Illinois Geologic Quadrangle Map
IGQ Renault-SD

Sinkhole Distribution and Density of Renault Quadrangle

Monroe County, Illinois

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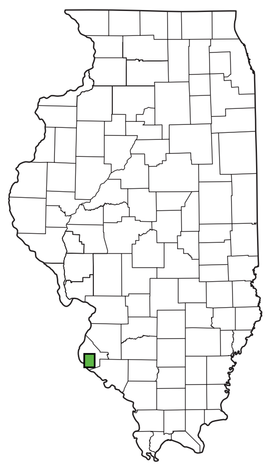

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Introduction

Sinkhole Distribution and Density of Renault 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 groundwater 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-

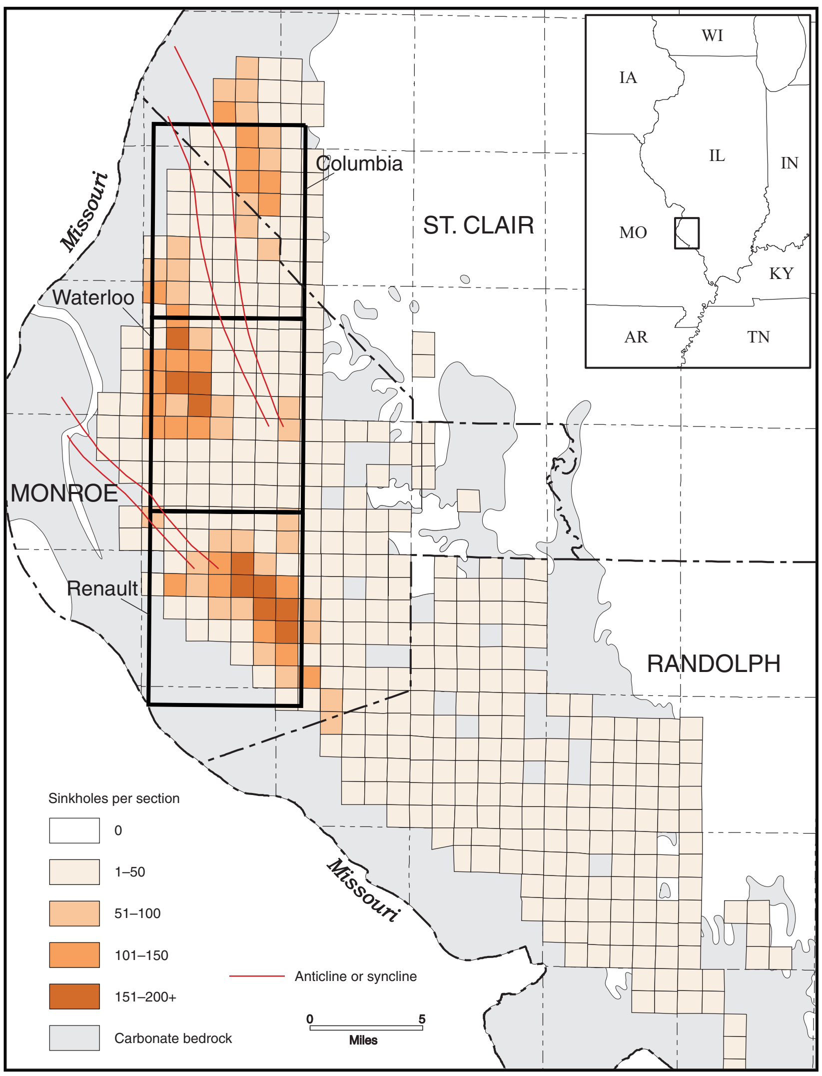

Figure 1 Map of sinkhole density within the sinkhole plain determined at the section level, showing the location of the Columbia, Waterloo, and Renault Quadrangles and major structural features. Sinkhole counts were derived from U.S. Geological Survey 7.5-minute quadrangle maps (modified from Panno et 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 Renault Quadrangle is located within Monroe County (fig. 1 and map). The population of the quadrangle expanded by 23.3% between 1990 and 2000 (U.S. Census Bureau 2000). Over 10,000 sinkholes lie within the greater south-western 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

