Karst Geology and Hydrology of the Spring Mill Lake and Lost River Drainage Basins in Southern Indiana

Indiana Geological Survey Field Trip Guidebook 15

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By Nancy R. Hasenmueller, Carl B. Rexroad, Richard L. Powell, Mark A. Buehler, and John L. Bassett

Guidebook 15

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Photographs on front cover

Left: Entrance to Donaldson Cave in Spring Mill State Park (John M. Day)

Right, top to bottom:

Aerial photograph of the Mitchell Plateau (Samuel S. Frushour)

Spring Mill Pioneer Village with grist mill in background (John M. Day)

Passageway in Hamer Cave in Spring Mill State Park (Richard L. Powell)

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The Indiana Geological Survey reminds users of this guidebook to obtain permission from landowners before entering privately owned property.

Karst Geology and Hydrology of the Spring Mill Lake and Lost River Drainage Basins in Southern Indiana

Introduction

This guidebook is concerned primarily with the karst geology, hydrology, and water quality of the Spring Mill Lake and Lost River drainage basins in southern Indiana. The guidebook is designed to be a self-guided field trip and includes a road log describing geologic features along the field trip route from Indianapolis, Indiana, to Spring Mill State Park near Mitchell in Lawrence County, Indiana. An appendix detailing the driving instructions for the entire field trip route is also included. If it is necessary to access or traverse private property during the field trip, seek permission from the property owner.

Karst is a distinctive type of landscape or topography. The presence of carbonate rocks (limestone and dolomite) and freely circulating slightly acidic rain water and soil water are necessary for the formation of karst terrain. The flowing rain and soil water slowly dissolve the fractured limestone and create solution features that are characteristic of karst landscapes. Karst environments are sensitive to contamination because most of the surface water flows directly into open subterranean drainage routes and is not filtered by the soil and bedrock.

In Indiana, two areas of karst terrain are present: the Mitchell Plateau and the Crawford Upland, which are located in southern Indiana, and the Muscatatuck Plateau, which is located in southeastern Indiana. The Mitchell Plateau is a broad limestone karst plateau dissected by a few entrenched major stream systems and is developed on Mississippian limestones. This plateau extends from the eastern part of Owen County southward to the Ohio River in Harrison County. The geology and hydrology of the Mitchell Plateau and the Crawford Upland, a hilly upland capped by resistant carbonate and siliciclastic rocks of Late Mississippian and Early Pennsylvanian age, are examined on this field trip.

Geologic Features from Indianapolis, Indiana, to Spring Mill State Park near Mitchell, Indiana

Departing from the Indianapolis metropolitan area, travel south to Indiana State Road 37. Take Indiana State Road 37 south (fig. 1) to the northern part of Morgan County, Indiana, traveling within the Central Till Plain (H. H. Gray, 2000) (Plate 1) and in part along the valley of the White River, a former glacial sluiceway. The Central Till Plain encompasses the same area as the Tipton Till Plain described by Malott (1922) except for a transitional area along the southeastern margin of the till plain characterized by low relief. The Central Till Plain is an expansive, nearly flat to gently rolling glacial plain covering the central portion of the state from just north of the Wabash River in northern Indiana to the southern limit of Wisconsin glacial deposits in the southern part of the state.

The Central Till Plain is composed of Wisconsin glacial drift that is sufficiently thick to completely obscure the general form of the underlying bedrock physiographic units. Throughout much of its area the plain is virtually featureless. The monotony of the till plain is broken by low eskers, esker troughs, moraines, and meltwater drainageways, most of which trend in a general

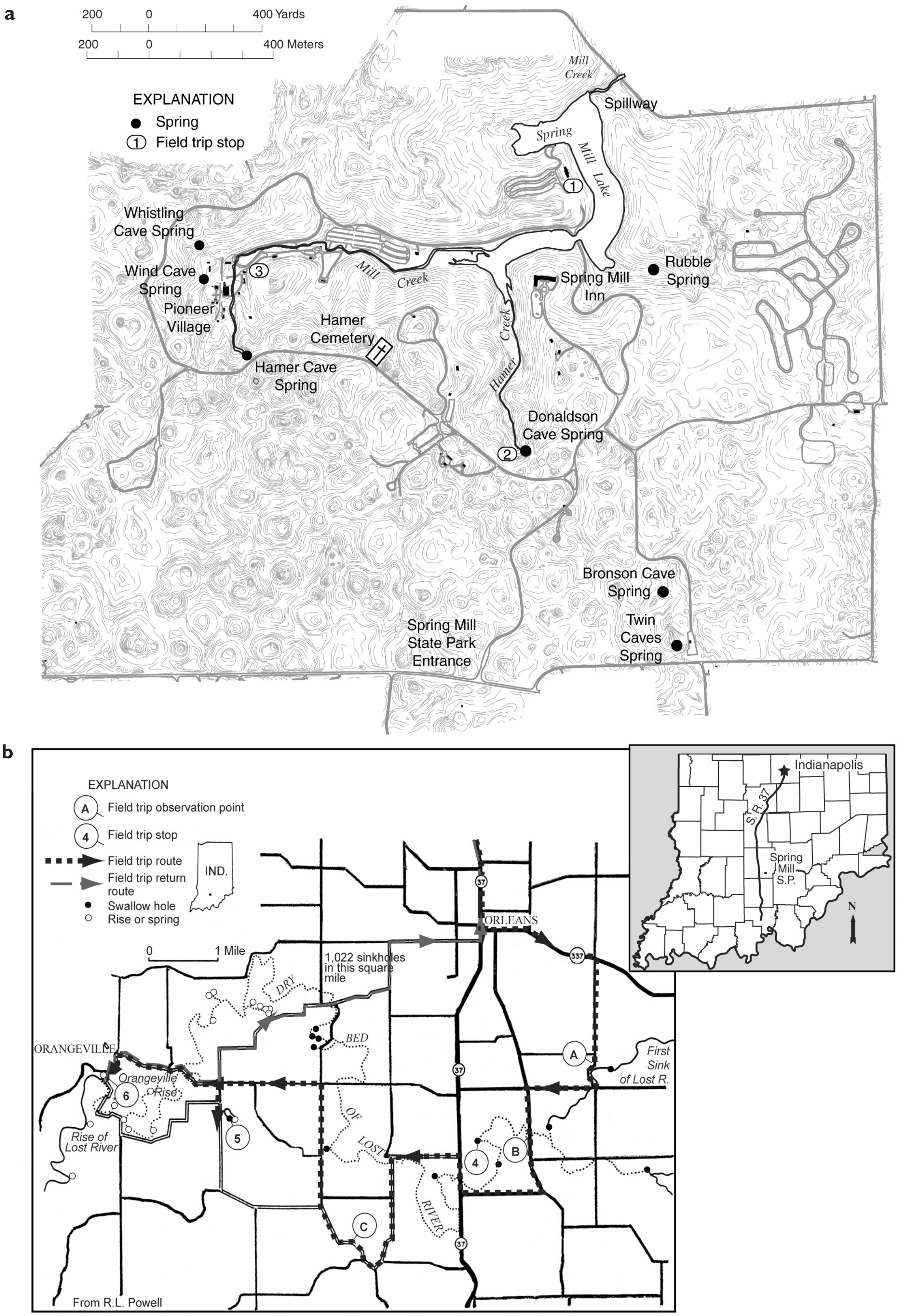


Figure 1. Maps showing field trip route. (Figure 1a modified from Buehler and others, 2002.)

northeast-southwest direction and form a subparallel drainage pattern (Schneider and others, 1963). Many outwash-floored channels are now occupied by modern streams, such as the White River.

