Testimony on HR 3681

Submitted by Jonathan D. Arthur, Ph.D.

July 19, 2022

Thank you, Chairman Lowenthal, Ranking Member Stauber, members of the subcommittee, bill sponsor Representative Soto, and co-sponsor Representative Bilirakis for the opportunity to provide testimony in support of HR 3681, the Sinkhole Mapping Act of 2021. I commend the committee's efforts to consider the importance of developing a better understanding of sinkhole formation, risk, and public access to related maps, as this geological hazard impacts many parts of the United States.

My name is Jonathan Arthur, and I am the executive director of the American Geosciences Institute (AGI), a not-for-profit federation of geoscience societies representing nearly 250,000 geoscientists. Simply put, the AGI mission is to connect earth, science, and people. Until August of 2021, and across the 13 years prior, I served as the state geologist of Florida and director of the Florida Geological Survey. I am also a member of the Water Science Technology Board of the National Academies of Sciences, Engineering and Medicine, and have previously served as president of the Association of American State Geologists. Today, however, I represent myself and bring to you my perspective regarding the need for and importance of the Sinkhole Mapping Act of 2021.

Sinkholes are areas of subsidence or collapse of the earth surface in response to naturally occurring cavities in the subsurface. Sinkholes can form suddenly or slowly, at times resulting in loss of human life and often causing significant damage to homes, private lands, businesses, and infrastructure. While many processes, natural and human-induced, lead to sinkhole development, the primary cause is naturally occurring cavities formed as rock dissolves over geologic time into which overlying rocks and sediment move. In these landscapes, sinkholes can provide rapid recharge to underlying aquifers, offer opportunities for geologic study of groundwater resources, host artifacts of past indigenous cultures (geoheritage sites), provide access to fossil discoveries, provide settings for the natural development of unique ecosystems, and offer outdoor recreation opportunities. My testimony today will focus on the science of sinkholes, their likelihood of formation, and their impacts.

Landscapes where rocks dissolve into cavities characterized by sinkholes, caves, and springs are called karst. Limestone, dolostone, and gypsum are the most common rocks that can host karst features. However, karst and resulting sinkholes are also possible in some volcanic landscapes (e.g., lava tubes) and in some thick sediments (e.g., soil piping in badlands). To understand where sinkholes may occur, it is important to understand the distribution of karst. Except for Delaware and Rhode Island, examples of karst occur in every state in the country (Weary and Doctor, 2014). In many cases, karst landscapes comprise the surface of prolific aquifers that provide water resources. In some cases, these water resources are accessed by private wells or springs. In other cases, such as the Edwards aquifer of Texas and Floridan aquifer of Florida, large wells or springs are important to large metropolitan areas. Because surface water and groundwater can readily interact through sinkholes, the potential for groundwater contamination in karst is high. Thus, the nexus between sinkholes and water resources includes their formation, sites for aquifer recharge, routes for groundwater contamination, and points of ecological connection between the surface and subsurface.

States with the highest number of known sinkholes are Florida, Texas, Alabama, Missouri, Kentucky, Tennessee, and Pennsylvania (Kuniansky and others 2015). In Kentucky, for example, Florea and others (2002) estimated that more than 101,000 topographically defined sinkholes occupy at least 3% of the land area. In these states, the rock type hosting sinkholes is primarily limestone and dolostone. In other parts of the country, such as western Texas and New Mexico, gypsum is an important rock for sinkhole development.

How and why do sinkholes form in soluble rock?

When exposed to groundwater over a period of hundreds to thousands of years, partings and cracks in bedrock will dissolve and widen into large cavities or even conduits for groundwater in the subsurface. These same enlarged partings may also transport soil from the surface and into these cavities. This slow hourglass effect over long periods of time can lead to surface depressions. These cover-subsidence sinkholes are the most common form of sinkhole. In other cases, when the cavity is too large to support the overlying weight of rock and sediment, the roof of the cavity may collapse in the timespan of years to minutes. In this testimony, I will focus on cover-collapse sinkholes that occur suddenly and catastrophically—those that take lives and make headlines.

