Kentucky Geological Survey

2022 - 2023 Annual Report

Kentucky Geological Survey, University of Kentucky

Letter From the Director Emeritus

William C. Haneberg, Ph.D., P.G.
State Geologist and Director

Fiscal year 2022-23 began tragically for too many Kentuckians when a 1000-year rainstorm and subsequent floods along the North Fork of the Kentucky River and its tributaries killed 45 people and displaced thousands during the last few days of July 2022. An estimated 1200 people were rescued by helicopter or boat. Even as I write this nearly a year later, the post-flood recovery is incomplete, many are still struggling to find safe housing, and the best path forward for eastern Kentucky is uncertain.

During a March 2023 trip to the town of Jenkins, Kentucky to inspect homes damaged by landslides that were reactivated during the 2022 storm, I was struck by the flood debris that remained lodged high in trees along the valley of the North Fork. Shoes, tattered clothing, household goods, pieces of fencing, and anything else swept up by the raging water offered silent testimony to the power and horror of the flood. U.S. Geological Survey records show that in the town of Jackson, the river stage rose from 7.4 feet at 10:00 pm on July 27 to 43.5 feet at 2:30 am on July 29. Before the rain that week, the stage was steady at 2.0 feet. Closer to the headwaters in Whitesburg, the stage rose from 2.9 feet to 22.0 feet overnight between 10:00 pm on July 27 and 11:00 am on July 28. We can debate the technical details of estimating the recurrence interval of such an extreme event from just a few decades of data, but I estimated a 600+ year recurrence interval for the flooding experienced in Whitesburg.

What does all that have to do with KGS? We are not first responders, so we were not in boats or helicopters rescuing people from roofs, but we do have a deep commitment to the Commonwealth and its people. Moving forward without learning as much as we can about the floods – and how we might anticipate and mitigate future disasters – would only deepen the tragedy.

In the aftermath of the floods, a KGS reconnaissance team documented nearly 1100 new landslides and debris flows visible from public roads in the hardest hit portion of eastern Kentucky. The total number of landslides and debris flows was no doubt far larger. KGS is continuing work on FEMA-supported, multi-jurisdictional landslide susceptibility and risk maps for eastern Kentucky, using a peer-reviewed approach combining Kentucky's statewide airborne lidar digital elevation model, human interpretation, and regionally specific machine learning models. We released a set of five susceptibility maps for the Big Sandy Area Development District during summer 2022 and currently working on another set for the Kentucky River Area Development District. Landslide susceptibility and risk maps are critical because many

eastern Kentuckians are literally stuck between flat but flood-prone valley bottoms and steep landslide-prone hillsides, limiting the amount of land safe for development. KGS scientists applied for and received a six-month post-flood National Science Foundation RAPID grant to collect perishable samples and field measurements for future analyses supported by longer-term NSF funding and our baseline state appropriation. Another of our researchers has been developing a Google Earth Engine application that will allow anyone in Kentucky to download and analyze multispectral satellite images potentially useful for disaster planning and responses. We are also working with the Kentucky Division of Geographic Information in Frankfort to determine the best ways to incorporate KGS maps and data into the emergency management dashboards that provide critical support during all kinds of responses. You can read more about our ongoing flood-related research throughout this report.

The Kentucky floods drew worldwide attention during a summer marked by extreme events around the world that included other floods, heatwaves, droughts, and uncontrollable wildfires. I responded to dozens of media requests for interviews and information ranging from local news outlets to CNN, BBC World News, and the China Global Television Network. A few of the journalists had been to eastern Kentucky at one time or another and understood its challenging terrain, but most had not. Virtually all asked what makes Appalachia prone to flooding and whether the floods of 2022 were exacerbated by coal mines or climate change. Those are complicated questions with potentially unsettling answers.

The non-profit organization SkyTruth has used publicly available satellite images and peer-reviewed algorithms to produce maps showing the impact of surface mining, especially the environmentally ruinous practice of mountaintop removal and valley fill mining, on central Appalachia. The results show that 2100 square miles in a 74-county area in Kentucky, Tennessee, Virginia, and West Virginia had been disturbed by surface mining

through 2015, with additional area disturbed since then. That is about 7 percent of the 74-county area and equivalent to about 92 percent of the area occupied by the state of Delaware. If you're not taken aback by that, imagine a square of barren ground measuring 46 miles on each side. That has been the impact of surface mining in central Appalachia. Peer-reviewed research based upon additional satellite image analysis has shown that very little of the disturbed area has been restored to naturally functioning forest land. More than 3200 km (2000 miles) of streams have been buried by valley filling. Existing peer-reviewed literature is equivocal about the effects of Appalachian surface mining on stream discharge during normal times. There are some aspects of surface mining that might reduce and others that might increase the severity of downstream flooding. None of the published literature that I have seen, however, are necessarily relevant to the relationship between surface mining and multi-hundred or thousand-year storm responses.

The effects of climate change, including increases in the frequency of extreme events, will continue to affect Kentuckians. A recently released report by the First Street Foundation predicts that in many parts of the country, including much of Kentucky, floods of a size that have historically occurred on average once a century may occur every five or ten years. Increased spring and winter rains coupled with summer droughts will likely further diminish the capacity of our land to buffer extreme rainfall. Although it remains impossible to say that any specific meteorological event was caused solely by climate change, the rapidly growing field of attribution science allows us to quantify how much more likely it was for that event to have occurred because of climate change.

How do we, or should we, rebuild communities in the aftermath of the 2022 floods knowing that floods of that size will likely to become more frequent if we follow our current emissions pathways? The answer extends far beyond geology, but understanding geology and geologic processes is an important

component of informed policy decision-making. Part of our job at KGS is to provide useful and contextually relevant geologic information to support wise decisions.

We at KGS have redoubled our efforts to help answer the complicated questions arising at the intersection of geology, land use, and climate change in ways that honor our legislative mandate, the land grant mission of the University of Kentucky, and our commitment to the people of Kentucky. We have a team of world-class geohazard specialists and geomorphologists in place. We have invested in computing resources that will allow us to simulate the effects of disturbances such as surface mining on the response of the landscape to extreme rainfall events. We are, and will continue to be, among the leaders developing more useful geologic hazard and risk models by integrating Kentucky's investment in geospatial data with rapidly evolving machine learning and artificial intelligence technology.

Beyond all that, KGS scientists are active in many areas that benefit the Commonwealth. We are continuing to implement archival and data management best practices to make our information as easily available to as many people as possible; actively participating in research related to carbon storage, compressed air energy storage, and critical minerals to support an energy transition; monitoring Kentucky's groundwater supplies and earthquake hazards; measuring methane emissions to determine the effectiveness of Kentucky's orphan oil and gas well plugging program; continuing our innovative collaboration with UK College of Nursing researchers to better understand geologic controls on indoor radon, which is the second leading cause of lung cancer in the United States; producing surficial geologic maps critical to support land use planning and engineering investigations as Kentucky continues on an upward trajectory of economic growth; and more.

One of the most pleasurable aspects of my role as the Kentucky State Geologist and KGS Director since 2016 has been watching

each year's annual report come together to paint a complete picture of the work KGS does on behalf of Kentucky and Kentuckians. I think you will share that sentiment as you read this year's report.

William C. Haneberg, State Geologist and Director, Kentucky Geological Survey (2016-2023)

Letter from KGS Acting Director

Dr. Bill Haneberg departed his position as State Geologist and Director of the Kentucky Geological Survey on June 30, 2023. Dr. Haneberg came to KGS from a distinguished career in international consulting. After completing his PhD at the University of Cincinnati, Bill worked at the New Mexico Geological Survey, rising to Assistant Director before over a decade of freelance consulting work in the Seattle, Washington area. Bill then moved to Houston to lead international quantitative geohazard assessments with Fugro.

After Bill arrived at KGS in September 2016, he championed a new strategic plan focused on raising the academic profile of the organization. Bill improved the digital infrastructure of KGS and established the Digital Earth Analysis Lab (DEAL) to support intensive analyses of lidar and other large quantitative datasets. He strengthened KGS collaborations in radon, public health, and climate resilience; renewed growth in our geologic hazards programs; and supported an ambitious reorganization and modernization of the Earth Analysis Research Library (EARL), our rock-core and well-sample repository. Additionally, Dr. Haneberg advocated for inclusive excellence and improved staff support at the Survey. Bill has returned to New Mexico to continue his career in freelance consulting.

The national search for a full-time KGS director will resume in 2024.

KGS remains steadfast in its dedication to being a highly regarded University of Kentucky research center, delivering impartial, responsive, and evidence-based science in support of *all* Kentuckians. As this report amply demonstrates, KGS researchers and support staff remain committed to a diverse blend of conventional and innovative research initiatives that support the university's land-grant mission.

William ("Drew") M. Andrews, Jr., PG, PhD; Acting Director, KGS; Head, Geologic Mapping Section

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Digital Earth Analysis Lab

KGS DEAL staff Jason Dortch (acting manager), Matt Crawford, Hudson Koch, Meredith Swallom, and Doug Curl (acting manager)

The KGS Digital Earth Analysis Lab (DEAL) was established by Director **Bill Haneberg** in 2017 to stimulate collaboration between researchers working with large datasets or modeling that requires significant computing capabilities. DEAL is a contemporary computing facility that hosts three high-end workstations and a large meeting screen. The lab is also connected to a data server hosting several virtual machines. As our vision is to acquire new equipment and expand the number of researchers utilizing the DEAL, co-acting manager **Jason Dortch** worked to include critical infrastructure updates in the University of Kentucky's recent application to the National Science Foundation initiative Established Program to Stimulate Competitive Research (EPSCoR). Through this, and other campus-wide collaborations we invite new KGS staff, students, and researchers from other departments

into our space. The physical components of the DEAL are managed by KGS IT team members **Michael Ellis** and **Fin O'Flaherty**. They facilitate access to computers and install and update sophisticated critical software. Making sure the newly installed programs work with the existing systems is no small task. DEAL is an integral part of numerous projects across several KGS sections. The list below highlights collaborative DEAL projects featured elsewhere in this report. The three projects explained in detail demonstrate the unique contributions to geologic research made possible by the DEAL infrastructure.

- **Meredith Swallom** and **Jason Dortch** used DEAL computers extensively to develop models to better understand the background conditions that contributed to catastrophic flooding in eastern Kentucky in 2022. (see *Geologic Mapping*)
- **Matt Crawford** and **Hudson Koch** and **Jason Dortch** generated many iterations of landslide susceptibility models on regional scales to assess Landslide Susceptibility and Risk in the Kentucky River Area Development District. **Matt Crawford** and **Hudson Koch** are also working with DEAL to improve the Kentucky Enhanced State Hazard Mitigation Plan Update for 2023. (see *Geologic Hazards*)
- **Matt Crawford**, **Sourav Saha** (post-doc), **Hudson Koch**, and Bill **Haneberg** (Director) process drone LiDAR at DEAL to assess the stability and cliff retreat of the Maxey Flats Disposal Site. (see *Geologic Hazards*)
- **Glynn Beck** used DEAL computers to process drone-based LiDAR data used to delineate sub-watersheds in a mature, wooded wetland in McCracken County. The sub-watershed delineation was part of an existing edge-of-field water monitoring project. (see *Water Resources*)
- **Glynn Beck** also processed drone-based LiDAR data for two proposed projects submitted to the Kentucky Water Resources Research Institute. (see *Water Resources*)

What's the DEAL with Low-Angle Slope Failures?

KGS geologic mappers working on our U.S. Geological Survey (USGS) cooperative STATEMAP projects have historically spent months on the process of digitizing surficial map unit contacts across several 7.5-minute quadrangles. Former KGS geologist **Max Hammond III** began investigating ways to efficiently digitize the contacts of colluvium map units, which had traditionally been delineated using slope angle thresholds supplemented by field checks. Working with **Jason Dortch** and **Bill Haneberg**, **Hammond** was able to expand his initial threshold-based models to include machine learning approaches based upon topographic attributes such as slope steepness, roughness, curvature, and topographic position information derived from lidar-based digital elevation models. This allowed the mapping team to identify colluvium with greater than 90% accuracy and produce maps arguably more robust than those made using traditional approaches. The significant speed increases realized from machine learning applications will allow KGS mappers to work more economically, efficiently, and safely by allowing them to prioritize fieldwork in rough terrain and reduce the chance of repetitive motion injuries in the office.

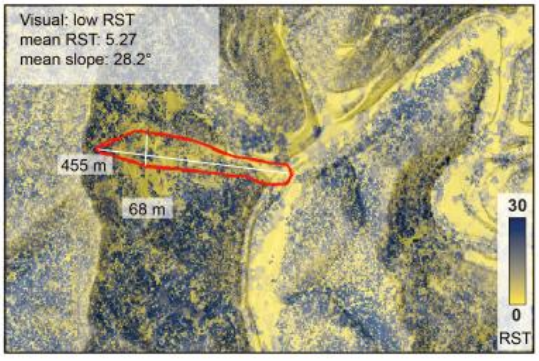


Figure 1. Map of root strength index.

A July 2022 storm event triggered over 1000 new landslides in eastern Kentucky over a five-day period, providing an ideally time-constrained dataset to assess root strength indices prior to the landslides. After generating maps of root strength index using 2014 Lidar coverage (Fig. 1), our team (**Meredith Swallom**, **Jason Dortch**, **Matt Crawford**, and **Hudson Koch**) examined the distribution of values contributing to the 2022 landslides. Overall, the median root strength index values of the area contributing to these new landslides were ~15% of the maximum values observed and appreciably lower than values observed on comparative intact slopes.

Moreover, there is a statistical threshold (Fig. 2) of root strength index below which even low-gradient slopes are susceptible to landslides. There is also an upper limit of slope where root strength can meaningfully bolster slope stability.

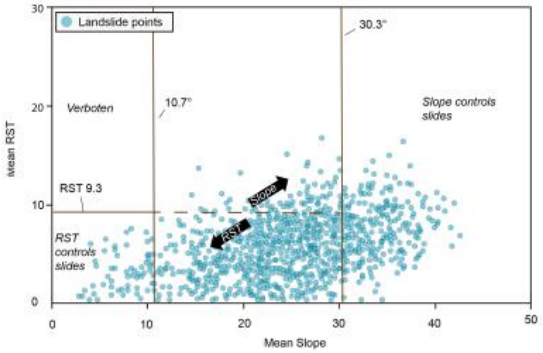


Figure 2. Graph of root strength index.

We propose that lidar-derived root strength indices and resulting threshold maps are a valuable GIS layer to incorporate into future assessments of landslide susceptibility. Further, we recommend additional studies involving traditional root strength and forestry expertise to directly compare root strength and root strength indices.

DEALing with the Nuances of Landslide Model Performance

As KGS continues to create landslide susceptibility models and maps for the Commonwealth of Kentucky, we aim to continue to improve our model performance and accuracy to ensure the information we provide is as useful as possible. There are many moving parts to landslide susceptibility modeling, and with the readily available high-resolution data inputs, such as Lidar topography, we are at the stage where we need to consider the minor nuances to fine-tune our models.

Many statistics-based landslide susceptibility models leverage an input inventory of some capacity, and these inventories vary in size and detail. What is unknown is the extent to which the number of landslides in an inventory affects how well a model performs. Using the high-end workstations of the DEAL, we **(Hudson Koch**, **Jason Dortch**, **Matt Crawford**, **Meredith Swallom**, and **Junfeng Zhu**) can begin to test our growing landslide data to see how the number of landslides included in a model increases model prediction accuracy. We used the increased computing power in DEAL to incrementally iterate some of our

landslide data with a Bagged Trees machine learning model. Gradually increasing the number of landslides tested, we developed over 25,000 landslide models and recorded model accuracy as a measure of model performance (Fig. 3). As the number of landslides increases, the average model accuracy increases – until around 750 landslides where average accuracy beings to level off. However, we note that the spread of model results tightens, indicating a steady increase in model precision with the number of landslides.

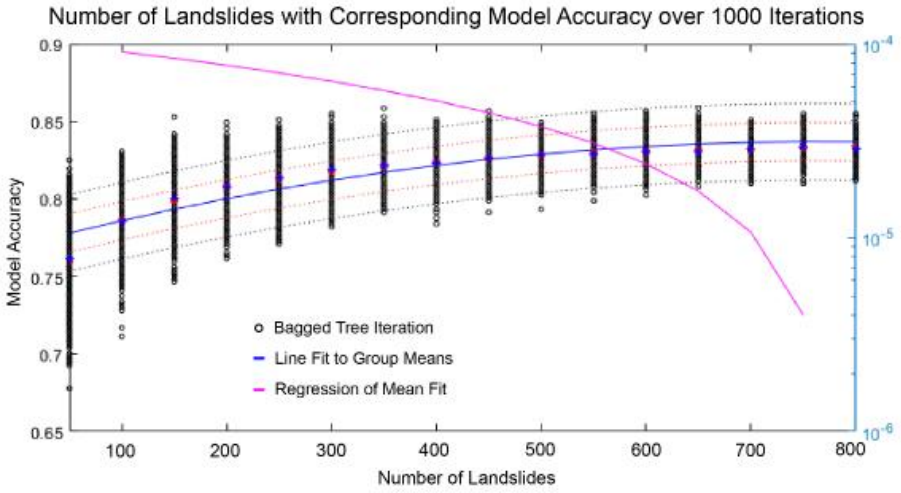


Figure 3. Graph of model accuracy as a measure of model performance.

Model accuracy is one metric to gauge how well these models are performing, but the resulting maps may show an entirely different picture. Our next step is to create maps from the high and low iteration points on graph for the landslide number iterations and compare them. There are many additional pieces of landslide modeling that still need to be considered, such as the impact of layers like topographic wetness, or root strength index. By analyzing all facets of landslide susceptibility models, we can create better landslide models for stakeholders and emergency managers.

Cave Resource Documentation

Kentucky is home to more than 5,000 known caves. These caves have significant hydrologic, geologic, biologic, and paleontologic resources that represent part of the geologic heritage of the commonwealth. Due to constant environmental conditions, these environments preserve a rich paleontologic history. This work has begun to shed light on these resources and has potential to provide great insight into the Holocene fauna of the commonwealth.

