HUMAN MODIFICATION OF KARST IN THE ST. LOUIS AREA, MISSOURI

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Abstract

The significance of karst to St. Louis is exceptional as this landscape dominates one of the oldest and most populous regions of Missouri. Many notable karst features have been variously used, misused, and eventually destroyed by humans over time, but the most severe impacts involve the gross modification of the region by urbanization and suburban sprawl. Rectangular remnants of the original topography are preserved in areas such as Carondelet Park, pockmarked by sinks, yet surrounded by expansive, topographically featureless development. Remarkably, the Old Jamestown Association has vigorously defended progressive zoning ordinances that have preserved their cherished natural landscape. Contrary examples are more common and include the destruction of numerous significant caves, obliteration of cave entrances, widespread topographic leveling, and the conveyance of polluted street runoff, and formerly untreated sewage, into karst drainage systems. Insufficient recognition of the consequences has caused groundwater pollution, and may have contributed to devastating historical cholera epidemics. Many small scale engineering problems have also arisen, such as cracked roads and foundations, as well as conspicuous leaky impoundments, including the repeated disappearance of 10 ha Lake Chesterfield. More balance is needed between development inevitabilities, construction standards, and environmental preservation.

Key words: urban karst, karst land management, contaminants, Missouri

Introduction

Carbonates and other soluble rocks underlie more than 20% of Earth's land surface, including 40% of the eastern and central parts of the United States (White et al. 1995). It follows that karst is a major landform, and that the special engineering and environmental problems associated with it have special significance to humans. An incomplete list of some widely-recognized problems is provided in Table 1. While not all of these problems are unique to karst, the special character of this landscape tends to make them all particularly common or severe.

Considered together, nearly two-thirds of the city and county of St. Louis are underlain by limestone or subordinate dolostone. The special features and problems associated with karst are thus common here, and the problems are magnified in different ways because parts of the region have been settled for centuries, while others are undergoing rapid urban and suburban development. This paper briefly describes some of the issues and the disparate approaches to land development taken by different local communities.

Geologic Setting

The St. Louis region is part of the Ozark border with special proximity to major rivers and to the southern limit of Pleistocene glaciation (Vineyard

Table 1	*Some Problems of Uninformed Development of Karst*
Habitat & Landform Destruction	
Structural Problems: roads, foundations, water and gas lines…	
Water Quality Degradation	
	Contamination: road salt, pesticides, oil, sewage, animal waste…
	Salinity & temperature fluctuation
	High Turbidity
	Excess Nutrients: organics, phosphates, fertilizers
Flooding & Drainage Problems	
	Flash Floods: Surface & Subterranean
	Drainage
	Leaky Lakes

1967). Elevations vary from about 115 m (380 ft.) along the Mississippi River in the southernmost St. Louis County to 278m (890 ft.) near its western border. The greatest relief occurs along the river bluffs, which are nearly 100 m (300 ft) high along Meramec River about 2 km north of Eureka.

The geologic section of the region includes Quaternary and Recent deposits that overlie a section of Paleozoic strata that is > 1 km thick (Harrison 1997). The youngest deposits predominantly consist of unconsolidated alluvial deposits along the rivers, streams and floodplains. These are flanked by surficial loess deposits that thin away from the rivers, and then by thin, residual soils with abundant chert clasts on hillsides; see Lutzen and Rockaway (1971) for more details. The youngest bedrock includes the Pennsylvanian shale and subordinate siltstone, limestone, and thin coal beds that predominantly crop out in the east-central part of St. Louis. As these uppermost units are dominantly clastic, however, they host few karst features, although they commonly mantle underlying karst or constitute the fill of sinkholes that formed during Paleozoic to recent times.

Beneath these predominantly clastic units, however, is the thick, carbonate-dominated, commonly karstified stratigraphic section that makes Missouri the "Cave State". Included are thick Mississippian strata, of which the St Louis and Burlington-Keokuk limestones have the greatest outcrop distribution. Devonian and Silurian strata are very thin or absent in this region, however. Beneath the major unconformity represented by these missing units are Ordovician strata dominated by the Kimmswick and Plattin limestones, the Joachim dolostone, and finally by the St. Peter sandstone which is the oldest unit that crops out in the area. Drill holes have penetrated about 600 m of subjacent Paleozoic strata, mostly Ordovician and Cambrian dolostones, that host many of the remarkable karst features of the Ozarks, but do not crop out near St. Louis.

Problems of Uninformed Development of Karst

Landform Destruction. The St. Louis area includes zones that have been settled for centuries, areas that are undergoing rapid development, and protected and unprotected areas that remain undeveloped. Karst has different relevance to these disparate areas.

Many long-settled parts of St. Louis were developed on karst, though their areal extent is difficult to quantify. This is because these areas are now devoid of outcrops, and because the landforms were profoundly modified long before accurate topographic maps were made. Some of the oldest maps (e.g., Paul 1844) show features such as Chouteau's Pond that have been described as impounded sinkholes whose waters became incredibly polluted (Schroeder 1997). Its place is now occupied by railroad yards and high-rise buildings in the heart of the city, within 2 km of the Arch. In such areas, nothing remains of the original landscape on which the geologist can base conclusive deductions.

