this phase of the project ended on June 30, 2018. Additional information about this project is on page 36, in the Geologic Information Management section of this report.

Williams also continued his research on paleochannels related to the most important coal-producing strata in the Western Kentucky Coal Field.

Glynn Beck is working on a groundwater inventory project for the University of Kentucky Research and Education Center at Princeton. The goal of the inventory is to help the Center locate an adequate groundwater supply for research on pivot irrigation.

Beck, in collaboration with researchers in the University of Kentucky College of Agriculture, Food and Environment, began two monitoring projects at the edges of farm fields in the lower Green River watershed and the Jackson Purchase. These projects will assess nutrient and sediment loss from active row-crop fields and restored wetlands. Field work for these projects is conducted by **Mark Akland** and **Leighia Eggett**, a scientist with Plant and Soil Sciences stationed in Mayfield.

Beck also collaborated with **Brad Lee** of the Department of Plant and Soil Sciences to assess the soil moisture of fragipan (impermeable zone) soils under pivot irrigation in the Jackson Purchase Region. Soil-moisture data were collected throughout the growing season, along with groundwater-elevation and discharge data from the pivot production well. The goal is to help crop producers better manage their local groundwater resource.

Additional information about the above projects is in the Water Resources section of this report.

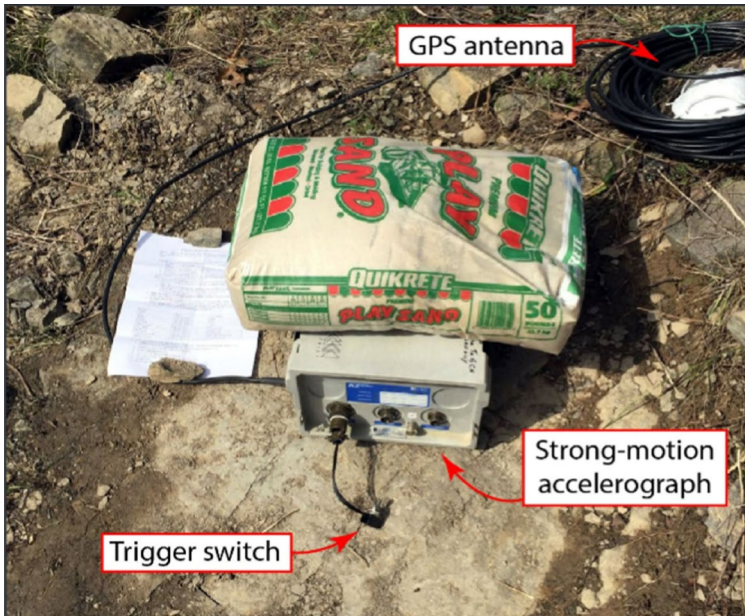
Amy Bleichroth-King split time between geologic mapping and water resources projects. Bleichroth-King conducted grain-size analysis of sediment samples collected by geologic mappers, using a laser particle-size analyzer. In addition, she entered geologic and hydrogeologic data into databases and performed GIS work. Additional information about mapping projects is in the Geologic Mapping section of this report (page 22).



Mark Akland of the UK Department of Plant and Soil Sciences checks one of the instruments used to monitor edge-of-field water quality, soil moisture, and groundwater in the lower Green River watershed. Akland collaborates on this project with **Glynn Beck**.

Staff activities

- **Dave Williams** serves on the Henderson City Planning Commission. He is also a member of the Interagency Advisory Committee for the I-69 Ohio River Crossing.



Instrumentation at one of the stations that measured ground motions, resulting in “Ground Motions Induced by the March 11, 2018, Implosion of the Capital Plaza Tower, Frankfort, Kentucky” (Report of Investigations 2, series 13).

