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Track 1: Karst

Kentucky Water Resources Research Institute, University of Kentucky

CHARACTERISTICS OF COVER-COLLAPSE SINKHOLES IN KENTUCKY

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Cover-collapse is the sudden and unpredictable collapse of the unconsolidated material (e.g. soil, alluvium) over karstic bedrock. Sixty-seven percent of Kentucky residents live on karst (Cecil, 2015, personal communication). The estimated cost of cover-collapse sinkholes to the economy ranges from $20 to $60 million a year. Sinkholes resulting from cover-collapse damage buildings, roads, utility lines, and farm equipment. Cover-collapse has killed livestock, including some thoroughbred horses, and has injured people. The development mechanisms of cover-collapse have been understood for years (White and White, 1992, Tharp, 1999), but predicting the precise location and timing of future collapse remains enigmatic (Beck, 1991, Wilson and Shock, 1996). The Kentucky Geological Survey (KGS) began collecting case histories of cover-collapse in 1997 and now receives nearly 50 reports annually. The database now contains over 360 reports from individual sites, yet the data are thought to represent less than one percent of the actual number of annual cover-collapse occurrences. Information collected about the physical and geological characteristics of 220 sites are accurately located and precisely dated sufficient to allow further evaluation.

The largest cover-collapse in the database was the Dishman Lane sinkhole in Bowling Green, at 48 meters long, 32 meters wide and a depth over 9 meters. The recent Corvette Museum cover-collapse, also in Bowling Green is the third largest. It was 12.2 meters long by 11.0 meters by 8.2 meters deep. Large cover-collapse sinkholes may be relatively rare, however, as the average length of the long axis of sinkholes in the database is only 2.8 meters, the short axis is an average of 1.9 meters and the depth averages 2.4 meters. The closer the asymmetry and circularity are to 1.0, the more perfect the circle of the collapse opening. For the database, the average opening diameter is 2.4 meters, the asymmetry is 1.96, and the circularity is 0.85. The depth, diameter, asymmetry, and circularity were also grouped by the stratigraphic age of the underlying karst bedrock (Mississippian, Silurian-Devonian, and Ordovician). The stratigraphic groups were tested for equivalency of the standard deviations (f-test) and the means (student's t-test, 95-percent confidence interval) using log transformed dimensions and Statgraphics software. There was no statistically significant difference between the Silurian-Devonian and the Ordovician cover-collapse for depth, asymmetry, or circularity. There was no difference in the depth between the Mississippian and Ordovician. There was, however, a significant difference in diameter, asymmetry, and circularity between the Mississippian and the Ordovician and between the Mississippian and the Silurian-Devonian. Other groupings include the reports from "urban" versus "rural" counties, and from high population versus lower population counties. No difference was found between these groups for log transformed data.

The frequency of occurrence data were also evaluated graphically. Figure 1 is the temporal distribution of the cover-collapse events over the calendar year. The seasonality is apparent among the wet months of the year when counts are greater. The number of cover collapse per month when plotted against the average monthly total precipitation (not shown) shows a linear alignment of only eight months. The poor correlation may be in part a result of the overly generalized precipitation data.

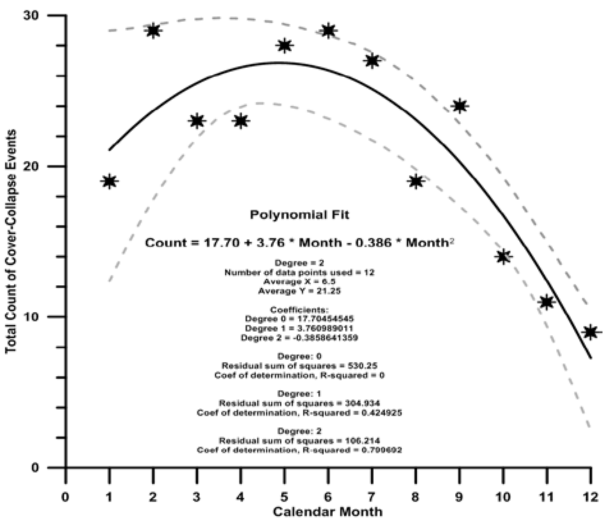

Figure 1 Relationship between the frequency of cover-collapse per month and the calendar month.