Inducing factors

Multiple factors control where sinkholes will occur and how fast they will develop. These factors subdivide into those that are naturally occurring and human-induced, or anthropogenic (Tihansky, 1999). The naturally occurring factors include the type of rock, sediment, and soil, vegetation cover, temperature, precipitation, geological structure, and the changes in groundwater level from seasonal, climate and extreme precipitation events. For example, Tropical Storm Debby during June 2012 delivered near record amounts of rain to peninsular Florida following a period of extreme drought. These conditions led to the formation of more than 220 sinkholes.

Anthropogenic factors also influence the formation of sinkholes. These factors include changes to land use, the construction of stormwater and recharge ponds, landfills, and reservoirs, increased groundwater pumping, construction, drilling, and terraforming. In a Florida example from January 2010, extensive groundwater pumping to frost-protect crops during an 11-day cold snap led to rapid decline in aquifer levels (>30 feet) and triggered the formation of more than 150 sinkholes.

Site investigation and monitoring

In areas with a high likelihood of sinkhole formation, or the presence of active or paleosinkholes (older, buried sinkholes), specialized geophysical or geotechnical site investigations can help detect ground anomalies and subsurface cavities prior to construction and during repair of subsidence damage. Schmidt (2005) compiled many of these investigation methods, and since then advancements in ground penetrating radar, seismic, resistivity, and microgravity surveys have yielded improved subsurface characterization. Real-time monitoring of cover-collapse sinkholes is accomplished by using geophones to “listen” for warning signs beneath existing infrastructure and through use of water pressure instruments (piezometers).

Societal impacts

Potential impacts of sinkholes must be considered in land use decisions, construction engineering designs, and emergency response. To be eligible for federal hazard mitigation funding, the U.S. Disaster Mitigation Act of 2000 requires states to have a State Hazard Mitigation Plan (SHMP) approved by the Federal Emergency Management Agency (FEMA). Weary (2015) reports that 29 states have SHMPs that include karst subsidence. Other states should follow this lead.

In a review of cost reports between approximately 2000 and 2015, Kuniansky and others (2015) found that the cost of karst collapses in the United States averages more than $300 million per year. The estimate is likely less than the real expense, especially when one considers the cost of infrastructure repairs, such as the phosphogypsum stack sinkhole that opened in September 2016 in southwest Florida. That alone required $84M in repairs (Bouffard, 2018). Another example in the region relates to growing concerns about karst subsidence, which led to repairs of cracks in a large drinking water reservoir that required nearly $129M in repairs (Porter, 2014). Currens (2018) reports annual costs of cover-collapse sinkholes in Kentucky ranging from $20M to $84M, and this estimate is "...sensitive to rare but expensive events such as the 2014 National Corvette Museum collapse."

On a more personal level, a homeowner experiencing sinkhole damage may incur loss of personal possessions, property, not to mention the cost of claim management, investigation, remediation, legal counsel, and possibly a trial. The loss of human life due to sinkholes is rare. Since 1960 in Florida there have been five fatalities reported, the most recent being a person whose home collapsed into an active sinkhole in February 2011 (Upchurch and others, 2019). Livestock and thoroughbred horses have been killed in sinkholes and people have been injured (Currens, 2018).

Environmental considerations

Sinkholes provide a pathway for surface water recharge to aquifers. In other cases, sinkhole flooding can occur where groundwater flows to land surface during large rain events. As natural connections between the surface and subsurface, sinkholes play a critical role in groundwater vulnerability (Arthur and others, 2007). In a karst landscape, each sinkhole may thus be a point source for contaminants that pose a threat to the environment and public health such as nutrients, pathogens, dissolved metals, herbicides and pesticides, petroleum products, road salts, pharmaceuticals; various land-uses (industry, agriculture, urban, etc.), stormwater runoff from roads and parking lots, effluent from poorly maintained septic systems, and wastewater spills. As an extreme case, the 2016 phosphogypsum stack sinkhole incident released 215 million gallons of contaminated water into the Florida Aquifer, which required long-term groundwater recovery operations.