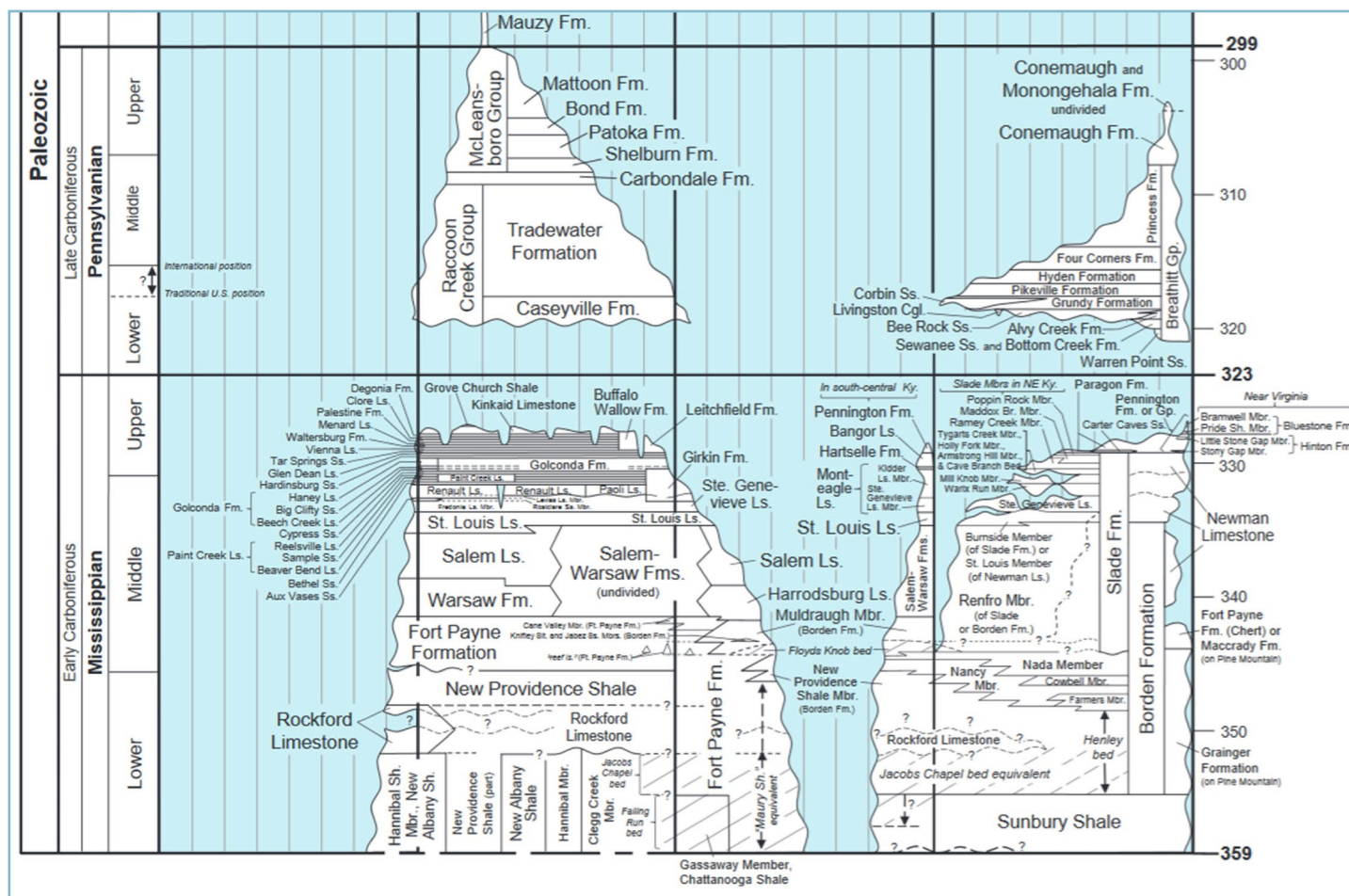
Capital Plaza Tower, Frankfort, Kentucky” (Report of Investigations 2, series 13). KGS seismologists set out three temporary seismic instruments situated an average of about 1,300 feet from the tower to record ground mo-

Publications for 2017-2018

KGS disseminates research results through its internal publication series, papers published in peer-reviewed scientific journals, and in published abstracts for presentations at major scientific conferences.

Survey geologists produced eight new KGS publications, all available from our online publications and maps catalog. Among them are four surficial geologic maps of quadrangles in northern Kentucky, funded by the USGS STATEMAP program. (More information on page 22.)