While documenting a cave in 2022, researchers led by **Ben Tobin** photographed a fully articulated bobcat skeleton. DEAL has provided the necessary computing power to use photogrammetry software to accurately document these resources in situ, without disturbing the fossils, and bring high-resolution digital models to the public.

High-resolution digital model of a a fully articulated bobcat skeleton.

Earth Analysis Research Library (EARL)

Introduction

The Earth Analysis Research Library (EARL), the survey's repository for geologic samples and documentation, saw many changes over the last fiscal year. Six new grant-funded EARL staff members joined our team to complete project-specific duties, while five members of our project team transitioned to new opportunities. This year also saw the addition of new analysis equipment, including a multi-sensor core logger, which expanded our in-house capacity to measure rock and soil core density and porosity, as well as natural gamma and magnetic susceptibility. We added the KGS soil core and samples collection to our purview and accessioned key rock cores from the Louisville MSD – Waterway Protection Tunnel project . The EARL staff looks forward to hosting workshops highlighting our equipment and collections in fiscal year 2023-2024 and providing updated forms for requesting samples and enhanced data tracking.

EARL staff, samples, and analysis equipment contributed to 17 research projects and education programs administered by KGS staff, industry representatives, and academics from the University of Kentucky, Sheffield University, Contrast Energy, SLG Resources, and Austin Peay State University. Forty-five rock cores were pulled for viewing, description, analysis, and sub-sample selection. **Ryan Pinkston** assisted our visitors in collecting one hundred and twenty sub-samples to further analyze the cores' geochemical, vitrinite, and crystallographic aspects for hydrothermal fluid, thermal maturity, and dolomitization research.

In addition to our research activities, our staff worked this year to build back post-COVID foot traffic in the building through visitor tours and educational outreach activities. This year we gave an updated tour to KGS staff and class tours for geology students at Morehead University and the Paul Potter summer interns. This year also included a tour to representatives of four key University of Kentucky research centers, including the College of Nursing, the Department of Epidemiology and Environmental Health, and the Center for Clinical and Translational Research. This tour was

part of a collaborative campus discussion about streamlining care and management of non-biological samples.

Figure 4. Jeff Kanney with the National Geodetic Survey is measuring absolute gravity for gravity modeling and determining precise surface elevations.

Working with the National Oceanic and Atmospheric Administration (NOAA)—specifically the National Coast and Geodetic Survey—Director Emeritus **Bill Hanenberg** helped coordinate the installation of an absolute gravity monitoring station for Kentucky at the EARL. The combination of EARL's accessibility to and from the highway and ability to provide a 1-meter by 1-meter space with truck access made it an ideal location for setting up the A10 absolute gravimeter and data gathering equipment (Fig. 4). The dedicated space is now marked with a Gravity Station Disk to ensure consistent equipment setup and accurate capture of data changes over time. At the time of the installation, **Haneberg** communicated its significance, explaining that "these stations are important because they support the development of geoid models—essentially 3D models of Earth's gravitational field—that are the underpinning of survey datums and coordinate systems, and the new spatial reference standard of 2023 will incorporate variations over time."

Saving America's Treasures for Future Research

In December, EARL hired **Kurstin McKinney**, **Cameron Gaines**, and **Emily Eastridge** to contribute to a mineral description project jointly funded by the National Park Service and Institute of Museum and Library Services (IMLS) (Fig. 5). The two-year project addresses 170 mineralized cores from the South-central Kentucky Mineral District (SCKMD) and Western Kentucky Fluorspar Mineral District (WKFD). The cores were drilled in multiple quarries in the 1960s and 70s and donated to KGS in the late 1980s. For this project, staff work diligently to identify, rehouse, describe, and

photograph each core. Geologists **Emily Eastridge**, **Kurstin McKinney**, and **Jason Millington** have contributed to the project describing core lithology, mineralization, and fractures (Fig.5). Our geologic photographer, **Natalie Fields**, takes high-resolution wet and dry photos of each core box and mineral photos for future social media, web, and publication use (Fig. 6).

Figure 5. KGS geologist Emily Eastridge measures a section of the core as she works to describe its lithologic and secondary features.

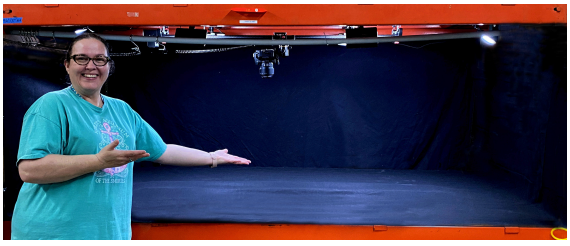
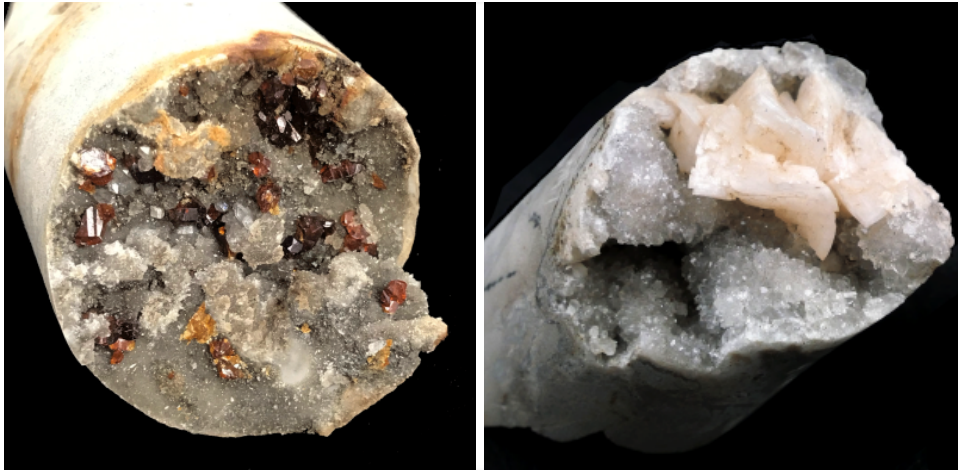


Figure 6. Natalie Fields showing off the newly configured soil core photography station.

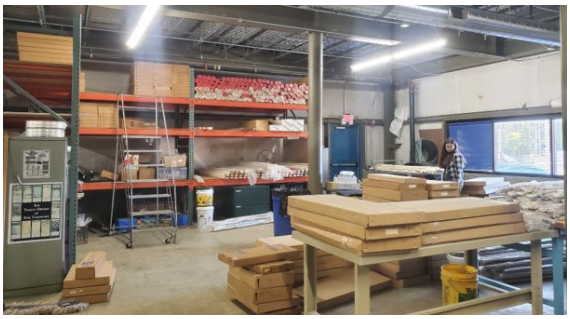
Ensuring this core collection is preserved and accessible is vital for understanding Kentucky mineralization and contributing to current energy and mineral-related EarthMRI projects. The selected cores contain many minerals on the Department of the Interior's critical minerals list including sphalerite, galena, fluorite, and barite which are necessary for the telecommunication and healthcare industries (Fig. 7). Dolomite, sulfur, bentonite, and glauconite are other features commonly found in this collection of cores (Fig. 8). These minerals are relevant for research into rare earth elements (REE), a shared area of exploration for KGS, as well as the University of Kentucky departments of Mining Engineering, Earth and Environmental Sciences, and the Center for Applied Energy Research (CAER). The project was also featured in this article from UKNow, the daily University of Kentucky news outlet.



Examples of the mineralization found in these cores. Figure 7 (left). Sphalerite overgrowth of dolomite vein. Figure 8 (right). Dolomite overgrowth of quartz rims in dolostone vug.

Rock Core Data, Oil and Gas Well eLogs, and Soils Now Accessible for Public Use

While EARL maintains an impressive rock core collection that includes almost 3,000 samples, the donated cores were not centrally organized. Documents were strewn across physical and digital spaces, organized by individual core, or grouped by drilling company or project. Documentation of donations often didn't match the physical locations. Project staff, including **Natalie Fields** and **Anthony Luken**, worked to untangle files and identify relationships between the cores. Proprietary data were protected from being posted online, core series were created to track these relationships, and PDF bookmarks helped keep everything organized. Upon completion, KGS Geoscience Information Section Head **Doug Curl** compiled and created a Rock Core Query to make the project information accessible and findable through the KGS website. This project provides a full picture of our collection, bringing connected cores to light.



Last fall, Geologic Archive Technician **Alex Arimes** joined the EARL staff to address our collection of 1,119 soil cores and 3,800 samples (Fig. 9). For six months she worked to reconcile data, register the cores and samples with IGSNs, and

Figure 9. Alex Arimes reviewing her progress mid-way through the project.

perform physical assessments before rehousing kept items. Under the guidance of KGS Geologist **Antonia Bottoms**, **Arimes** collated analysis data tied to the collection and created standard operating procedures for processing new soil cores and samples. At the end of the project, Web and Database Specialist **Fin O'Flaherty** created the KGS Soil Core Viewer to display our collection and associated data.

To complete the next step in the preservation workflow, Archives Manager **Liz Adams** and Geoscientist **Antonia Bottoms** worked with Research Facility Manager **Ryan Pinkston** to coordinate the installation of a new outdoor refrigeration unit for the storage of future soil cores. The new storage space will ensure proper preservation of soil cores and allow for expanded geochemical and organic analysis, as well as relevance to related earth science fields such as climatology, agriculture, and ecology. The final step in the process included the design and construction of a new soil core photography station for new core accessions (Fig. 9). The station will produce high-resolution photos stitched together to provide a seamless image of a core run. These will be available to the public through the KGS Map Service. These projects were generously funded by the USGS National Geological and Geophysical Data Preservation Program.

Click on the interaction map service (linked above) to view the KGS collection of soil cores by depth

New Analysis Capabilities with a Multi-Sensor Core Logger (MSCL)

In June, technicians from the London-based company Geotek, Inc. visited EARL to install a new piece of high-tech equipment called an MSCL. This newest addition to EARL includes sensors for measuring a rock or soil core's natural gamma, density and porosity, and magnetic susceptibility. Purchased with funds from the University of Kentucky's Energy-Research Priority Area equipment grant program, the MSCL will expand the analysis capabilities at UK for research in fields including energy, agriculture, and climate change. Collaborators on the multidisciplinary proposal are situated in departments across the University, including Anthropology, Civil Engineering, and Earth and Environmental Science.

Click on the YouTube video above to watch a time-lapse video of the MSCL installation at EARL.

Energy & Mineral Resources

Introduction

The Energy & Minerals Section experienced strong growth in several research programs during the 2022-23 fiscal year. The USGS-sponsored Earth Mapping Resources Initiative (Earth MRI) continued to expand, coordinated by program manager **Gina Lukoczki**. Earth MRI funded a new research project focused on the South-Central Kentucky–North-Central Tennessee Mineral District. The three-year project will involve assessment of the critical mineral resources of this active mining district and adjacent areas in Kentucky. **Lukoczki** and **John Hickman** are the project leads. Geologist **Edit Kiraly**, who started at KGS this year, is assisting with the project, analyzing hundreds of mineral cores in the KGS Earth Analysis Research Library (EARL). Lukoczki also received funding for a new Earth MRI study to inventory non-coal mine waste that may have critical mineral resource potential. Critical minerals in Pennsylvanian black shales are the focus of **Cortland Eble**'s Earth MRI project, leveraging his extensive knowledge of Pennsylvanian stratigraphy. More details on the Earth MRI program can be found below.

Additional work to preserve older minerals data was funded by the National Geological and Geophysical Data Preservation Program (NGGDPP). **Gina Lukoczki** and **Paul Puckett** are developing a mine map for the entire Illinois-Kentucky Fluorspar District from historic records, expanding a previous map in Illinois. This project will also develop digital data mining techniques and provide new geochemical analyses.

The potential for rare earth elements (REE) in Pennsylvanian coals and related rocks is the focus of two U.S. DOE-funded projects, one in eastern Kentucky (Appalachian Basin) and one in western Kentucky (Illinois Basin). The national CORE-CM program is evaluating coals and coal mining waste material for REE resource potential and extraction. **Cortland Eble** and **Steve Greb** are managing these projects. **Tom Sparks** is assisting with building a spatial database of selected coal slurry ponds for both projects. Phase 1 tasks will be completed in the fall of 2023, and we anticipate a continuation of both projects into Phase 2.

The environmental impact of orphan oil and gas wells has been the focus of **Marty Parris**' research for many years, and this year he received significant funding from the 2021 Bipartisan Infrastructure Law. This law provided funds to plug thousands of orphan wells across the country. KGS is working with the Kentucky Division of Oil and Gas to develop methane measurement methodologies and to quantify emissions from orphan wells prior to plugging. Geologist **Deron Zierer** joined KGS to work with **Parris** and **Steve Webb** to prioritize orphan wells and measure methane emissions. This project is also described in more detail in the Measuring Methane section below.

Interest in geologic carbon storage increased significantly this year as the Environmental Protection Agency announced draft rules that could impose new limits on CO_2 emissions from fossil-fuel-fired power plants and other industries. The section participated in two proposals to the U.S. Dept. of Energy for carbon storage feasibility studies. **John Hickman** will be principal

investigator on these studies if funded. KGS continued its participation in the Midwest Regional Carbon Initiative (MRCI), which completed its Phase 1 project and an interim report in late 2022. **Steve Greb** and **Tom Sparks** continued their work with project manager Battelle Memorial Institute and other MRCI states on this regional study. A summary of the Phase 1 MRCI findings is included below. **Rick Bowersox** began a carbon storage site assessment for a power plant in Clark County. This is based in part on his previous work on compressed air energy storage. In addition to his CO_2 work, **Bowersox** was also invited to present a paper with **David Harris** at the 2023 North American Helium Conference in Denver. They summarized Cambrian helium resources in the Rome Trough, which may be commercially produced in the future.

Finally, this year the section officially "adopted" **Carrie Pulliam**, database manager and geologist who maintains KGS energy databases. **Pulliam** has worked closely with the section and the Kentucky Division of Oil and Gas at KGS for years, and it is great to now have her in the section. **Pulliam** gave a key paper at the 2023 Oil History Symposium where she showed the importance of historical oil and gas drilling records in locating orphan wells for the current federal plugging program.

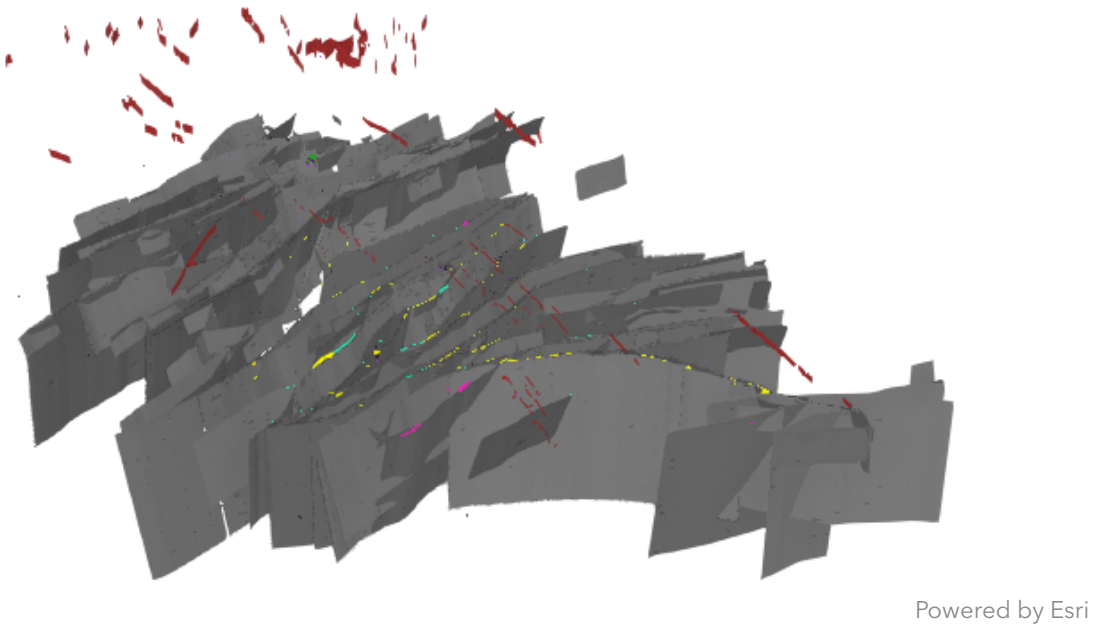
Searching for Critical Minerals in Kentucky

KGS has seen a further expansion of the Earth Mapping Resources Initiative (Earth MRI) program funded through the US Geological Survey in the fiscal year of 2022-2023. KGS is currently actively engaged in three Earth MRI projects in addition to supporting Data Preservation projects.

Western Kentucky Fluorspar District 3D Geological Modeling

The Western Kentucky Fluorspar District 3D Geological Modeling project performance period ended July 31, 2023 with the final report preparation currently in progress. The major deliverable of

this project is the 3D geological map of the Illinois-Kentucky Fluorspar District (see Updated IKFD 3D Model below).



Updated IKFD 3D Model (May 2023)

In addition to the main stratigraphic surfaces and faults, magnetic anomalies representing potential igneous centers and dikes, drill cores with critical mineral data, as well as old mines and mining prospects are also shown in the model. A recently added capability of this 3D model is to measure distances of geochemical samples to the nearest faults, dikes, igneous centers, and to the crystalline basement to help understand spatial trends in the distribution of critical minerals in the district. The 3D model incorporates elemental concentration data of over 300 samples collected from drill cores and outcrops over the entire district in collaboration with the Illinois State Geological Survey. The final report will include an evaluation of the petrogenesis of the igneous rocks that host rare earth elements and other critical minerals in the district.

KGS project personnel: **Gina Lukoczki** and **Drew Andrews** as PIs, **Devan Robinson** and **John Hickman** as contributors, **Anna Pearson** former employee. Outside collaborators Craig Dietsch,

University of Cincinnati, and Zach Walton UK Earth & Environmental Science, and several people at ISGS.