Farther from downtown, in areas that have not been settled quite as long, several parks and other protected areas preserve remnants of the original topography (Table 2). A good example is Carondelet Park (Figure 1), pockmarked by sinks, yet surrounded by developed expanses that are topographically featureless. Clearly, much land has been grossly modified and leveled. The Webster Grove area has many similar examples (Table 2), but also includes some subdivisions where sinkholes remain.

Even farther out, near the western, southern, northern, and southeastern boundaries of St. Louis County, are many large parks that preserve mostly unmodified topography. Of these, Cliff Cave County Park and Rockwoods Reservation are the best areas to observe karst features (Table 2, Missouri Speleological Survey 1966). An interesting difference, however, is that Cliff Cave park preserves part of the sinkhole plain that is similar to the terrane upon which the City of St. Louis was built, whereas Rockwoods Reservation preserves mostly hilly, wooded terrane with few sinkholes. The latter type of area is common in the Ozarks, and in part can be described as "mantled" karst.

Cave and Habitat Destruction. Caves and cave habitat are commonly destroyed during the gross modification of the topographic surface described above, but are here considered separately as caves and their special life forms are remarkable

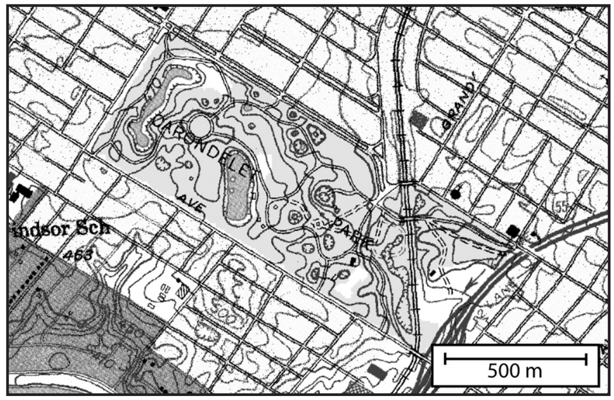

Figure 1 Map of Carondelet Park (light grey), showing the preservation of several sinkholes and other karst features within its rectangular boundary, and the comparatively featureless topography outside. Just west of the railroad tracks is a sinuous depression that may represent collapsed cave passage, that formerly included features called Carondelet Park Cave (now blocked) and Big Spring (Light 2007). Modified after part of the USGS Webster Groves 7.5" topographic quadrangle.

parts of the subsurface (Elliott 2007). The pattern of intensive use, modification, and ultimate destruction of caves has been ongoing in St. Louis for two

Table 2 Area Parks Preserving Significant Karst Features

Park	Size, ha	Karst Features
Carondelet Park	73	Sinkholes, former cave and spring
Tower Grove Park	117	Sinkholes
Blackburn Park	13	Sinkholes, karst window
Bohrer Co. Park	7	Sinkholes
Sylvan Springs Co. Park	28	Sinkholes, spring
Cliff Cave Co. Park	104	Sinkholes, caves, springs
Jefferson Barracks	172	Sinkholes, springs
Ft. Bellefontine Co. Park	124	Spring, sinkholes, small cave
Forest 44 Cons. Area	388	Springs, swallow hole
Lone Elk Co. Park	221	Spring, leaky lake, small sink
Babler State Park	988	Small cave, springs
Greensfelder Co. Park	711	Caves, pits, springs, few sinkholes
Rockwoods Reservation	768	Springs, swallow holes, small caves, pits, estavelle, few sinkholes

centuries. None of the dozens of caves once present in what is now the City of St. Louis resemble their original character (Rother and Rother 1996). Few of these caves are even enterable, and their waters have become heavily polluted by sewage and other urban wastes. For example, Cherokee Cave once served as beer cellars, its rooms expanded by quarrying and blasting. Next it was used for waste disposal, and then it was cleaned out and further excavated to facilitate its use as a tour cave. Finally, in the 1960s the commercial cave was closed and partially filled and grouted to permit construction of I-55 (Weber 1964). Cherokee Cave is probably the most intact city cave, and parts of it are yet reported as enterable, but only via the basements of private businesses.

Moving outward into the next successive "shell" of historical development, external to the original city, are densely populated karst lands where many caves survive, albeit with significant modifications or impacts. Many of these caves are now enterable only through culverts, as they are commonly integrated into systems for storm-water drainage (e.g., Cave of the Falls). Others are reported to be very foul or to contain bad air, as they were formerly used to convey raw sewage. The entrances to many others have been filled, so they are no longer enterable. More than 10% of the county's caves mapped or described by Missouri Speleological Survey contributors have been destroyed or blocked in the last few decades (Criss et al. 2006). Many other significant caves were destroyed before they were documented. For example, former caves along Meramec River near Kirkwood were allegedly used for powder storage during the Civil War (Yegge 2007).

