Illinois Geologic Quadrangle Map
IGQ Columbia-SD

Sinkhole Distribution and Density of Columbia Quadrangle

Monroe and St. Clair Counties, Illinois

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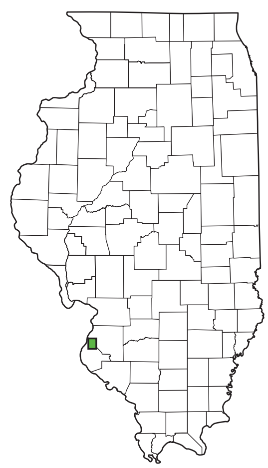

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Introduction

Sinkhole Distribution and Density of Columbia Quadrangle is part of a series of maps published by the Illinois State Geological Survey (ISGS) that portrays the geology of quadrangles in the Metro East Illinois area of greater St. Louis at 1:24,000 scale (fig. 1). The area is experiencing rapid population growth and increasing environmental concerns. The distribution and density of sinkholes are being documented to aid in urban planning (e.g., for location and type of wastewater treatment facilities), land use planning (e.g., for roadways and landfills), and water resource management (Magdalene and Alexander 1995). These maps may be useful for planning by state and local governments, utilities, developers, and home buyers. Sinkhole distribution, density, and area maps can identify those places most likely to have potential geohazards and/or contaminated ground water problems associated with karst and sinkhole formation.

In general, map areas with densities of 25 or more sinkholes per section (one square mile) and sinkhole areas exceeding 5% of the total area of a section may indicate that at least part of the underlying bedrock contains numerous and well-developed karst features. Such conditions should be considered and the land carefully examined prior to development. However, even in areas with relatively low sinkhole density, care should be taken when building on properties possessing at least one sinkhole.

Sinkholes in the sinkhole plain are predominantly cover-collapse features. Sinkholes are circular or ovoid surficial depressions in unconsolidated materials originating from solution-enlarged crevices in underlying carbonate bedrock (fig. 2). Crevices in the bedrock are typically about 15 cm or wider at the bedrock surface (Panno and Weibel 1998). Soil and overlying unconsolidated materials can move via soil piping and collapse into these crevices, forming large cylin-