Several KGS scientists contributed to “Ground Motions Induced by the March 11, 2018, Implosion of the Capital Plaza Tower, Frankfort, Kentucky” (Report of Investigations 2, series 13). KGS seismologists set out three temporary seismic instruments situated an average of about 1,300 feet from the tower to record ground mo-



Detail from “Kentucky Stratigraphy,” by Steve Greb.

tions created by the 28-story office tower's planned destruction; a fourth instrument was placed about 2.5 miles away. The 11-page report, which received national media attention, summarizes findings from this monitoring. KGS geologist **Steve Greb** compiled "Kentucky Stratigraphy" (Map and Chart 211, series 12). It shows updated correlations of Kentucky's bedrock units, based on the International Commission on Stratigraphy time scale. He also compiled a similar chart, "Kentucky Stratigraphy With Stage Correlations" (Map and Chart 210, series 12), which shows the same units correlated to more detailed subdivisions of time, including North American, European, and international stages. Ages and correlations are subject to change, so periodic updates to stratigraphic charts are important contributions to Kentucky geologic knowledge.

To make KGS publications easier to find online, the Survey began working with UK's W.T. Young Library to assign digital object identifiers to hundreds of earlier publications. A DOI is a unique string of numbers and letters assigned to a publication that identifies its content and provides a persistent link to its location on the internet. If a KGS reference appears in another publication, and its DOI is included, a reader can link directly to the KGS publication without a search. Copies of older KGS publications assigned DOIs will be found at the library's UKnowledge webpage. KGS will assign DOIs to new publications and the publications will be posted at UKnowledge, as well as on the KGS website.

Kentucky-related papers published in peer-reviewed publications in 2017-2018

- Allmon, W.D., Picconi, J.A., Greb, S.F., and Smith, C.C., 2016, Geologic history of the southeastern U.S.: Reconstructing the geologic past, in Swaby, A.N., Lucas, M.D., and Ross, R.M., eds., *The teacher-friendly guide to the earth science of the southeastern U.S.* [2nd ed.]: Ithaca, N.Y., Paleontological Research Institute, p. 9–39.
- Anderson, W.H., 2016, 2012–2013 minerals yearbook: Kentucky: U.S. Geological

Survey, minerals.usgs.gov/minerals/pubs/state/2012_13/myb2-2012_13-ky.pdf.

- Buckler, C.S., Nester, P.L., Greb, S.F., and Moye, R.J., 2016, Energy in the southeastern U.S., in Swaby, A.N., Lucas, M.D., and Ross, R.M., eds., *The teacher-friendly guide to the earth science of the southeastern U.S.* [2nd ed.]: Ithaca, N.Y., Paleontological Research Institute, p. 227–270.
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- Crawford, M.M., and Bryson, L.S., 2017, Assessment of active landslides using field electrical measurements: *Engineering Geology*, v. 233, p. 146–159, doi:10.1016/j.enggeo.2017.11.012.
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- Jerrett, R.M., Bennie, L.I., Flint, S.S., and Greb, S.F., 2016, Extrinsic and intrinsic controls on mouth bar and mouth bar complex architecture: Examples from the Pennsylvanian (Upper Carboniferous) of the central Appalachian Basin, Kentucky, USA: *Geological Society of America Bulletin*, v. 128, nos. 11–12, p. 1696–1716, doi.org/10.1130/B31429.1.

- Moecher, D.P., Bowersox, J.R., and Hickman, J.B., 2017, Zircon U-Pb geochronology of two basement cores (Kentucky, USA): Implications for late Mesoproterozoic sedimentation and tectonics in the eastern Midcontinent: *The Journal of Geology*, v. 126, no. 1, p. 25–39, doi:10.1086/694825.
- Moye, R.J., Greb, S.F., and Picconi, J.A., 2016, Mineral resources of the southeastern U.S., in Swaby, A.N., Lucas, M.D., and Ross, R.M., eds., *The teacher-friendly guide to the earth science of the southeastern U.S.* [2nd ed.]: Ithaca, N.Y., Paleontological Research Institute, p. 191–226.
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Kentucky Geological Survey Staff

