SOIL-COVER KARST COLLAPSE: A GEOLOGIC HAZARD IN MISSOURI

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Abstract

Soil-cover karst collapses often may be seen as small local nuisances, but large collapses pose a significant threat to public health, safety and welfare. In May of 1978 a catastrophic soil-cover karst collapse occurred within the basin of the 15-ha (37-ac.) City of West Plains, Missouri, sewage lagoon, rapidly draining 284 million L^3 (75 million gal.) of sewage into the regional unconfined Ozark aquifer, forming a series of new sinkholes. This type of collapse represents one of several large, soil-cover collapses that have threatened infrastructure and groundwater supplies in Missouri. Catastrophic collapses have also occurred in Farmington, rural southwest Missouri, and in St. Louis County. The roots of many collapses are large karst conduits that may have little or no surface expression, such as visible sinkholes, yet these "blind karst" features can form abruptly, surprising landowners and municipalities.

Many of the environmental geology sites undertaken by geologists with the Division of Geology and Land Survey (DGLS) involve assessing the potential for soil-cover karst collapse in areas underlain by limestone or dolomite bedrock. These assessments are based on geologic and geohydrologic characteristics observed at known soil-cover collapses. These are, (1) groundwater greater than 15 m (50 ft.) below the surface, (2) thick and porous residual soils, (3) weathered limestone or dolomite bedrock terrane and, (4) sinkholes or losing streams in the area. Some collapses may be feasibly repaired, but at potentially high capital and environmental cost. The high potential for damage to groundwater supplies and infrastructure warrants care when evaluating proposed waste disposal or construction sites in soil-cover, karst-collapse settings.

Key words: epikarst, Missouri, sinkhole collapse, soil-cover karst collapse, geologic hazard

Hazards of Soil-Cover Karst Collapse

Soil-cover karst collapses in Missouri are not uncommon in areas of dolomite and limestone bedrock, and have occurred in a number of southern Missouri locations. Collapses most often occur in regions that have active karst features (Figure 1), but may also occur in areas that locally have little or no surface evidence of subsurface karst features. The early stages of a soil-cover karst collapse may appear as a soil-piping feature, but can rapidly grow to proportions that threaten urban infrastructure (Figure 2). Since the pre-collapse field conditions may reveal little evidence of subsurface karst, the collapses could be considered "blind karst." There are, however, geologic characteristics that are common to most collapse locations. These are:

1. Groundwater >15 m (50 ft.) below the surface,
2. Soil materials dominated by permeable, thick (≥9m or 30 ft. thick) residual silty-clay soils of-

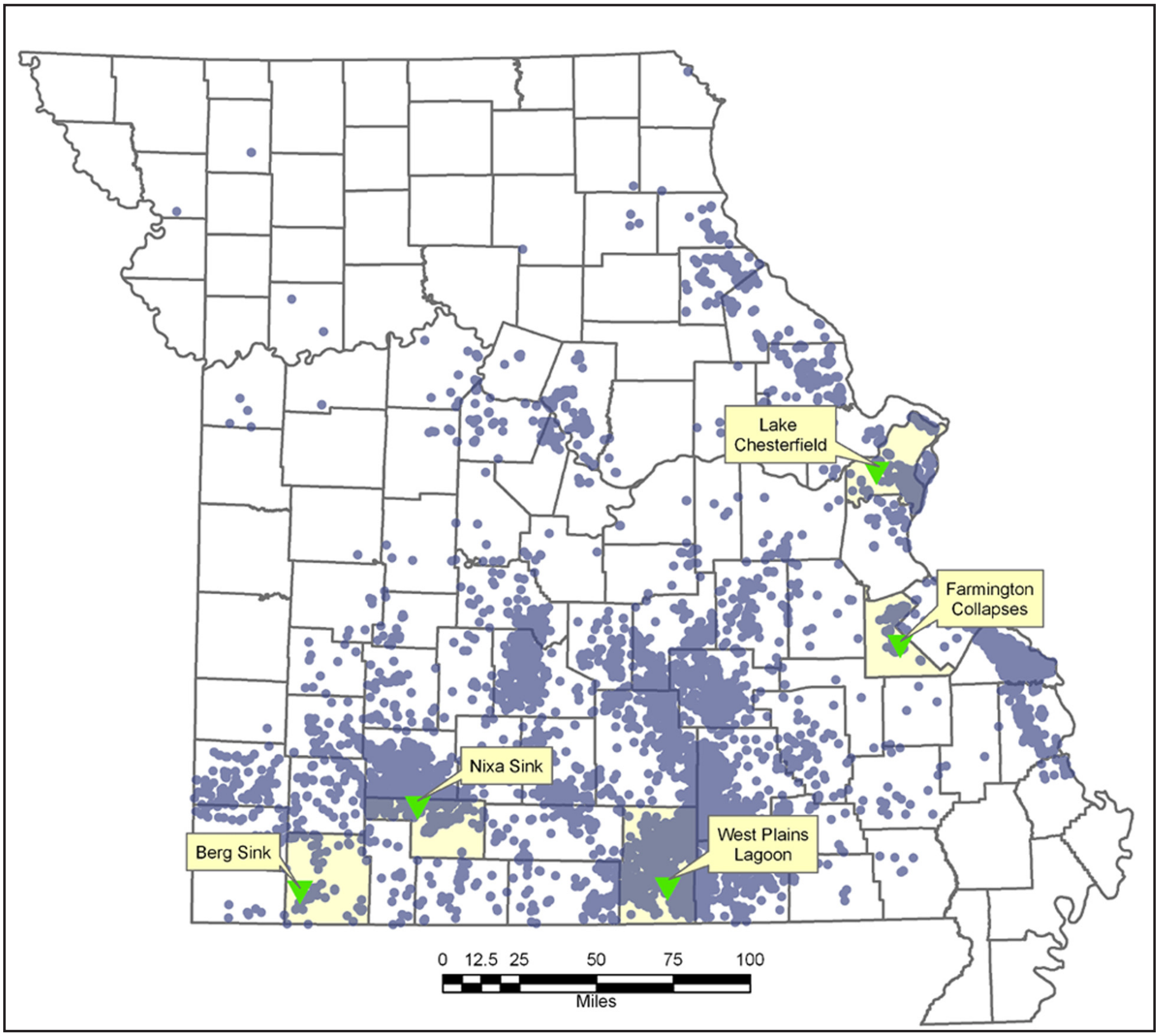
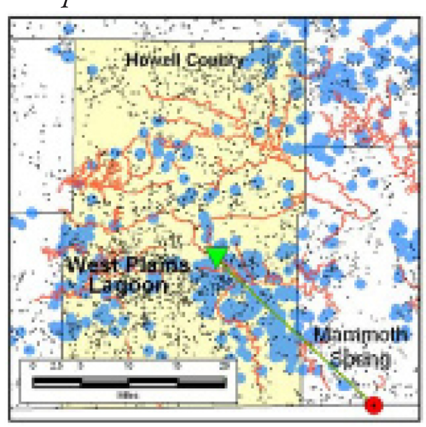