Risk or likelihood

Upchurch and others (2019) report that the capability to qualitatively estimate sinkhole risk is good; however, to quantify risk is difficult as it requires high-quality data and improved reporting mechanisms for sinkhole occurrence. Some states have these reporting mechanisms in place (e.g., Florida, Kentucky, Missouri, and Ohio; Kuniansky and others, 2015), but often the data are biased toward population centers and not all cover-collapse incidents are sinkholes. Rather, many in urban centers are from erosion under failing infrastructure.

Mapping known sinkholes is a good beginning to understand the scale of karst and the risk of collapse, as there is a general likelihood that where they have formed, more will form. Maps that reflect known closed topographic depressions include data that can be generalized to reflect feature density mapping (sinkholes per unit area). However, anthropogenic sinkhole-inducing activities respond to population expansion and climate change, thus sinkholes may occur in areas where few have previously been reported. The 2010 frost-protection sinkhole event in Florida, for example, did not occur in an area of previously existing high sinkhole density. Brinkman and others (2008) also suggest a change in sinkhole distribution patterns over time.

Lidar, which involves the use of pulsed laser light to map surfaces with high accuracy, had vastly advanced the ability to produce 3D elevation models of the earth's surface, including the ability to detect and map karst features. This underscores the importance of the U.S. Geological Survey 3DEP program, which has a goal of acquiring high-resolution lidar for the coterminous U.S. Zhu and others (2014) utilized advanced geospatial techniques applied to lidar data in a portion of Kentucky to reveal four times more sinkholes from lidar than found in earlier conventional mapping. Reflecting on this and later work, Zhu and others (2020) demonstrate that "...machine learning is a promising method for improving sinkhole identification efficiency in karst areas in which high-resolution topographic information is available." Kromhout and others (2018) noted that statewide lidar in Florida would tremendously improve the ability to spatially model and interpret closed topographic depressions. Not only would this improve the accuracy of predictive sinkhole models, repetitive collection of lidar datasets over consecutive years would allow for change detection analysis, such as identifying areas of increased subsidence activity.

Although quantifying sinkhole risk may be difficult, determining favorability for sinkhole occurrence is indeed possible. However, as learned in Pinellas County Florida by Brinkmann and others (2007), it is more complex than simply using lidar as other earth system processes must be considered. To characterize these processes, subsurface geologic data is required. Geologic maps, including soil maps, borehole data including geology and water level, and topographic data are needed. The study by Kromhout and others (2008) found that, in Florida, three geospatial datasets held the strongest association with predicting favorability of sinkhole formation: 1) the thickness of sediment overlying limestone geological formations; 2) proximity to circular closed topographic depressions; and 3) the vertical distance between the elevation of limestone in the subsurface relative to the pressure (potentiometric) surface of the aquifer. Among other factors, sinkhole occurrence in Florida is most strongly associated with locations where the top of the limestone in the subsurface is within 28 feet of the aquifer potentiometric levels.

Developing models like that of Kromhout and others (2018) can rival the cost of geologic mapping. Their study, which was co-funded by the Florida Division of Emergency Management (FEMA funds) and the State of Florida, required 3.5 years and a total of $1.1M. It is important to recognize the cost of such investigations when implementing the Sinkhole Mapping Act of 2021. Moreover, there are nuances in the effective development of predictive or risk models for use by planners, emergency responders, and the public, such as having a full understanding of the laws surrounding sinkhole insurance in each state.

Solutions and partnerships – applied geoscience

An opportunity exists for the implementation of the Sinkhole Mapping Act of 2021 to achieve the same success as the U.S. Geological Survey's National Cooperative Geological Mapping Program (NCGMP) in that part of the highly productive program represents a cost-effective partnership with state geological surveys. This partnership not only distributes the cost of the mapping on a 1:1 basis with the states, but also encourages consistency of digital products and terminology, and recognizes that geoscience expertise and data exist within both state and federal government geological surveys. Moreover, some state geological surveys (e.g., Colorado, Florida, Illinois, Indiana, Kentucky, Minnesota, Missouri, Ohio, Pennsylvania, Tennessee and perhaps others) have developed maps of sinkhole occurrences, density, or favorability.