Fiscal Year 2017-2018

State Geologist's Office

Haneberg, William. State Geologist and Director
Cobb, Jim. State Geologist Emeritus

Administrative

Ellis, Kati. Administrative Staff Officer II
Long, Mandy. Administrative Support Associate I
Phillips, Gwen. Staff Support Associate II

Communications and Outreach

Banks, Roger. Stores Supervisor
Burroughs, Haley. Student Worker
Lynch, Mike. Technology Transfer Officer
Smath, Meg. Geologic Publication Manager

Digital Earth Analysis Lab

Dortch, Jason. Post-Doctoral Fellow

Energy and Minerals

Harris, Dave. Section Head
Anderson, Warren. Geologist V
Bowersox, Rick. Geologist IV
Eble, Cortland. Geologist V
Greb, Steve. Geologist V
Hickman, John. Geologist IV
Nuttall, Brandon. Geologist V
Parris, Marty. Geologist V
Sparks, Tom. Geologist III

Geologic Hazards

Wang, Zhenming. Section Head
Carpenter, Seth. Geologist IV
Crawford, Matt. Geologist III
Holcomb, Andrew. Geological Technician Senior
Woolery, Ed. Geophysics Faculty Associate

Geoscience Information Management

Curl, Doug. Section Head
Adams, Elizabeth. Program Coordinator I
Bryant, Trevor. Student Worker
Ellis, Mike. Computer Support Specialist II
Hackett, Megan. Student Worker
Mullins, Seth. Student Worker
Piening, John. Student Worker

Pulliam, Carrie. Geologist II
Smath, Richard. Geologist III
Thompson, Mark. Information Technology Manager I
Wang, Rebecca. Database Analyst
Young, Holly. Student Worker

Geologic Mapping

Andrews, William. Section Head
Bottoms, Antonia. Geologist I
Hammond, Max. Geologist II
Hounshell, Terry. Chief Cartographic Illustrator,
retired Oct. 2017
Martin, Steve. Geologist III
Massey, Matt. Geologist IV
Morris, Emily. Cartographic Data Manager
Overfield, Bethany. Geologist III

Laboratory

Backus, Jason. Geologist III/Laboratory Manager
Conner, Andrea. Geologist II
Davis, Ethan. Student Worker

Water Resources

Taylor, Chuck. Section Head
Beasley, Kalli. Student Worker
Davidson, Bart. Geologist IV
Merrick, Jason. Student Worker
Nolte, Adam. Geological Technician Senior
Tobin, Ben. Geologist IV
Webb, Steve. Geologist II
Zhu, Junfeng. Geologist V

Well Sample and Core Library

Gooding, Patrick. Geologist IV/Manager
Daniel, Ray. Principal Research Analyst
Pinkston, Ryan. Research Analyst

Western Kentucky Office

Williams, Dave. Section Head
Beck, Glynn. Geologist IV (Water Resources Sec-
tion)
Bleichroth-King, Amy. Temporary Technician
Keimig, Holly. Temporary Technician
Mayes, Jessica. Temporary Technician

Research Projects

Fiscal Year 2017-2018

Energy

Carbon management

Midwest Regional Carbon Sequestration Partnership (for the Appalachian Basin)

End date: 12/31/2019 FY funding: \$37,307 6-year project total: \$400,011
Funding source: U.S. Department of Energy through Battelle Memorial Institute

Coal resources

Identification and characterization of coal and coal byproducts containing rare earth elements

End date: 4/30/2018 KGS FY funding: \$31,748 UK 2-year project total: \$400,000
Funding source: U.S. Department of Energy through UK Center for Applied Energy Research

Geochemistry

Geochemistry of rock

Rare earth elements (REEs) in U.S. coal-based resources: Sampling, characterization, and resource assessment

End date: 9/30/2019 KGS FY funding: \$3,378 UK 2-year project total: \$150,000
Funding source: University of North Dakota

Fundamental studies on the recovery of rare earth elements from coal and coal byproducts