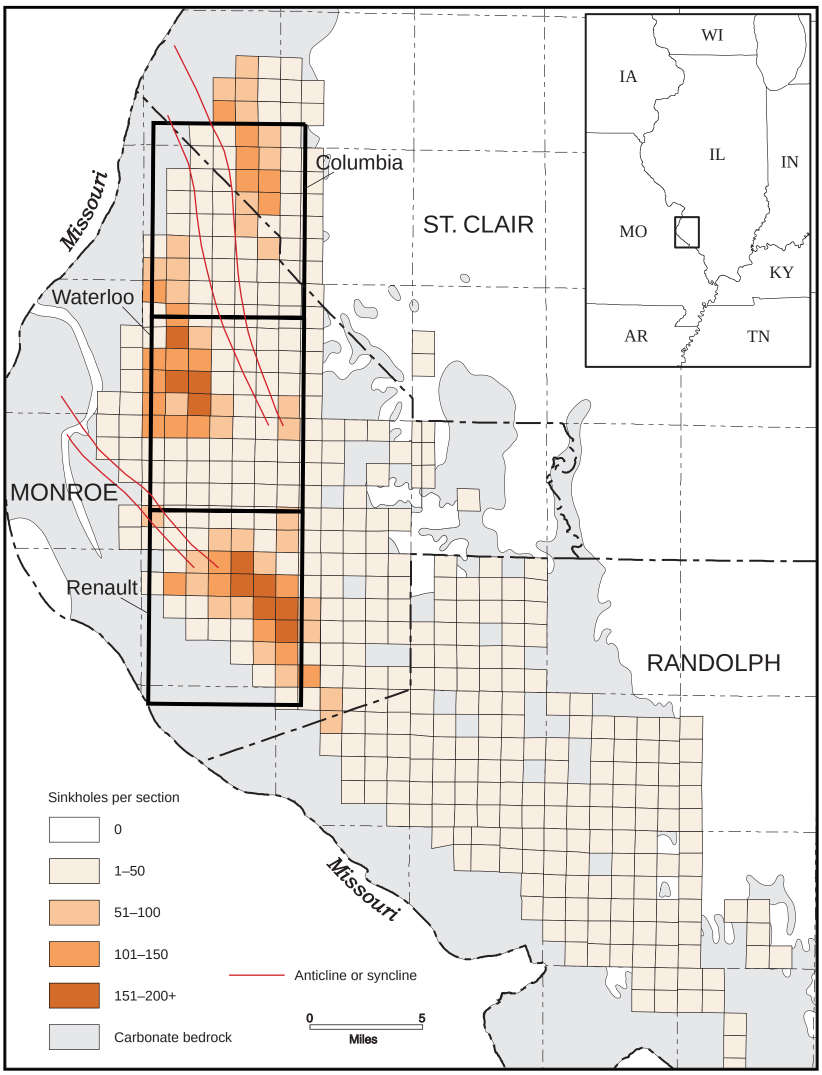

Figure 1 Map of sinkhole density within the sinkhole plain determined at the section level, showing the location of the Columbia, Waterloo, and Renault Quadrangles and major structural features. Sinkhole counts were derived from U.S. Geological Survery 7.5-minute quadrangle maps (modified from Panno et al. 1998).

drical holes. Later, erosion transforms these holes into bowl-shaped surface depressions referred to as sinkholes (fig. 2). Rarely, a sinkhole will form as a result of the collapse of a cave ceiling, forming a relatively deep, steep-walled, nearly circular hole that can provide an entrance to the cave.

The Columbia Quadrangle is divided about equally between St. Clair and Monroe Counties (fig. 1 and map). St. Clair County decreased in population by 2.6% between 1990 and 2000; during the same period, the population of Monroe County expanded by 23.2% (U.S. Census Bureau 2000). Over 10,000 sinkholes lie within the greater southwestern Illinois sinkhole plain (figs. 1 and 3). Sinkholes are diagnostic of karst topography (formed from the dissolution of carbonate bedrock) and indicate an underlying karst aquifer system. Sinkholes act as small watersheds, collecting runoff and snowmelt and funneling water into the aquifer via the bedrock crevices. Because of this open pathway, shallow groundwater in karst regions is typically contaminated with surficial pollutants such as agrichemicals, lawn chemicals, road salt, industrial waste, and wastes from livestock, humans (effluent from private septic systems), pets, and wildlife (White 1988). The formation of sinkholes near infrastructure can cause major damage to roads, structural foundations, and utilities. Sinkhole distribution can also yield clues to the location of groundwater basin boundaries and, potentially caves (Panno and Weibel 1999).

Maps of sinkhole distribution, density, and area, when used with dye-tracing results and estimated groundwater basin boundaries (Aley et al. 2000), may be useful in predicting the subsurface pathway of contaminants in the event of a surface spill. In karst terrain, spills of toxic materials can flow directly into sinkholes and caves that provide direct