In the northern part of Morgan County, one enters the Southern Hills and Lowlands physiographic region (H. H. Gray, 2000) (Plate 1). This area lies to the south of the Wisconsin glacial boundary; glacial deposits, if present, are pre-Wisconsin and are generally less than 50 feet in thickness (H. H. Gray, 1983). Therefore, the nature of the bedrock units rather than the nature of the glacial deposits more strongly influences the character of the physiographic units in this region.

The Martinsville Hills part of the Southern Hills and Lowlands Region extends from northern Morgan County to just south of the town of Martinsville, Morgan County, Indiana. The section is distinguished by bedrock hills of high relief that were strongly modified by pre-Wisconsin glacial activity (H. H. Gray, 2000). This upland is characterized by the relatively resistant siltstones and interbedded softer shales of the Borden Group (Mississippian) (fig. 2). Along State Road 37, approximately 3.3 miles south of the turnoff to Indiana Highways 39 and 67 in Martinsville, are two large road cuts in the Borden Group on the west side of the highway [Hindustan Quadrangle].[1] These beds are bioturbated and show few other primary sedimentary structures (Horowitz and Horowitz, 1979). In Indiana Geological Survey Drill Hole 315, located about 0.5 miles southeast of this road cut, the eroded top of the Borden Group was at an elevation of approximately 625 feet and the unit was 473 feet thick.

This drill hole is located near the northern terminus of the Mt. Carmel Fault, a normal fault that trends slightly east of south along the regional strike for 47 miles from southernmost Morgan County into northwestern Washington County (Tanner, 1985). Maximum throw on the fault is 250 feet. The Leesville Anticline was formed on the downthrown side of the fault zone. Several structural domes are associated with the Leesville Anticline and three of the domes have yielded minor amounts of gas or oil. The gas has been produced primarily from the upper part of the Middle Devonian limestone of the Muscatatuck Group in the Unionville Dome and the oil has been reported as produced from near the top of the Ordovician Trenton Limestone in the Dutch Ridge Dome (Melhorn and Smith, 1959). Today, several of the structural features along the Leesville Anticline are being used for gas storage (Keller, 1998).

CHRONOSTRATIGRAPHIC UNITS		ROCK UNITS	
SYSTEM	SERIES	GROUP	FORMATION
MISSISSIPPIAN	CHESTERIAN	BUFFALO WALLOW	(13 FORMATIONS)
		STEPHENSPORT	
		WEST BADEN	
	VALMEYERAN	BLUE RIVER	PAOLI LS.
			STE. GENEVIEVE LS.
			ST. LOUIS LS.
		SANDERS	SALEM LS. HARRODSBURG LS. RAMP CREEK FM.
		BORDEN	EDWARDSVILLE FM.
			SPICKERT KNOB FM.
			NEW PROVIDENCE SHALE
	KINDERHOOKIAN		ROCKFORD LS.
			NEW ALBANY SH.

Figure 2. Chart showing classification of Mississippian strata in Indiana. Modified from Hattin and Dodd, 1992.

In southernmost Morgan County, one enters the Norman Upland physiographic unit (Plate 1). The Norman Upland is an area of strong local relief and is characterized by flat-topped narrow divides, steep slopes, and deep V-shaped valleys. Most of the shorter tributary streams have only incipient floodplains or none at all; the larger streams are marked by conspicuous narrow flat valleys. The area is nearly all slope and is well drained by a well-developed dendritic drainage system. The rugged topography of the area is owing to the siltstones of the Borden Group that underlie the upland. We will remain in the Norman Upland physiographic section from southernmost Morgan County to just north of the city of Bloomington in Monroe County, Indiana.

The southern boundary of the pre-Wisconsin glacial deposits is just to the south of the Morgan-Monroe County boundary. Bryant Creek, in northernmost Monroe County, formed along the margin of this glacier and contains abundant erratics transported by the glacier from as far away as Canada (Fleming and Thompson, 1999) [Modesto Quadrangle].

Just to the south of Bryant Creek on both sides of the highway is a series of exposures of the Edwardsville Formation of the Borden Group (fig. 2). The Edwardsville consists of siltstone, sandy shale, and sandstone and represents submarine clastics of the Borden delta. Discontinuous lenses of limestones including bioherms are also found in the Edwardsville.

[1] The U.S. Geological Survey 7.5-minute topographic quadrangle maps for selected points along the field trip route are indicated in brackets.

Near the junction of Indiana State Road 37 and Crossover Road (about 2.2 miles south of Bryant Creek) is the boundary between the Mississippian limestones of the Mitchell Plateau physiographic section and the clastics of the Borden Group [Modesto Quadrangle]. Originally named the Mitchell Plain by Malott (1922), the physiographic unit has been renamed the Mitchell Plateau by H. H. Gray (2000) because the area consists of a low limestone plateau dissected by entrenched major stream systems. The Mitchell Plateau is an area of relatively low relief and is formed on a moderately thick sequence of Mississippian carbonate rocks of the Sanders and Blue River Groups (fig. 2) characterized in part by karst development. The plateau exhibits some of the best examples of karst topography in the world and extends from the eastern part of Owen County to the Ohio River in southernmost Indiana (Plate 1). The Mitchell Plateau extends into central Kentucky where it is known as the Pennyroyal Plain.

Immediately south of Crossover Road, the Harrodsburg Limestone (Mississippian) (fig. 2) of the Sanders Group is exposed on the east and west side of the highway for the next 3 miles (Horowitz and Horowitz, 1979). The Harrodsburg is a well-cemented calcarenite and calcirudite, but also includes some dolomite, shale, and argillaceous limestone, and minor amounts of chert. An impure unit 1 to 11 feet above the base of the unit is present in some areas and contains geodes and silicified material. The upper part of the formation contains lenses that are lithologically almost identical to the overlying Salem Limestone.