Finally, several enterable caves are preserved along the fringes of St. Louis County, particularly in protected areas such as the large county parks listed in Table 2. Unfortunately, many adjacent areas are undergoing rapid deforestation and suburban development, and several small caves have been recently destroyed by this process (Criss et al. 2006). The rapidity of this "urban sprawl" process is remarkable given that both the city and county of St. Louis have had negative population growth since 2000 (U.S. Census Bureau 2006).

Structural Problems. Problems associated with construction on karst are common in the St. Louis area, though most are of small scale. Examples are collapses that damage streets or foundations, repeated cracking of streets and sidewalks, and pipe breaks. These problems are typically corrected soon after they occur, and they seem not to have been systematically described. Such problems may be particularly common in the Concord (Appendix) and Spanish Lakes areas. A systematic study would be useful.

One significant sinkhole, about 30 m in diameter, formed since WWII at Washington University's Tyson Research Center, possibly because of groundwater pumping. No economic loss occurred at this forested collapse site, but the potential for damage is evident. Two small ponds on this property have experienced water-retention problems, one via a small sink that rapidly formed on its bottom ca. 1991, but far more larger examples of this sort are described below.

Water Quality Degradation. Ground and surface waters are intimately connected in karst terranes, so they are similarly impacted by human development. The everyday concept of degraded water quality actually embodies many different chemical and physical effects. Even the notion of "contamination" is not simple. One type of contamination is the deleterious increase in the concentrations of naturally-occurring substances, including road salt or certain toxic metals, or human and animal wastes. A particularly important class of such contaminants are nutrients, such as organics, phosphates, and fertilizers, that are commonly applied in great excess to cultivated fields, lawns, and golf courses. Moreover, in populated areas raw or insufficiently-treated sewage is an important contaminant that can pollute both surface streams and groundwater by several paths, including pipe leaks, septic systems, and combined sewer overflows (CSOs). Another type of contamination embodies the presence of unnatural substances such as pesticides, herbicides, or petroleum products, which now occur in local ground and surface waters (e.g., Hauck and Harris 2005). Stueber and Criss (2005) demonstrated the close interrelationships between ground and surface waters in nearby Monroe County, Illinois, and proved that both concentrations and loads of many substances of concern are greatest during storm flow. Additional study of St. Louis waters is needed, but it is evident most of our streams have biodiversity far below natural levels, and most are not even fit for human contact.

A commonly overlooked type of water quality degradation involves changes to its physical character. Most obvious are large increases in turbidity, which is also the most serious problem because bacteria, viruses, and many toxic metals are hosted by suspended particles. Like many chemical contaminants, turbidity of surface waters and many cave streams is greatly increased during storm flow (for example, Stueber and Criss 2005).

A final class of problems that is largely unstudied is related to rapid and large fluctuations of physical and chemical properties. Large fluctuations in the temperature and salinity of groundwaters and springs may be harmful to animals in these habitats, particularly to troglobitic organisms that are highly adapted to a nearly invariant subsurface environment. Clearly, increased contributions of surface waters to cave streams will amplify such variations. Examples include gross changes in salinity because of road salt applications, rapid fluctuations in discharge, turbidity and temperature related to the use of caves for storm-water conveyance, and large seasonal variations because of leaking impoundments (Figure 2).

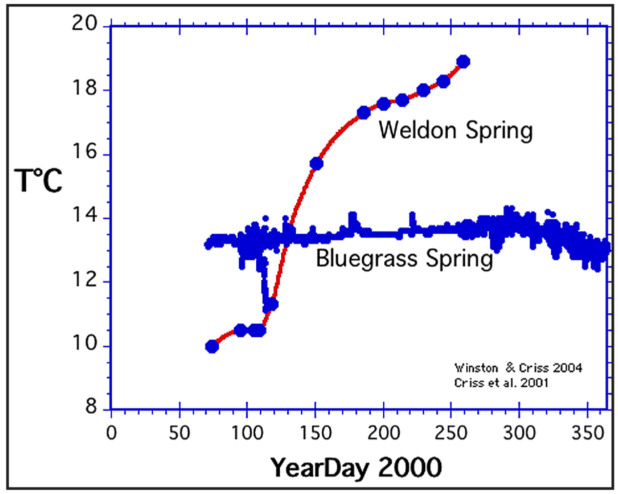

Figure 2 The subsurface environment normally has very uniform temperatures, as seen in the small temperature variations in Bluegrass Spring at Tyson Research Center. In contrast, Weldon Spring in southern St. Charles County now has flow dominated by lake leakage, and its temperature variations have become comparatively large. Data from Winston and Criss (2004) and Criss et al. (2001).