In addition, completion of the U.S. Geological Survey 3DEP lidar data acquisition projects will allow high-resolution mapping of karst terrains to inform sinkhole mapping. The increased accuracy and precision of lidar elevation models will vastly advance the utility of sinkhole and related karst maps for use in environmental protection and public safety measures. Consider, for example, a stream to sinkhole feature along a major transportation corridor. This combination of landforms and land-use could be devastating to underground drinking water supplies if a liquid contaminant spill were to occur. It is for this reason that the Florida Geological Survey developed a tool that uses lidar data to identify these features. Understanding their location relative to highways will allow improved response to such events.

There are also benefits to partnerships with non-profit organizations that can support geoscientific collaboration and public outreach efforts. The National Cave and Karst Research Institute (NCKRI) is a non-profit government-supported institute headquartered in the city of Carlsbad, New Mexico. It was created through the National Cave and Karst Research Institute Act of 1998 to conduct, support, facilitate, and promote programs in cave and karst research, education, environmental management, and data acquisition and sharing. It is part of their mission to foster interdisciplinary cooperation in cave and karst research programs and promote public education. The Karst Waters Institute is another non-profit organization supporting karst geoscience professionals and promoting karst geoscience through sharing knowledge, information, and public outreach. Both organizations are part of the geoscience federation served by the American Geosciences Institute.

Partnerships with academic institutions, some of which are also co-located with state geological surveys, would also be important in this sinkhole mapping effort. Academic settings are ideal incubators for the development of new methods of data analysis, predictive models, and advancements in technology. Research fostered in this environment can be impactful and inform applied geoscience as it relates to characterizing and mapping the favorability (or susceptibility), or risk, of this geological hazard (e.g., Kim and others, 2022).

In closing, I fully support HR3691, the Sinkhole Mapping Act of 2021. Implementation of the Act provides opportunity to benefit public health, safety, and the environment and it also realizes efficiencies through collaborations between the U.S. Geological Survey and state partners, non-profit programs, and academia. An enhancement of the bill text is suggested to include susceptibility or favorability alongside risk. Both an authorization and an appropriation are strongly recommended as the task of mapping sinkhole risk is complex, and appropriate levels of funding will allow this important work to proceed unimpeded.

Citations

Arthur JD, Wood HAR, Baker AE, Cichon JR, Raines GL (2007) Development and implementation of a Bayesian-based aquifer vulnerability assessment in Florida: Natural Resources Research v.16, no.2, p.93–107. DOI: 10.1007/s11053-007-9038-5

Brinkmann R, Wilson K, Elko N, Seale LD, Florea L, Vacher HL (2007) Sinkhole distribution based on pre-development mapping in urbanized Pinellas County, Florida, USA: Geological Society London Special Publications v.279, no.1, p. 5-11. DOI: 10.1144/SP279.20305-8719/07

Brinkmann R, Parise M, Dye D (2008) Sinkhole distribution in a rapidly developing urban environment: Hillsborough County, Tampa Bay area, Florida: Engineering Geology, v.99, p. 169-184. DOI: 10.1016/j.enggeo.2007.11.020.

Bouffard K (2018, May 30, Updated June 6) Mosaic Co.: $84 million sinkhole repair complete in Mulberry: The Ledger https://www.theledger.com/story/news/local/2018/05/30/mosaic-co-84-million-sinkhole-repair-complete-in-mulberry/12047901007/ Last accessed July 15, 2022.

Currens JC (2018) Characteristics of Cover-Collapse Sinkholes in Kentucky: Kentucky Geological Survey Report of Investigation no. 3, 28 p.