On the west side of State Road 37, 0.5 miles south of Beanblossom Creek, is a 63-foot-thick exposure of Mississippian rock [Bloomington Quadrangle]. The lower part of the exposure consists of siltstones of the Edwardsville Formation, the middle part of skeletal grainstones and argillaceous dolomites of the Ramp Creek Formation, and the upper part of skeletal packstones and grainstones of the Harrodsburg Limestone. The Ramp Creek, and to a lesser degree the Harrodsburg, contains geodes, which are considered secondary in origin. The sequence of carbonate units exposed at this site was interpreted by Forbes (1975) as representing the following depositional sequence, in ascending order: (1) a normal shallow marine platform environment, (2) a recurrent restricted marine environment, and (3) a semirestricted marine environment. Forbes (1975) suggested that the geodes formed in intertidal lagoonal sediments underlying an evaporitic supratidal environment and that they serve as an indicator of sabkha conditions rather than as a sedimentological feature in direct association with evaporitic sediments.

Through the years a number of theories have been proposed relating to the origin of the quartz geodes found in the Mississippian cherty dolomitic limestones of Indiana, Kentucky, Tennessee, and Iowa. Chowns and Elkins (1974) proposed that quartz geodes in the dolostones of the Fort Payne Chert and Warsaw Limestone in Tennessee were pseudomorphs after early diagenetic anhydrite nodules. They suggested that the anhydrite developed in an arid tidal flat or sabkha environment and that silicification took place prior to compaction and lithification of the sediments. The solution of opaline sponge spicules was believed to be the source of the silica. Maliva (1985) agreed that the presence of anhydrite inclusions in geodes of the Ramp Creek Formation and Harrodsburg Limestone of Indiana supports interpretations that geodes are early diagenetic anhydrite nodules replaced by quartz. However, he proposed that the environment of deposition was shallow, normal marine rather than sabkha. He suggested that the release of calcium ions during dolomitization in a normal marine environment may have resulted in supersaturation with respect to calcium sulfate. This resulted in the precipitation of anhydrite or gypsum that was later dehydrated to form anhydrite. Maliva suggested that a possible source of the magnesium for dolomitization was the percolation of hypersaline magnesium-rich brines produced during the deposition of the overlying St. Louis Limestone.

Dimension stone quarries in the Salem Limestone formerly existed on the west side of the highway at the junction of Indiana Highway 46 Bypass and Indiana State Road 37 [Bloomington Quadrangle]. The Salem Limestone is composed of several lithologies; the dominant lithology is tan (buff) to gray medium- to coarse-grained skeletal grainstone characterized by massive thick beds (fig. 3). The formation is commonly 60 to 100 feet thick in the central and southern parts of the outcrop belt. The Salem has been quarried in southern Indiana at least since 1827, when a quarry was opened by Richard Gilbert near the town of Stinesville in northern Monroe County (Hopkins and Siebenthal, 1897, p. 357). The Salem Limestone has been a popular building stone, used in numerous public buildings, including the Washington National Cathedral and the Empire State Building, and in private homes in the eastern United States. Although the Salem has been produced from east-central Owen County, Indiana, to central Washington County, Indiana, at present all the active Salem Limestone dimension stone quarries are in Monroe and Lawrence Counties, Indiana (Shaffer, 1998).

As part of the modifications to Indiana State Road 46 West, the new right-of-way for the road extends across

Figure 3. Exposure of the Salem Limestone showing thick massive beds and well-developed vertical solution channels called grikes. Photograph by John M. Day.

the reclaimed quarry complex at the intersection of State Road 37 and the 45/46 Bypass. The Bennetts Dump Superfund Site is located in the northern part of the quarry complex to the west of State Road 37. The surface drainage at the intersection is designed to prevent runoff from moving northwesterly into the quarry complex, entering the buried quarries, and increasing the ground-water flow through the clay-capped dump (J. H. Keith, written communication, 1999).

As we travel south, note the massive beds of the Salem and the well-developed vertical channels, or grikes (cutters), formed by the solutional widening of joints in the limestone (fig. 3). The grikes are usually filled with soil and act as a drainage network for ground water, which moves both laterally and downward.

At a distance of 10.6 miles south of the junction of State Road 46 Bypass and State Road 37, the Salem Limestone is exposed on both sides of the highway. Pleistocene vertebrate remains were found in one of the grikes on the east side of the highway; the site was studied by both Volz (1977) and Parmalee, Munson, and Guilday (1978) [Clear Creek Quadrangle]. Volz (1977) thought the deposit formed because the fissure acted as a natural trap from which the animals could not escape.

Nevertheless, Parmalee, Munson, and Guilday (1978) thought the fissure served as a den or shelter for large carnivores and perhaps peccaries. Bones accumulated from animals that died while inhabiting the fissure, from remains of kills brought into the site, and possibly from the contents of fecal matter deposited at the site.

Along the State Road 37 road cut immediately north of the junction of State Road 37 and the road to the town of Harrodsburg, Monroe County, and Monroe Reservoir, nearly the entire section of the Sanders Group is exposed. At this site, Nicoll and Rexroad (1975) described a 128-foot section that includes the uppermost 3 feet of the Borden Group in addition to the Ramp Creek Formation, Harrodsburg Limestone, and the lower part of the Salem Limestone [Clear Creek Quadrangle].

In the road cut immediately south of Gulletts Creek, the contact of the Salem Limestone with the overlying St. Louis Limestone is exposed [Oolitic Quadrangle]. The St. Louis Limestone is defined primarily by its bounding units, the underlying Salem Limestone, and the overlying Ste. Genevieve Limestone (Hattin and Dodd, 1992). The St. Louis is composed of mostly fine to very fine grained limestones, dolomitic limestones, and calcitic dolostones that are commonly separated by thin shale beds. This formation is characterized by thin beds and closely spaced joints (fig. 4). In the subsurface of southern Illinois, southwestern Indiana, and north-central Kentucky, beds of anhydrite and gypsum are interbedded with the limestones and dolostones in the lower to middle part of the St. Louis Limestone section. At this site, Sheikh Ali (1974) placed the contact of the Salem with the overlying St. Louis at an irregular, undulating surface having several feet of relief; he regarded the surface as erosional. The basal bed of the St. Louis in this area is a greenish-gray shale composed mainly of illite and is interpreted to represent a change to more or less restricted depositional environments that included open lagoon, restricted lagoon, hypersaline intertidal flat, supratidal flat, and subaerial exposure (Hattin and Dodd, 1992).

The gypsum beds in the lower part of the St. Louis Limestone are mined in two underground mines at depths ranging from 400 to 450 feet near the town of Shoals in Martin County, Indiana. For additional information on the gypsum beds in the lower part of the St. Louis Limestone in Indiana, see French and Rooney (1969) and Carr and Ault (1983).