Integrated Studies of Overlapping Critical Mineral Systems in South Central Kentucky and North Central Tennessee

A new Earth MRI grant was awarded to KGS with the title Integrated Studies of Overlapping Critical Mineral Systems in South Central Kentucky and North Central Tennessee. The goal of this project is to develop regional stratigraphic framework and mineral system conceptual models to support the critical mineral assessment of the area. Samples are being collected for geochemical and petrographic analysis to study the control on distribution of critical minerals in this area.

Figure 10. KGS staff John Hickman, Gina Lukoczki, and Dave Harris on a sampling trip to Nyrstar Mine in Tennessee.

Stratigraphic and geochemical data are compiled and integrated into a geological framework model and accompanying databases. Completion of this project will improve overall understanding of the geometry and architecture of mineralization and associated features in south central Kentucky and north central Tennessee and will provide essential data for evaluation of critical and strategic mineral resources. More clearly understanding the framework geology and more accurately characterizing the geochemistry of the prospective area for critical mineral exploration will aid in interpreting the origin and evolution of the mineralizing fluids, metals, ligands, and other ore components that created the strategically important mineralization in this area. This work is necessary to calculate resources and guide future exploration for critical minerals in the district. Overall, this project will lead to an improved understanding of the distribution, geologic context, structural controls, and mineralogical associations of critical minerals in this focus area.

Project personnel: **Gina Lukoczki** and **John Hickman** as PIs, **Edit Kiraly** as contributor. Outside collaborators: Esteban Gazel, Cornell University, and Michelle Abshire, Valley City State University.

Critical Minerals in Pennsylvanian Black Shales of the US Midcontinent

Figure 11. Edit Kiraly with a pXRF in the field.

KGS also participates a multi-state Earth MRI project Critical Minerals in Pennsylvanian Black Shales of the US Midcontinent coordinated by the Kansas Geological Survey. The goal of this project is to evaluate the critical mineral content of dark-colored (black) organic rich shales, which represent a common lithology in the Pennsylvanian section of the Eastern and Western Interior Basins. In addition to having elevated amounts of organic carbon, these shales commonly contain elevated amounts of base metal elements (e.g., chromium, nickel, cobalt). This project focuses on the collection and testing of black shale samples, sampled from exploration drill cores and active underground mines, to better determine the composition of the shales and their potential as sources of critical and strategic elements.

Project personnel: **Cortland Eble** and **Gina Lukoczki** as PIs, **Edit Kiraly** as contributor.

Measuring Methane of Orphaned Oil and Gas Wells

The U.S. has approximately 3.5 million abandoned oil and gas wells, the majority of which occur in Texas, Pennsylvania, Kansas, and West Virginia. Kentucky has about 14,000 known abandoned wells (Fig 12). In Kentucky, the term "orphaned oil or gas well" describes wells that, after thorough investigation by the Kentucky

Division of Oil and Gas, have no known operator or owner with legal responsibility or the parties are financially insolvent.

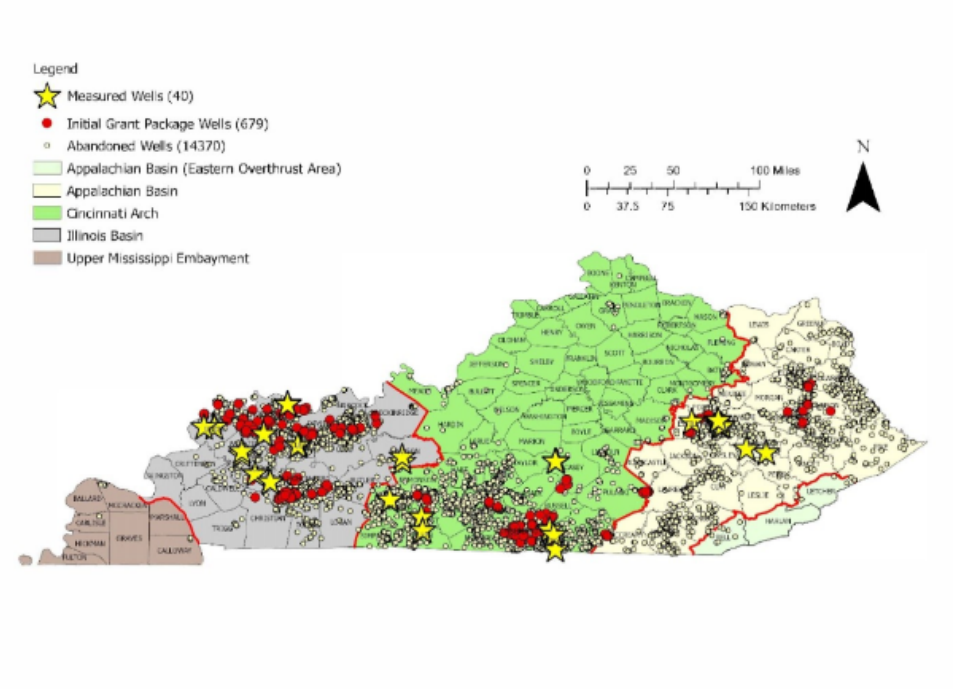


Figure 12. Distribution of known orphaned wells, initial grant wells, and methane measurements.

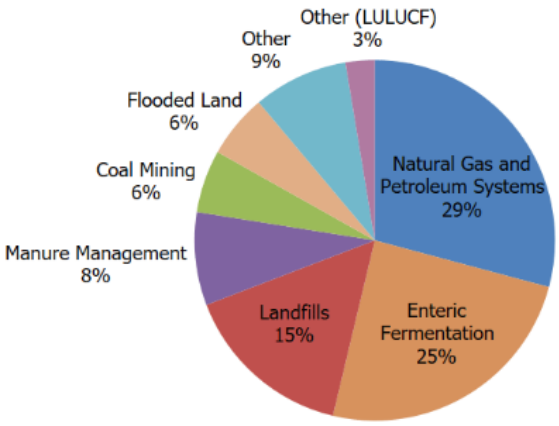
Orphaned wells are potential environmental hazards that can emit methane – a powerful greenhouse gas – and other harmful gases, such as, volatile organic compounds and hydrogen sulfide. Methane emissions also contribute to the formation of ground level ozone that causes respiratory problems. Locally, oil, gas, and brine may leak into the surrounding soil, and groundwater and surface water. Orphaned wells can impede recreation, farming, and other beneficial land uses (Fig. 13).

Figure 13. Permit #15297 in McLean County with brine leaking from base of well.

When compared to carbon dioxide, the main driver of long-term global warming, methane is about 84-times more powerful

as a greenhouse gas over a 20-year period. Domestically, oil and gas operations accounted for 29% of the 30 million tonnes of methane emissions reported to the EPA in 2021. (Fig. 14). Per the EPA Greenhouse Gas Reporting Program, orphaned wells account for estimated 0.06 to 1.0 million tonnes of methane emissi ons. The large range reflects the uncertainty in the total number of orphaned wells and large range of emissions magnitudes.

Because methane has a short atmospheric residence time of 12 years, reducing methane emissions is viewed as one of the most effective measures to decrease near-term global warming over the next several decades. Plugging orphaned contributes to this reduction as well as removing the previously described local hazards.



U.S. Environmental Protection Agency (2023). Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2021

Figure 14. Domestic methane emissions by sector.

With funding from Bipartisan Infrastructure Law (BIL) through the Kentucky Division of Oil and Gas, KGS researchers **Deron Zierer**, **Steve Webb**, and **Marty Parris** are leading the effort to estimate methane emissions from orphaned oil and gas wells being plugged during the initial phase of funding from the BIL. With 627 wells across 27 counties targeted for plugging, the large number of wells precludes methane measurements on all wells (see map).

To address the challenge, we are measuring methane emissions on a sample set 75 to 100 orphaned wells that are part of the larger population of wells to be plugged. Measurements on the sample set will attempt to mimic the distribution of orphaned wells based on geologic provinces and well subtypes (e.g., geologic age of the reservoir and type of produced hydrocarbon (oil versus gas)). This framework allows us to systematically target wells for methane emissions measurements and to apply inferential statistics to assess whether well subtypes have characteristic emission ranges and tend to be low or high emitters. In addition, we are using

geospatial analysis to assign a hazard ranking based on other environmental impact and factors, such as, proximity to important human and natural resource features and location in flood zones.

Figure 15. Methane emissions measurement with Well Done Foundation in Webster Co. (Permit #8019 WF).

Working with the Well Done Foundation, measurements on 40 wells (Fig. 15) shows that about 25% percent of the wells account for more than 90% of methane emissions (11 tonnes per year). When considering a 20-year global warming potential, this is equivalent to ~924 tonnes of carbon dioxide emissions per year or the annual emissions of about 200 vehicles. To date, high emitters tend to occur in gas well subtypes. This recognition underscores the potential to maximize emissions abatement using the well subtype classification.

Midwest Regional Carbon Initiative (MRCI)

The Midwest Regional Carbon Initiative (MRCI) is a carbon storage and utilization research project led by the Battelle Memorial Institute and Illinois Geologic Survey and sponsored by the U.S. Department of Energy. MRCI aims to advance carbon capture, utilization, and storage (CCUS) research by addressing key technical challenges, obtaining and sharing data to support CCUS, facilitating regional infrastructure planning, and performing regional technology transfer. The MRCI area includes a large region of the eastern United States including parts of the Midcontinent, the northern end of the Mississippi Embayment, the Illinois Basin, the Michigan Basin, the northern and central Appalachian Basin, and parts of the Atlantic coast and offshore mid-Atlantic.

Steve Greb and **Tom Sparks** worked on collecting subsurface stratigraphic data and results from past carbon storage research in Kentucky to put into centralized databases for easier technology transfer (Fig. 16). This task included compiling subsurface isopachs, structure maps, and metadata for a regional map database. **John Hickman** worked with **Sparks** and **Greb** on a new Basement (Precambrian west of the Appalachian and pre-Mesozoic east of the Appalachians) structure map for the region. A new isopach and structure map was constructed for the Mount Simon-Lamotte Sandstone, which is a primary potential carbon storage reservoir in the Illinois basin region. New regional structure maps were also constructed for the top of the Eau Claire-Bonneterre-Conasauga Formations, and the top of the Ordovician, which are important confining intervals in the region. Steve worked with researchers from across the region to make an updated regional stratigraphic correlation chart for comparing rock units relative to their carbon storage potential (reservoir, confining unit, etc.). **Seth Carpenter** and **John Schmidt** worked on characterizing the state-of-stress across parts of the region. That work is discussed in the Hazards Section of the annual report.

For more information about the MRCI project, data sets, and reports, go to www.midwestccus.org.

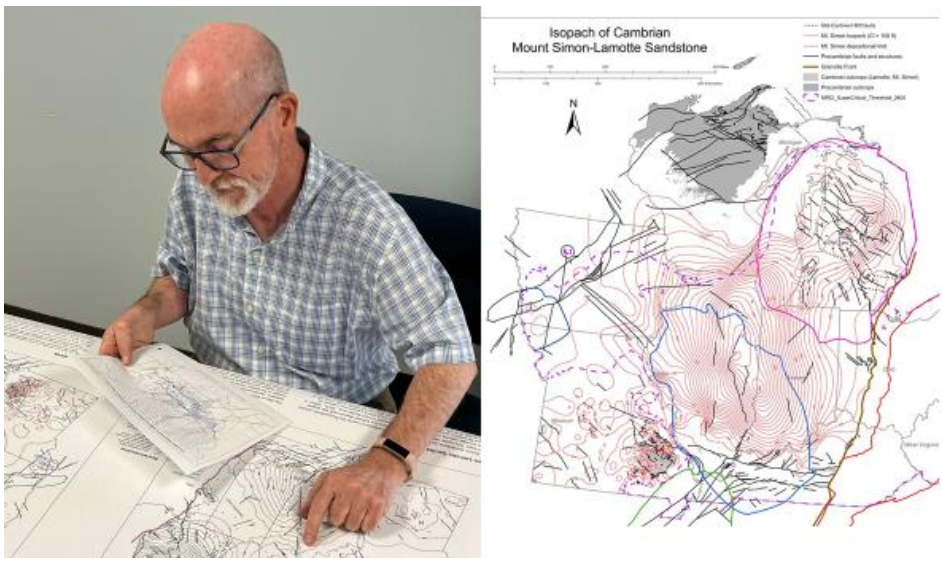


Figure 16. On left, Tom Sparks compares maps. On right is an isopach map.

Geologic Hazards

Introduction

The Hazards Section continued to make significant contributions to both the KGS and UK, strategic goals in research, services, and professional developments in FY 2022-23. The Hazards Section was able to conduct a field reconnaissance of landslides and debris flows associated with the July 2022 Flooding in parts of eastern Kentucky and published a report timely for the stakeholders, and all staff earned the 2023 KGS director award for these efforts. The section conducted eight external and internal funded projects, including the U.S. Federal Emergency Management Agency (FEMA) funded landslide hazard and risk assessments for the Kentucky River Area Development District, Department of Energy (DOE) funded seismicity monitoring in western Kentucky and characterizing earthquake activity and tectonic stress at candidate sites for Carbon Capture, Usage, and Storage (CCUS) in norther-central and northeastern US, and USGS funded installation and evaluation of Raspberry Shake seismographs and development of national landslide susceptibility. The section produced six manuscripts for peer-reviewed journal publications, 11 abstracts, six KGS publications, three project reports, and seven professional and public presentations. The section actively engaged in internal collaborations with the staff in other sections at KGS and external collaborations with researchers on UK campus and beyond. The section also actively engaged in public and student services, including media interviews and supervising students. The section emphasized staff professional development through participating in the UK Human Resource training and courses, professional conferences and workshops, and others.

Figure 17. Left to right: 1. Matt Crawford, Zhenming Wang, and Hudson Koch conducted field reconnaissance of the landslides and debris flows caused by the July 2022 Flood in eastern Kentucky. 2. Rick Olsen (NPS), Lloyd Cross (VLF Manufacturing), Jon Schmidt, Zhenming Wang, Greg Steiner (KGS), and Seth Carpenter installed the seismic station MCKY in the Mammoth Cave National Park. 3. Hudson Koch, Matt Crawford, and Sourav Saha collected field data with the 6-rotor UVA carrying a YellowScan Surveyor LiDAR laser scanner at Maxey Flats. 4. Jason Dortch and Sarah Arpin were helping Jon Schmidt to install new strong-motion sensors behind Mining and Mineral Resources Building.

Reconnaissance of Landslides and Debris Flows Associated with the July 2022 Flooding in Eastern Kentucky

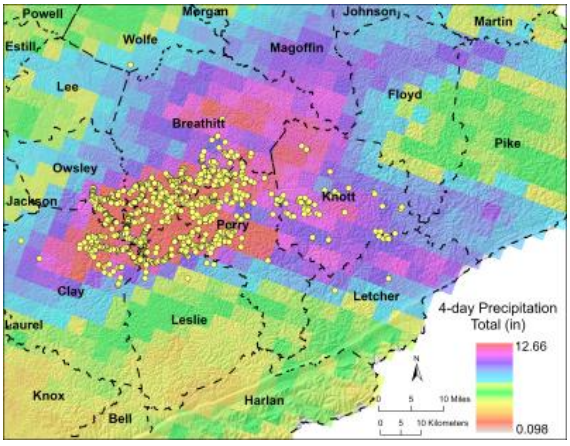


Figure 18. Documented landslides and debris flows (yellow dots) caused by the July 2022 Flooding in eastern Kentucky. Map is combined storm radar and observed rainfall totals.

Exceptionally heavy rain during late July 2022 caused catastrophic flooding that killed 43 people and triggered thousands of landslides and debris flows and caused damages to roads and homes in parts of eastern Kentucky. The Hazards Section conducted a preliminary field reconnaissance to observe and document the landslides and debris flows from late August to early November 2022 using (1) visual field inspection methods and (2) a remote sensing technique called normalized differencing vegetation index. A total of 1,100 landslides and debris flows were documented (Fig. 18). Rapid reconnaissance balances time, data collection, and data quality as landslides are considered perishable field data. We used field GPS locations and desktop GIS to document landslide locations. We also used remote sensing and satellite image differencing to identify landslides. Documenting landslides before

they become challenging to identify is important for future rainfall threshold and landslide occurrence studies.

The results from this reconnaissance will provide data for future landslide hazard studies and help geologists to better understand how landslides in Kentucky are related to rainfall and climate change. The results will also provide lessons on how to avoid or mitigate potential landslide damages to homes and roads in eastern Kentucky mountainous areas (Figs. 19 and 20). Continued compilation and evaluation of landslide inventory data associated with storm events, seasonal landslide occurrence patterns with rainfall, and analysis of landslide occurrence with rainfall rate and duration data.

Figures 19 and 20, left to right. Fig. 19: Home damaged by landslides/slums occurred on the cut slope. There is no or little buffer between the house and slope. Fig 20: Measures preventing landslide damage to home. There is a large space and a concrete wall between the house and cut slope. Also, there is a large drainage to divert the rainwater.

Earthquake Monitoring and Seismic Hazard Study for the Paducah Gaseous Diffusion Plant

The Paducah Gaseous Diffusion Plant (PGDP) is located near Paducah in McCracken County of western Kentucky and faces potential seismic hazards due to its proximity to the New Madrid Seismic Zone (NMSZ). However, the seismic hazards estimated by the U.S. Geological Survey are significantly high for the New Madrid area (Fig. 21). The resulting engineering designs and other

mitigation policies by the federal agencies have caused problems at PGDP and in the area. For example, the Department of Energy had difficulty obtaining a permit to construct a landfill at PGDP for environmental cleanup. The seismic design requirement for residential building near PGDP is higher (i.e., E zone) than that (i.e. D zone) in San Francisco, Calif., according to the 2000 International Residential Code (Fig. 22). The high seismic hazard assessments and the resulting mitigation policies by the federal agencies have a significant impact on the economic development in western Kentucky, the Jackson Purchase Region in particular.