Flooding and Drainage Problems. Both surface streams and cave streams commonly experience flash flooding in the St. Louis area, and the frequency and magnitude of these events have increased in response to development of the land surface. Many local waterways that once had perennial flow are now mostly dry, but experience severe intermittent flash floods. These high, intermittent flows are well documented by gauging stations, and are evidenced by many physical characteristics including erosion, entrenchment of the stream channels below the natural floodplain, and the removal of fine sediments so that the channels are now lined with coarse gravels and cobbles. These changes are aggravated by the construction of impervious surfaces, and more widely by deforestation and the disturbance of soils that mantle the karst, which are quite thin on many local hillsides.

Now, what do the aforementioned conspicuous processes have to do with karst groundwater? Probably a great deal, because the excess runoff that is now delivered rapidly to stream channels represents water that no longer slowly infiltrates the soil. This change has reduced recharge to the shallow groundwater systems that sustain the flow of streams during dry spells. It would be expected under these circumstances that many springs are drying up. However, many cave streams are experiencing increased flow because of the intentional routing of urban and suburban runoff directly into large cave conduits, described above, which clearly would amplify subterranean flash floods. Here again, monitoring of area springs is insufficient to clearly establish these trends, even though they may be very significant.

In contrast, problems with drainage and with the catastrophic failure of impoundments occurs so rapidly that they cannot be overlooked. Drainage problems occur when conduits cannot remove storm waters as rapidly as they are delivered, which is very fast where impervious surfaces are common or where natural soil infiltration has been reduced. Storm-water detention basins are commonly constructed in St. Louis County to offset these problems.

Finally, the catastrophic failure of lakes is common in the St. Louis area. Interestingly, the most important examples have occurred in areas under-

Table 3 Disparate Zoning Ordinances of two St. Louis Co. Communities

Oakville	**Old Jamestown**
High Density Residential & Commercial	Low Density Residential (mostly 3 to 5 acre lots)
Homes, roads commonly built on filled sinkholes	Topography preserved by mandated construction setbacks
Stormwater diverted into sinks, caves	Alterations to natural flows are prohibited

lain by the Burlington-Keokuk Limestone, which hosts many deep, clay-filled grikes and fractures. If excavations remove too much epikarst so that such fractures are intersected, their clay fill can be removed by percolating waters, and the conduits rapidly enlarged. The most notorious example is Lake Chesterfield, which catastrophically failed in 2004, was grouted, then failed again in 2005. Lone Elk Lake has not failed in such a manner, but it is unable to retain water depths as great as originally planned, and is clearly leaking to a spring near Meramec River (Criss 2001). Similarly, Prairie Lake in southern St. Charles County is constructed on the Burlington-Keokuk limestone, and its leakage has significantly affected Weldon Spring (Figure 2, Criss et al. 2001).

Different Zoning Approaches. Different municipalities in the St. Louis area have remarkably different approaches to development. It is useful to contrast and compare the approaches of the Old Jamestown (Smith et al. 1988) and the Oakville areas, respectively located in the northernmost and the southernmost parts of St. Louis County (Table 3). In particular, the Old Jamestown Association has attempted to minimize the impacts to its karst areas by mandating low density housing, requiring construction setbacks from sinkholes, and prohibiting changes to natural drainage patterns. In contrast, topographic leveling and construction of roads and high-density housing is common in the Oakville area, and caves are commonly filled or incorporated into storm-water drainage systems. Figure 3 exemplifies these differences.

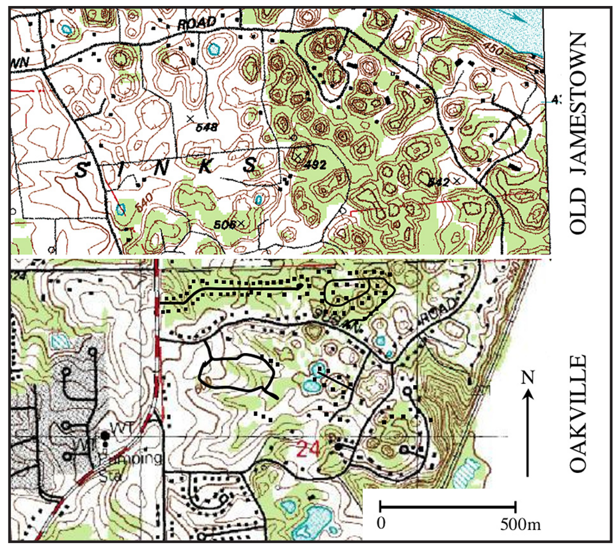

Figure 3 Comparison of parts of the Old Jamestown and the Oakville areas in St. Louis County, showing the difference in the locations and density of construction relative to karst features. Modified after the USGS Florissant and Oakville 7.5' topographic quadrangles, but included on the latter map are the approximate positions of some of the new roads and buildings shown on satellite photographs (Appendix).