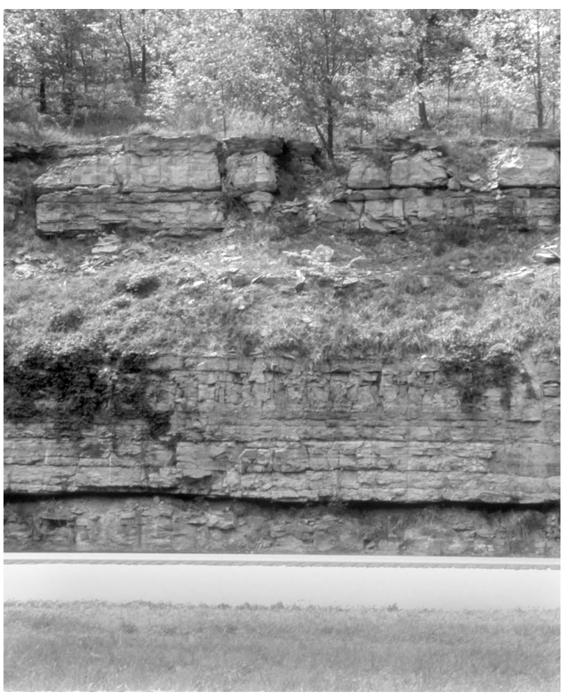


Figure 4. Exposure of the fine-grained limestones and calcitic dolostones of the St. Louis Limestone. Note the thin beds and closely spaced joints that characterize this formation. Photograph by John M. Day.

At the junction of State Road 37 with State Road 58, which leads to the town of Avoca, Indiana, the uppermost bed of the Salem Limestone and the lower part of the St. Louis Limestone are exposed in the cut on the east side of State Road 37. Again, the thin greenish-gray shale composed mainly of illite serves as the marker bed that separates the thicker-bedded grainstones of Salem Limestone from the thinner-bedded packstones and mudstones of the lower part of the St. Louis Limestone (Hattin and Dodd, 1992).

In the northern half of the Mitchell Plateau, which lies to the north of the East Fork of the White River, the plateau is dissected by a few deeply incised meandering streams. Steep slopes and limestone ledges are common in this part of the plateau. To the south of the East Fork of the White River, the plateau is characterized by large areas of classic karst topography having hundreds of sinkholes per square mile (fig. 5). Most of the drainage in the area is through extensive, complex, underground drainage systems; surface streams in this area are generally short and intermittent in nature. To protect the ground water in this sinkhole plain area south of the East Fork of the White River, the Indiana Department of Transportation established a zone of no spraying and low salt application adjacent to State Road 37 South.

Bluespring Caverns, a 20.8-mile-long cave developed in the Salem Limestone and the lower part of the St. Louis Limestone (Samuel S. Frushour, oral communication, 1999), is located 2.1 miles west of the junction of State Road 37 and U.S. Highway 50 West [Bedford West Quadrangle]. The stream that flows through the cave and into the East Fork of the White River is about 8 feet in depth (Powell, 1961b) and is a habitat for the northern cavefish, *Amblyopsis spelaea,* a blind species (fig. 6). The cave probably represents the northernmost extent of the known range of *A. spelaea* (Pearson and Boston, 1995).

Dye tracing conducted for the Indiana Department of Transportation indicates that the two large sinkholes immediately south of the intersection of State Road 37 and U.S. Highway 50 West drain westerly to Pless Cave (Duwelius and others, 1995) (Plate 2). The remainder of the sinkholes along State Road 37 between Highway 50 West and the town of Mitchell were dye traced to Bluespring Caverns. Of these sinkholes, the northerly two sinkholes were dye traced to the dock at Bluespring Caverns; the more southerly sinkholes were traced to the Fourth Discovery Stream and East Passage of Bluespring Caverns (Bassett and others, 1996). The sinkhole located in the former Carpenter Bus

Figure 5. Aerial photograph of the surface of the Mitchell Plateau showing open sinkholes as well as several plugged sinkholes, which are filled with water. Photograph by Samuel S. Frushour.

factory parking lot on the west side of Mitchell is the southernmost sinkhole that traced to Bluespring Caverns (Duwelius and others, 1995) [Mitchell Quadrangle.]

In the vicinity of the intersection of State Road 37 and State Road 60 West, a 2.8-mile segment of State Road 37 was converted to a four-lane highway. The southernmost sinkhole along the construction route has been traced to Hamer Cave in Spring Mill State Park (Keith and others, 1997). The runoff from the highway will be intercepted by several retention basins constructed within the right-of-way. The majority of the common highway pollutants (namely, total suspended solids, recoverable metals, grease and oil) will be removed from runoff by settling and filtration in the retention basins before the waters discharge to subsurface waters (Keith and others, 1997). These structures will also function as potential temporary traps for spills of any hazardous materials that occur on or near the highway.

Figure 6. The northern cavefish, *Amblyopsis spelaea,* a blind species. Photograph by Samuel S. Frushour.

Just north of the junction of State Road 37 and State Road 60, the Ste. Genevieve Limestone is exposed in several cuts along the road [Mitchell Quadrangle]. In south-central Indiana, the Ste. Genevieve paraconformably overlies the St. Louis Limestone and contains a number of lithofacies. It ranges from 45 to 220 feet in thickness (Carr and others, 1986). Lithologic components include ooids, skeletal fragments, peloids, dolomite, and minor amounts of siliciclastic rocks (Hattin and Dodd, 1992). Although most of these carbonate lithologies were deposited on high-energy shoals or in lagoons, some units of the Ste. Genevieve exposed to the south in Harrison County consist of carbonate grains reworked by eolian processes (Hunter, 1989).

At the junction of State Road 37 and State Road 60 East turn left (east) and proceed 3.3 miles to the entrance to Spring Mill State Park. Note the many large sinkholes along State Road 60.

Karst Topography of the Spring Mill Lake and Lost River Drainage Basins

The karst drainage basins described in this field guide are situated within two physiographic units, the Mitchell Plateau and the Crawford Upland. These units are underlain by Middle Mississippian carbonates and Late Mississippian to Early Pennsylvanian carbonates and siliciclastics. The regional dip of the strata is approximately 30 ft/mi to the west. The gentle dips of the strata are the result of crustal subsidence and arching contemporaneous with deposition (Palmer and Moore, 1976). This corresponds to the Illinois Basin to the west and to the Cincinnati Arch to the east.

The Mitchell Plateau is a slightly dissected low plateau, underlain by Mississippian limestones, in which much of the surface has been subjected to karst development. The plateau is made up of the following three landform types: (1) areas of sinkhole plain developed along the down-dip edge of the Mitchell Plateau in the vicinity of major entrenched rivers, at relatively low elevations; (2) areas mantled with residuum and unconsolidated sediment to the east of the sinkhole plain, farther removed from the entrenched rivers; and (3) finely dissected areas of nonkarsted limestone and shale ridges, at relatively high elevations in the furthest up-dip parts of the Mitchell Plateau (Palmer, 1976).

The Crawford Upland is a hilly upland composed of relatively resistant carbonate and siliciclastic rocks of Middle to Late Mississippian and Early Pennsylvanian age. Sinkholes are numerous in karst valleys entrenched below the base of the clastic cap-rock (Palmer and Moore, 1976).