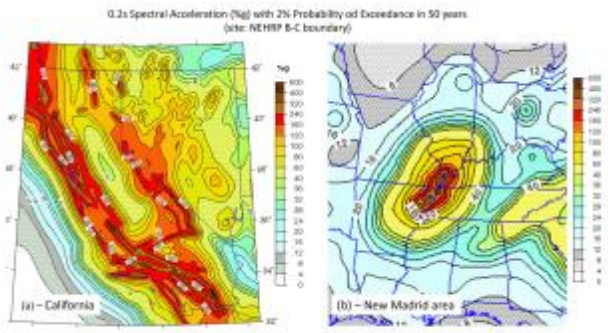


Figure 21

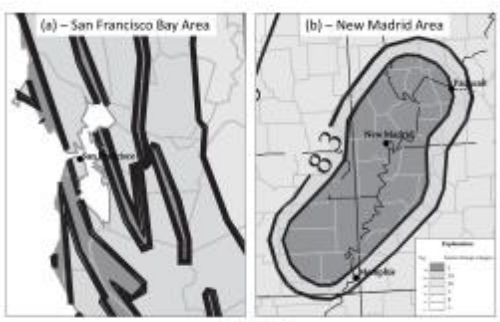


Figure 22

Figures 21 and 22, left to right. Figure 21: 0.2s spectral acceleration (percent of gravity) with 2 percent probability of exceedance in 50 years produced by the U.S. Geological Survey in 1996 for California (a) and the New Madrid area (b). Figure 22: The seismic category of the 2000 International Residential Code for the San Franscisco Bay Area (a) and New Madrid area (b).

A dense and unique seismic and strong motion network, including the deepest borehole strong-motion array – the Central U.S. Seismic Observatory (CUSSO), was installed and operated in western Kentucky and provided the data for better understanding seismicity and seismic hazards. The research on seismic hazards has led to the identification of a mathematical error in probabilistic seismic hazard analysis (PSHA) which was used by the national seismic hazard mapping project. The research has also led to the development of scenario seismic hazards for mitigation policy considerations in Kentucky (Fig. 23). The seismic group will continue to monitor earthquakes and conduct research on seismic hazards in the vicinity of PGDP.

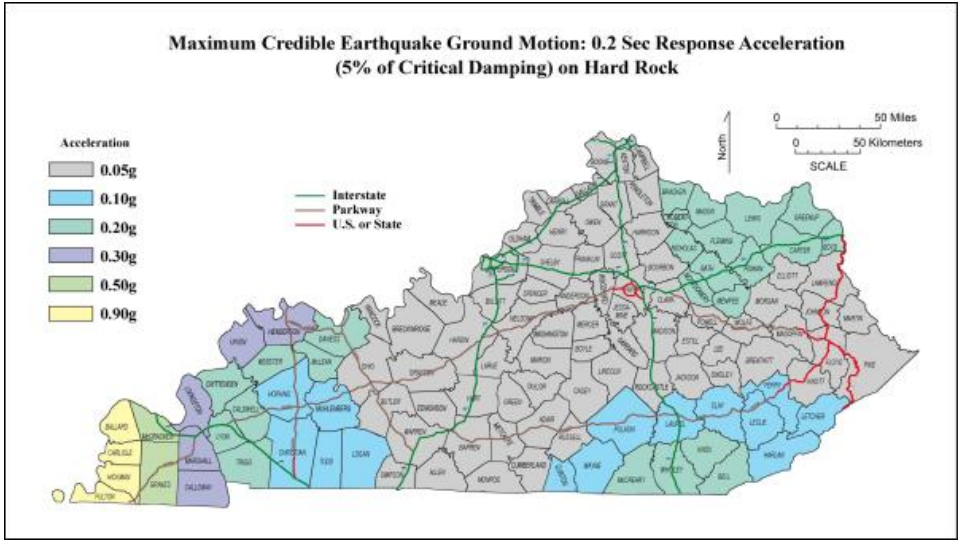


Figure 23. 0.2s spectral acceleration (percent of gravity) on hard rock from the maximum credible earthquakes considered for Kentucky.

Kentucky Seismic and Strong Motion Network (KSSMN)

The Kentucky Seismic and Strong Motion Network (KSSMN) continued to monitor strong shaking and earthquakes in Kentucky and around the world. The network consists of 24 stations, 19 of which send data to KGS computers in near real-time, which provide the necessary information to study earthquakes that affect the Commonwealth (Fig. 24). The data were used to locate and estimate the sizes of 15 earthquakes that occurred in Kentucky this year, as well as additional events outside of the state. With support from the USGS National Earthquakes Hazard Reduction Program (NEHRP), the KSSMN continued to operate six Raspberry Shake seismographs at five KSSMN sites: BAKY, CUSSO, HEKY, HZKY, and VSAP. This year, seismologist **Jon Schmidt** continued to collect and process earthquake recordings, primarily from the New Madrid seismic zone, but also from the Wabash Valley and Eastern Tennessee seismic zones, that will be used to evaluate the capabilities of the low-cost Raspberry Shake seismographs and accelerographs. In total, Schmidt determined that 17 earthquakes recorded on the Shakes will be useful for analysis.

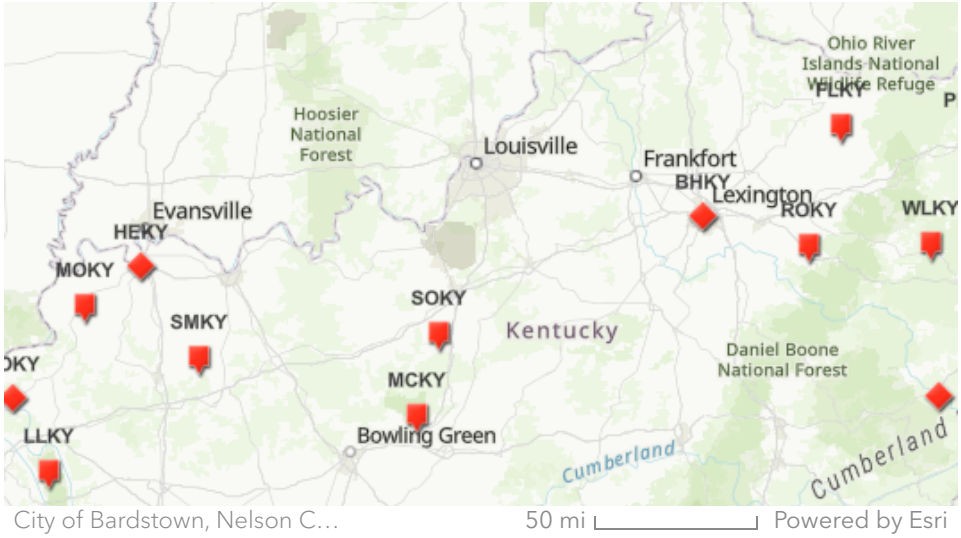


Figure 24. Kentucky Seismic and Strong-Motion Network (KSSMN). Click on the interactive map to view data from the stations.

KGS supported a major upgrade to the KSSMN, which was completed this year. Seismologists Seth Carpenter, Zhenming Wang, and Jon Schmidt installed the first networked seismograph in Mammoth Cave. Through a testing process that began in January 2020, the KGS team found a site in the Miller Avenue passage that offered seismically "quiet" conditions. Combining the quiet location with the sensitive broadband seismometer that has been installed allows this station to record very small signals from earthquakes that occur nearby and around the world and from other seismic events. With help from park staff, the team completed installation of the station on February 8 and the data are being received in real-time at the University of Kentucky to contribute to earthquake monitoring as part of the KSSMN.

KSSMN data, especially the real-time online recordings, provide reliable information on earthquakes and other activities for stakeholders and media, including interviews this year with WHAS, WEKU, and WKYT. Some KSSMN data streams are also made available to earthquake researchers around the globe via real-time sharing with the IRIS Data Management Center. The group will continue to upgrade and operate the KSSMN seismic and provide earthquake information for the stakeholders in Kentucky.

UAV-Based Elevation Differencing and Landslide Hazard Assessment at Maxey Flats

Figure 25. Matt Crawford was flying the 6-rotor UAV carrying a YellowScan Surveyor lidar laser scanner at Maxey Flats.

The Maxey Flats Disposal Site has experienced several landslides along the south, west, and east borders of the facility. Some hillslope displacements are observable at the heads of catchments near the ridgetop. Larger rotational landslides exist mid-slope extending towards the base of the slope, particularly along an old road of the southern border. The landslides go through variable stages of movement primarily related to precipitation and slope modification. KGS will quantify the hillslope elevation change (differencing) using UAV-derived digital elevation models. KGS will evaluate landslide activity, determining areas of accelerated or non-movement. A particular focus will be on the toe slopes as those areas have historically been active. The possibility of retrogressive displacement further upslope near the ridgetop will also be evaluated. Maxey Flats is part of the Division of Waste Management within the Energy and Environment Cabinet.

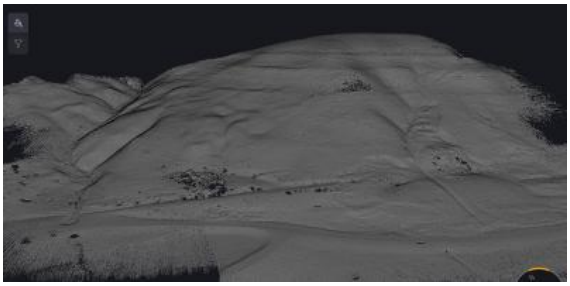


Figure 26. LiDAR classified ground points on the south facing slope at Maxey Flats. Note the landslide on the right side of the image.

KGS will conduct semi-annual UAV flights in the Maxey Flats area of interest. KGS will use a DJI Matrice 600 Pro UAV. The UAV is a 6-rotor flying platform with the capability to carry a YellowScan Surveyor lidar laser scanner (Fig. 25). The lidar surveyor has the capability for 360-degree scanning, 2 laser echoes, and 4cm and 5cm precision and accuracy, respectively. KGS will collect the lidar data and process the raw point cloud files using YellowScan's CloudStation software (Fig. 26). The software allows for flight strip adjustment, point classification, and digital terrain model exporting. Flight trajectory correction

will be controlled using the Applanix software called POSPac. Computers in the KGS DEAL are central to data processing and map generation.

Landslide Susceptibility and Risk in the Kentucky River Area Development District

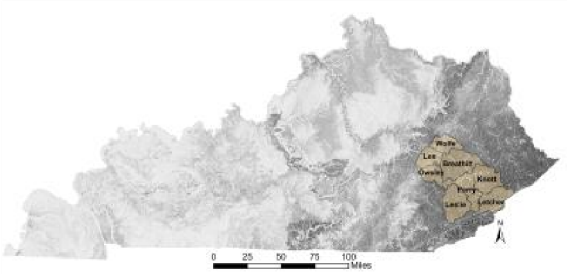
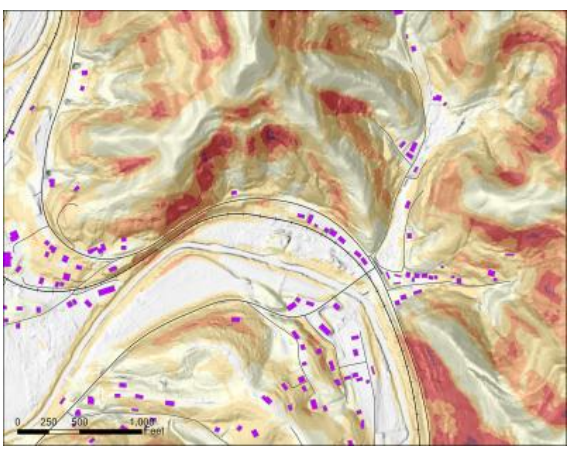


Figure 27. Eight counties of the Kentucky River Area Development District.

This project will implement measures designed to evaluate landslide hazards and reduce risk to individuals and property in the Kentucky River Area Development District (Fig. 27). The results contain useful information for each community to incorporate mitigation strategies that will support building and infrastructure needs, land-use planning, event awareness, response, and recovery actions for communities in the region.

Funded by FEMA's Hazard Mitigation Grant Program, this project supports hazard mitigation planning and actions. Mitigation plans identify the landslide hazards that impact communities, identify actions to reduce losses from the hazards, and establish a coordinated process to implement the plan. Integration of landslide susceptibility data and risk information into a multi-jurisdictional plan revolves around goals of establishing resilience as a value of the community.



This work is innovative as we have established a reliable framework for assessing landslide susceptibility at a regional scale using a statistics and geomorphic-based approach. We incorporate landslide inventory data with two traditionally distinct machine-learning methods that complement each other to produce a final susceptibility

map (Fig. 28). Hillslope factors such as slope, curvature, plan curvature, elevation, aspect, topographic wetness, proximity to streams, and proximity to roads are used in a decision-tree and logistic regression analysis to determine significant factors for generating the map. Using the susceptibility map as a key input to a risk assessment, we also produce a socio-economic risk map that includes landslide effects on assets such as population, roads, railroads, buildings, and land class. Computers in the KGS DEAL are central to data collection and map generation.

Figure 28. Example landslide susceptibility published from the Big Sandy Area Development District. A similar, yet improved modeling approach will be implemented for the Kentucky River Area Development District counties. The purple polygons are buildings or residential homes. Black lines are roads.

Assessing Induced Seismicity Potential with the Midwest Regional Carbon Initiative

As part of the Midwest Regional Carbon Initiative (MRCI), a project funded by DOE and managed by Battelle, KGS is assessing the potential for inducing earthquakes from future carbon capture, use, and sequestration (CCUS) across a broad 20-state region of the northeastern U.S. Recent studies of induced seismicity (IS) in the states near Kentucky, specifically in Illinois, Indiana, Ohio, Pennsylvania, and West Virginia, suggest that an injection zone's proximity to crystalline basement is a major factor related to IS susceptibility. To assist with identifying candidate reservoirs for CCUS with low IS susceptibility, **Seth Carpenter** and **Jon Schmidt** are assessing this correlation in detail. This fiscal year, **Carpenter** and **Schmidt** completed a compilation of an earthquake catalog that contains all known events of magnitude 2.2 and greater and all known events of any magnitude since 2009 (Fig. 29). The list, which consists of more than 13,600 events, includes earthquakes induced

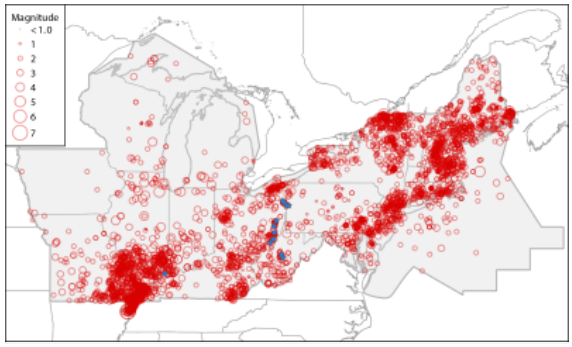


Figure 29. Map of earthquakes – natural and manmade – compiled for the MRCI. Zones where known or suspected induced earthquakes have occurred from oil and gas production, or wastewater disposal are indicated by blue stars.

or likely induced by wastewater disposal and fracking gathered from the literature.

Using the earthquake catalog, Hazards Section seismologists observed that the Rome Trough in eastern Kentucky is seismically quiet compared to surrounding regions (Fig. 30). In collaboration with other MRCI researchers, **Carpenter** is assessing the tectonic stress field in and around the Trough using the tectonic stress data and the Precambrian fault data compiled during the previous year by **Carpenter** and by **John Hickman**.

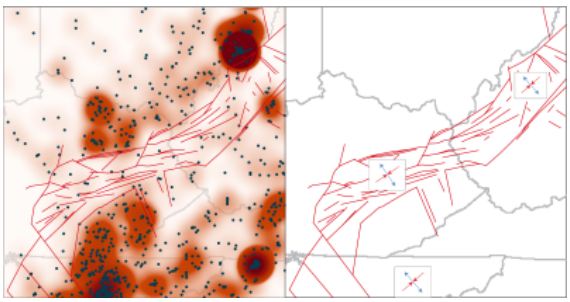


Figure 30. Heatmap of earthquake activity and Rome Trough faults (left) and resolved tectonic stress field (right): red arrows show direction of maximum horizontal compression and blue arrows show the direction of maximum horizontal extension.

Induced earthquakes can be a nuisance to communities near injection sites. Of greater consequence, events induced by CCUS could compromise reservoir integrity, resulting in a larger impact to such communities. This work will provide important geological characterizations of zones where induced or shallow earthquakes have occurred to facilitate informed selection of future CCUS sites. This work will also facilitate identifying zones where earthquakes are rarer, such as beneath the Rome Trough. To classify seismic events as earthquakes or mine blasts, **Jon Schmidt** used a machine learning approach that automatically categorized events recorded across the project area using characteristics extracted from waveform data. High-resolution characterization of locations more susceptible to induced earthquakes are made possible through detailed geological characterizations and high-precision earthquake locations.

As part of ongoing MRCI work, **Carpenter** and **Schmidt** are collaborating with **John Hickman**, **Steve Greb**, and **Tom Sparks** to characterize the stratigraphy where sequences of induced seismicity have occurred and where shallow (< 5 km) natural earthquakes have occurred, both of which indicate regions with

potentially greater risk of future induced seismicity. Also, the slip potential of faults in the Rome Trough and elsewhere in the MRCI project area are being assessed to help characterize the potential to induce earthquakes by fluid injection.

Kentucky Enhanced State Hazard Mitigation Plan Update for 2023

The 2023 State Hazard Mitigation Plan assesses the Commonwealth of Kentucky's risks over the last five (5) years. The plan supports hazard mitigation activities and qualifies the state to receive pre- and post-disaster federal assistance. KGS will conduct the assessments for specified geologic hazards. The results will be used to understand each identified hazard and as the blueprint for the Commonwealth's mitigation strategy. Funded by FEMA's BRIC Grant Program, a continued understanding of risk and of each geologic hazard's potential effect on the Commonwealth is imperative to the mitigation strategy and provides the information needed to produce an effective risk assessment.