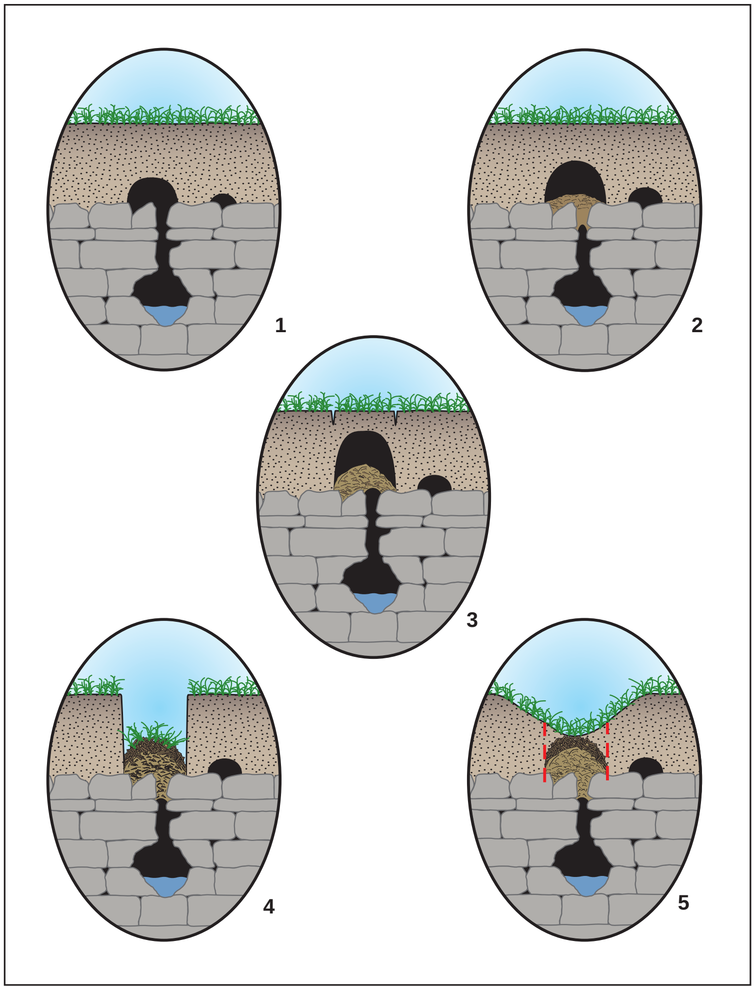

Figure 2 Sinkholes develop where the soil overlying creviced bedrock collapses into a crevice, forming a hemisphere-shaped void in the soil (1 and 2). Groundwater flows through the bedrock to remove the material in the crevice during formation. As soil collapse continues, the void grows upward toward the surface (3), resulting in the eventual collapse of the surface material into a nearly circular hole (4). Erosion smooths out the land surface, forming a bowl- or cone-shaped depression (5). The sinkhole then functions as a small drainage basin, focusing runoff and snowmelt into a conduit system in bedrock (Panno et al. 2004).

Figure 3 Aerial photograph of sinkholes that dimple agricultural land in the Columbia Quadrangle.

access to groundwater in the shallow karst aquifer and eventually discharge to surface waters at springs. In Illinois' sinkhole plain, these springs flow into streams that eventually enter the Kaskaskia and Mississippi Rivers. Knowledge of underground pathways taken by toxins following a spill or intentional dumping is thus necessary to intercept contaminants (within a cave or at the mouth of a spring) to prevent a more widespread problem.

Mapping Methods

Sinkhole density is the number of sinkholes per unit area. For this investigation, a unit area equals one section of a 7.5-minute quadrangle map (usually one square mile). Sinkhole distribution and density maps were compiled from U.S. Geological Survey (1991) 7.5-minute quadrangle maps at a scale of 1:24,000. The aerial photographs from which this map was compiled were taken in 1986. Initially, the sinkholes and sinkhole ponds (naturally occurring sinkhole depressions that retain water) on the map were counted by hand for each section and summed to the nearest 0.25 sinkhole. Counts were later rounded to the nearest whole number for each section. To quantify the number of sinkholes in each section, sinkholes were defined as any closed-contour topographic depression or sinkhole pond. Thus, if a compound sinkhole had two or more separate closed-contour depressions, each depression was counted as a sinkhole. Each sinkhole pond was counted as one sinkhole. Partial sections that lay on the boundaries of the map were counted in full using adjacent quadrangle maps.

These hand counts were tested against digitally automated counts made with a Geographic Information System (GIS) technique developed by Angel et al. (2004). The results of these two techniques were statistically equivalent with a difference of 0.25%. The sinkhole area map was made using similar GIS techniques also developed by Angel et al. (2004); the area of each sinkhole was determined and summed for each section. The area within each closed depression was summed for each complete section of the quadrangle map. Sinkhole areas within a partial section at the quadrangle edges were not determined.

