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Session 2B: Groundwater and Karst

Kentucky Water Resources Research Institute, University of Kentucky

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In Situ 3D Electrical Resistivity Method for Understanding Water Dynamics in Shallow Karst Features*

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Understanding how water infiltrates and recharges subsurface aquifers is important for protecting groundwater resources. The water infiltration process is complex, however, especially in karst areas where many surface karst features, such as sinkholes and sinking streams, provide different pathways connecting surface water to groundwater. To monitor the water-infiltration process, we deployed time-lapse electrical resistivity surveys with permanently installed electrodes in Royal Spring groundwater basin in central Kentucky.

In a typical electrical resistivity survey, electrodes are placed in the ground during the survey and retrieved after the survey. For this project, we built electrodes that can be installed and left in the field for a long period to improve data accuracy and reduce field work. The electrodes are made using 10-in. stainless steel rods that are tightly wrapped with 18 AWG copper wire and secured with room-temperature vulcanizing silicone and 0.5-in. shrink tubing.

Two in situ electrical resistivity survey sites were established at the Kentucky Horse Park in the middle of Royal Spring basin. One site is at a sinkhole near well 20 and the other in a perched aquifer near well 22. For the sinkhole site, a 6 X 6 grid was used, with 3-ft spacing, and at the perched aquifer site, another 6 X 6 grid was used but with 5-ft spacing. At each site, the electrodes were placed evenly and buried into the subsurface. After burial, the contact resistivity was measured to ensure good connections between electrodes and soil. Field data acquisition focused on various storms; surveys were conducted before, during, and after storms. Daily surveys were conducted for the perched aquifer site between April 6 and April 12, 2021, and for both sites between June 14 and June 25, 2021.

The time-lapse survey data in April for the perched aquifer site showed temporal changes in resistivity corresponded well with precipitation events. There were no obvious resistivity changes in the first three days, when there was little precipitation. A decrease in resistivity occurred on April 10 when rainfall of 0.6 in. was recorded (Figure 1). An additional, but small, amount of rainfall on April 11 further reduced resistivity. The surveys also revealed that the change in resistivity was not uniform.

Our next step will be to analyze the time-lapse survey data collected in June 2021 and compare the results for the two sites. We expect that data will reveal different water dynamics for the two sites and provide insights into how soil water responds to rainfall in karst regions.

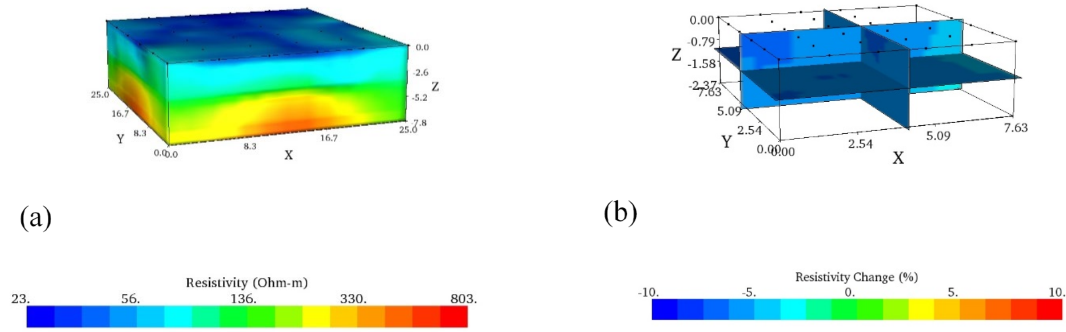

Figure 1. (a) Inverted resistivity volume for the perched aquifer (well 22) site on April 6, 2021. The depth to bedrock is around 6 ft, with a general trend of increasing resistivity with depth. (b) Percent change of resistivity for the site between April 10 and April 6, 2021. The decreasing resistivity shown in (b) corresponds to rainfall on April 10, 2021.

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Identifying the Intersection of Contaminated Karst Water and Off-the-Grid Communities in Southcentral Kentucky Using GIS*

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Amish and Mennonite communities in Kentucky's Pennyroyal Plateau live with limited modern infrastructure, in some cases including water treatment, and rely on karst water sources. The karst landscape offers little or no surface water, and karst springs are likely to be contaminated in this area by agricultural land use.

Previous studies of four family water supply karst springs in Barren and Monroe Counties found that all water samples tested positive for both total coliforms and *E. coli*, bacteria that come from human and/or animal waste. According to World Health Organization guidelines every sample of non-treated water from these springs was classified as *polluted* with respect to water quality and had *high* gastrointestinal health risk. We have identified other areas where families are drinking untreated karst groundwater and, in some cases, have become ill as a result.

There is a good possibility that many more families and communities with limited water treatment in southcentral Kentucky depend on similarly polluted karst groundwater. In order to address this issue, a team of researchers from Western Kentucky University is using Geographic Information Systems (GIS) computer mapping technology to help locate areas where such off-the-grid communities may be relying on contaminated karst groundwater. We are focusing on the 10-county area within the Barren River Area Development District (BRADD) in southcentral Kentucky, which is home to extensive karst terrain and a relatively high density of Amish and Mennonite communities.

We collected data on the physical landscape. GIS information about the geology and hydrology of the BRADD region, as well as groundwater quality, are publicly available through the Kentucky Geological Survey. Layers generated from geological maps outline the extent of carbonate rocks which define the areas of karst terrain, and data showing the locations of springs and wells indicate potential water sources for local communities. Spatial information about the locations of sinkholes suggests areas where pollutants may rapidly enter the underground water supply, potentially rendering the water unsafe to drink.