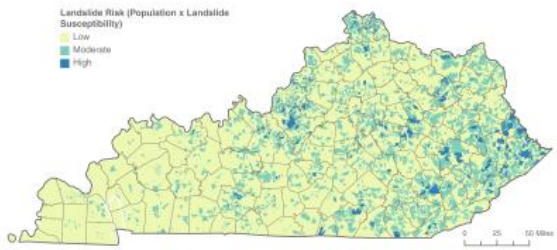


Figure 31. Landslide risk map. Risk is the product of U.S. Census block population data and the landslide susceptibility generated for the state.

KGS geologists will identify and assess earthquakes, landslides (Fig. 31), karst hazards, mine subsidence, and radon (Fig. 32). We will compile and update hazard information that includes hazard descriptions, occurrence, spatial extent, impact, economic losses, and hazard mitigation. Climate change phenomena, such as increased precipitation and drought, and its potential effects on the pertinent hazards will be included. KGS will leverage existing hazard data, update

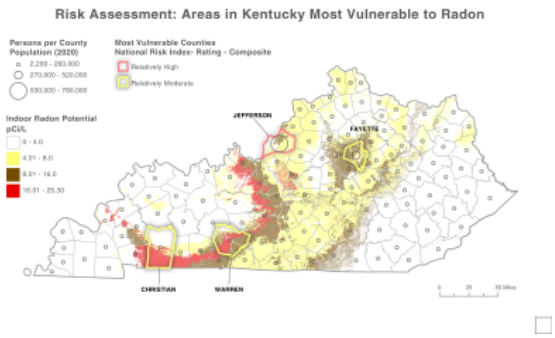


Figure 32. Radon risk map showing several counties that are deemed most vulnerable to radon. The risk is calculated as a function of indoor radon potential and a FEMA National Risk Index that assesses vulnerability scores for multiple metrics.

existing assessments and maps, and create new assessments. The assessments will range from qualitative spatial intersections to quantitative modeling.

Mapping

Introduction

The KGS Geologic Mapping Section produced nationally recognized 2D surficial and 3D mapping of and for Kentucky during the 2022-23 fiscal year. Through detailed data collection and analysis, the Mapping team created geospatial products for KGS stakeholders and the Commonwealth at large, with an emphasis on education and public safety.

Eastern Kentucky Flooding

Figure 33. KGS geologist Meredith Swallom measuring flood height at Knott County Little League's Veteran's Field

Geologists **Jason Dortch**, EES faculty **Ryan Thigpen**, Director **Bill Haneberg**, **Matt Crawford**, **Meredith Swallom**, **Ben Tobin**, **Sarah Arpin**, **Jason Backus**, **Antonia Bottoms**, **Steve Webb**, and CAFE-PSS scientist **Shristi Shrestha** traveled into eastern Kentucky along the North Fork of the Kentucky River after the July 27-28, 2022 flooding to collect water and sediment samples as well as flood indicators to capture the extent and height of the flooding. The USGS deemed this a 1000-year flood event, and the flooding caused heavy damage to roads, community infrastructure, homes, and significant loss of life. The KGS team's work, funded through a National Science Foundation RAPID grant, enabled the group to collect perishable data and samples that would otherwise be disturbed by cleanup efforts and natural erosion (Fig. 33).

Research efforts focused on Robinson Forest, located in Breathitt, Perry, and Knott counties, along with Letcher County due to the two areas providing distinct endmember examples of initial river conditions before the flood. Ongoing efforts are focused on developing accurate flood models in KGS's Digital Earth Analysis Laboratory (DEAL). The unmined versus mined catchments in Robinson Forest are expected to provide excellent contrasting validation for flood models while the more distributed mine areas in Letcher County will provide a more typical scenario. These models will harness data from prehistoric terrace sediments to more accurately predict flooding trends in eastern Kentucky over the next few hundred years.

Surficial Mapping

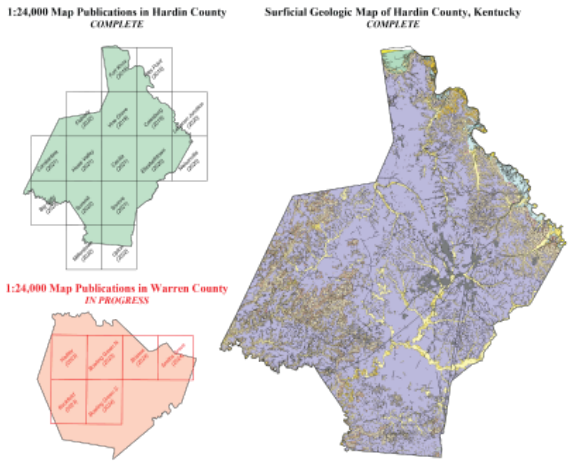


Figure 34.

Geologists **Matt Massey**, **Max Hammond**, **Antonia Bottoms**, **Meredith Swallom**, **Wes Buchanan**, **Ann Hislop**, and **Michelle McHugh** completed a four-year project mapping and characterizing the surficial geology as exposed in Hardin County (Fig. 34). This project was funded through USGS STATEMAP and KGS and supported the completion of five new 1:24,000-scale quadrangle map reports (Big Clifty, Flaherty, Millerstown, Summit, and Upton) and the compiled GIS dataset. These locations were selected by Kentucky's State Mapping Advisory Committee and KGS due to their location on the Interstate 75 corridor, recent and projected residential and industrial development, need for geologic maps to guide land use planning, and local GIS offices that help distribute the data to the public. This recent mapping was added to the KGS surficial mapping web service, with current mapping efforts moved south to Warren County starting in September 2022. Funded by STATEMAP, KGS delivered three new quadrangles (Rockfield, Hadley, and Bowling Green North) at the end of 2023. The surficial

mapping group will continue working to complete a Warren County map (in addition to individual quadrangle maps) until 2024 or 2025.

3D Geoframework Projects

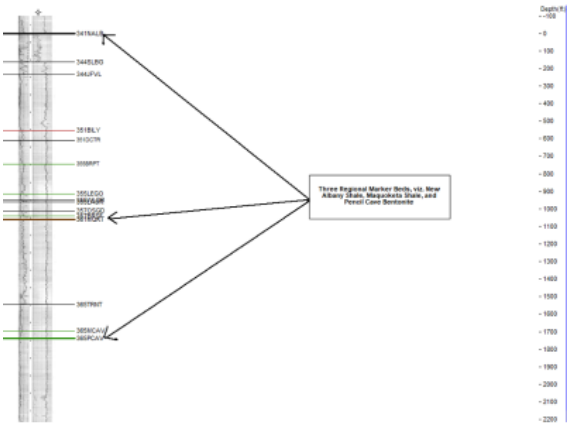
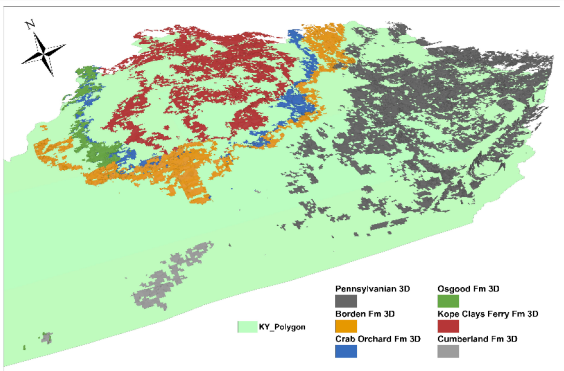


Figure 35. Three regional marker beds.

Funded by the USGS National Cooperative Geologic Mapping Program's National Geoframework Initiative (funded with STATEMAP support), the KGS geoframework team continues to develop 3D data elements from best available 2D resources, with new tools and resources being developed and utilized to lead future 3D projects. A 3D database, which is based on geophysical log analysis from various wells in Kentucky, contains information about subsurface formations and members. Geologist **Dibya Koirala** prepared the 3D well database for 124 reference wells before picking formation tops from around 1000 wells in the Western Kentucky-Illinois Basin. Marker beds such as Devonian Shale, Maquoketa Shale, and Pencil Cave Bentonite were identified (Fig. 35), before other members or formations were interpolated between these regional marker beds, considering the regional geologic architecture. The last step was preparation of cross sections using Petra software, which aided in correlating subsurface lithology using multiple wells and ensuring that other formation picks align with the regional geological context. The regional geology was consistent with the current 3D dataset in Western Kentucky.



Geologist **Devan Robinson** used best available KGS 2D geologic data to bring clay-shale units in central and eastern Kentucky into 3D using established automated methods in Esri's ArcGIS Pro, to support future landslide modeling and analysis. These units included the

Figure 36. Image of the 3D clay-shale units map.

Cumberland Fm, Kope Clays Ferry Fm, Osgood Fm, Crab Orchard Fm, Borden Fm, and Pennsylvanian Marine Coal-baring Shales (Fig. 36). An in-depth inventory of available data for surface interpolation in the Jackson Purchase was also conducted. Datasets containing relevant structure contours were geo-referenced, digitized, converted to 3D, and added to the KGS 3D database. Stratigraphic-top surfaces in the Jackson Purchase were created for Paleozoic strata, McNairy Fm, Porters Creek Clay, Wilcox Fm, and New Albany Shale (Fig. 37).

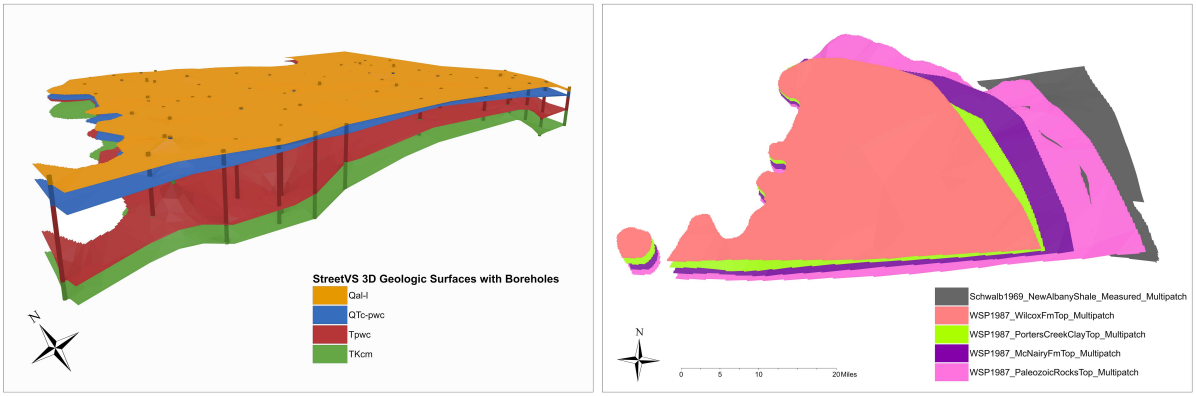
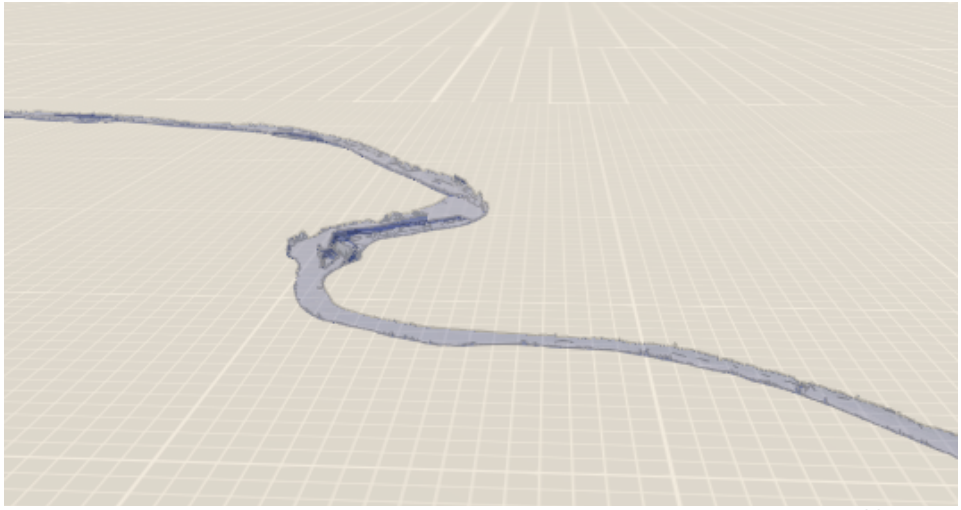


Figure 37.

Lastly for STATEMAP, a draft bedrock model for the Ohio River Valley in Kentucky was interpolated using predictive modeling by Shangguan et al. (2016) for depth to bedrock and USACE hydrographic surveys for detailed Ohio river bathymetry (see 3D Ohio River Valley Model below).



3D Ohio River Valley Model

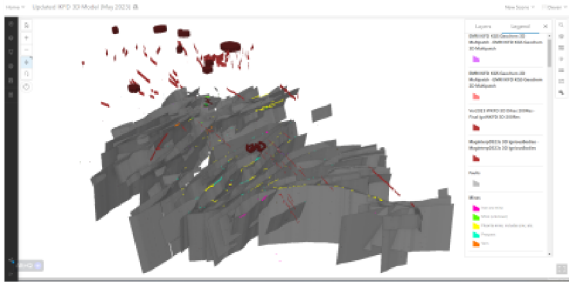


Figure 38.

Geologists **Devan Robinson** and **John Hickman** also assisted geologist **Georgina Lukoczki** with updating KGS's 3D model framework for the IL-KY Fluorspar Mineral District with new geochemical data, igneous features, and metadata on fault and dike geometries (Fig. 38). This improved model can be used to conduct statistical and spatial analyses on geochemical points in relation to 3D faults and igneous intrusions. All 3D models are easily viewable through the KGS ArcGIS online data portal.

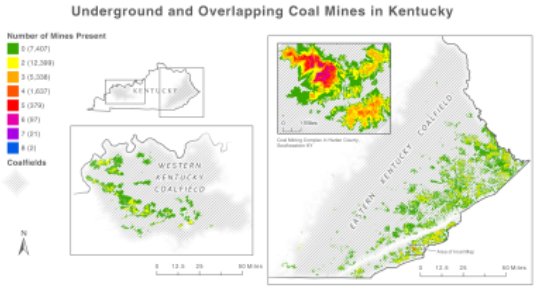


Figure 39.

Lastly, as part of the 2023 State Enhanced Hazard Mitigation Plan funded by FEMA, a Kentucky risk assessment map for indoor radon was created by geologist Devan Robinson and cartographer Emily Morris using the geologically based indoor radon potential map for Kentucky by Haneberg et al. (2020) and the 2023 National Risk Index (NRI) dataset by FEMA (see Figure 32 of annual report). An updated map was also created for the 2023 mine

subsidence section of the plan, showing overlapping coal mines in Kentucky's Coal fields (Fig. 39).

Fracture Mapping

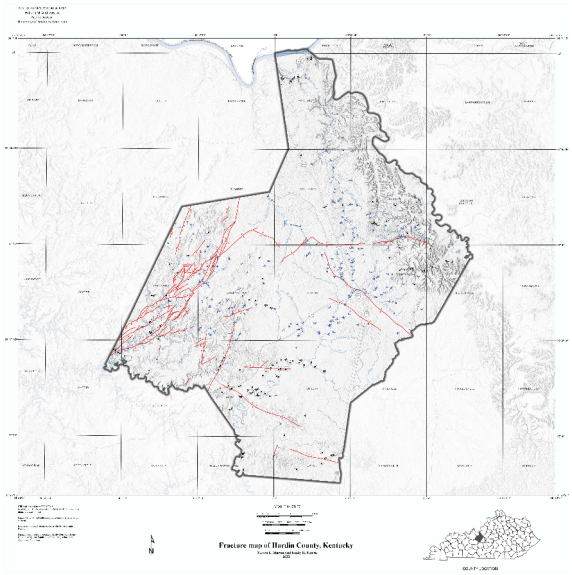


Figure 40.

Geologist **Steve Martin** compiled a fracture map of joint locations and faults in Hardin County, Kentucky to be published as part of the KGS Map and Chart series (Fig. 40). The joint data includes orientations collected in 2009 and from 2022 to 2023, and those collected during the geologic mapping of the 7.5-minute quadrangles from 1962 to 1977. Dominant joint orientations for all map units trended 0-20 degrees and 70-80 degrees, with minor orientations trending 40-50 degrees and 290-310 degrees, with many joint orientations parallel to subparallel to nearby faults. Most joint orientations were measured in the Middle Mississippian St. Louis and Ste. Genevieve Limestones.

Geoscience Information

The GIMS section is responsible for maintaining and managing data, IT infrastructure, communications, and the physical collections at the KGS Earth Analysis Research Library (EARL). While much of our section work is ongoing and supports all research areas and sections at KGS, section staff completed several noteworthy, funded projects, primarily in the area of data preservation and data dissemination. EARL staff continued their work to both preserve and disseminate core and sample data through several funded projects and prepared for future data gathering by overseeing the installation of a new soil core storage refrigerator and a new multi-sensor core logger which was acquired through the University of Kentucky Energy Research

Priority Area equipment grant program. Detailed information about these projects and new facilities is included in the EARL section of the annual report.

In January, we welcomed **Rebekah Frazier** as our new Communications Officer and in February we hired **Cheyenne Hohman** to help manage our newly rebranded Publication Resource Center. Along with coordinating KGS media, tabling at conferences and events, and editing the Big Blue RockPod podcast, **Frazier** manages and writes content for all the KGS social media channels. Read more about **Hohman's** work in our Publication Resource Center below. Both new employees hit the ground running by making an immediate impact on our general communications, social media, and physical publication collection.

Figure 41. The GIMS section gather for a yearly team building field trip to the Mother Ann Lee Hydroelectric Station. Back row (left to right): Doug Curl, Ryan Pinkston, Bill Haneberg (Director), Rebekah Frazier, and Monte Rivers. Front row (left to right): Elizabeth Adams, Sarah Arpin (Water section), Rachel Noble-Varney, Cheyenne Hohman, and Fin O'Flaherty.