Figure 1 *Missouri karst hazard potential areas. Karst-related geologic hazards, such as groundwater pollution or sinkhole collapse, are obvious in areas with abundant, large sinkholes. The map above shows the locations of sinkhole areas (dots) and collapse locations.*



Soil-cover karst collapse beneath the West Plains Lagoon in Howell County (right), affected groundwater in a large area. The line represents a water trace from the West Plains Lagoon to Mammoth Spring in Arkansas (bullseye). Small squares are drinking water supply wells.

Well data, losing streams, sinkhole and water trace data are from the Missouri Environmental Geology Atlas (2007). Only streams that have been classified previously by DGLS are shown.

ten with relict bedrock structure,

3. Highly weathered underlying limestone or dolomite bedrock,
4. Nearby active sinkholes, or within a losing stream valley.

Large collapses have occurred in valleys that appear ordinary except that they lack perennial streams. Groundwater no longer discharges to the surface in these valleys, but instead has been pirated to subsurface flow paths that may cross multiple drainage basins (Williams and Vineyard, 1976, Harvey et al., 1983). These so-called "losing streams" are widespread in southern Missouri (Figure 1). Valleys with losing streams typically have poorly developed channels, and are often completely dry except during high rainfall periods. Geologists at DGLS have applied the field characteristics observed at known collapse sites to evaluate the "collapse potential" at proposed waste sites for over 30 years. Areas of Missouri that have these collapse characteristics include portions of the outcrop regions of Cambrian, Ordovician, and Mississippian limestone and dolomite bedrock formations.