The solution landform developed on the Mitchell Plateau is primarily a soil-mantled karst, common to the temperate United States. The rolling karst lands of Indiana, Kentucky, Missouri, Tennessee, Virginia, and West Virginia have a sculptured bedrock surface that lies below the soil. The landscape that one sees in the field or on topographic maps is smoothed and subdued by the soil cover. Only in a few places—quarries, road cuts, and areas of extreme erosion—can the bedrock surface be seen. Fluviokarst is a term used to describe a landscape of deranged drainage, blind valleys, swallow holes, large springs, closed depressions, and caves. In many fluviokarst regions, the larger rivers maintain their surface courses and are fed by underground tributaries; these characteristics are exhibited on the Mitchell Plateau along the East Fork of White River in south-central Indiana.

Dissolution features are in the upper part of the bedrock beneath the soil and are evident along most of the road cuts seen along State Road 37. Grikes—solution depressions guided by single joints or fractures—act as collector systems for infiltrating ground water, which moves laterally under the regolith from minor grikes to larger grikes and then downward. Features such as these may be the precursors to larger sinkhole systems and are the headwaters of subsurface conduits.

Spring Mill Lake Drainage Basin

Stop 1, Spring Mill State Park Nature Center Adjacent to Spring Mill Lake

Spring Mill Lake is a reservoir in Spring Mill State Park in Lawrence County (fig. 1). The two main tributaries to the lake are Mill Creek and Hamer Creek, which discharge from Hamer and Donaldson Caves, respectively. The watershed of Spring Mill Lake comprises at least 21 square miles in Lawrence and Orange Counties in southern Indiana (fig. 7). Nearly the entire watershed, except for the southeastern tip, is characterized by abundant sinkholes. The Indiana Department of Conservation used funds from the National Park Service and labor supplied by the Civilian Conservation Corps in the early 1930s to begin work on the dam, lake basin, and other facilities at this park. Construction of the dam and reservoir basin was completed in 1936 (fig. 8). The dam is 360 feet long and the top of the dam is 19 feet above the original stream channel (Commonwealth Engineers, Inc., 1994). The dam is earth-filled and has a concrete spillway at the northwest end (figs. 1a and 8).

Siltation has been a problem throughout the history of the lake. Originally, when water storage began in October 1938, the lake had a surface area of about 28 acres, a storage capacity or volume of 178 acre-feet (Brune, 1949), and an average depth of 6.4 feet (Commonwealth Engineers, Inc., 1994). Within ten years, the surface area of the lake had been reduced to 25.2 acres and the capacity had been reduced to 127 acre-feet due to the sedimentation in the reservoir. Brune (1949) noted that the upper portions of the lake, in particular, had become very shallow due to the influx of sediment. Nearly all of the sediment is poorly compacted silt, with some clay in the lower portion of the lake.

An Indiana Department of Natural Resources Division of Water sediment survey of the lake in 1993 determined that the lake had an average water depth of 3.7 feet, a surface area of 23.6 acres, and a volume of 89

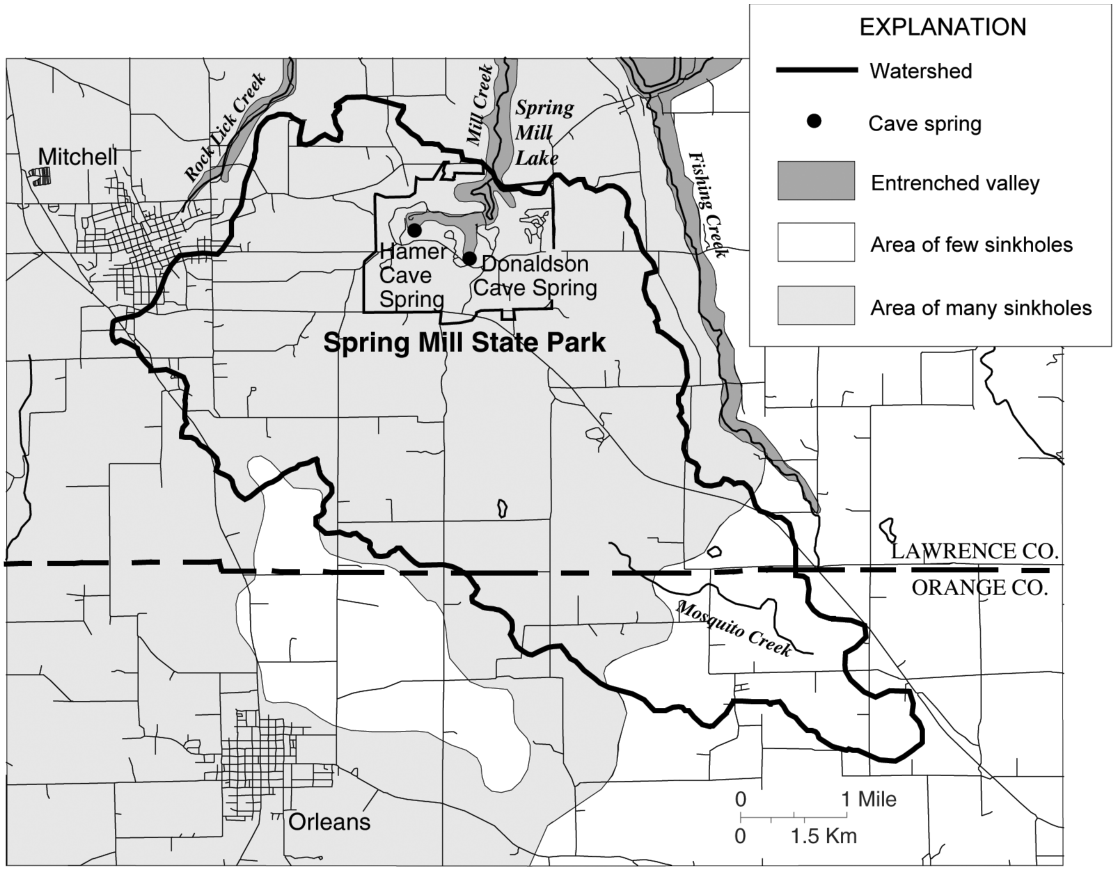


Figure 7. Map of Spring Mill Lake watershed in Lawrence and Orange Counties, Indiana. Compiled by Richard L. Powell and Denver Harper of the Indiana Geological Survey.

acre-feet (Commonwealth Engineers, Inc., 1994) (fig. 9). Thus, the lake has lost substantial area and volume due to the transport of sediment by Mill Creek and Hamer Creek during major storm events (see figs. 10a, b). The decrease in the depth of the lake has resulted in more of the lake area being in the photic zone and an increase in the amount of aquatic vegetation growing in the lake.