Geology and Groundwater Basins of the Sinkhole Plain

Most of the Columbia Quadrangle is within Illinois' sinkhole plain (fig. 1). Previous work (Panno 1996, Panno et al. 1998, Bade et al. 2002) showed approximately 10,000 sinkholes concentrated in three distinct clusters (fig. 1). The northernmost cluster in western St. Clair County and northern Monroe County is associated with a single relatively long, large-diameter cave and associated groundwater basin. A second cluster in northwestern Monroe County is associated with numerous small caves and conduit systems (Panno et al., 2007a). The third sinkhole cluster (mostly within the Renault Quadrangle) is located in the south central third of Monroe County, an area known for its relatively long, large-diameter cave systems and relatively large groundwater basins (Panno et al. 2007b).

Bedrock in the sinkhole plain consists mostly of calcite-rich, Mississippian-age limestone that either crops out or is less than 15 m (50 feet) below the surface (Herzog et al. 1994). In most places, the upland area is covered with as much as 15 m (50 feet) of Pleistocene Glasford Formation till and outwash, bedrock residuum, and loess (wind-blown silt). Sinkholes are partially filled with redeposited glacial till, residuum, and loess. The bedrock surface is predominantly St. Louis Limestone, with minor exposures of the Ste. Genevieve and Salem Limestones. In general, sinkhole formation in this area occurs in sediment that almost exclusively overlies bedrock made up of the St. Louis and Ste. Genevieve Limestones. Sinkholes and caves in the study area form predominantly in fine-grained sediments overlying and within the bedrock made up of these two limestones, respectively. Karst formation is controlled by lithology (especially in calcite-rich limestone), poor primary porosity coupled with well-developed secondary porosity (e.g., vertical fractures and dilated bedding planes), the presence of overlying fine-grained sediments, and a deep water table.

The Ste. Genevieve Limestone is light gray and fossiliferous with some very distinctive beds of white, oolitic limestone. This limestone is relatively thin in this area (3 to 6 m) and is exposed in the Columbia Quarry where it can be seen overlying the St. Louis Limestone. The St. Louis Limestone is a more fine-grained, micritic limestone in the study area and is well-known for sinkholes developed in the sediments that overlie it (Willman et al. 1975). The Salem Limestone is a fossiliferous grainstone used extensively as building stone (Willman et al. 1975). Although it is calcite-rich, thick-bedded, and possesses the requisite secondary porosity, this unit appears less susceptible to karstification than do the St. Louis and Ste. Genevieve Limestones based on bedrock geology and sinkhole distribution (Thornbury 1969).

The majority of the caves in the sinkhole plain are the branchwork type and formed along bedding planes within the St. Louis Limestone (Panno et al. 2004). Because they typically formed by groundwater dissolution between bedding planes, they are sinuous in map view (reminiscent of meandering streams). The main "trunk" of Stemler Cave, a 1.8-km- (1.1-miles-) long cave (Webb et al. 1998) trends northwest-southeast and parallel to the Waterloo-Dupo Anticline axis (Columbia Quadrangle). The overall trends of the passages of Fogelpole Cave and Illinois Caverns in the more southern part of the sinkhole plain are also northwest-southeast and similarly parallel the trend of the Valmeyer Anticline in the Renault Quadrangle (Panno and Weibel 1999). In the Columbia Quadrangle, bedrock units regionally dip gently a few degrees to the east. Geologic structures in the quadrangle include the northwest-southeast–trending Waterloo-Dupo Anticline and the Columbia Syncline (Nelson 1995, unpublished mapping by J.A. Devera). The Waterloo-Dupo Anticline is an asymmetric fold that dips 2 to 4° on its western limb and can exceed 45° on its eastern limb. The anticline was named after the two oil fields in the area whose traps are associated with the Waterloo-Dupo Anticline (Nelson 1995).

In the highlands of western St. Clair County, the trend of the relatively long Stemler Cave system parallels the axis of the Waterloo-Dupo Anticline (Panno and Weibel 1999, Panno et al. 2007a). An initial investigation in the sinkhole plain showed that the groundwater basin of a large spring that drains Stemler Cave and its extension, Sparrow Creek Cave, is the headwaters of Sparrow Creek (Panno and Weibel 1999). Through the use of tracer dyes, Aley et al. (2000) defined the boundaries of the Stemler Cave groundwater basin (see map).