Cases of Soil-Cover Karst Collapse

The five collapses described here are in slightly

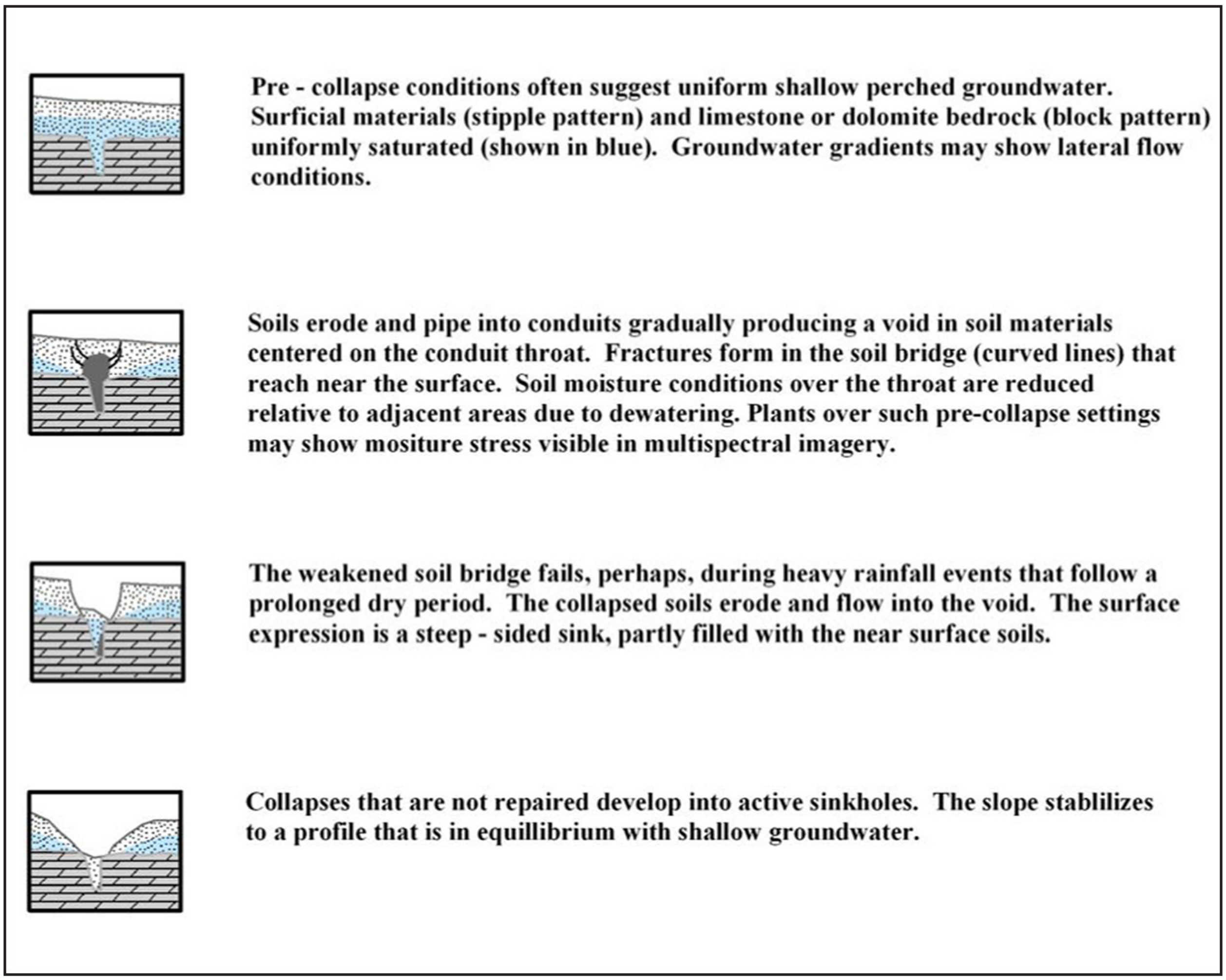


Figure 2 *Geologic model of soil-cover karst collapses resulting in typical sinkhole shapes if they are not repaired. Collapses near sinkholes are not uncommon in losing stream valleys that have thick, residual, bedrock soils over weathered, carbonate bedrock, and steep, vertical groundwater gradients. DGLS geologists use these field characterisitcs to assess collapse potential in carbonate bedrock areas. Vegetation over pre-collapse areas may show differential moisture conditions visible in infrared wavelengths. Satellite imagery, as resolution improves, may provide additional tools to predict locations prone to soil-cover collapse.*

different local settings, but have similar site characteristics as described above.

West Plains Lagoon Collapse

The city of West Plains is located within the Ozark Plateau. The surrounding region has numerous sinkholes and losing-stream segments (Figure 1). The West Plains lagoon was located in the valley of Howell Creek, which had been previously classified as a losing stream. The valley has a poorly developed channel, and borings for the site encountered silty and clay-rich gravelly soils >9 m (30 ft.) thick. Shallow bedrock at the site is weathered and porous lower Ordovician-age Jefferson City Dolomite that locally exhibits karst features. The Jefferson City Dolomite is in the upper part of the unconfined Ozark aquifer and serves as a major water supply for southern Missouri. Water traces from the site before and after the collapse shows flow to the southeast into Arkansas and discharge at Mammoth Spring (USEPA 1978, Duley 1997).

On or about May 5, 1978, the lagoon basin floor collapsed (Figure 3). Following the collapse more than 800 people living near West Plains reported illnesses ranging from flu-like symptoms, including severe nausea and diarrhea (DGLS unpublished files). Since the initial construction of the lagoon, small collapses had occurred at the site in 1964 and again in 1966 (Aley et al. 1972), providing evidence of active recurrence of collapse in these settings. In each instance the collapse features were repaired using cement, clay and bentonite, and then put back into active service.