The lake was originally constructed as a recreational lake for swimming, fishing, and boating. Not long after the reservoir was filled, the boat docking facilities were moved from the upper part of the lake to the lower part because the influx of sediments made the docks inaccessible from the water. The swimming area was closed because sedimentation made the beach and the concrete diving platform area unsuitable for use. The former diving platform is along the shoreline in front of the nature center. When the diving platform was originally built, the water in the area was 17 or more feet deep; in 1994, the water around the platform was only 8 to 9 feet deep (Commonwealth Engineers, Inc., 1994).

Mill Creek drains the western portion of the Spring Mill Lake watershed and Hamer Creek drains the eastern portion. The southeastern portion of the watershed drained by Mosquito Creek has few sinkholes, but drains into a large swallow hole near the Lawrence-Orange County line.

In 1977 and 1978, the Indiana Department of Natural Resources, Division of State Parks and Reservoirs employed a hydraulic dredging operation to remove sediment from Spring Mill Lake (Commonwealth Engineers, Inc., 1994). It is estimated that 11 to 14 acre-feet of sediment was removed from the lake. The sediment was pumped uphill into a sinkhole near Hamer Cemetery and into the recreational area between the western edge of the lake basin and the former boat rental shelter (Commonwealth Engineers, Inc., 1994).

In the early 1990s, Commonwealth Engineers, Inc., conducted a sediment control study of the reservoir for the Divisions of State Parks and Reservoirs. Commonwealth Engineers, Inc. (1994) proposed that

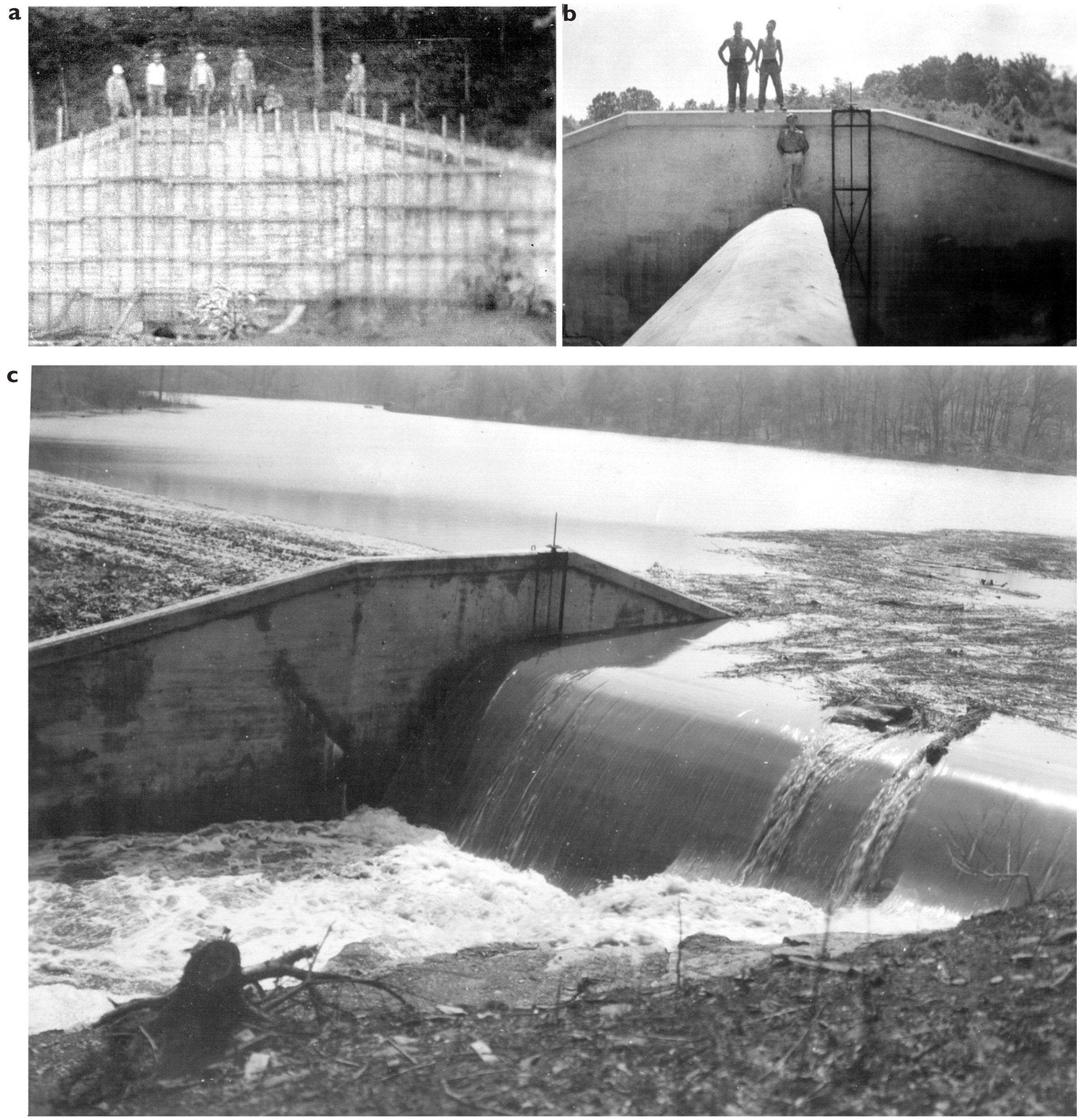


Figure 8. Historic photographs of the Spring Mill Lake dam and reservoir being constructed by the Civil Conservation Corps. (**a**) The spillway wall of the dam at Spring Mill State Park being constructed by members of the Civil Conservation Corps. (**b**) The completed spillway structure prior to the filling of the reservoir. (**c**) The reservoir in the late 1930s after it was completed and filled. Photographs courtesy of the Indiana Department of Natural Resources, Division of State Parks and Reservoirs.

the most feasible method of sediment removal from the lake was to use hydraulic dredging equipment. They proposed five potential dewatering sites for the dredged sediment and five disposal areas for the dewatered sediment. It was estimated that for total restoration of the lake, 90 acre-feet of sediment would need to be removed.

Controlling soil erosion in the watershed is the most economical means of preserving topsoil in the area from erosion and preventing siltation of the reservoir. The soils in the watershed area are well-drained silt loam of the Crider-Frederick association (Thomas, 1985); slopes average 6 to 20 percent. The Agricultural Stabilization and Conservation Service of the U.S. Department of Agriculture has initiated the Conservation Reserve Program (CRP) in this area. This program encourages farmers to voluntarily plant permanent areas of grass and trees on the land that needs protection from erosion; the farmers enter into contracts with

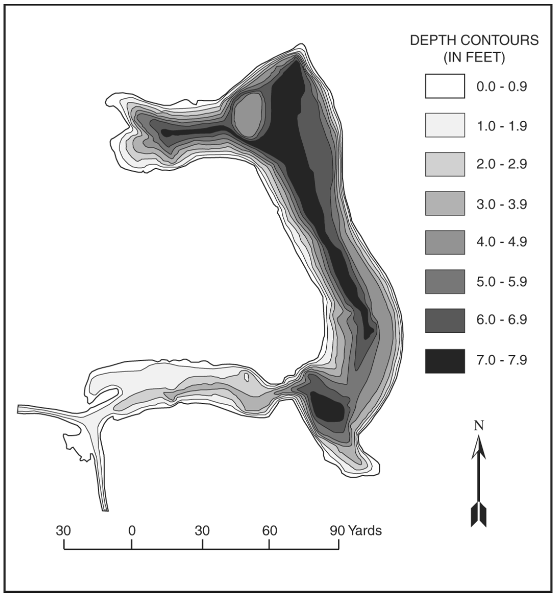


Figure 9. Bathymetric map of Spring Mill Lake in 1993. Modified from Commonwealth Engineers, Inc. (1994) by Buehler and others (1999).

the CRP lasting between 10 and 15 years. In return for participating in the program, the farmers receive annual rental payments, incentive payments for certain activities, and cost-share assistance to establish the protective vegetation.