Collapse events plotted on a digitized base map of closed topographic contours of sinkholes results in only 7.5 percent of the cover-collapse sites falling inside the mapped sinkhole depression. The small number (11 percent) of the sites that had buried trash exposed by a new collapse also suggests that cover-collapse typically initiates new sinkhole development, as opposed to being a mechanism for the continued erosion and growth of an established sinkhole. Although the collapse outlet may still function as a drain for the larger sinkhole, the reestablishment of cover and a new arch is unlikely.

In conclusion, there is a strong correlation between the frequency of cover-collapse and the wet months of the year. A similar trend is displayed by the count of cover - collapse and average monthly precipitation. Precisely measured and recorded field data have greatly improved the data set and more high quality data are needed. Substantial progress has been made in understanding cover-collapse in the last two decades. The elusive goal that remains is to find a characteristic of the soil arch, before it fails, that can be detected by airborne, orbital, or ground level remote sensing.

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DATA AND MODEL INVESTIGATION OF A FLUVIOKARST SYSTEM IN THE BLUEGRASS REGION: WATER, SEDIMENT, AND CARBON INTERACTIONS

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Mature karst topography is well recognized within the hydrology and geology communities to include subterranean fluid pathways that act as turbulent conduits conveying fluid from surface stream sinks called swallets to sources called springs. The extensive karst topographical potential in Kentucky is of particular importance to municipalities and users who draw their drinking water supplies from karst aquifers. Understanding sediment and contaminant transport processes is vital in water resources decision making at the local and state level within Kentucky. Water flow within karst aquifers has been heavily dissected, measured, and modeled. However, we find that little knowledge has been reported with regards to the transport and fate of terrestrially-derived sediment organic carbon (SOC) within karst watersheds. This study investigated the hypothesis that karst pathways could act as biologically active conveyors of SOC that temporarily store sediment, turn over carbon at higher rates than otherwise considered, and recharge depleted SOC back to the surface stream within the fluvial system.

Mixed research methods were applied within a mature karst network. Methods included high resolution measurements of water and sediment characteristics of surface streams, carbon and stable carbon isotope measurements of transported sediment, and numerical physical and biogeochemical modeling of sediment and carbon. The mixing of sediment during net zero deposition and erosion was investigated in this study using a parameter calibrated to collected SOC data.

Results of this study indicate the ability of phreatic karst conduits to temporarily trap surface-derived sediment during storm events due to downstream flow controls and fluid energy limitations. Exchange of bed and suspended sediment plays an important role in providing carbon-rich sediment to microbial communities in the surface fine grain laminae layer of the conduit bed for later decomposition. Data results show that 29.7% of the sediment organic carbon is depleted when comparing inputs to outputs. This contrasts surface dominated systems in the Bluegrass which show a 50% enrichment in carbon during transport in the fluvial system. Modeling results of this study suggest that heterotrophic bacteria in the subsurface conduit oxidize 0.05 $tCkm^{-2}y^{-1}$ resulting from the temporary storage of terrestrial carbon in the karst conduit. The subsurface conduit transports 0.15 $tCkm^{-2}y^{-1}$ out of the fluviokarst watershed.

SOURCING AND DYNAMICS OF KARST HYDROLOGIC INPUTS ON HARMFUL ALGAL BLOOM OCCURRENCES IN KENTUCKY LAKES

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Almost half of Kentucky is underlain by a well-developed karst aquifer/landscape system in which water resource access and protection challenges are common. Surface water supplies are often limited, groundwater is typically vulnerable to contamination, and even basic delineation of aquifer recharge areas requires specialized methods. The surface water that does exist is often in the form of rivers. Many of these rivers are fed by springs and serve as baselevel for their drainage areas. Often, rivers are dammed for various reasons, typically for flood prevention, recreational use, hydropower, and to aid in navigation. Much of the rainfall in Kentucky is drained internally through the karst system. Due to this, Kentucky has only three naturally occurring lakes. Most importantly, these lakes also provide a drinking water source for several communities. In particular, Nolin River Lake and Rough River Lake, located in south-central Kentucky (Figure 1) and created under the Flood Control Act of 1938, are important and heavily used recreational lakes that also serve several of the aforementioned functions, particularly flood mitigation.