The section continued to support KGS's robust online data and information capacity by adding new information and data to existing services, implementing new methods for securing our data and infrastructure, and bolstering the back end of our data services to provide more reliable and faster data access. GIMS staff also led staff development through leading an internal writing group, organizing the KGS Annual Seminar, and participating and presenting at several conferences throughout the year.

Big Blue Rock Podcast

KGS is now in year two of the Big Blue Rock Pod, a Kentucky-themed earth science podcast where hosts **Matt Crawford**, **Sarah Arpin**, and **Doug Curl** invite guests, typically geoscience

researchers, to join in a relaxed, impromptu conversations about specific geologic topics. The aim of the podcast is to highlight how geology and earth processes impact daily life. Formatted around monthly themed episodes and guest experts, the show explores what host **Matt Crawford** describes as "the tentacles of geology that reach out to all the other sciences."

Figure 42. KGS employees (left to right) Sarah Arpin, Matt Crawford, and Doug Curl host the Big Blue Rock Pod.

Along with having fun talking shop, the hosts of the Big Blue Rock Pod are serious about improving science communication and spreading awareness of geology. As **Crawford** shares in the introductory episode, despite growth in science podcasts, the number of earth science podcasts trails far behind similar fields like physics, biology, and ecology.

Fourteen episodes were released this year which range in topics such as discussions about GIS and spatial data, geologic time, surface hydrology, earthquakes, science communication, and Cumberland Gap. The Big Blue Rock Pod is hosted on PodBean and available on multiple applications, including Apple Podcasts, Amazon Music, Spotify, and Google Podcasts. The podcast series is also available for download from the KGS homepage.

Big Blue Rock Pod Player.

KGS Annual Seminar

The Kentucky Geological Survey (KGS) hosted its 62nd Annual Seminar on May 25th at the Jacobs Science Building on the University of Kentucky campus. This year's theme was Of Hills and Hazards and all the presentations revolved around Kentucky geological hazards. The goal of the event is to present truly collaborative and interdisciplinary work related to the KGS mission. GIMS worked diligently on the planning, logistics, communications, and event management to support the seminar.

Figure 43. Dr. David Applegate and State Geologist and KGS Director Dr. William C. Haneberg

U.S. Geological Survey (USGS) Director Dr. David Applegate, the seminar's keynote speaker, set the direction for the day with his presentation Geohazards and Geological Surveys: Bringing Science to Bear When and Where It Matters Most. Dr. Applegate emphasized that both the USGS and KGS had a commitment to unbiased scientific geohazard research in support of society. The two organizations shared the goal of translating hazard research into meaningful and actionable information about geohazard risks and potential impacts.

Dr. Applegate also highlighted the need to partner with experts in other disciplines, including social and economic sciences, environmental justice, and communications professionals to help bridge the gap between science providers and science users. One such expert, illustrator and author Martha Park, discussed her experience illustrating the comic *Washed Away*, which she created collaboratively with author Austyn Gaffney. The header art for this report is also taken from the comic. The comic is set in eastern Kentucky and tells the story of a Kentucky family dealing with the impact of a landslide triggered by the July 2022 floods. KGS's landslide susceptibility map was featured in the comic and

highlights areas susceptible to landslides in a geologic and geomorphic context in five eastern Kentucky counties.

Following the July 2022 floods in eastern Kentucky, KGS researched the associated landslides and debris flows and published the report Reconnaissance of Landslides and Debris Flows Associated with the July 2022 Flooding in Eastern Kentucky. At the seminar, seven KGS staff members were awarded this year's Director's Awards for their excellent analysis and work on that project: **Seth Carpenter, Matt Crawford, Jason Dortch, Hudson Koch, Rachel Noble-Varney, Jonathan Schmidt**, and **Zhenming Wang** (Fig. 44).

Figure 44. Recipients of the Director's Awards (left to right): Jason Dortch, Hudson Koch, Jonathan Schmidt, Zhenming Wang, Matt Crawford, and Rachel Noble-Varney. Director Bill Haneberg at right.

The slate of KGS geohazard presentations included talks from scientists **Matt Crawford, Jason Dortch, Sourav Saha, Seth Carpenter, Junfeng Zhu**, and **Marty Parris**. The presentations focused on a range of geohazard issues pertinent to Kentucky: post-flood landslide and debris flow mapping, earthquakes, karst sinkhole hazards, measuring and monitoring methane emissions of orphaned oil and gas wells, and a new KGS-developed Google Earth Engine application that provides easy, public access to statewide satellite imagery for change detection and hazard analysis.

There were also non-KGS presenters at this year's seminar. Kent Anness, a geographic information officer at the Commonwealth of Kentucky's Division of Geographic Information, discussed how geographic information system (GIS) dashboards can turn geospatial data into accessible, actionable information for the public. UK colleague Mary Kay Rayens from the College of Nursing presented Geologic, Seasonal, and Atmospheric Predictors of Indoor Home Radon Values. She discussed the ongoing National

Institute of Environmental Health Sciences (NIEHS)-funded citizen science project Radon on the RADAR.

Figure 45. Audience at the KGS 62nd Annual Seminar

KGS Director and State Geologist **Bill Haneberg** closed the seminar with his talk titled Geohazards in the Anthropocene: A Risk Assessment, Climate, and Environmental Justice Perspective. **Haneberg** explained that while hazards have always existed, the risks to humans are increasing because of population growth and the increased severity of the geological hazards due to climate change. Unfortunately, the exposure to, and impacts of, geological hazards are inequitably distributed. In Kentucky, low-income communities with increased social vulnerability and decreased community resilience bear disproportionate geohazard risks.

Conferences and Presentations

KGS participates in both regional and national conferences, seminars, and presentations. This year, KGS had conference tables at American Geophysical Union (AGU)'s Fall Meeting, Geological Society of America (GSA)'s Annual Meeting, Lend-A-Hand Center's Creek Cleanup, UK College of Engineering's E-Day, Bluegrass Greensource's Sustainability Summit, and Kentucky Oil and Gas Association's Annual Meeting.

Figure 46. From left to right: KGS staff at the GSA conference, Sustainability Summit, E-Day, and Lend-A-Hand.

When time and talent permits, GIMS also conducts tours of the two facilities. In February, Fayette County 4-H's Nature Club toured the displays and specimens at the Mining and Mineral Resources Building. In July, Kentucky Governor's Scholars Program toured the Earth Analysis Research Program as part of their science communication summer curriculum.

Figure 47. Left side: Fayette County 4-H tour of Mining and Mineral Resources Building. On right, Kentucky Governor's Scholars Program tour of the Earth Analysis Research Library.

Social Media

KGS operates four social media channels (LinkedIn, Facebook, Instagram, and X (formerly Twitter). As a communications tool, social media is vital for the mission of KGS. Social media is a great vehicle for disseminating important KGS news and messages. It also fosters community and creates communication opportunities. KGS makes an effort to increase social media engagement and audience size by publishing both general and research-specific content. KGS's media presence also allows job seekers a look at KGS culture, which helps sell candidates on their decision to join the organization. All of these efforts increase KGS's status in the online geology and geoscience communities.

Figure 48. Sample social media posts from all four platforms: LinkedIn, Instagram, Facebook, and Twitter.

Writing Group

Stimulating new publications and developing research capacity are important elements of growth at a research center like KGS. This fiscal year, KGS supported two writing development groups, a six-week pilot in Summer 2022 and a 12-week writing group that met in Winter/Spring 2023. Made up of junior, mid-career, and senior researchers, the

Figure 49. KGS Writing Group. From left to right: Meredith Swallom, Jon Schmidt, Doug Curl, Rachel

Nobel-Varney (co-lead), Hudson Koch (co-lead), Ben Tobin, and Devan Robinson

writing groups met weekly to discuss elements of academic writing like selecting a journal, developing an argument, and refining structure. Working through the chapters and exercises in Wendy Laura Belcher's *Writing Your Journal Article in Twelve Weeks: A Guide to Academic Publishing Success*, group members celebrated their research progress, worked through barriers, and discussed trends in geoscience publishing. Geologic Publications Manager **Rachel Noble-Varney** and KGS Geologist and EES PhD student **Hudson Koch** co-lead the twelve-week group. As participants focused on issues across geologic subdisciplines, the group provided a space to share best practices and approaches across fields. Based on the success and feedback of the group, KGS offered a series of abstract development workshops to help researchers planning to present at the 2023 Geological Society of America (GSA) conference. In FY 2023, the GIMS section will also run a series of grant development workshops modeled after the writing group format.

Publication Resources Center

Figure 50. 'Before' of the cluttered Publication Resource Center

To kick off 2023, KGS rebranded the Public Information Center (PIC) to the Publication Resources Center (PRC) elevating archival practices to preserve the KGS Publications and Maps collection. Prior to the rebranding we needed to clean up the space. **Kati Ellis** and **Liz Adams** (with help from the Administrative, Energy, and Geoscience Information sections) spent several days removing clutter, labeling and organizing file cabinets, and moving desks and other equipment (Fig. 50). Their efforts created a spacious office space and working area.

We hired **Cheyenne Hohman** who has a master's in library science and extensive experience with monographs, mixed media collections, and copyright law. Working with our researchers, **Hohman** has addressed immediate storage concerns and worked toward organizational systems for our section's collections. An institutional knowledge capture project is on the horizon along with a scanning project to ensure our collection is fully available online and with improved metadata. Her projects of note this year include a digital audit of our USGS material reviewing available copies and historical sales, removal of several moldy boxes of available stock (Fig. 51), a review of historical material, and working with the staff at UK Libraries to register our publications and datasets with DOIs and adding the collection to their UKnowledge repository.

Figure 51. Cheyenne clearing out moldy material damaged during a water leak in the ceiling.

Analytical Laboratory

KGS analytical laboratories support geological and environmental research by analyzing water, coal, and mineral resources. The KGS laboratory also facilitates student research within the University of Kentucky and the state through training and analytical instrument time. Student research from civil engineering, chemistry, mining engineering, agriculture, and the Department of Earth & Environmental Science (EES) is being conducted on

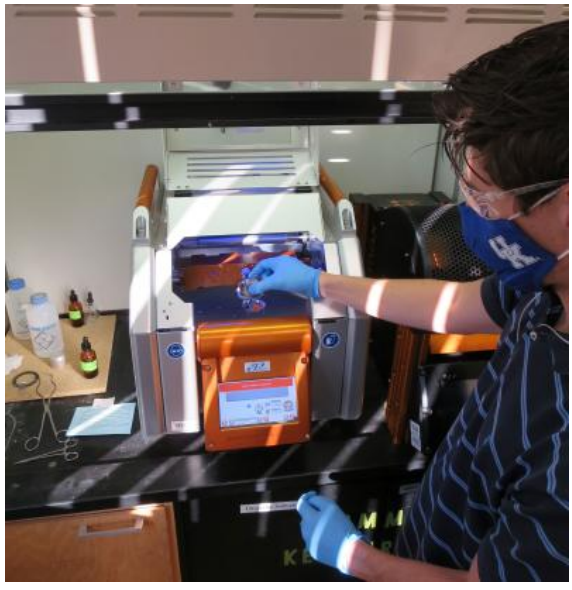


Figure 52. Ethan Davis prepares a sample for analysis on our wavelength Xray fluorescence spectrometer.

instrumentation and/or being analyzed by researchers in the laboratory, alongside other KGS and UK research projects.

The sample is being fused into a glass disc to be analyzed for elemental and oxide concentrations.

The shared use X-ray diffractometer (XRD) was utilized by 25 different students, faculty, and researchers this year. The instrument served as a teaching aid to Dr. Moecher's mineralogy class, where the class learned to scan and identify a set of unknown samples. The XRD was also utilized by KGS researchers to analyze class prepared samples for Dr. Ladipo's CHE412 class.

The LECO total carbon and sulfur analyzer, along with the inorganic carbon coulometer, were used by graduate students from EES for their ongoing research. The wXRF and pXRF spectrometers were utilized by researchers from KGS, EES, UK Plant and Soil Sciences, and UK Material Sciences (Fig. 52). The spectrometers were also used to analyze samples for Dr. Erin Haynes' (UK Public Health) citizen science project investigating metals in soil near the Kentucky river and ongoing KGS state map research involving soil characterization.

Samples were prepared and analyzed for coal quality and rare earth elements (REE) for the Illinois Basin Core critical minerals project, and included samples from the Illinois and Indiana Geological Surveys. Coal samples from Virginia McLemore of New Mexico Tech were also processed and analyzed for REE and coal quality. Collaboration continues with Dr. Rick Honaker's (UK Mining Engineering) REE research projects.

Figure 53. The Thermo Elemental ICP-OES (ion coupled argon plasma optical emission spectrometer) is utilized in the determination of rare earth element concentrations in coal ash and seam rock samples, as well as trace element levels in ground and surface water samples.

Water quality analyses are being conducted on several projects from graduate students in UK Civil Engineering (Dr. Jimmy Fox) and UK Biosystems Engineering (Dr. Tiffany Messer). KGS researchers also were involved with the

eastern Kentucky flooding project, analyzing water and sediment samples from the area. KGS lab was also involved with the Kentucky River Watershed Watch program, analyzing the samples from the fall nutrients and metals sampling event on the Kentucky River.

Paul Edwin Potter Internship Program

Introduction

The past fiscal year encapsulated the final month of the 2022 Paul Edwin Potter summer internship program and the preparation and beginning of the 2023 program. Despite some logistical challenges that temporarily reduced the number of internships available, the program was able to expand its recruitment pool to include students form all Kentucky higher education institutions. In 2023, the program received applications from the University of Kentucky, Eastern Kentucky University, Western Kentucky University, Berea College, and Kentucky State University. We hope to build stronger connections with these institutions and their students while we continue our focus on recruiting students from diverse backgrounds and interested in interdisciplinary work.

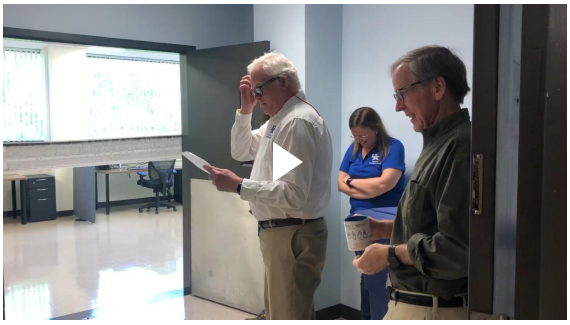


Figure 54. KGS Director Bill Haneberg delivers an opening proclamation for the newly renovated intern workspace.

In preparation for the 2023 experience, KGS staff worked to create a dedicated internship workspace. A 1,565-square-foot room filled with oil and gas, tar sands, limestone quarry archival records, and 70s-style cubicles was transformed into a modern, flexible multi-use center. Administrative Section Head **Kati Ellis** led the effort, enlisting help from **Liz Adams**, **Ambre Armstrong**, **Mike Ellis**, **Gwen Phillips**, **Dave Harris**, and the Energy Section staff. The project took several months of furniture removal and repairs to

complete a reorganized space with a new kitchenette space, dry-erase boards, and worktables for meetings and poster display. **Bill Haneberg** gave a rousing speech at the space's dedication (Fig. 54), where KGS staff could tour the space before the internship program started (Fig. 55).

Figure 55. At left and middle, KGS staff touring the newly renovated intern kitchen and workspace. On right, the interns working diligently in the space.

2022 Interns Showcase

The 2022 program culminated in an Interns Showcase (Fig. 56), which included a two-minute oral presentation and a poster presentation reception. Each intern compiled a formal poster communicating the results of their internship work and practiced the science communication skills necessary for participation in disciplinary conferences and research showcase events. KGS staff and UK faculty members were invited to attend the event and provided feedback on the talks and posters.

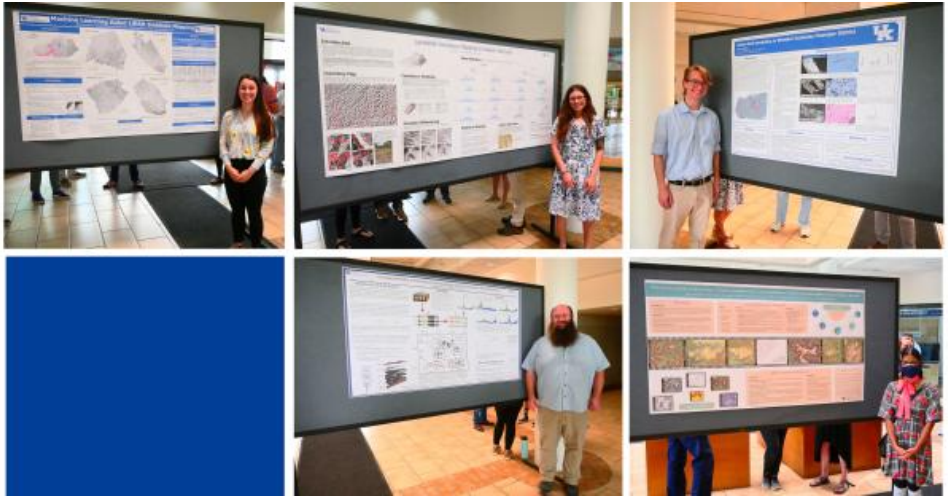


Figure 56. Our interns showing off their posters at last year's Internship Showcase. Left to right: Ellie Stevenson, Alex Arimes, Zach Walton, Alex Thomas (not pictured), Russel Rogers, and Dilni Abeyrathne

2023 Projects

This year, four graduate and undergraduate students participated in our summer internship project (Fig. 57). They worked to develop new skills in petrography, machine learning, and dye tracing.