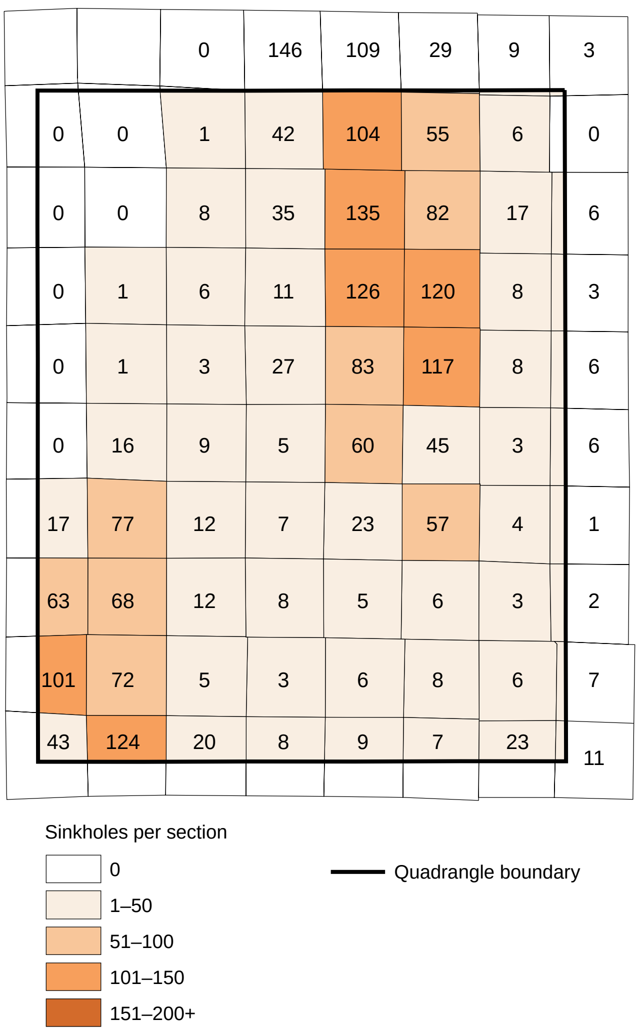

Figure 4 Sinkhole density of the Columbia Quadrangle determined at the section level. The sinkhole density values for the partial sections at the margins of the map represent the sinkhole density of the entire section.