Figure 3 *This post-collapse view of the West Plains Lagoon shows two sinkholes that developed as the lagoon drained.*

DGLS geologists had noted the potential for groundwater contamination at this location in a site evaluation in 1964. Investigations prior to May 1978 concluded that a catastrophic failure could occur in Howell Creek valley, and that groundwater in the region would

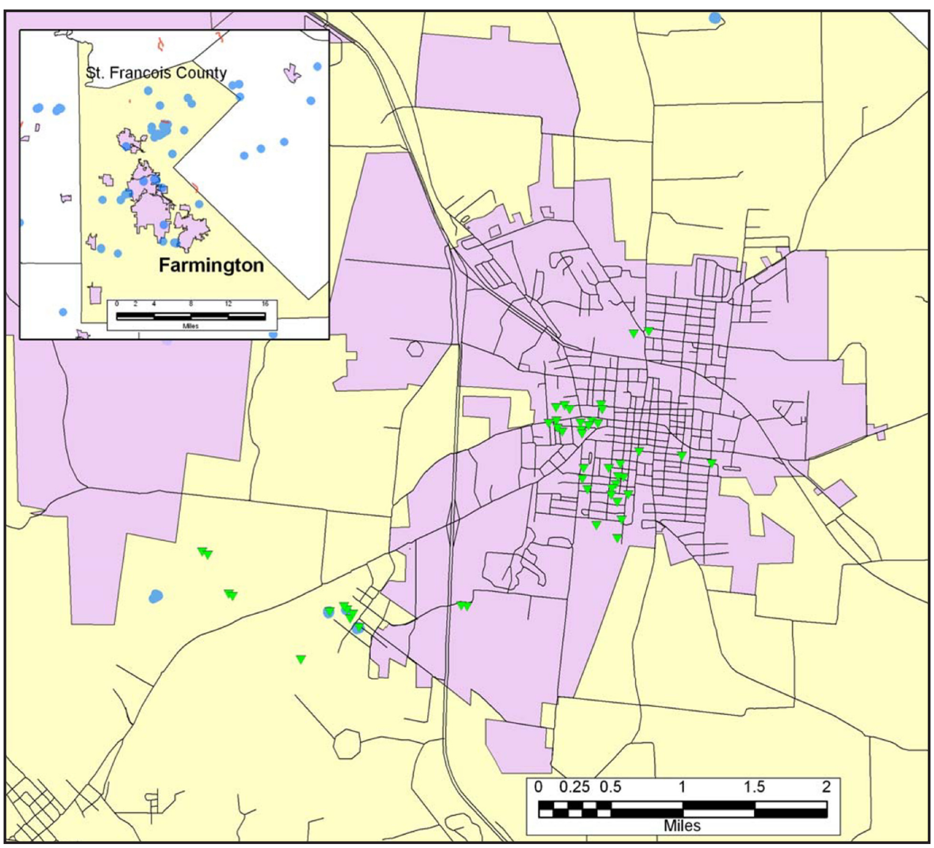


Figure 4 *Forty-eight soil-cover karst collapses were reported in Farmington, Missouri. The bedrock in the shallow subsurface consists of fine to medium-crystalline dolomite of the later, upper Cambrian Bonneterre Formation. Little karst development had been recorded in either the Bonneterre Formation or in* **continued**

the Farmington area, but fractures and open joints were observed in outcrops and in the collapses themselves. Small dolines were observed near the city. Groundwater draining into bedrock joints erodes and pipes the soils, creating cavities. As the draining progresses, shallow water table conditions reflect soil dewatering near the joints. Most reported collapses were in urban areas, many occurring in residential yards, others forming near or under streets. One formed at a street intersection along a joint in dolomite, over 25 m (80 ft.) deep and nearly 19 m (60 ft.) in diameter, severing utilities and swallowing pavement and sidewalk.

be threatened. The 1978 catastrophic failure led to the construction of a mechanical treatment plant for West Plains, which could meet applicable discharge standards for losing streams. These non-earthen structures, while expensive, are less likely to induce soil piping into bedrock conduits and are not as susceptible to damage from a catastrophic, soil-cover collapse. The series of collapses at the West Plains lagoon demonstrates that these soil-cover type collapses can and do recur, even when mitigating strategies are employed.

Farmington Collapses

For more than 50 years soil-cover karst collapses have been reported in the city of Farmington, Missouri. Surface expressions of karst features are not common in this area (Figure 4). However, soil-cover collapses have damaged residential building foundations and collapsed sections of city streets resulting in broken municipal water, sewage, and gas lines. Known collapses have a diameter up to 9 m (30 ft.), and are rooted in karst joints as deep as 19 m (63 ft.). Poorly designed urban drainage may contribute to soil piping in these areas, but the karst joints were present prior to collapse (Figures 5a and 5B). Small soil pipes were observed at the surface at some locations prior to collapse, but no other surface expressions have been recognized. These collapses are not known to hold water after failure, demonstrating that near-surface groundwater is drained rapidly into the bedrock karst joints. The collapses that have been excavated and repaired show partial to complete piping of soils from the karst bedrock joints.