Conclusions

The St. Louis area has abundant karst lands with great aesthetic, environmental, and economic value. However, problems have arisen historically and recently with the use of these special lands, especially with inappropriate construction. Karst lands are now being severely impacted by the regional urbanization and suburban sprawl, which has severely degraded shallow groundwaters and greatly impacted surface streams. Local zoning regulations and construction standards are commonly inappropriate for karst, causing problems that are costly to homeowners, costly to taxpayers, or harmful to natural habitat. Many of these problems could be easily avoided if more balance were found between these standards and environmental preservation.

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Appendix

Urban Karst Field Trip, St. Louis County, Missouri

Bob Criss and Bob Osburn, Washington University

Abstract

This three-hour tour will provide an introduction to some historical karst features of St. Louis County and their modification by human and natural processes. Surviving karst features include the antebellum Rott Springhouse (stop 1), which now issues contaminated water, and the sinkhole plain and associated features in Cliff Cave County Park (stop 6). Problems associated with residential and commercial development of karst lands include ground collapse, cracking, and settling (Stop 2), associated drainage problems (stop 3), and the destruction or gross modification of caves and sinkholes by infilling, topographic leveling, and/or their incorporation into stormwater drainage systems (stops 4 & 5). The remarkable historical efforts to preserve public lands in the St. Louis area are being offset by rapid urban sprawl and by construction standards that commonly prove inappropriate for karst.

Road Log.

0.0 Leave Holiday Inn/Viking Conference Center at Lindbergh Ave & Watson Rd., go West (right) on Watson Rd. for 0.4 mi. to light