Figure 57. 2023 Paul Edwin Potter interns (left to right): Will Hemenover, Olivine Painter, Maxwell Mickelson, Ethan Davis

- WKU undergraduate student, Will Hemenover, was mentored by **Ben Tobin** conducting dye traces in the Daniel Boone National Forest to determine groundwater flow paths.
- Berea College undergraduate student, Olivine Painter, was mentored by **Junfeng Zhu** while exploring sinkholes using LiDAR, machine learning techniques, and field checks in five counties.
- UK graduate student, **Maxwell Mickelson**, was mentored by **Glynn Beck** collecting data for a hydrogeologic assessment of the McNairy Aquifer in Marshall and Calloway Counties.
- UK graduate student, **Ethan Davis**, was mentored by **Gina Lukoczki** investigating origin theories of the Jeptha Knob structure in Western Kentucky.

Program Experiences

The 2023 internship built upon the success of the weekly presentations and field trip structure developed in the inaugural year. Foundational topics, including data and sample management, safe fieldwork, and Geo heritage were repeated this year. New focus areas included abstract writing, presentation skills, mock interviews, and a revised seminar on resume and interview preparation. The 2023 cohort also toured the KGS Earth Analysis Research Library and attended a field trip to Camp Nelson and surrounding road cuts (Fig. 58). In collaboration with UK Human Resources, the interns received formal presentation training from trainer Rob Hays and participated in mock interviews with American Institute of Professional Geologists (AIPG) members: Tim Crumbie with GeoScience, Bill Brab with AST Environmental, Inc., and Austin Dilla with Thoroughbred Firm. Each intern provided an updated resume and letter of interest for each position before participating in three thirty-minute interviews.

Figure 58. Program field experience at Camp Nelson National Monument and the surrounding area. The Camp Nelson portion focused on geoheritage and the roadcut analysis focused on geology. The field experience was led by KGS geologist Drew Andrews.

Overall, feedback from the interns about their experiences has been very positive. Stating they better understood what it means to work as a geologist, leaving the program feeling more confident entering the job market. The showcase, interviews, resume seminar, field trip, annual seminar, and data & physical samples management seminar were all extremely useful and will be included on the schedule next year. We will also plan more field trips to expose our interns to more Kentucky geology, geologic field methods, and safety fieldwork practices.

Special thank you goes out to **Ben Tobin, Sarah Arpin, Rachel Noble-Varney, William Andrews, Ryan Pinkston, Kati Ellis, Ambre Armstrong,** and **Cheyenne Hohman** who led the weekly

events and helped our interns prepare for the Internship Showcase.

Water Resources

Introduction

As in most years, karst groundwater and other related hydrogeological topics, such as sinkhole formation and hazards, have occupied much of the attention of our water staff. We have a long history – a tradition, really – of being in the forefront of karst hydrogeology research and data collection-dissemination efforts. Many of the projects we undertook or engaged with during 2022-2023 demonstrate our continuing focus and contributions to these critically-important topics. For example, our ongoing projects include: researching applications of AI and machine-learning to improve and speed the process of remote mapping of sinkholes and other karst hazards, the NSF-funded karst "data fusion" project – which involves combining various types of collected aquifer-response data with novel computer-modeling to better characterize 3D-variability in karst aquifer permeability and groundwater flow, and an investigation of the relationship between hydrology and aquatic ecosystems of caves and springs in the Tom Dornan Nature Preserve. To improve the ability to search for, compile, and use available karst dye-tracing data – data fundamental to our knowledge and understanding of underground water flow paths and the physical flow connections between sinkholes or sinking streams and karst springs and surface streams, we've also made significant progress on a USGS-funded project to improve the quality and contents of karst data in the KGS groundwater data repository, including the creation of a new, web-based graphical user interface to search and display spring inventory and dye-tracer test data.

Of course, we are doing much more than just karst-related research. We've continued our very successful and productive partnership with the UK Martin-Gatton College of Agriculture, Food and Environment and USDA-NRCS to conduct and expand edge-of-field (EOF) water-quality monitoring to help identify and assess water-quality and soil-conservation impacts of various land conservation and crop management practices in different agricultural and wetland settings. And we've also been actively working to increase, and make more accessible, groundwater-level data being collected from several major aquifers within the state. As a result of this ongoing effort, water-level measurements collected from seven KGS groundwater observation wells are being transmitted to the USGS, and included as data, for inclusion in the National Groundwater Monitoring Network (NGWMN). (Fig. 59)

Figure 59. Interactive NGWMN web map showing the locations, and a pop-up menu listing, of KGS groundwater-level observation wells included in the national network.

Improving Karst and Sinkhole Susceptibility Evaluation and Risk Assessment for the Lincoln Trail Area Development District

Karst-related subsidence and sinkhole collapses are nationally recognized hazards. In Kentucky, approximately 50 to 60 percent of the state has karst or potential for karst and about three million

Kentuckians live in karst areas. Although injuries and deaths to people from sinkholes are rare, damage to buildings, highways, and other infrastructure is common and costs tens of millions of dollars in damages annually for Kentucky. Understanding karst and sinkhole hazard is critical in assisting mitigation activities and reducing losses from sinkhole-related events. However, existing karst and sinkhole hazard evaluation has relied on insufficient and outdated data.

The Lincoln Trail Area Development District (LTADD), including communities in Breckinridge, Grayson, Hardin, LaRue, Marion, Meade, Nelson, and Washington Counties, is one of the Kentucky communities most affected by karst-related hazards. With funding support from the Federal Emergency Management Agency, **Junfeng Zhu** (Water Resources Section) and **Hudson Koch** (Hazard Section) developed improved karst and sinkhole susceptibility and risk assessment for LTADD using lidar-derived high-resolution elevation data, machine learning, and ranking-based vulnerability models (Figs. 60 and 61). KGS will continue this research effort with a goal to improve karst and sinkhole susceptibility and risk assessment for the entire state.

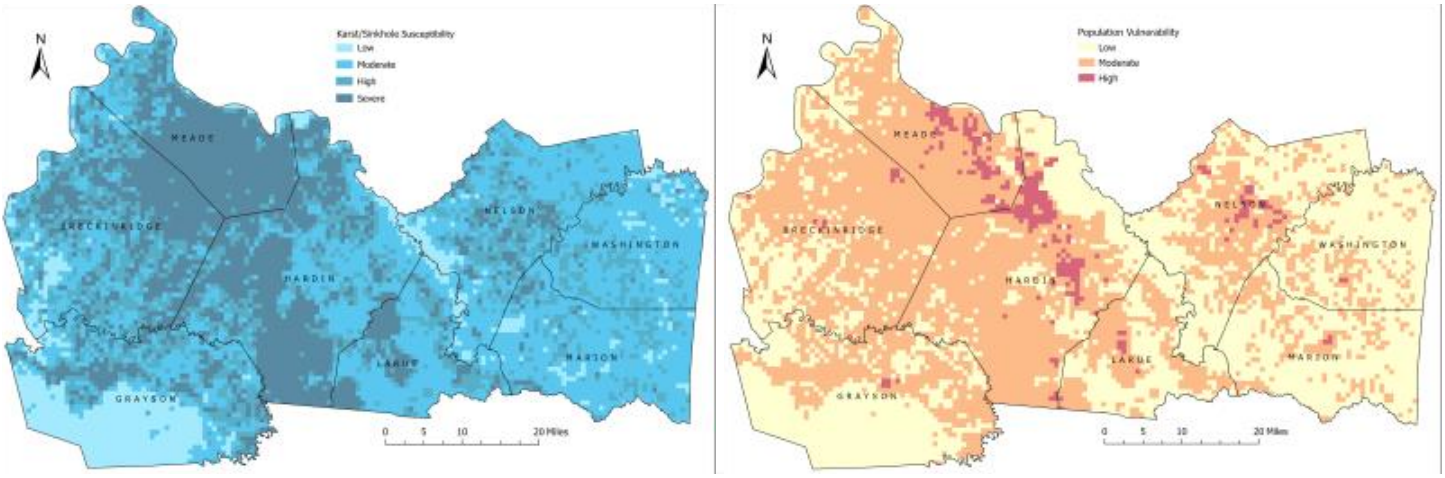


Figure 60 (left): Karst and sinkhole susceptibility for the Lincoln Trail Area Development District. Figure 61 (right): Population vulnerability to karst and sinkhole hazards for the Lincoln Trail Area Development District.

Investigation of Shallow Karst at Tom Dorman Nature Preserve

Understanding water flow through the unsaturated zone in karst terrains – the subsurface area between the land's surface and the underlying karst aquifer – is critical to understanding and solving challenges related to groundwater vulnerability to contamination and protection of cave-obligate ecosystems. Focusing on the karst area in Tom Dorman Nature Preserve in Gerrard Co., we are collecting a variety of field data from springs and cave streams, and using it to help characterize the interrelation between the hydrology of karst groundwater basins in the area and their water-ecosystems (Figs. 62 and 63). These data include continuous data (water level and temperature), water chemistry, and biological inventories. This information is in turn being used to develop new approaches to quantifying and modeling karst groundwater vulnerability through the modification of existing index-based model approaches. This innovative work is expanding our efforts to compile and use diverse, interdisciplinary datasets to better understand karst groundwater hydrologic processes.

Figure 62. KGS student employee, Solomon Nketsia, documenting cave biology during an inventory trip to a cave on Tom Dorman Nature Preserve.

The data and associated modeling outcomes obtained from this project have great potential to provide karst scientists, water resource managers, and citizens of the Commonwealth with an improved understanding of the vulnerability of groundwater to contamination from our activities on the surface, and help identify gaps in our knowledge of the symbiotic relationship between karst groundwater and ecosystems, and guide future research efforts. As to next steps for 2023

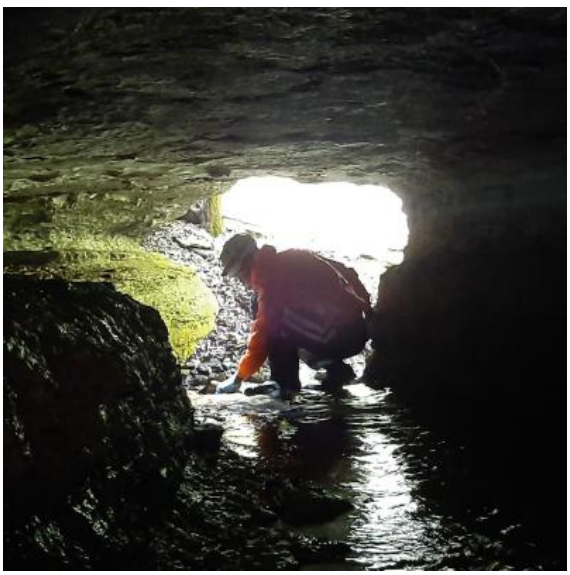


Figure 63. KGS student employee, Solomon Nketsia, documenting cave biology during an inventory trip to

a cave on Tom Dorman Nature Preserve.

and beyond: Our data collection is expanding beyond the Tom Dorman Nature Preserve. We are beginning to compile field-survey data about cave-adapted species collected from other locations across the Commonwealth to better identify their spatial and temporal distribution statewide, and improve our understanding about the interrelation between variability in seasonal hydrology and the potential vulnerability of these ecosystems.

Figure 64. Tom Dorman Nature Preserve groundwater vulnerability map

Edge-of-Field Water-Quality Monitoring Projects

Nutrient and sediment loss from no-till row-crop fields in western Kentucky

Nutrients (nitrogen and phosphorus) and sediment derived from urban construction as well as food production activities are leading contaminants resulting in stream and river impairment in Kentucky. While agricultural producers commonly employ best management practices (e.g., crop rotation, cover crops,

Figure 65. Soil erosion after a 2+ inch precipitation event and before planting at one of the monitored, edge-of-field row-crop watersheds.

no-till, etc.) to mitigate nutrient and sediment losses to retain nutrients in-field, studies evaluating the efficacy of best management practices on the reduction of nutrient and sediment in agricultural runoff are limited in western Kentucky. To further understand the relationships between agronomic practices and water quality, **Glynn Beck** is collaborating with researchers (Brad Lee, Zach Creech, Sarah Longacre, Jason Unrine, Erin Haramoto and John Grove) from the University of Kentucky Martin-Gatton College of Agriculture, Food and Environment to conduct edge-of-field water quality monitoring in the lower Green River and lower Cumberland River watersheds. This project is part of a national effort to evaluate the efficacy of best management practices and assist the agricultural community in making informed nutrient management decisions. Funding sources include the U.S. Department of Agriculture - Natural Resources Conservation Service, Kentucky Soybean Promotion Board, Kentucky Agriculture Development Board, and five western Kentucky agricultural producers.

During the 2022-23 fiscal year, year-round sampling of surface water runoff from 10 no-till corn/soybean field watersheds (3 to 12 acres in size) in the lower Green River watershed continued. Also, in 2022-23, year-round sampling of surface water runoff from 8 no-till corn/soybean/wheat and 4 soybean/wheat row crop operations (3-11 acres in size) in the lower Cumberland River watershed continued. Monitoring of these row-crop watersheds will improve our understanding of nitrogen, phosphorus, and sediment loads from active row crop fields in western Kentucky. For example, siltation (soil erosion) is consistently in the top three water-quality impairments of all monitored Kentucky waterways. Data from this project indicates that row-crop agriculture is a contributor of siltation to Kentucky's waterways (Figs. 65-67). Edge-of-field monitoring in the lower Green River and lower Cumberland River

watersheds is expected to continue through 2026 and 2028, respectively.

Nutrient and sediment loss from wetland watersheds in the northern Mississippi Embayment

Wetland conservation easements are promoted by the U.S. Department of Agriculture Natural Resource Conservation Service to return floodplains and other flood-prone, row-crop agricultural fields to natural vegetation to filter nutrients and sediments in surface water runoff prior to reaching a stream or river. **Glynn Beck** is collaborating with researchers (Brad Lee, Leighia Eggett, and Jason Unrine) from the University of Kentucky Martin-Gatton College of Agriculture, Food and Environment to conduct edge-of-field water quality monitoring (nitrogen, phosphorous, and sediment) on six wetland watersheds in the northern Mississippi Embayment (Jackson Purchase) and one watershed in the lower Green River watershed (Henderson County). Surface water runoff sampling of the seven watersheds began in 2019 and continued during the 2022-23 fiscal year. A drone-mounted multispectral camera was used to collect images of each watershed to document leaf on and leaf off, which will be used to correlate with surface-water quality. Surface water sampling is scheduled to continue through 2024. Funding is provided by the U. S. Department of Agriculture Natural Resource Conservation Service Agricultural Conservation Easement Program.

Figure 66. Sediment deposited in a flume during a runoff event at one of the monitored, edge-of-field row-crop watersheds.

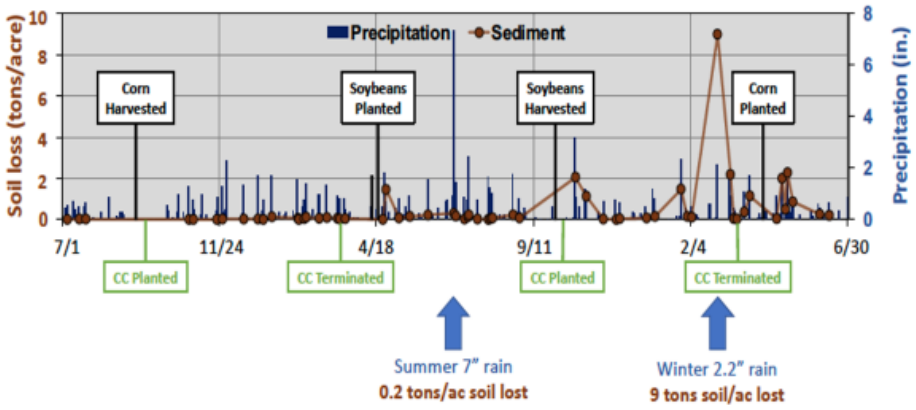


Figure 67. Soil loss and precipitation overtime at a monitored, edge-of-field row-crop watershed. CC means cover crop. The timing of a precipitation event (large blue arrows) and the land-cover type can determine the amount of soil erosion in a row-crop field.