Figure 5A *Collapse in residential neighborhood, Farmington, Missouri. This collapse had been repaired with soil fill only, but it reactivated.*

Figure 5B *Karst joint in Bonneterre Formation dolomite in Farmington, Missouri. Red soils are clay-rich silt. Joint walls have irregular, scalloped surfaces typical of karst conduits in carbonate rocks.*

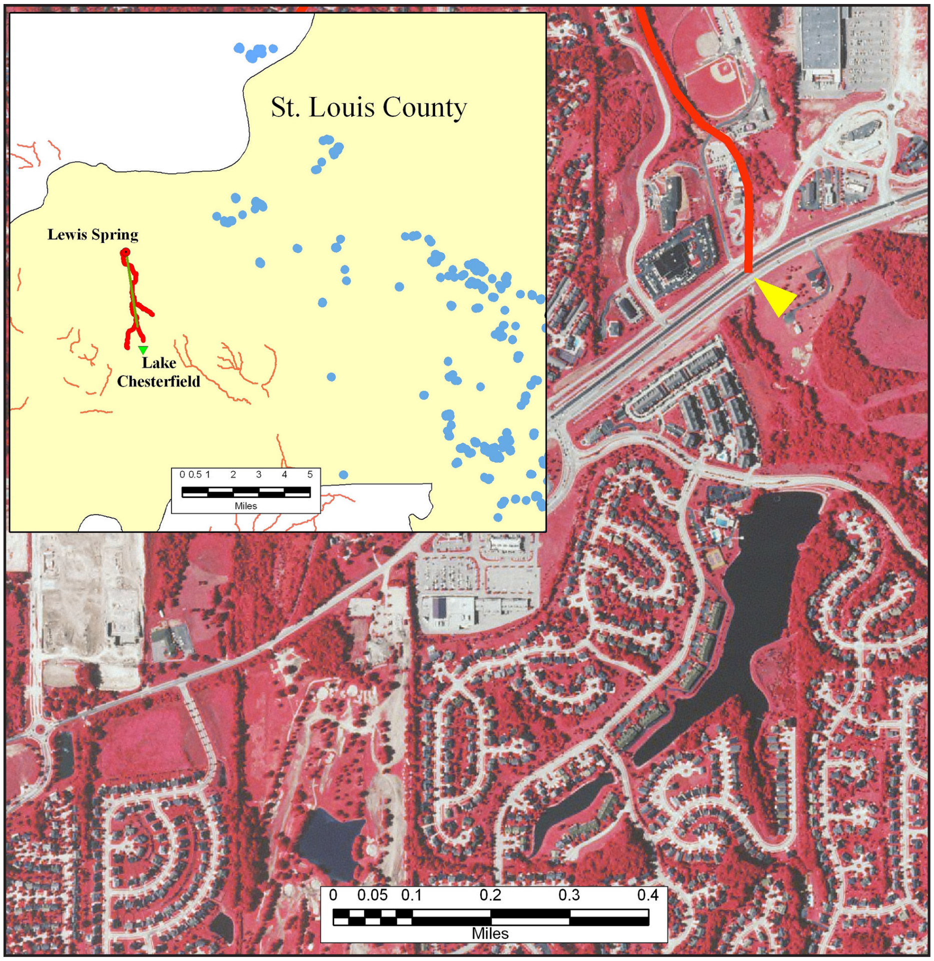


Figure 6A *Infrared aerial photograph showing the location of the Lake Chesterfield Collapse. The nearest mapped sinkholes (inset, dots) are more than 11 km (7 mi.) from Lake Chesterfield, but the lake site is within 400 m (¼ mi.) of a previously mapped losing stream (bold line at upper right, marked by pointer). A water trace from near the site (inset) indicates water lost to the ground near lake site flows to Lewis Spring (dot).*

Lake Chesterfield Collapse

Built in 1987 to control storm water runoff from a large residential development, Lake Chesterfield was a 9-ha (23-ac.) recreational lake for a community in west St. Louis County (Figures 6A–6C). The lake was formed by construction of an earthen dam across a portion of Caulks Creek. Shallow bedrock at the site consists of the Mississippian-age limestone. Although this unit is highly weathered and contains solution features indicative of karst, the nearest mapped sinkhole is over seven miles from the lake site.

In a 1978 engineering geology report, DGLS staff geologists noted a severe collapse potential for earthen wastewater storage facilities and lake sites constructed in this general location. Studies of waste disposal issues along Caulks Creek revealed that the stream was a losing drainage and did not support a surface flow during normal hydrologieriods. Water tracing was conducted in order to gain further understanding of subsurface groundwater flow. Analysis of the water trace data indicated that surface waters were rapidly infiltrating the subsurface and emerging at Lewis Spring nearly 6.4 km (4 mi.) to the north.

In June 2004, a large sinkhole formed in the lake bottom and completely drained the impoundment (Figures 6B and 6C). Reportedly, repairs of small collapses and excessive leakage had been made to the lake several times in the preceding years.