Florea LJ, Hasenmueller NR, Branam TD, Frushour SS, Powell RL (2018) Karst geology and hydrogeology of the Mitchell Plateau of south-central Indiana, in Florea LJ, ed., Ancient Oceans, Orogenic Uplifts, and Glacial Ice: Geologic Crossroads in America's Heartland: Geological Society of America Field Guide no.51, p. 95–112, DOI: 10.1130/2018.0051

Florea LJ, Paylor RL, Simpson L, Gulley J (2002) Karst GIS Advances in Kentucky: Journal of Cave and Karst Studies, v. 64, no. 1, p. 58-62

Kim YJ, Nam EH, Jung YH, Liu X, Choi S, Kim D, Kim S (2022, in press) Probabilistic spatial susceptibility modeling of carbonate karst sinkhole: Engineering Geology: DOI: 10.1016/j.enggeo.2022.106728.

Kromhout K, Baker AE, Albritton CK, Scott TM, Cichon JR, Miller SR, (2018) The Favorability of Florida's Geology to Sinkhole Formation, Appendix H, in Enhanced Florida State Hazard Mitigation Plan. https://www.floridadisaster.org/contentassets/c6a7ead876b1439caad3b38f7122d334/appendix-h_sinkhole-report.pdf Last accessed July 16, 2022.

Kuniansky EL, Weary DJ, Kaufmann, JE (2015) The current status of mapping karst areas and availability of public sinkhole-risk resources in karst terrains of the United States: Hydrogeology Journal v.24, p. 613–624. DOI: 10.1007/s10040-015-1333-3

Porter S (2014, July 5) Reservoir repairs nearing completion - Tampa Bay Water makes plans to refill storage facility: Tampa Bay News Weekly https://www.tbnweekly.com/pinellas_county/article_647961f5-dda0-5f75-92e8-59c2db890800.html Last accessed July 16, 2022.

Schmidt W, (2005) Geological and Geotechnical Investigation Procedures For Evaluation of the Causes of Subsidence Damage in Florida: Florida Geological Survey Special Publication 57, 22 p.

Seale L, Florea L, Vacher L, Brinkmann R (2008). Using ALSM to map sinkholes in the urbanized covered karst of Pinellas County, Florida - 1, Methodological considerations: Environmental Geology v.54, p. 995–1005. DOI: 10.1007/s00254-007-0890-8

Tihansky AB (1999) Sinkholes, west-central Florida, in Galloway D, Jones, DR, Ingebritsen SE, eds., Land subsidence in the United States: U.S. Geological Survey Circular 1182, p. 121-140.

Upchurch S, Alfieri MC, Scott TM, Fratesi T, Dobecki TL, 2019, The Karst Systems of Florida – Understanding Karst in a Geologically Young Terrain, Springer Cham, 450 p. DOI: 10.1007/978-3-319-69635-5

Weary DJ, Doctor DH (2014) Karst in the United States: a digital map compilation and database: US Geological Survey Open File Report 2014-1156. DOI:10.3133/ofr20141156

Weary DJ (2015) The cost of karst subsidence and sinkhole collapse in the United States compared with other natural hazards: in Doctor DH, Land L, Stephenson JB, eds, Sinkholes and the Engineering and Environmental Impacts of Karst: Proceedings of the Fourteenth Multidisciplinary Conference, October 5-9, Rochester, Minnesota: NCKRI Symposium 5. Carlsbad, New Mexico: National Cave and Karst Research Institute. DOI: 10.5038/9780991000951

Zhu J, Taylor TP, Currens JC, Crawford MM (2014) Improved karst sinkhole mapping in Kentucky using lidar techniques: a pilot study in Floyds Fork Watershed: Journal of Cave and Karst Studies, v. 76, no. 3, p. 207–216. DOI: 10.4311/2013ES0135

Zhu J, Nolte AM, Jacobs N, Ye M (2020) Using machine learning to identify karst sinkholes from lidar-derived topographic depressions in the Bluegrass Region of Kentucky: Journal of Hydrology v. 588. DOI: 10.1016/j.jhydrol.2020.125049