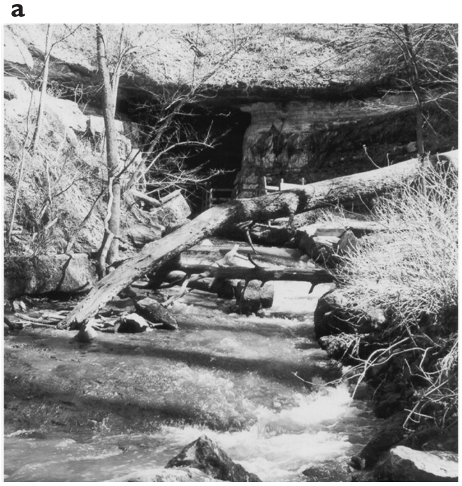
Currently, about 21 percent of the watershed of Spring Mill Lake is in forest (Buehler and others, 2002). Approximately 31 percent of the watershed is in agricultural use. Sixteen percent of the watershed area is enrolled in CRP.

Stop 2, Donaldson Cave

The two springs having the highest discharge within Spring Mill State Park are those flowing from Donaldson and Hamer Caves (figs. 10a, b and 11). Water contributing to the spring at the mouth of Donaldson Cave has been traced using fluorescent dye from Mosquito Creek, a small sinking stream in the southeastern portion of the Spring Mill Lake watershed. Water entering the Mosquito Creek swallet, or swallow hole, eventually flows into the passages of Upper Twin Cave. The entrance of Twin Caves formed when a portion of the cave passage collapsed exposing the cave passage to the surface. This feature is known as a karst window. A small dam maintains a relatively static water level in Upper Twin Cave and a guided boat tour allows access to this "wet" cave. Water flowing over the small dam exits the Twin Caves karst window through Lower Twin Cave and then flows through the Bronson/Donaldson Cave system. (Donaldson Cave was once known as Shawnee Cave.)

At the entrance to Donaldson Cave, two distinct levels of passageways are evident—an upper borehole passage and a lower keyhole passage. It is believed that a late Pleistocene drop in the elevation of the East Fork of the White River caused entrenchment along the lower reaches of the tributary valleys. Initially, the cave

a



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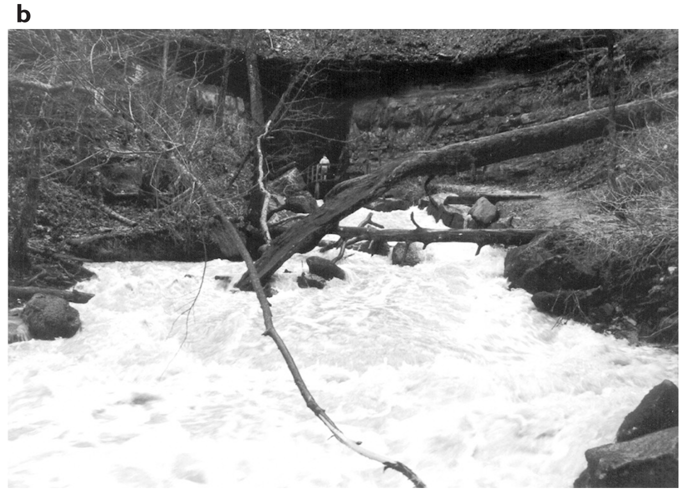


Figure 10. Hamer Creek exiting Donaldson Cave during normal flow discharge and storm event discharge. (**a**) During normal flow discharge, Hamer Creek carries a low sediment load as it emerges from Donaldson Cave. Photograph by Kenneth Arroyo. (**b**) During major storm events, sediment is eroded from fields, transported into open sinkholes and moved into the underground drainage systems. Hamer Creek is turbid due to the increased sediment load after a major storm event. Photograph by Jason M. Melady.

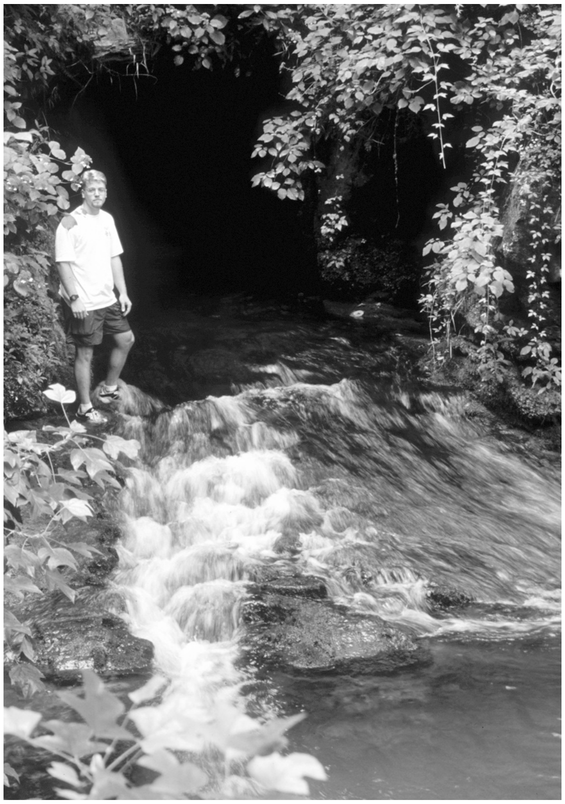


Figure 11. Mill Creek carries a low sediment load as it emerges from Hamer Cave during normal flow. Photograph by John M. Day.

developed in the midsection of the tributary basin at a relatively shallow depth. In the vicinity of the cave exit, the piezometric surface gradually steepened and was eventually lowered through a combination of valley headwall retreat and the incremental concentration of flow through master conduits. Upper-level passages were abandoned once the original high-level flow paths were replaced by lower-level routes (Johnson and Gomez, 1994). The lower keyhole passage appears to have preferentially downcut along a fracture in the bedrock, which is evident near the ceiling of the cave entrance. Low-flow discharges from Donaldson Cave range from 2 to 4 cubic feet per second, but the discharge can jump at least two orders of magnitude within 5 hours of heavy rainfall. Continuous monitoring of discharge and water temperature began in the fall of 1998 and continued through the spring of 2002. The water chemistry and mapping of the cave system indicate that the cave is a significant conduit. Meteoric water probably flushes through the system quickly. Future investigation of the isotopic signature of the water may help quantify pre-storm and post-storm water contributions to the spring's discharge following a storm event. Similar investigations have taken place in the Lost River watershed (Lakey and Krothe, 1996). Understanding how the spring responds to rain events, combined with knowledge of land-use practices within the contributing drainage basin will help assess potential contamination of the integrated environment.