0.4 Turn S (left) on Geyer Rd, continue S on Rott Rd for 0.9 mi., right at stop sign (go under I 270)

1.5 Left into drive at 9268 Rott Rd.

1.6 Stop 1 Springhouse at Rott Spring

1.7 Return to Rott Rd. go S (left)

2.4 Continue 1.4 mi. then left on Weber Hill Rd

3.8 Jog left to ramp, I 270 South, go SE for 2.8 mi. and get off at next exit

5.1 Exit Tesson Ferry Rd., go NE (left) on Tesson Ferry for 0.5 mi.

6.2 SE (right) on E. Concord Rd, go 0.35 mi. to T intersection at Theis Rd.

6.6 Short jog to right, take immediate left on Conger Dr, go 0.1 mi.

6.7 Stop 2 Conger Drive

7.0 Return to E. Concord Dr, go NW and proceed 0.1 mi.

7.1 Right turn on Tescord Dr, proceed NE for 0.45 mi., & park in cul de sac

7.6 Stop 3 Tescord Drive

7.6 Turn around & return to E Concord Rd.

8.0 Go NW (right) and go 0.4 mi. to Tesson Ferry Rd.

8.3 SW (left) at light on Tesson Ferry, go 0.5 mi. to I 270 ramp

8.9 SE on I 270/ I 255, get to center lane & go 3.7 mi. to Telegraph Rd exit.

12.6 Exit Telegraph Rd, go S (right) on Telegraph Rd. for 2.2 mi.

14.9 Reliance Bank parking lot on right, SW corner of Telegraph and England Town Rd.

14.9 Stop 4 Detention Basin Overlook

14.9 Continue S on Telegraph for 0.8 mi.

15.7 Go East (left) on Susan Rd & proceed for 0.4 mi., left on Clifton Oaks Pl.

16.1 Stop 5: Clifton Oaks Place

16.8 Return to Susan Rd, go W (right) & go 0.4 mi. to return to Telegraph Rd.

17.2 N (right) on Telegraph Rd, go 1.1 mi. to Cliff Cave Rd.

18.3 Go E (right) on Cliff Cave Rd, for 1.5 mi., down steep hill, and park

19.8 Stop 6: Cliff Cave County Park

20.0 Stop 7: Riverside Park & Mississippi River Trail

21.7 Return to Telegraph via Cliff Cave Rd, go

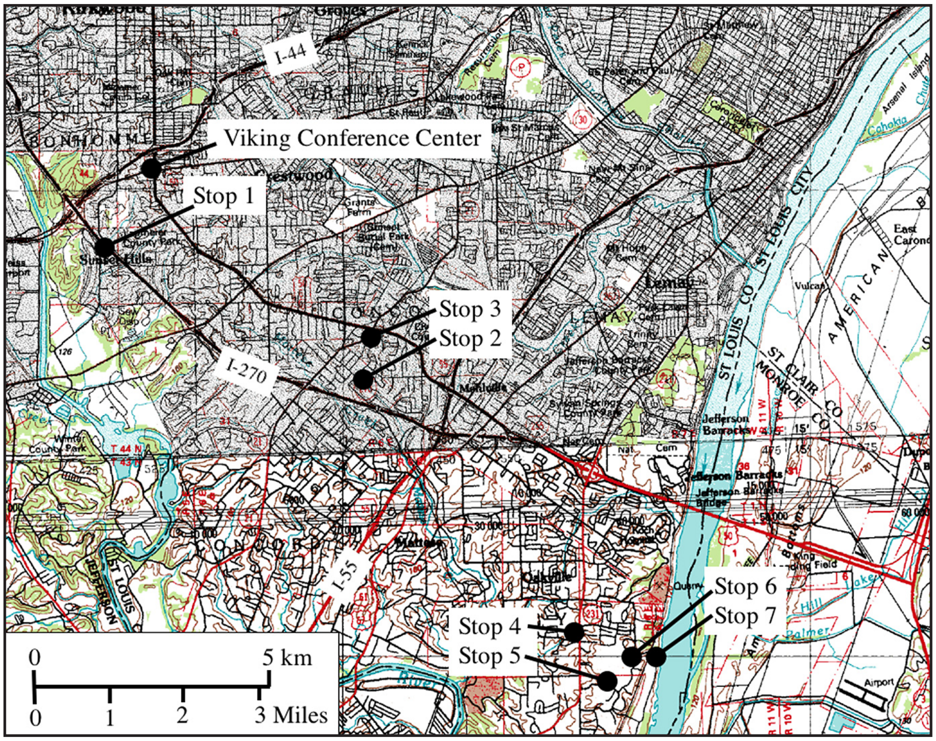

Figure 1 *Map showing the urban karst field trip stops, modified after the USGS 100k topographic sheets for the St. Louis and Festus quadrangles.*

N (right) for 1.9 mi. to I 255/I 270 ramp on right

23.6 Take I 255/I 270 to west (left) & go 7.7 mi. to Watson Rd. exit.

31.3 Go E (right) on Watson Rd. for 1.2 mi. to Viking Conference Center

32.5 Viking Conference Center on left

Site Descriptions

Stop 1 Springhouse at Rott Spring

Private Property T.44N R.5E NWSENE Sec. 23 Kirkwood 7.5″ Quadrangle

Rott Spring emerges from what is arguably the best surviving example of an antebellum springhouse in St. Louis Co., on the property of Clarence Morrison, 9268 Rott Rd. (Fig. 2). The watershed for this remarkable spring clearly includes forested hillsides and low-density suburban areas to the northeast, but development has had several impacts. First, the watershed was greatly modified by the construction of I-270, located only 100 m to the northeast of the springhouse, and this has visibly decreased the flow of the spring according to field trip participant Earl Biffle. Second, the spring has conductivity in excess of normal values, perhaps due to road salt, and was contaminated in 1994 by oil from a leaking tank located a few thousand feet to the NE. This leak caused a fish kill in the pond and imparted a petroliferous odor that is still noticeable today, though the fish have returned. The host rock at the springhouse is mapped as Warsaw Fm. (Harrison 1997).

Figure 2 The antebellum Rott Springhouse has survived much development in St. Louis County, though its watershed has been impacted (Stop 1).

Stop 2 Conger Dr.

Private Property T.44N R.6E NENWNW Sec. 33 (proj) Webster Groves 7.5″ Quadrangle

The Concord area of St. Louis Co. is built on a sinkhole plain developed in the St. Louis Limestone, and has associated engineering, structural, and drainage problems. A pronounced, 1-km-long line of sinkholes, parallel to E. Concord Rd., extends into a SE-trending valley that includes a spring (now dry), and at least one small cave with a flowing stream (Fiedler Cave; SLO 114). Diversion of storm water into sinkholes and caves is common in the Concord area. Concord residents described several water line breaks this month, and mentioned historical instances of sinkhole collapses and gas line leaks.

Several homes along Conger Dr. were constructed along the side of a large sink, that according to one lifelong resident formerly hosted a cave entrance. The area was partly filled and graded, and is now traversed by an MSD storm sewer. Several homes in the immediate vicinity still have septic systems, while others are connected to municipal sewer lines. Evidence for continued settling and/or collapse are abundant on this block. These include 1) a 10m-long, 10 cm-high scarp displacing the turf in a front yard, that is associated with a septic system trickle field; 2) numerous small, recent collapse pits proximal to the MSD line, and 3) numerous cracks and patches in Conger Drive.

Stop 3 Tescord Drive

Private Property T.44N R.6E NW NESE Sec. 28 Webster Groves 7.5″ Quadrangle

The residence of Alice Bradenberg at 11606 Tescord Drive has experienced repeated flooding since 1966 due to backflow from a sinkhole into which too much storm water has been diverted (Fig. 3). Ms. Bradenberg reports that the water from the "drain" can "geyser" several feet into the air following storms. MSD has attempted to excavate, rebuild and relocate the drain into the limestone several times, but has not been able to correct the problem, and commercial development on proximal Lindbergh Ave. has probably exacerbated the situation. Note the 6 m-diameter, 25 cm-high, circular subsidence "scarp" around one of these drains. The neighborhood was converted from septic systems and connected with the municipal sewer system ca. 1997.