Geospatial data representing the locations of local off-the-grid communities do not currently exist. As a starting point, we estimated the locations of these communities by searching for businesses, farms, and other locations associated with common Amish/Mennonite/Anabaptist surnames. We also searched for schools, churches, and community centers with the key works "Amish" and "Mennonite". A data point was collected for each establishment, and a five-mile radius was created around each point representing the possibility of an Amish or Mennonite plain community in the vicinity. The five-mile radius represents the average maximum travel for a horse and buggy. These focus points have served as a starting point to direct continuing fieldwork.

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Groundwater Characterization: How Much Data is Enough?

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Efforts to quantify groundwater properties and behavior often require the use of complex methodologies to uncover the temporal and spatial patterns between different components of the hydrogeologic system. Characterizing groundwater systems using major ions provides a basis for understanding the baseline conditions of a groundwater system to then assess potential impacts to these critical water resources. The use of a variety of multivariate statistical techniques has become a standard procedure in studies on groundwater hydrochemistry and developing an understanding of aquifer types. Each method provides a different insight into the data; however, enough data to run these complex analyses are not always available. We used a combination of multivariate techniques, including principal component analysis (PCA) and hierarchical cluster analysis, to investigate characterization and hydrogeologic grouping of aquifers based on similarities and differences in geochemistry. From these groupings we then determined which and how many parameters can be removed without changing the classifications.

Using a combined PCA–cluster analysis approach, and groundwater-quality data available for 60 well sites spread throughout Kentucky, we identified six distinct groundwater systems. These systems are primarily distinguished by variability in conductivity, sodium, and potassium, and secondarily by calcium and magnesium concentrations and match the previously identified physiographic regions of the state. These data suggest that as a basis for characterizing a groundwater system, at a minimum, these five hydrochemical parameters are essential to collect.

Examining Hydrogeological Dynamics of Baselevel and Reverse Flow of the Green River and Major Springs of Mammoth Cave, Kentucky*

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Mammoth Cave is one of the most studied caves in the world, but lacks hydrological data on the recharge/discharge dynamics of its primary spring outlets, Echo and Styx Springs, during varying moisture conditions and river reversal events. The Green River, which is the primary receiving stream for these springs, can backflood and reverse flow into the springs, causing an influx of river water that can cause contamination and influence the dissolution of the cave. Recharge dynamics of varying storm events and baseflow conditions are also not well understood between the two adjoining springshed basins for Styx and Echo. Data were collected starting in January, 2021 and include weekly water samples for isotope and geochemical analyses at 13 sites on the surface and in-cave, water levels at six sites (four surface, two in-cave), and discharge data for the two springs and Green River. These data were used to determine the conditions during which river reversals occur at the two springs and how epikarst and surface rainfall recharge the system during storm events to create competing hydraulic head pressures. Results from this study aim to improve the understanding of karst groundwater flow and its implications in teleogenetic karst systems under the influence of human impacts, including dams and landuse change. River reversals appear to be moderated by cave recharge dynamics during certain flow conditions to a threshold at which the springs dominate the flow regime, while during high river discharge, the system can exceed this threshold and the Green reverses into the cave via the springs and creates a new hydrologic regime. The system responds within weeks to return to baseflow, except during anomalous flood conditions, which was captured in a February, 2021 major flooding event, indicating that sustained flood conditions overwhelm the springs for longer periods of time. Recharge points in the cave have varying geochemical signatures and indicate the complex residence time dynamics that control the discharge in the springs during different seasons and antecedent moisture conditions. These results have implications for the management of the cave system and adjacent Green River with respect to a variety of hydrologic and biological parameters, including the potential future response under a changing climate.

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Soil Moisture Micronet in the Daniel Boone National Forest

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Recognizing that in-situ soil moisture observations record conditions only at Kentucky Mesonet monitoring sites, the value of those observations is directly related to the representativeness of the Mesonet site. While some simple terrains can be served by soil moisture observations collected at a discrete point, more complex terrains consisting of differing slopes, soils and geology cannot. In these complex terrains, it is not reasonable that a single monitoring site could be broadly representative of the surrounding area. This is the case in Kentucky's Daniel Boone National Forest and more broadly across the Cumberland Plateau. The Daniel Boone National Forest is dominated by the soil order Ultisol, largely of the Udult suborder. It is topographically diverse and representative of the larger Cumberland Plateau.

Thus, we are developing a high-density micro-scale soil moisture monitoring network in the Daniel Boone National Forest. This network will involve the establishment of a micronet with monitoring sites selected to represent the diversity of terrain characteristic of the Cumberland Plateau. The micronet will be designed to monitor and analyze soil moisture-terrain relationships. Thus, soil moisture probes will be installed at topographically diverse positions within a small area. For example, within an area containing a ridge, slopes at various elevations, aspects, and types, and adjoining valleys. The hub of the micronet will be a fully equipped Kentucky Mesonet station sending data back to a live webpage using a cellular network. Micronet stations will communicate with the hub via radio telemetry. Extensive metadata will be collected and strategically catalogued for each station in the network. This project will serve as a pilot for similar networks in other locations, developing standard operating procedures and best practices for intensive monitoring in complex terrains.

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