Figure 6B *Post-collapse aerial view of Lake Chesterfield showing sinks that formed at the cave beneath the lake.*

Figure 6C *Soil cover collapsed beneath Lake Chesterfield into a well-developed cave.*

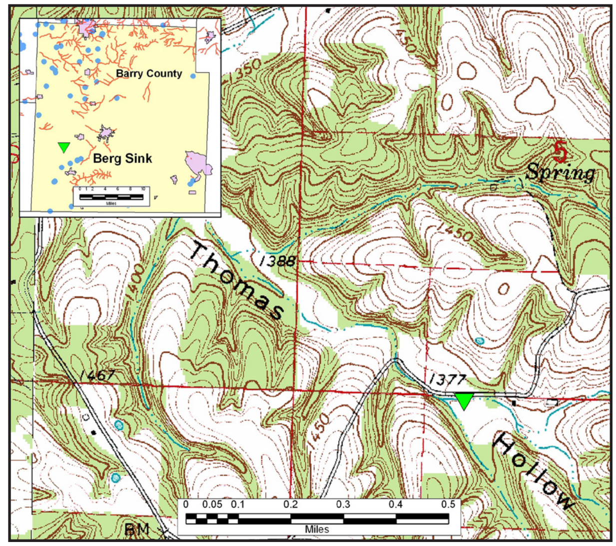


Figure 7 *Berg Sink, Barry County. The bedrock in the shallow subsurface is the variably cherty limestones of the Mississippian Elsey Formation. Streams in the vicinity of the collapse (triangle) had not been classified, but investigations since the collapse showed losing flow above the collapse and within 60 m (200 ft.) downstream. Surficial materials in the valley floor appear to be greater than 9 m (30 ft.) thick based on electrical resistivity. During the first week of March 2005, the collapse flowed to the adjacent losing stream. If the collapse is about 45 m (150 ft.) deep, the conduit would be in the Ozark Aquifer. The nearest sinkholes are approximately 4.3 km (2.7 mi.) from the collapse. Base map: USGS Exeter 7.5' Quadrangle.*

However, there was no physical evidence that a collapse of this magnitude was imminent. In an effort to repair the catastrophic collapse, an extensive drilling and grouting program was undertaken. To date, the small lakeside community has expended over $650,000 in an attempt to remedy the situation.

Berg (Exeter) Collapse

Located in Barry County near Cassville (Figures 7–10), this collapse is also within a losing stream valley, in an area of cherty limestones of the Mississippian-age Elsey and Reeds Spring formation, and has residual soils that are from 9 to >18 m (30 to >60 ft.) thick. The collapse was first observed by the landowners during the third week of February 2005 as a 3-m-diameter (10-ft.), water-filled depression in an open pasture. The owners indicated that the depth of this first opening was about 12 m (40 ft.). By the second week in March of 2005, the collapse had expanded to nearly 76 m (250 ft.) wide by 30 m (100 ft.) long (Figure 8A and 8B), and at one stage appeared to be greater than 46 m (150 ft.) deep. At this depth, the feature would breech the lower Ordovician bedrock and recharge the Ozark Aquifer.

At one time in early March 2005, the collapse behaved as a spring discharging to the adjacent small channel. Since that time the water level reportedly fell below the level of the adjacent dry stream channel, as the collapse became a sinkhole. One end of the sink is within a few feet of a county road, which has been closed to all traffic. It seems likely that the road will be impacted by the formation of the sinkhole.

Figure 8A *Berg Sink, last week of February 2005. The collapse margin has a well-defined scarp. The near background tree line is along a county road.*

Figure 8B *Berg Sink, second week of March 2005. The collapse had developed to a water-filled "spring" and had dimensions of 76 by 30 m (250 by 100 ft.).*

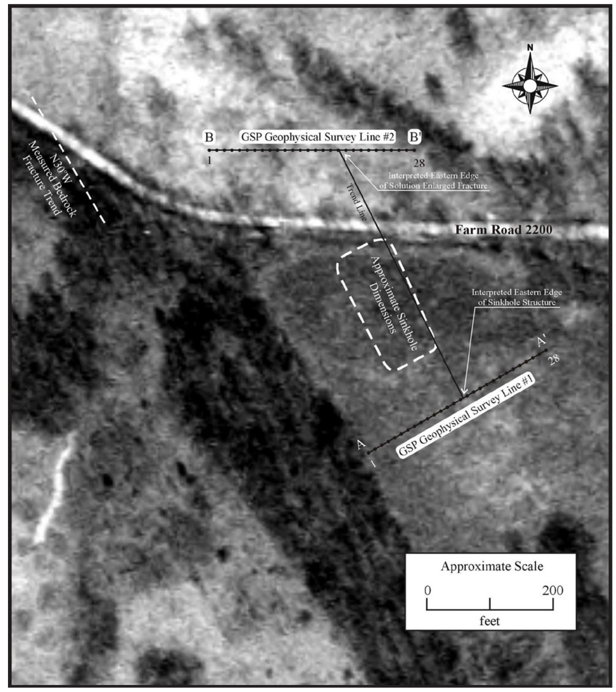


Figure 9 *Site Map of Berg Sink showing the approximate locations of the geophysical survey lines and the surface expression of the sink structure.*