Stop 4 Telegraph Road detention basin

Commercial Property T.43N R.6E SESENE Sec. 14 Oakville 7.5″ Quadrangle

This 1.5-ha detention basin (Fig. 4) is developed above a large composite sinkhole that formerly contained two cave entrances, Cave of the Falls (SLO 98; see Vandike et al., 1989), and Jagged

Figure 3. Collapse near a storm drain situated in a sinkhole in the Concord area. The capacity of the natural bedrock conduits is too small to drain storm water as fast as it is delivered, so this yard frequently floods to depths of several feet (Stop 3).

Pit (SLO 86), that are not now enterable through these concrete drain structures. Though little information is currently available, the Cave of the Falls is alleged to be the largest cave in St. Louis County, with more than 2 km of passage.

Cave of the Falls terminates about 1 km to the northwest at a natural entrance hosting a flowing cave stream. Thus, this detention basin exemplifies the routing of urban storm water into caves. These cave conduits of course provided drainage for waters entering the large sinkholes that originally occurred in this location, so the argument is commonly advanced that this pattern of drainage is basically "natural." Questions that arise include the following: (1) Is water being diverted from adjacent areas, so that mean flows in the cave are now significantly greater than before? (2) Are storm waters from impervious surface now delivered to cave systems at faster rates than under natural conditions, so that peak flows are now greater? (3) Is the quality of water delivered from impervious, urban and suburban surfaces degraded in its chemical and physical nature compared to the quality under natural conditions? (4) What effects do these changes have on the cave environment and habitat?

Figure 4. This detention basin near Telegraph Road in Oakville diverts storm runoff into culverts that intersect two caves, including the longest cave in St. Louis County (Stop 4).