Funded Research Projects

Energy and Minerals

Regional Initiative to Accelerate CCUS Development

- Start date: 4/22/20
- End date: 9/30/24
- *Project total: $280,524
- Funding source: Battelle Memorial Institute

Integrated Studies of Overlapping Critical Mineral Systems in South Central Kentucky and North Central Tennessee

- Start date: 1/23/23
- End date: 1/22/26
- Project total: $300,000
- Funding source: U.S. Geological Survey

Kentucky part of the Carbon Ore, Rare Earth and Critical Minerals (CORE-CM) Resource Assessment of the Appalachian Basin (MAPP-CORE)

- Start date: 10/1/21
- End date: 9/30/23
- KGS funding (not PI): $108,046
- Funding source: U.S. Department of Energy

Illinois Basin (IB) Carbon Ore, Rare Earth, and Critical Minerals (CORE-CM) Initiative

- Start date: 9/21/21
- End date: 9/20/23
- Project total: $99,999
- Funding source: University of Illinois

Critical Minerals in Pennsylvanian Black Shales of the US Midcontinent

- Start date: 1/10/23
- End date: 1/9/26
- Project total: $38,548
- Funding source: University of Kansas

Illinois Basin Geologic State Compilation to Support Utilization and Storage of Carbon and Energy Gases

- Start date: 4/1/22
- End date: 09/30/25
- Project total: $12,500
- Funding source: U.S. Geological Survey

Methane Emission Measuring on Orphaned Oil and Gas Wells

- Start date: 12/1/22
- End date: 9/30/24
- Project total: $835,145
- Funding source: Kentucky Energy and Environment Cabinet

Geochemistry

Earth MRI Western Kentucky Fluorspar District 3D Geological Modeling

- Start date: 8/1/21
- End date: 7/31/23
- Project total: $99,996
- Funding source: U.S. Geological Survey

Geology

EarthMRI Geochemistry of Pennsylvanian Underclays

- Start date: 7/1/20
- End date: 6/30/23
- Project total: $75,000
- Funding source: U.S. Geological Survey

New Surficial Geologic Mapping and NCGMP GeMS Compilation Projects for Kentucky

- Start date: 9/17/21
- End date: 9/16/22
- Project total: $449,188
- Funding source: U.S. Geological Survey

Kentucky Geologic Survey StateMap Fiscal Year 2022

- Start date: 9/20/22
- End date: 9/19/23
- Project total: $391,747
- Funding source: U.S. Geological Survey

RAPID - Geomorphologically Contextualized Flood Deposit Sampling and Mapping of Toxic Hazards: Insights from the Catastrophic July 2022 Floods in Eastern Kentucky

- Start date: 9/1/22
- End date: 6/30/23
- Project total: $49,786
- Funding source: National Science Foundation

Geologic Information

KGS Categorizing and Documenting Geologic Map Discontinuities

- Start date: 9/1/21
- End date: 11/30/22
- Project total: $60,000
- Funding source: U.S. Geological Survey

Kentucky Watershed Watch Portal Maintenance

- Start date: 5/25/22
- End date: 4/30/24
- Project total: $15,000
- Funding source: Watershed Watch in Kentucky Incorporated

Preserving Collections from the Western Kentucky Fluorspar and South-Central Kentucky Mineral Districts

- Start date: 12/1/22
- End date: 11/30/24
- Project total: $423,227
- Funding source: Institute of Museum and Library Services

Kentucky Geological Survey FY2023 Geologic Data Preservation Project

- Start date: 6/1/23
- End date: 5/31/25
- Project total: $319,499
- Funding source: U.S. Geological Survey

Kentucky Geological Survey FY2022 Geologic Data Preservation Project

- Start date: 6/1/22
- End date: 5/31/23
- Project total: $220,389
- Funding source: U.S. Geological Survey

Geology and Human Health

Radon on the Radar

- Start date: 2/20/20
- End date: 11/30/24
- KGS (not PI) funding: $111,297
- Funding source: National Institute of Environmental Health Services through UK College of Nursing

Hazards

Kentucky Enhanced Hazard Mitigation Plan Update for 2023

- Start date: 9/19/22
- End date: 2/14/25
- Project total: $61,810
- Funding source: Kentucky Department of Military Affairs

Landslide Monitoring Project at Maxey Flats Disposal Site

- Start date: 1/1/23
- End date: 6/30/24
- Project total: $47,819
- Funding source: Kentucky Energy and Environment Cabinet

IPA: Building on Federal and State Landslide Research Collaboration

- Start date: 10/1/22

- End date: 9/30/24
- Project total: $70,857
- Funding source: U.S. Geological Survey

Multi-Jurisdictional Hazard Mitigation Planning-Related Activity for Landslides for the Kentucky River Area Development District

- Start date: 2/11/22
- End date: 4/24/24
- Project total: $319,791
- Funding source: Kentucky Department of Military Affairs

Kentucky Research Consortium for Energy and Environment (KRCEE) Earthquake Monitoring and Research in the Jackson Purchase Region

- Start date: 4/1/16
- End date: 9/30/23
- KGS (not PI) funding: $23,000
- Funding source: Department of Energy

Acquisition of Strong Ground Motion Data in the New Madrid Seismic Zone Using Novel Devices

- Start date: 1/1/22
- End date: 12/31/22
- KGS (not PI) funding: $59,230
- Funding source: U.S. Geological Survey

Water Resources

Collaborative Research: Data Fusion for Characterizing and Understanding Water Flow Systems in Karst Aquifers

- Start date: 3/1/20
- End date: 2/29/24
- Project total: $421,448

- Funding source: National Science Foundation

Multi-Jurisdictional Hazard Mitigation Plan for Karst/Sinkholes for the Lincoln Trail Area Development District

- Start date: 5/1/19
- End date: 10/1/23
- Project total: $293,984
- Funding source: Kentucky Department of Military Affairs

Interdisciplinary Approach to Understanding Epikarst Processes

- Start date: 9/1/22
- End date: 8/31/23
- KGS (not PI) funding: $15,119
- Funding source: U.S. Geological Survey

Nutrient and Sediment Runoff Assessment in the Upper Mississippi River Embayment

- Start date: 9/13/17
- End date: 9/15/23
- KGS (not PI) funding: $123,413
- Funding source: U.S. Department of Agriculture through Natural Resources Conservation Service through UK Martin-Gatton College of Agriculture, Food and Environment

Blue Water Farms: Edge-of Field Water Monitoring in Kentucky Soils

- Start date: 7/1/22
- End date: 6/30/23
- KGS (not PI) funding: $31,737
- Funding source: Kentucky Soybean Promotion Board through UK Martin-Gatton College of Agriculture, Food and

Environment

Comprehensive Biodiversity Inventory and Hydrological Analysis of the Key Cave System at Key Cave National Wildlife Refuge

- Start date: 8/1/21
- End date: 7/31/23
- Project total: $20,000
- Funding source: Department of the Interior

No P On My Lawn

- Start date: 10/1/21
- End date: 9/18/23
- KGS (not PI) funding: $2,888
- Funding source: Lexington Fayette Urban County Government through UK Martin-Gatton College of Agriculture, Food and Environment

Awards & Honors

Staff Honors and Service (2022-2023)

William Andrews

- Kentucky Association of Mapping Professionals, President (2022)
- National Geologic Map Database Technical Working Group
- Association of American State Geologists
- Geological Society of America (GSA), Florence Bascom Geologic Mapping Award Committee member
- UK Strategic Materials and Recovery Technologies (SMaRT) Center, Management Committee Member
- U.S. Advisory Group on Geoheritage, Interim Member

Sarah Arpin

- Association for Women Geoscientists, Southeastern Bluegrass Chapter, Treasurer
- Kentucky Speleological Survey, Board of Directors, Member-at-Large
- Geological Society of America (GSA), Member
- International Association of Hydrologists, Member
- National Speleological Society, Member

Rick Bowersox

- American Association of Petroleum Geologists, Member
- Geological Society of America, Member
- American Geophysical Union, Member
- American Institute of Professional Geologists, Member
- Registered Professional Geologist (Kentucky, California, and Florida)
- Kentucky Board of Registration for Professional Geologists, 2018-2026

Seth Carpenter

- American Geophysical Union, Member
- Geological Society of America, Member
- Seismological Society of America, Member
- Eastern Section of the Seismological Society of America, Secretary (2021 - present)

Matt Crawford

- Geological Society of America, Member
- Geological Society of America Environmental & Engineering Geology Division, Member
- Kentucky Association of Mitigation Managers, Member
- 2023 KGS Director's Award Recipient

Doug Curl

- Kentucky River Watershed Watch, Board Member (2014–present)
- KYFromAbove Kentucky Aerial Photography & Elevation Data Program, Technical Advisory Committee
- National Geologic Map Database Working Group
- Association of American State Geologists (AASG), Associate Member
- Kentucky Academy of Science, Member

Jason Dortch

- American Geophyiscal Union (AGU), Member
- Geological Society of America (GSA), Member
- Kentucky Association of Mitigation Managers (KAMM), Member
- 2023 KGS Director's Award Recipient

Cortland Eble

- Geological Society of America (GSA), Member
- The Society for Organic Petrology, Member
- The Palynological Society, Member
- Kentucky Geological Society, Member

Stephen Greb

- American Association of Petroleum Geologists, Member
- Certified Kentucky Geologist
- Geological Society of America, Fellow and Member
- Geological Society of Kentucky, Member
- International Association of Sedimentologists, Member
- Kentucky Paleontological Society, Member

Bill Haneberg

- National Geospatial Advisory Committee, Member
- Environmental Engineering Geologists Foundation, Board of Directors, Member

- Quarterly Journal of Engineering Geology and Hydrogeology editorial board
- Admiral of the Great Fleet of the Commonwealth of Kentucky by the Secretary of the Energy and Environment
- Kentucky Colonel Commission by the Governor of the Commonwealth
- Kentucky Geographic Information Advisory Council
- Kentucky Board for Registration of Professional Geologists
- UK Center for Applied Energy Research (CAER) Advisory Board, Member
- Kentucky Water Resources Research Institute (KWRRI) Board, Member

David Harris

- American Association of Petroleum Geologists (AAPG), Member
- Eastern Section AAPG Energy and Minerals Division Best Poster Award (with **John Hickman**)

John Hickman

- Geological Society of America (GSA), Member
- Seismological Society of America (SSA), Member
- American Geophysical Union (AGU), Member
- Eastern Section AAPG Energy and Minerals Division Best Poster Award (with Dave Harris)

Hudson Koch

- Geological Society of America (GSA) , Member
- American Geophysical Union (AGU), Member
- KGS 2023 Director's Award Recipient

Gina Lukoczki

- Association for Women Geoscientists, Southeastern Bluegrass Chapter: president, Steering Committee (October 2019–present)

- Földtani Közlöny (Bulletin of the Geological Society of Hungary): English language editor (March 2021–present)

Rachel Noble-Varney

- American Association of Geographers (AAG), Southeastern Divison, Member
- Earth Information Science Professionals (ESIP), Member
- Kentucky Rural-Urban Exchange (RUX) Creative Leadership Program, 2023-2024 Cohort
- 2023 KGS Director's Award Recipient

Devan M. Robinson

- Kentucky Association of Mapping Professionals (KAMP), Member
- Kentucky Climate Consortium (KYCC), Member
- American Institute of Professional Geologists (AIPG), Member

Jonathan Schmidt

- 2023 KGS Director's Award Recipient

Meredith Swallom

- Geological Society of America (GSA), Member
- Kentucky Association of Mitigation Managers (KAMM), Member

Charles Taylor

- Kentucky Agriculture Water Quality Authority
- Kentucky Water Well Drillers Certification Board

Ben Tobin

- Geological Society of America (GSA), Member
- American Geophyiscal Union (AGU), Member

- National Speleological Society, Board of Directors Member (2023-2026)
- International Association of Hydrogeologists, Karst Commission co-chair (2021–2025)
- Ecological Society of America, Member

Zhenming Wang

- American Geophysical Union (AGU), Member
- Seismological Society of America (SSA), Member
- 2023 KGS Director's Award Recipient

Junfeng Zhu

- American Geophyiscal Union (AGU), Member
- Groundwater, Associate Editor (December 2017–present)
- Consortium of Universities for the Advancement of Hydrologic Science, Inc. (CUAHSI), University of Kentucky Representative

Deron Zierer

- Geological Society of America (GSA), Member

Publications

KGS Publications

Bottoms, A.E., Hislop, A., Massey, M.A., Hammond III, M.L., McHugh, M., Morris, E.R., 2022, Surficial Geologic Map of the Summit 7.5-Minute Quadrangle, Kentucky, Kentucky Geological Survey, ser. 13, Contract Report 53. https://uknowledge.uky.edu/kgs_ri/70/.

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Crawford, M.M., Koch, H.J., Dortch, J.M., Haneberg, W.C., 2022, Landslide Susceptibility Map of Magoffin County, Kentucky: Kentucky Geological Survey, ser. 13, Contract Report 48, 1 p. https://doi.org/10.13023/kgs.ri48.13.

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Hislop, A., Massey, M.A., Hammond III, M.L., Bottoms, A.E., McHugh, M.M., Morris, E.R., 2022, Surficial geologic map of the Flaherty 7.5-minute quadrangle, Kentucky. Kentucky Geological Survey, ser. 13, Contract Report 51. https://uknowledge.uky.edu/kgs_ri/68/

Lukoczki, G., Dietsch, C.**, Hickman, J.B., Morris, E., Curl, D.C., Pulliam, C.**, Vicroy, S.R., **Andrews, W. M.**, 2022, Phase I Activities of the Earth Mapping Resources Initiative (Earth MRI) in the Western Kentucky

Fluorspar District: Kentucky Geological Survey, ser. 13, Report of Investigations 12, 22 p. https://doi.org/10.13023/kgs.ri55.13.

Massey, M.A., Hammond, M.L. III, Bottoms, A.E., Hislop, A., McHugh, M.M., Morris, E.R., 2022, Surficial Geologic Map of the Millerstown 7.5-Minute Quadrangle, Kentucky, Kentucky Geological Survey, ser. 13, Contract Report 52, https://uknowledge.uky.edu/kgs_ri/69/.

Swallom, M.L., Massey, M.A., Hammond, M.L. III, Bottoms, A.E., Hislop, A., McHugh, M. M., Morris, E.R., 2022, Surficial Geologic Map of the Upton 7.5-Minute Quadrangle, Kentucky, Kentucky Geological Survey, ser. 13, Contract Report 54, https://uknowledge.uky.edu/kgs_ri/71

KGS Research Publications in Journals and Books

Arpin, S.M., and Kambesis, P.N., 2022, Exploring best practices in data management: Examples from cave and karst research and resource management: Carbonates and Evaporites, v. 37, no. 3, https://doi.org.10.1007/s13146-022-00772-7

Bettel, L., Fox, J., Husic, A., **Zhu, J.**, Al Aamery, N., Mahoney, T., and Gold-McCoy, A., 2022, Sediment transport investigation in a karst aquifer hypothesizes controls on internal versus external sediment origin and saturation impact on hysteresis: Journal of Hydrology, v. 613, https://doi.org.10.1016/j.jhydrol.2022.128391.

Bledsoe, L. A., **Tobin, B.W.**, and Groves, C., 2022, Stronger together: Understanding and protecting karst resources: Carbonates and Evaporites, v. 37, no. 1, https://doi.org.10.1007/s13146-021-00752-3.

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Bowersox, J.R., **Greb, S.F.**, and **Harris, D.C.**, 2022, Reservoir properties and CO_2 storage capacity of the Rose Run Sandstone (Lower Ordovician, Knox group) in the Central Appalachian Basin, northeast Kentucky: Frontiers in Energy Research, v. 10, https://doi.org.10.3389/fenrg.2022.832969.

Clary, R. M., **Andrews, W.M.**, and Connors, T., 2022, Geoheritage: Progress toward preservation: GSA Today, v. 32, no. 8, p. 18-19. https://doi.org.10.1130/GSATGeoH-v32.1.

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Dapkus R.T., Fryar, A.E., **Tobin, B.W.**, Byrne, D.M., Sarker, S.K., Bettel, L., Fox, J.F., 2023, Utilization of Tryptophan-like Fluorescence as a Proxy for *E. coli* Contamination in a Mixed-Land-Use Karst Basin: Hydrology. v. 10, no. 4, p.74. https://doi.org/10.3390/hydrology10040074.

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Fiscal Year 2022 - 2023 Staff List

State Geologist's Office

- Haneberg, William. State Geologist and Director

Administrative

- Ellis, Kati. Administrative Business Officer
- Armstrong, Ambre. Administrative Support Associate I
- Hohman, Cheyenne. Publication Resources Curator
- Phillips, Gwen. Staff Support Associate II

Communications and Outreach

- Noble-Varney, Rachel. Geoscience Publications Manager
- Frazier, Rebekah. Communications Officer

Digital Earth Analysis Laboratory

- Dortch, Jason. Geologist V
- Saha, Sourav. Post-Doctoral Scholar
- Thomas, Alex. Research Assistant

Energy and Minerals

- Harris, Dave. Section Head
- Bowersox, Rick. Geologist IV
- Eble, Cortland. Geologist V
- Greb, Steve. Geologist V
- Hickman, John. Geologist IV
- Kiraly, Edit. Geologist II
- Lukoczki, Gina. Geologist IV
- Parris, Marty. Geologist V
- Puckett, Paul. Geology Database Support
- Pulliam, Carrie. Geologist II
- Sparks, Tom. Geologist III
- Zierer, Deron. Geologist II

Geologic Hazards

- Wang, Zhenming. Section Head
- Carpenter, Seth. Geologist V
- Crawford, Matt. Geologist IV
- Koch, Hudson. Geologist II
- Schmidt, Jon. Geologist II
- Woolery, Ed. Geophysics Faculty Associate

Geoscience Information Management

- Curl, Doug. Section Head
- Adams, Elizabeth. Research Administrative Coordinator Principal
- Ellis, Mike. IS Technical Support Specialist IV
- Frazier, Rebekah. Communications Officer
- Noble-Varney, Rachel. Geologic Publication Manager
- o'Flaherty, Fin. Web and Database Specialist
- Rivers, Monte. Geologist I
- Thompson, Mark. Information Technology Manager I

Geologic Mapping

- Andrews, William. Section Head
- Bottoms, Antonia. Geologist II
- Buchanan, Wesley. Geologic Field Technician
- Dortch, Jason. Geologist IV
- Hayes, Hannah. Geologic Field Technician
- Koirala, Dibya. Geologist I
- Martin, Steve. Geologist III
- Massey, Matt. Geologist IV
- Morris, Emily. Cartographic Data Manager
- McHugh, Michele. Student Worker
- Robinson, Devan. Geologist I
- Swallom, Meredith. Geologist II
- Wells, Charles. Geologic Field Technician

Water Resources

- Taylor, Chuck. Section Head
- Arpin, Sarah. Geologist II
- Link, Adam. GIS Karst Technician
- Nketsia, Solomon. Student Geologist
- Tobin, Benjamin. Geologist IV
- Webb, Steve. Geologist II
- Zhu, Junfeng. Geologist V

Analytical Laboratory

- Backus, Jason. Geologist III/Laboratory Manager
- Conner, Andrea. Geologist II
- Davis, Ethan. Laboratory Technician

Earth Analysis Research Library

- Pinkston, Ryan. Research Facility Manager
- Adams, Elizabeth. Archive Manager
- Arimes, Alex. Soil Lab Assistant
- Daniel, Ray. Principal Research Analyst
- Eastridge, Emily. Geologist I

- Fields, Natalie. Geologic Photographer
- Gaines, Cameron, Geologic Archive Technician
- Luken, Anthony. Geologic Archive Technician
- McKinney, Kurstin. Geologist I
- Millington, Jason. Geologist I

Western Kentucky Office

- Beck, Glynn. Geologist IV/Manager
- Ruckdeschel, Lucas. Student Geologist

KGS Paul Edwin Potter Internship 2023

- Adams, Elizabeth. Internship Coordinator
- Davis, Ethan. Potter Intern
- Mickelson, Maxwell. Potter Intern
- Hemenover, William. Potter Intern
- Painter, Olivine. Potter Intern