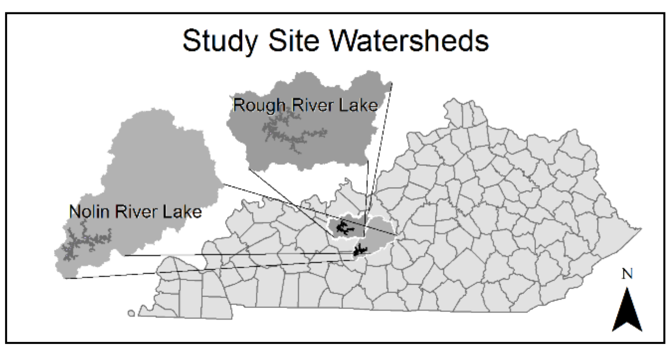

Figure 1: The study sites watersheds. Rough River Lake's watershed is smaller and influenced more by agriculture. Nolin River Lake's watershed is larger and includes the urban center of Elizabethtown.

Recently, freshwater Harmful Algal Blooms (HABs), predominantly made of cyanobacteria (blue-green algae), have been occurring in Rough River Lake and Nolin River Lake and may be caused by nutrient loading introduced through karst hydrologic inputs. Currently, there exists little data regarding the cause of these HAB's with only recent efforts underway to investigate these inputs.

The purpose of this research was to investigate the possible influences of karst hydrologic inputs to Nolin and Rough River Lakes, which are two separate water bodies that share the commonality of having karst inputs and being managed by the USACE. The main goal of the project was to discover the level of influence the karst inputs have on the eutrophication of the reservoirs from water quality impacts, primarily examining nutrient inputs and *E. coli* bacteria contamination, in addition to hydrometeorological influences. To accomplish this task, monitoring of the nutrient loading, *E. coli*, and the stable isotopes of nitrate, ^{15}N and ^{18}O, at three sites per lake and the output of each lake's dam has been conducted since summer of 2015.

A look at the preliminary isotope data indicate that the detectable portion of the nitrate loading at Nolin River Lake is a mix of anthropogenic sources, while at Rough River Lake, the nitrate loading is primarily derived from nonpoint agricultural contributions. The hydrological data collected so far indicate that the lakes both are influenced by karst groundwater sources. Some sites see more influence than others, but an influence is detectable. The extent and magnitude of the influence has yet to be established. More data need to be collected before concrete conclusions can be drawn, but this project still has several more months of data collection ahead.

This project continues to be done in partnership with the USACE and other community groups who help manage the lake for the citizens who live around it, such as Friends of Nolin, and the Kentucky Division of Water. These stakeholders originally approached us to help in developing a research strategy to investigate possible causes and enhance their current data and knowledge in order to best manage the lakes' watersheds and surrounding inputs against HABs. The project involves collecting high-resolution scientific data and reducing it in a way that will be communicable to the public to help enhance behavioral changes to minimize possible contaminant inputs that may increase the likelihood and proliferation of freshwater HABs.

INVESTIGATION OF FECAL CONTAMINATION IN THE LITTLE RIVER BASIN, KENTUCKY USING MICROBIAL SOURCE TRACKING AND FECAL INDICATOR BACTERIA, 2013-2014

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This study evaluated general, human, ruminant (cattle, sheep, deer), canine, and waterfowl genetic markers and found the primary source of fecal contamination in the North Fork Little River (NFLR) was human waste and the main source in the South Fork Little River (SFLR), particularly the headwaters, was ruminant-animal waste. In 2009, the Kentucky Energy and Environment Cabinet—Division of Water developed a pathogen Total Maximum Daily Load for the Little River Basin including the NFLR and the SFLR. From 2013 to 2014, the U.S. Geological Survey (USGS), in cooperation with the Little River Consortium, used *E. coli* concentrations to assess fecal contamination and microbial source tracking (MST) to isolate sources of fecal contamination in the Little River basin near Hopkinsville, Kentucky. Water and fluvial sediment samples were collected at 19 sites and MST samples were collected at 10 of these sites. Thirty-four percent of water samples were above the U.S. Enviromental Protection Agency statistical threshold value of 410 col/100 mL for *E. coli*. Lower densities of *E. coli* in fluvial sediments were found more in the headwaters than downstream. The human-associated marker (qHF183) was found above the detection limit in 100 percent of samples from the NFLR basin compared to 15 percent in the SFLR basin. The median ruminant-associated marker (BoBac) was up to three-fold greater in the SFLR headwaters compared to the NFLR. The results of this study will help resource managers prioritize areas where waste management and remediation are the most necessary due to high levels of fecal contamination.

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