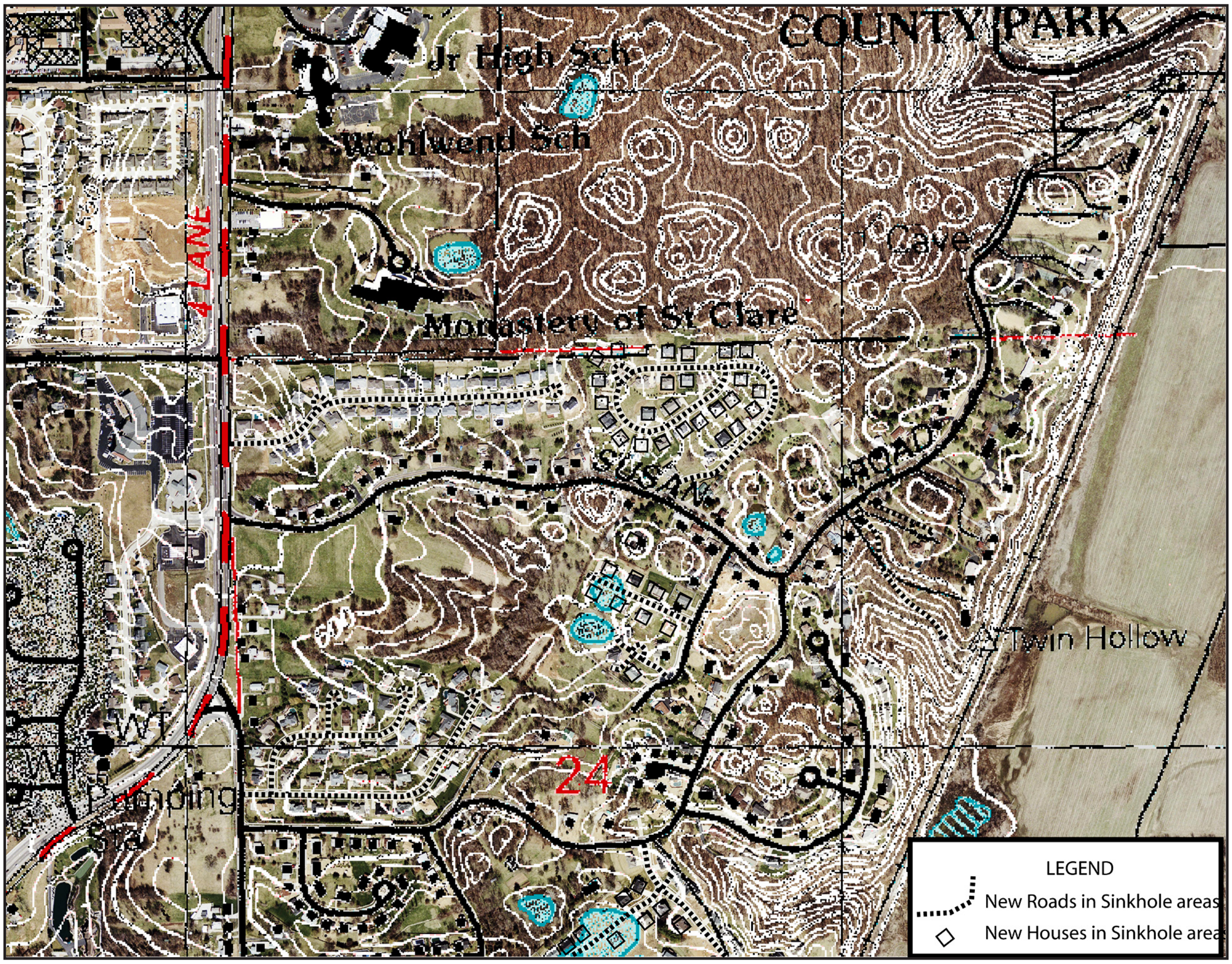

Figure 5 *Topographic contours (white, from Oakville 7.5" map 1991) superimposed on a recent satellite image (USGS Urban Area Imagery, March 2004) of an area within and immediately south of Cliff Cave County Park. Many houses and roads have been constructed on filled sinkholes and sinkhole ponds, and others are directly above caves.*

Stop 5 Clifton Oaks Place

Private Subdivision T.43N R.6E NENENW Sec. 24 Oakville 7.5″ Quadrangle

The roads and houses in this relatively new residential area have been developed over several prominent sinkholes (Fig. 5). Some of these sinkholes contained the entrances to small caves, no longer enterable, but now used to convey storm water. Only 250 m to the SW, several homes along Briartree Ln. are constructed above former sinkhole ponds.

Stop 6 Cliff Cave County Park

County Property T.43N R.6E SESWNE Sec. 13 Oakville 7.5″ Quadrangle

Much of section 13 is protected by Cliff Cave County Park, preserving a topographic remnant of the forested sinkhole plain. At least 10 caves occur in this section. Best known is Cliff Cave (SLO 13; Fig. 6), the second longest cave in the county with more than 4700 feet of passage (MSS 1966, Marty et al. 1982). The picturesque entrance to this cave, some 16 m wide and 7 m tall, contains a stone archway that is a remnant of its former use as a storage area. Before that, Cliff Cave was used by native Americans. Eastern pipistrelles (*Perimyotis subflavus*) and Big Brown bats (*Eptesicus fuscus*) hibernate in the cave (William R. Elliott, pers. comm.), and the perennial cave stream that exits from the main entrance hosts abundant flatworms, isopods, and amphipods.

Cliff Cave has three additional entrances, one now collapsed, located in sinkholes to the south-

Figure 6 NCKMS field trip participants at the main entrance to Cliff Cave (Stop 6). Photo by Bill Elliott.

west. These are part of the overlying sinkhole plain which clearly lacks an integrated, dendritic system of surface streams. The cave clearly serves as the subsurface drain of this sinkhole plain, and was probably developed at the water table in this setting. The cave mostly consists of air filled passages above a flowing stream with either a gravel or bedrock floor. The cave walls have well-developed scallops, and the ceiling has remarkable cupolas, but speleothems are uncommon, particularly in the main passage, probably because they are broken by subterranean flash floods. Cliff Cave was gated following a fatal incident in 1993 that involved several spelunkers caught in such a flood.

Spit Cave (SLO-079), a cavelet located only 200 m east of the main entrance to Cliff Cave, has had its entrance modified by natural collapse since it was mapped in 1977 (Koenen and Eddleman 1977, Criss et al., 2006).

Stop 7 Mississippi River Bluff and Floodplain at MRT Park

County Property T.43N R.6E Sec. 18
Oakville 7.5″ Quadrangle

This site abuts the "Middle" Mississippi" River at Mile 167, approximately 28 river mi. (45 km) below the Missouri confluence. Above confluence point, navigation on the "Upper" Mississippi River is facilitated by a network of huge locks and dams that extends all the way to Minneapolis-St. Paul. Downstream of the confluence the river flows freely to the Gulf of Mexico, and navigation is facilitated only by dredging and wing dikes, prominent examples of which are visible here at low water (Criss and Wilson, 2003). Barge activity will be conspicuous as this is a "fleeting area", so called because the huge tows are appropriately resized or reconfigured for the next stage of their passage. The Mississippi River at this point drains a watershed of just over 1,810,000 km^2 (700,000 mi^2), 3/4 of which is represented by the huge Missouri River basin. The elevation of the river here is only about 150 m MSL (380 ft.), even though it must flow 1,800 km (1120 mi.) to the Gulf. Although the topographic gradient over this huge distance is very small, the flow sustained by the tiny slope is colossal. Mean flow of the Mississippi River at St. Louis (Mile 180) is 5,350 cms (189,000 cfs), but peak flows during the 1993 flood exceeded 29,700 cms (1 Mcfs; Hauck and Harris, 2005).

At this site the Mississippi River is about 60 m (200 ft.) below the elevation of the sinkhole plain to the immediate west, separated by a prominent bluff visible along the railroad tracks. Middendorf and Brill (1991) include the entire bluff and proximal sinkhole plain within the St. Louis Limestone, though their map and cross section require about 100m (300') of thickness for this unit in this area, which may be excessive. Several caves are developed along and near the river bluff, and they clearly provide conduits for the internal drainage system of the proximal sinkhole plain.

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