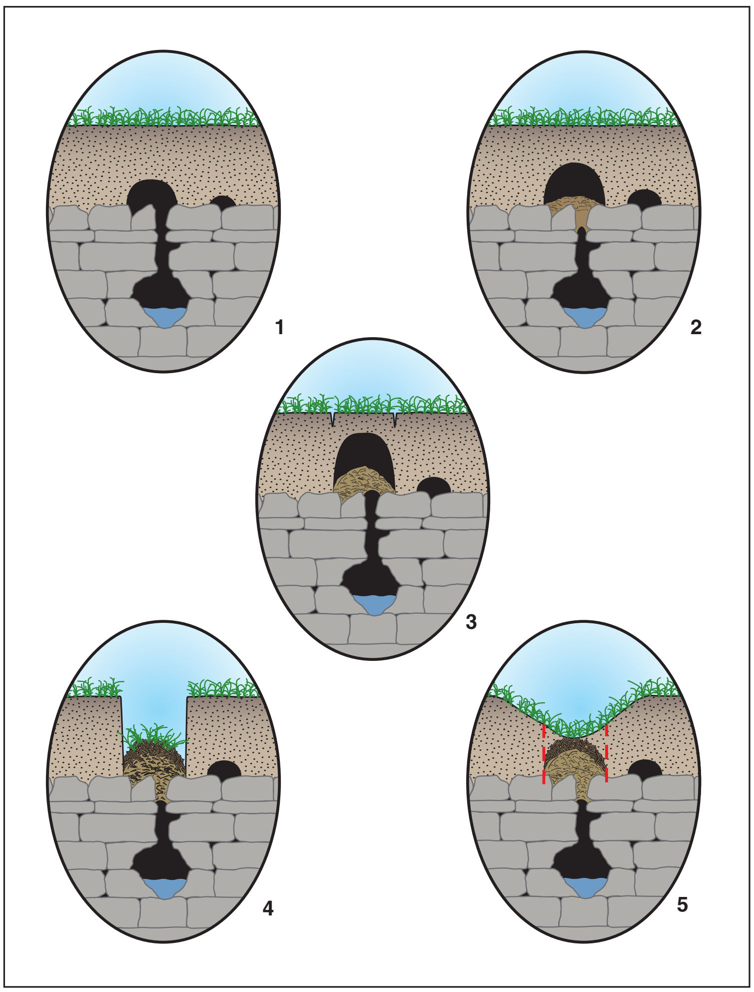

Figure 2 Sinkholes develop where the soil overlying creviced bedrock collapses into a crevice, forming a hemisphere-shaped void in the soil (1 and 2). Groundwater flows through the bedrock to remove the material in the crevice during formation. As soil collapse continues, the void grows upward toward 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).

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 Renault 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).

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

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 Renault Quadrangle, bedrock units regionally dip gently a few degrees to the east. Geologic structures in the quadrangle include the northwest-southeast–trending Valmeyer Anticline and Monroe City Syncline (Nelson 1995, unpublished mapping by J.A. Devera). The Valmeyer Anticline is an asymmetric fold with bedrock layers dipping 2 to 3° northeast in the northeast limb and 9 to 18° southwest in the southwest limb. The trend of the anticlinal crest (axis) is about N40° W (see map). The Monroe City Syncline is a more subtle feature whose location is poorly defined (unpublished mapping by F.B. Denny); consequently, it is shown with a dashed line to indicate uncertainty. The bedrock is jointed in two principle directions, N30–40° W and N20–30° E. The dominant joint set is northwest and parallel to the axis of the Valmeyer Anticline and Monroe City Syncline.

The main "trunk" of Fogelpole Cave is 24 km (15 miles) long (F.P. Wightman, personal communications, 2001), trends northwest-southeast, parallel to the Valmeyer Anticline axis, as does the overall trend of the passages of Fogelpole Cave and Illinois Caverns (not shown on the maps because they are protected by the State). An initial investigation in the sinkhole plain showed that groundwater basins of two of the largest springs (Indian Hole, which drains Fogelpole Cave, and Collier Spring) lie within the larger surface watershed of Horse Creek (Panno and Weibel 1999). Through the use of tracer dyes, Aley et al. (2000) showed that the Collier Spring groundwater basin lies, in part, south

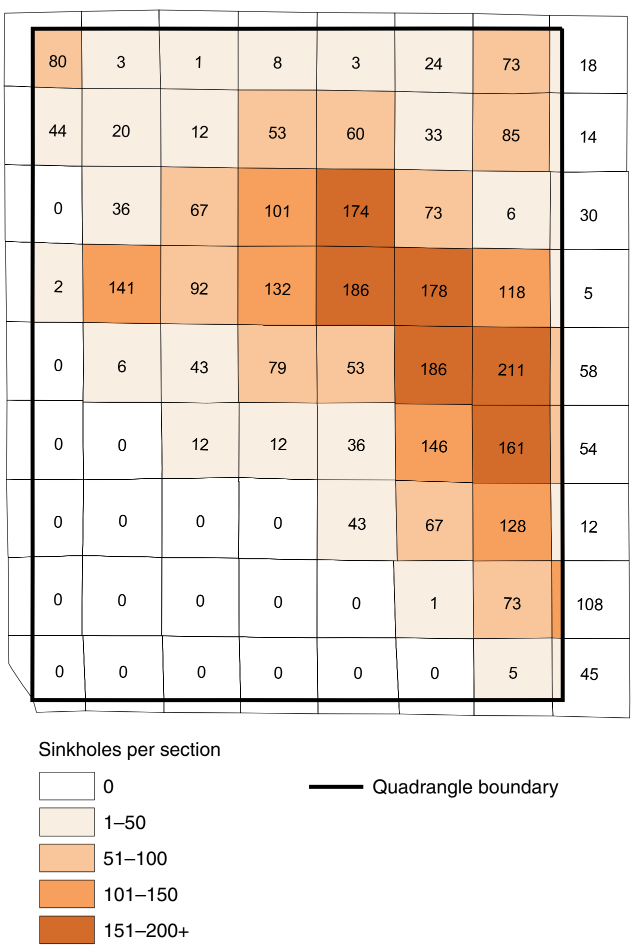

Figure 4 Sinkhole density of the Renault Quadrangle determined at the section level. The sinkhole density values for the partial sections at the margins of the map represent the sinkhole density of the entire section.