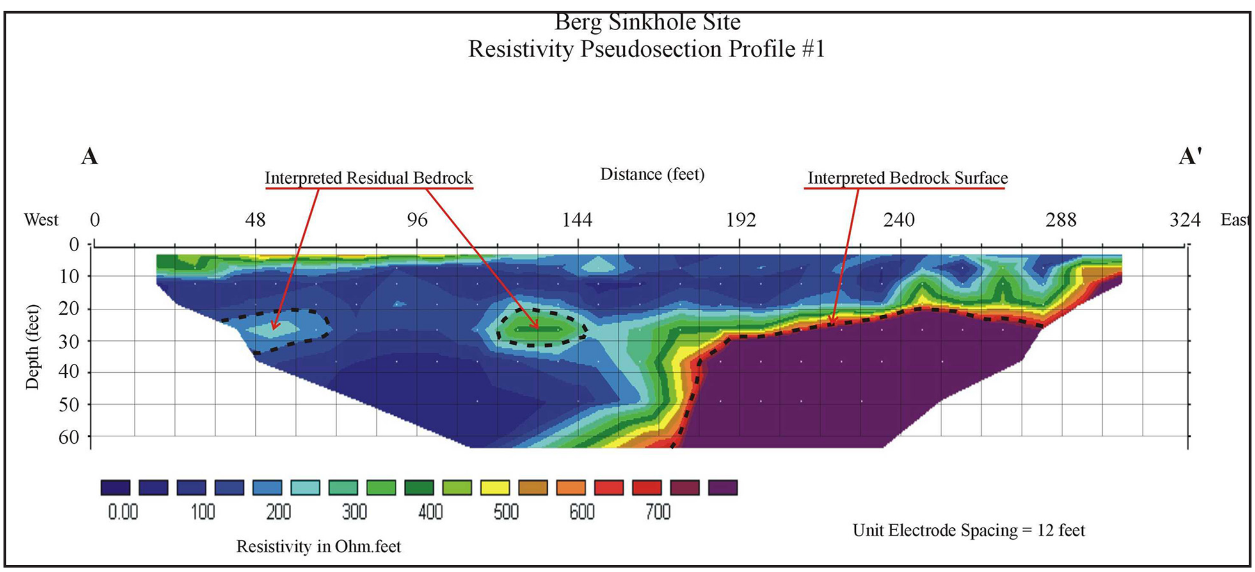


Figure 10A *Electrical resistivity pseudosection profile on the south side of Berg Sink.*

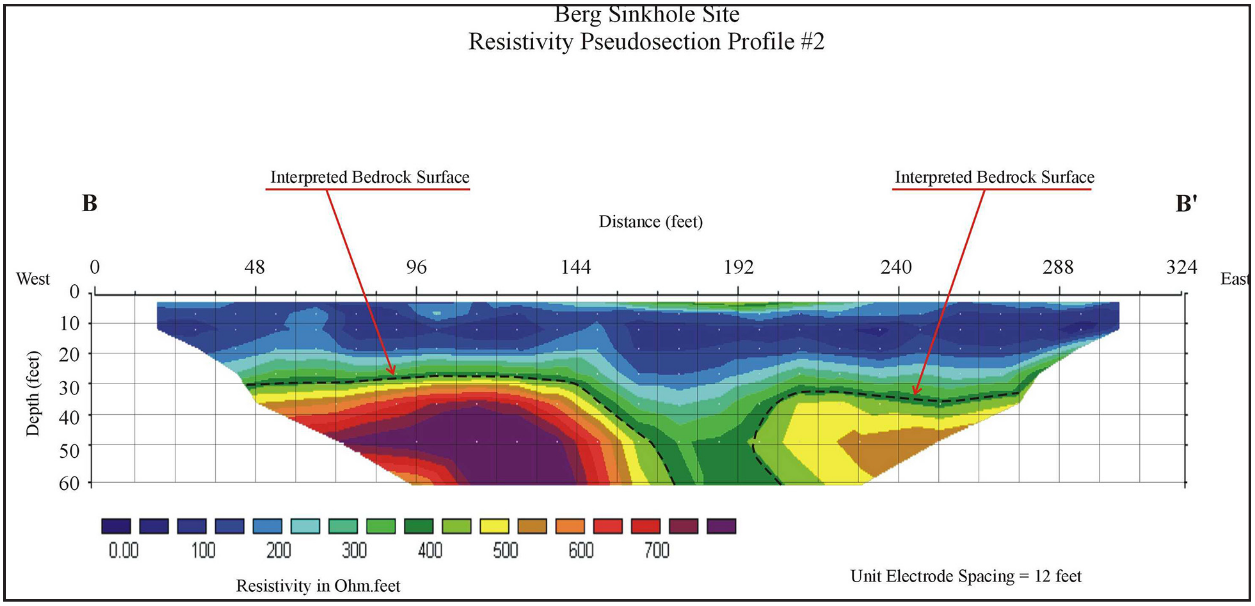


Figure 10B *Electrical resistivity pseudosection profile on the north side of Berg Sink.*