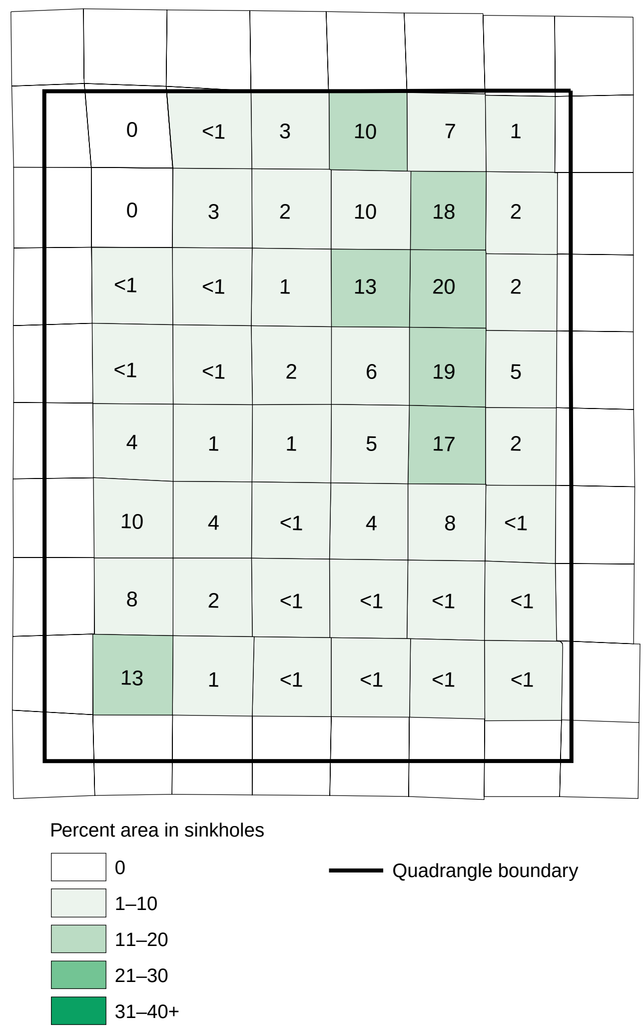

Figure 5 Sinkhole area of the Columbia Quadrangle determined at the section level. Proportional sinkhole areas for partial sections on the boundaries of the map could not be calculated because digital data were unavailable.

Sinkhole Distribution and Density

Sinkhole Origin and Morphology

Sinkhole morphology within the quadrangle ranges from simple circles to ellipses with a single closed contour to complexly shaped (in places branching) compound sinkholes with multiple, separated closed contours. Groundwater basins of the longest caves in the quadrangle are characterized by very large sinkholes whose size appears closely related to the size of the conduits in the subsurface (Panno and Weibel 1999). The reason for this sinkhole-conduit relationship is that the larger-diameter conduits are capable of removing very large volumes of runoff through the sinkhole during and following large rainfall events. The smaller conduits tend to quickly reach their drainage capacity, and the water levels may rise above the throats of sinkholes feeding the conduits, resulting in the formation of temporary ponds within the sinkholes. Temporary ponding creates a low-energy environment that promotes sedimentation that may plug or partially plug the bottom of the sinkhole with sediment and debris. Where ponding occurs, sinkholes tend to remain relatively small. Conversely, those sinkholes that form over large-diameter conduit systems rarely, if ever, pond and represent high-energy environments where continued erosion of sinkhole flanks cause the sinkholes to enlarge (Panno and Weibel 1999).

Density and Distribution

Color-enhanced sinkhole fill-ins on the Columbia Quadrangle map show the non-random distribution of sinkholes across the uplands (fig. 1 and map). We mapped 1,803 sinkholes within its boundaries. The total rises to 2,269 if all sinkholes in sections partially within the quadrangle are included (fig. 4). From this latter total, the mean and median concentration of sinkholes in the 77 sections within and intersected by the Columbia Quadrangle are 31 and 8 sinkholes per section, respectively. Sinkhole density within the quadrangle ranges from 0 to 52 sinkholes per km^2 (0 to 135 sinkholes per square mile or per section). The greatest density of sinkholes occurs within the Stemler Cave Groundwater Basin (see map). At that location, the Ste. Genevieve and St. Louis Limestone bedrock displays abundant and widespread dissolution features, typically exposed in Columbia Quarry and in sinkhole excavations.

Figure 5 shows the percentage of the area within each section included in the closed depressions of sinkholes in the Columbia Quadrangle. Distribution is slightly different from that shown on figure 4. The greatest area covered by sinkholes (20%) lies within a section immediately over passages of Stemler Cave (see map).

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References

Aley, T., P. Moss, and C. Aley, 2000, Delineation of recharge areas for four biologically significant cave systems in Monroe and St. Clair Counties, Illinois: Ozark Underground Laboratory unpublished report for the Illinois Nature Preserves Commission and the Monroe County Soil and Water Conservation District, 254 p.

Angel, J.C., D.O. Nelson and S.V. Panno, 2004, A comparison of manual and GIS-based methods for determining sinkhole distribution and density: An example from Illinois' sinkhole plain: Journal of Cave and Karst Studies, v. 66, no. 1, p. 9–17.

Bade, J., J.J. Lewis, S.J. Taylor, D. Tecic, D.W. Webb, D. Brand, S.V. Panno, K. Hartman, Jr., and P. Moss, 2002, Illinois cave amphipod *(Gammarus acherondytes)* recovery plan: Ft. Snelling, Minnesota, U.S. Fish and Wildlife Service, 63 p.