End date: 1/31/2019 KGS FY funding: \$15,358 UK 2-year project total: \$400,000
Funding source: Virginia Polytechnic Institute and State University through UK Department of Mining Engineering

Geochemistry of water

Aquifer quality study at the H.L. Disney Training Site

End date: 10/31/2018 KGS FY funding: \$5,174 UK 2-year project total: \$146,946
Funding source: Kentucky Department of Military Affairs through UK Department of Earth and Environmental Sciences

Watershed management activities within the Kentucky River Basin

End date: 6/30/2018 KGS FY funding: \$9,377 UK 1-year project total: \$122,506
Funding source: Kentucky River Authority through UK Kentucky Water Resources Research Institute

Geologic information

Coal information

Computerized coal resources for the National Coal Resources Data System

End date: 8/31/2017 FY funding: \$2,265 2-year project total: \$30,000
Funding source: U.S. Geological Survey

Data preservation

National Geological and Geophysical Data Preservation Program

End date: 6/30/2018 FY funding and project total: \$68,081

Funding source: U.S. Geological Survey

Geotechnical information

Kentucky mitigation plan geologic hazards assessment

End date: 4/15/2018 FY funding and project total: \$51,463

Funding source: Federal Emergency Management Agency through Kentucky Department of Military Affairs

Water information

Water-quality analysis in municipal water-supply system for Lexington, Ky., with a focus on corrosivity

End date: 2/28/2018 FY funding and project total: \$5,000

Funding source: U.S. Geological Survey through UK Kentucky Water Resources Research Institute

Geology

Geologic mapping

Quaternary and surficial geological mapping for multiple applications in Kentucky

End date: 6/30/2018 FY funding and project total: \$154,726

Funding source: U.S. Geological Survey

Geology and human health

Prescription for radon: County-scale maps of geologic radon potential

End date: 6/30/2018 KGS FY funding: \$8,229 UK 1-year project total: \$130,000

Funding source: Kentucky Department for Public Health through UK College of Nursing

Water resources

Groundwater characterization

Aquifer designation—Kentucky Division of Water: Water Use Program

End date: 6/30/2019 FY funding: \$17,229 2-year project total: \$94,367

Funding source: U.S. Geological Survey through Kentucky Energy and Environment Cabinet—Division of Water

Groundwater monitoring

Groundwater modeling at the Paducah Gaseous Diffusion Plant

End date: 3/31/2019 KGS FY funding: \$15,000 UK 3-year project total: \$795,000

Funding source: U.S. Department of Energy through UK Center for Applied Energy Research

Groundwater resources

Investigation of groundwater availability for irrigation at the UK Research and Education Center at Princeton, Ky.

End date: 6/30/2018 FY funding: \$9,146 2-year project total: \$24,202

Funding source: UK College of Agriculture, Food and Environment

Surface-water monitoring

Adapting edge-of-field monitoring for water quality and soil health assessments in sinkhole-dominated crop fields

End date: 12/31/2018 FY funding: \$1,000 2-year project total: \$70,641

Funding source: U.S. Department of Agriculture through Homeplace on Green River Inc.

Blue Water Farms: Edge-of-field water monitoring in Kentucky soils

End date: 6/30/2018 KGS FY funding: \$29,822 UK 1-year project total: \$206,184

Funding source: Kentucky Soybean Board through UK College of Agriculture, Food and Environment

Nutrient and sediment runoff assessment in the Upper Mississippi River Embayment

End date: 9/15/2022 KGS FY funding: \$17,037 UK 5-year project total: \$904,300

Funding source: U.S. Department of Agriculture through Natural Resource Conservation Service through UK College of Agriculture, Food and Environment

Surface-water resources

Head-of-Rough Spring discharge and water-quality characterization study in Hardin County Water District No. 1

End date: 6/30/2018 FY funding: \$5,668 2-year project total: \$49,999

Funding source: Kentucky Energy and Environment Cabinet–Division of Water through Hardin County Water District No. 1

KGS Annual Report

KGS Director and State Geologist

William Haneberg

Editors

Mike Lynch

Meg Smath

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Meg Smath

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