Nixa Collapse

On the morning of August 13, 2006 a collapse occurred at 327 N. Delaware Avenue in the City of Nixa (Christian County) beneath part of a house owned by Mr. Norman Scrivener. On that day the depth of the structure was reportedly measured at about 25 m (75 ft.) (Figure 11). This was after engulfing the garage, which included a medium-sized sedan. Neither groundwater nor bedrock was ever observed in the collapse. Bedrock beneath the structure is the Mississippian-age Burlington Limestone. The Burlington Limestone typically weathers severely along fracture traces to create a very irregular (cutter and pinnacle) bedrock surface. The collapse structure developed in a structured reddish-brown, cherty, and clayey residuum (Figure 12).

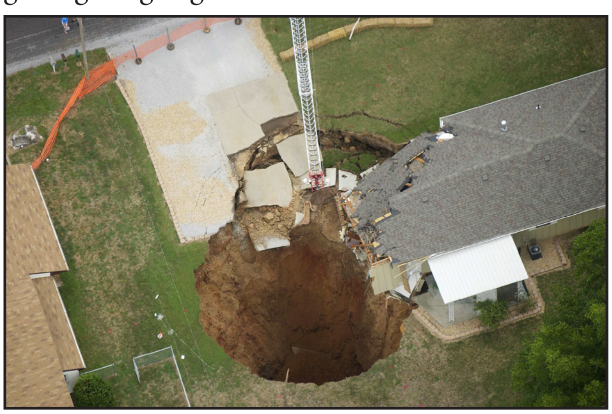


Figure 11 *Aerial view of the a collapse at 327 N. Delaware Avenue, Nixa, Christian County, Missouri, beneath part of a house owned by Mr. Norman Scrivener. The depth of the structure was measured at about 25 m (75 ft.). This was after engulfing the garage, which included a medium-sized sedan.*

The Nixa area is well known for the development of sinkholes. Forty sinkholes have been

Figure 12 *The collapse structure developed in a structured reddish-brown, cherty, and clayey residuum as can be seen from this view. From the angle of this picture the lack of subsidence of the area is apparent. Also visible is an abandoned steel septic tank.*

mapped within the Nixa municipality using USGS 1:24,000 scale topographic maps. The highest concentration in the general area is just to the north of the city limits. The closest mapped sinkhole to the Nixa collapse is about 400 m (¼ mi.) to the south. Considering the concentrated development of sinkholes in this area, it is interesting to note that no signs of subsidence were observed at the site prior to the collapse.

Evaluation of Collapse Potential

Sites that have potential for soil-cover collapse, as described above, are not always in areas of obvious karst development. Collapses have occurred at sites that are quite remote from active sinkholes, but are commonly within valleys that lose surface water flow to dolomite or limestone bedrock. Since the 1978 collapse of the West Plains Lagoon, geologists at DGLS have evaluated collapse potential of proposed lagoon sites, with the goal of avoiding future catastrophic collapse and widespread groundwater contamination. A high collapse potential, based on these geologic evaluations, requires the construction of a structurally reinforced treatment system. No similar collapses have been reported at a state-regulated waste treatment facility constructed after 1978.

DGLS has also worked with local governments and individuals to better define and locate soil-cover karst collapse hazards. The recent Berg Collapse did not immediately threaten groundwater, but there was a need to address the potential threat to an adjacent county road. DGLS geologists completed a geophysical survey of the site using electrical resistivity methods to determine the depth of bedrock and locate possible extensions of karst conduits on either end of the collapse (Figure 10). These surveys suggest the road may be damaged through natural equilibration of the sinkhole walls, or through renewed collapse and expansion of the current sink margin.

Techniques for Future Site Assessment

Shallow groundwater in soils and its effect on plants near pre-collapse locations, may play an important role in the future detection of soil-cover collapses. If soil groundwater levels are depressed in the vicinity of active soil-cover collapses, the vegetation in these areas may be stressed compared to adjacent areas. Satellite imagery in appropriate spectral bands can detect small differences in color and moisture content in vegetation. These data, when combined with geologic data in a geographic information system, can identify targets for ground truth investigations (Rouse et al., 2004). Currently, the available imagery resolution is too low to identify small pre-collapse targets. Other ground factors such as urban development can also impede target identification. As satellite imagery resolution and availability improves, this type of analysis may lead to more efficient site investigations and regional analyses for soil-cover karst collapse hazards.

Conclusions

Catastrophic soil-cover karst collapses have been costly in Missouri, causing groundwater contamination and damage to municipal and private property. The geologic settings in which collapses occur are well understood, and pre-construction site evaluations can reduce the risk of possible, future soil-cover collapse. Collapse-prone areas are commonly in losing stream settings, regardless of the proximity to active sinkholes or other indicators of subsurface karst. Therefore, pre-construction investigations are often necessary to determine collapse potential in the area.

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