Herzog, B.L., B.J. Stiff, C.A. Chenoweth, K.L. Warner, J.B. Sieverling, and C. Avery, 1994, Buried bedrock surface of Illinois: Illinois State Geological Survey, Illinois Map 5, 1:500,000.

Magdalene, S., and E.C. Alexander, 1995, Sinkhole distribution in Winonca County, Minnesota revisited, *in* B.F. Beck, ed., Proceedings of the Fifth Multidisciplinary Conference on Sinkholes and the Engineering and Environmental Impacts of Karst, Karst Geohazards, Gatlinburg, TN, April 2–5, 1995, p. 43–51.

Nelson, J.W., 1995, Structural features in Illinois: Illinois State Geological Survey, Bulletin 100, 144 p.

Panno, S.V., 1996, Water quality in karst terrane: The Karst Window, v. 2, no. 2, p. 2–4.

Panno, S.V., J.C. Angel, D.O. Nelson, C.P. Weibel, D.E. Luman, and F.B. Denny, 2007a, Sinkhole distribution and density of Waterloo Quadrangle, Monroe County, Illinois: Illinois State Geological Survey, Illinois Geologic Quadrangle Map, IGQ Waterloo-SD, 1:24,000.

Panno, S.V., J.C. Angel, D.O. Nelson, C.P. Weibel, D.E. Luman, and J.A. Devera, 2007b, Sinkhole distribution and density of Renault Quadrangle, Monroe County, Illinois: Illinois State Geological Survey, Illinois Geologic Quadrangle Map, IGQ Renault-SD, 1:24,000.

Panno, S.V., S.E. Greenberg, C.P. Weibel, and P.K. Gillespie, 2004, Guide to the Illinois Caverns State Natural Area: Illinois State Geological Survey, GeoScience Education Series 19, 106 p.

Panno, S.V., W.R. Kelly, C.P. Weibel, I.G. Krapac, and S.L. Sargent, 1998, The effects of land use on water quality and agrichemical loading in the Fogelpole Cave groundwater basin, southwestern Illinois: Proceedings of the Eighth Annual Conference of the Illinois Groundwater

Consortium Research on Agricultural Chemicals in Illinois Groundwater: Status and Future Directions VIII, Makanda, IL, April 1–2, 1998.

Panno, S.V., and C.P. Weibel, 1998, Karst landscapes of Illinois: Dissolving bedrock and collapsing soil: Illinois State Geological Survey, Geobit 7, 4 p.

Panno, S.V., and C.P. Weibel, 1999, The use of sinkhole morphology and distribution as a means of delineating the groundwater basins of four large cave systems in southwestern Illinois' sinkhole plain: Proceedings of the Karst Modeling Symposium, Charlottesville, VA, February 24–29, 1999, p. 244. (Abstr.)

Panno, S.V., C.P. Weibel, P.C. Heigold, and P.C. Reed, 1994, Formation of cover-collapse sinkholes in a karst area of southern Illinois: Interpretation and identification of associated buried cavities: Environmental Geology, v. 23, no. 3, p. 214–220.

Thornbury, W.D., 1969, Principles of geomorphology, 2nd ed., New York, Wiley and Sons, 594 p.

U.S. Census Bureau, 2000, State and county quickfacts. http://quickfacts.census.gov/qfd/index.html.

U.S. Geological Survey, 1991, Columbia, IL. U.S. Geological Survey 7.5 minute quadrangle map: Denver, Colorado, U.S. Geological Survey, 1:24,000.

Webb, D.W., L.M. Page, S.J. Taylor and J.K. Krejca, 1998, The current status and habitats of the Illinois cave amphipod, *Gammarus acherondytes* Hubricht and Mackin (Crustacea: Amphipoda: Journal of Cave and Karst Studies, v. 60, p. 172–178.

White, W.B., 1988, Geomorphology and hydrology of karst terrains: New York, Oxford University Press, 464 p.

Willman, H.B., E. Atherton, T.C. Buschbach, C. Collinson, J.C. Frye, M.E. Hopkins, J.A. Lineback, and J.A. Simon, 1975, Handbook of Illinois stratigraphy: Illinois State Geological Survey, Bulletin 95, 261 p.