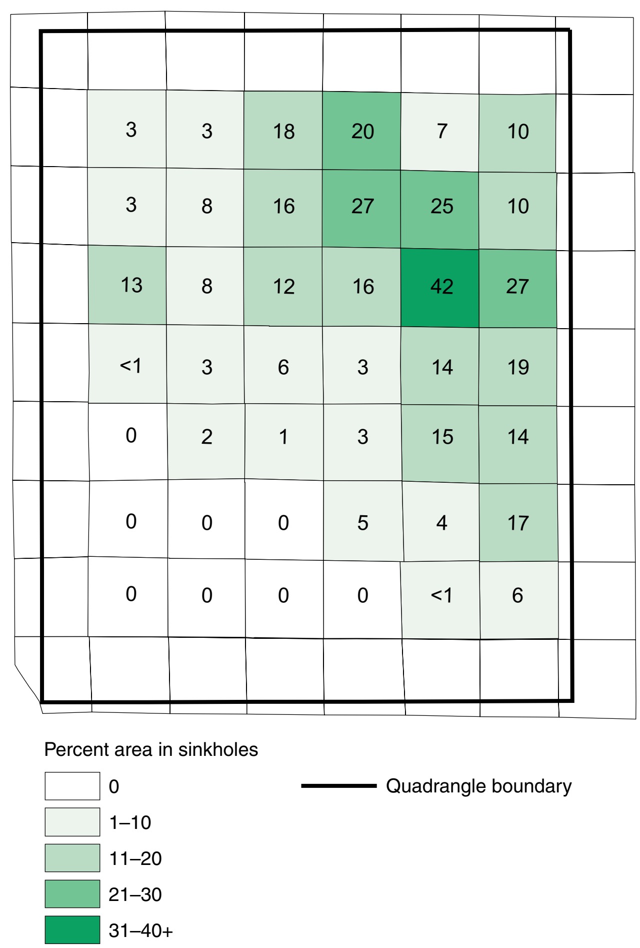

Figure 5 Sinkhole area of the Renault Quadrangle determined at the section level. Proportional sinkhole areas for partial sections on the boundaries of the map could not be calculated because the digital data were unavailable.

of the Fogelpole Cave groundwater basin, and the areas of recharge for the two basins overlap slightly (see map). The Fogelpole Cave and Collier Spring groundwater basins are bounded on the north and northeast in the Renault Quadrangle by the groundwater basins of Krueger's Dry Run Cave, Illinois Caverns, and Lantz Spring (Aley et al. 2000).

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 Renault Quadrangle map show the non-random distribution of sinkholes across the uplands (fig. 1 and map). We mapped 3,127 sinkholes within its boundaries. The total rises to 3,411 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 72 sections within and intersected by the Renault Quadrangle are 47.4 and 22 sinkholes per section, respectively. Sinkhole density within the quadrangle ranges from 0 to 81 sinkholes per km^2 (0 to 211 sinkholes per square mile or per section). The number of sinkholes on the bluff slopes and deep gullies adjacent to the Mississippi River floodplain is very small due to erosion that redistributed and removed most glacial till and loess.

The greatest density of sinkholes occurs within the Fogelpole Cave and Collier Spring Groundwater Basins (see map and fig. 4). At that location, the St. Louis Limestone bedrock displays abundant and widespread dissolution features. Along the bluff in the southwestern half of the quadrangle, the Warsaw Formation and Salem Limestone are exposed in southwest-flowing stream valleys where sinkhole counts are significantly smaller (map). Evidence of sinkhole control by the lithologies is seen along the Valmeyer Anticline in the northwest corner of the map. Few sinkholes are present along the Valmeyer Anticline where the Salem Limestone occurs at the bedrock surface.

Figure 5 shows the percent area for closed-depression (sinkholes) within each section in the Renault Quadrangle. Distribution is slightly different from that shown on figure 4. The greatest area covered by sinkholes (42%) lies within a section immediately over passages of Fogelpole Cave (map). Sections where sinkholes cover 21 to 30% of the total area lie within the Fogelpole Cave and Collier Spring Groundwater Basins (fig. 5 and map).

The boundary between the Illinois Caverns and Fogelpole Cave groundwater basins is characterized by a conspicuous lack of sinkholes (see map). Preliminary mapping indicates that the water table lies above the soil-bedrock interface along this groundwater basin boundary (Panno and Angel, unpublished data). The paucity of sinkholes along this groundwater divide is consistent with portions of other karst areas in Illinois where the water table lies above the soil-rock interface. In such areas, the hydrostatic pressure within the sediments provides support and significantly reduces the propensity for sinkhole formation (Panno et al. 1994). Pumping of large volumes of groundwater from these areas could lower the water table below the soil-bedrock interface and cause sinkhole formation and associated damage and hazards in areas where they were previously unknown.

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