The spring at the mouth of Hamer Cave is similar in chemistry and magnitude of flow to the spring at Donaldson Cave. The western and central portions of the Spring Mill Lake watershed contribute to its flow. Its cave passage wraps around the south and western portion of the local valley, terminating just short of the spring at Wind Cave. Although a hydraulic connection probably exists, a connecting passageway has not been found. Like most caves within the area, there are two distinct levels. Water that flows out of Hamer Cave enters the cave from a spring located in a southerly branching passageway. Water also flows into a lower passage from the west-southwest and continues toward the spring at Wind Cave. At the cave entrance, a small impoundment was created for pumping water out of the park for use in the Lehigh Cement Company plant located at Mitchell. The St. Louis Limestone (77 feet thick), Salem Limestone (55 feet thick), and Harrodsburg Limestone (33 feet thick) are extracted at the Lehigh quarry and are used in the production of cement (Shaffer, 1998).

Downstream at the dam, a valve controls the diversion of water toward the aqueduct that supplies the grist mill with flowing water. Continuous monitoring of discharge and water temperature began in the fall of 1998 and continued through the spring of 2002.

Investigations of water chemistry at the park indicate very similar properties for Donaldson and Hamer outflows with moderately elevated sulfate levels from Wind and Whistling outflows. Nitrate varies seasonally, and peaks occur during the summer months (Bolton, 1980).

Stop 3, Spring Mill Pioneer Village[2]

The first name of prominence in the history of Spring Mill is that of Samuel Jackson, a Canadian volunteer in American service during the War of 1812. Upon retirement from the military, Jackson traveled to Spring Mill valley in southern Indiana and is reported to have built a cabin and 15-foot square wooden grist mill near the mouth of Hamer Cave (L. M. Gray,

[2] Much of the information about the history of Spring Mill in this section is from "A History of Spring Mill Village" (1985), an unpublished manuscript by M. S. Ansari.

1985; Guernsey, 1931). Jackson was issued a patent by President James Madison in October of 1816 to three tracts of land; one of the tracts of land was in the immediate vicinity of the mill. In March of 1817, Jackson deeded the mill and 480 acres of land to Cuthbert and Thomas Bullitt, two brothers from Louisville. The Bullitts brought skilled craftsmen from Louisville to construct the three-story stone grist mill that still stands on this site (fig. 12). Construction began in the spring of 1817 and is said to have been completed by the fall of that same year.

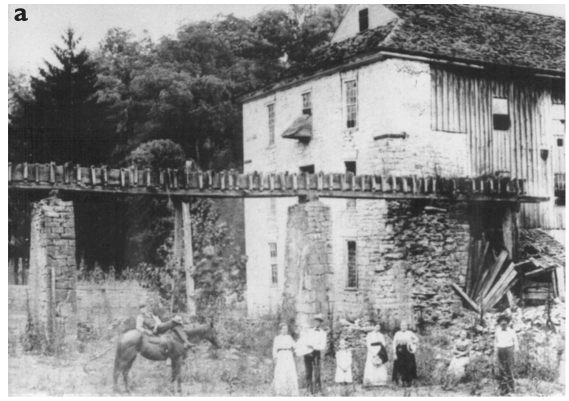
In 1823, the grist mill, the village, and 1,440 acres of land were sold by the Bullitts to Philadelphia merchants William and Joseph Montgomery (Guernsey, 1931). In turn, the mill and adjacent land were sold to Hugh and Thomas Hamer in 1832 by the son of Joseph Montgomery. During the proprietorship of the Hamer brothers, the growth in the mill business was also accompanied by growth in the distillery and sawmill in the village.

In the mid- to late 1850s, several events took place that affected the prosperity of Spring Mill. First, the passage of a prohibition law by the state of Indiana in 1855 most likely resulted in the closing of the distillery at Spring Mill from 1855 to 1856. Secondly, the Ohio & Mississippi Railroad established a stop at Mitchell's Crossing (known as Mitchell at present), and bypassed the village in 1857. Finally, the possibility of civil war over the issue of slavery raised concerns about the villagers maintaining their close economic ties with the South.

After the Civil War there was a period of inflation that caused economic hardship for local farmers, including the people of Spring Mill. Industrialization was also moving forward rapidly during the late 1860s. When Hugh Hamer died in 1872, his son Robert became the legal owner of the village property. Robert Hamer managed the mill until 1881, when he "leased the mill and other village establishments to Jonathan Turley." Turley continued to operate the mill and distillery and established a lime-burning business using a kiln near the mill. (Several old abandoned kilns are located along the walking trails in the park.)

Eventually the village was abandoned. In 1902, the Lehigh Cement Company purchased a large deposit of limestone near Mitchell, which included the site of the village of Spring Mill, and erected a plant. In 1927, Lehigh sold the site of Spring Mill village and the surrounding area of approximately 300 acres to the state of Indiana for one dollar, but retained the rights to the water from Hamer Cave for their plant at Mitchell (Guernsey, 1931).

a



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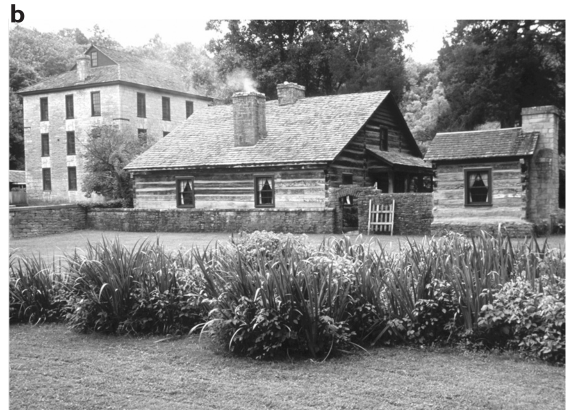

Figure 12. The grist mill at Spring Mill State Park. (**a**) The grist mill prior to the restoration of the village that began in 1928. Photograph courtesy of the Indiana Department of Natural Resources, Division of State Parks and Reservoirs. (**b**) Spring Mill Pioneer Village with the grist mill in the background in 1998. Photograph by John M. Day.

In 1865, a Scotsman named George Donaldson, who was interested in nature and in "the exploration of cavern regions of America," purchased two adjacent parcels of land totaling slightly more than 180 acres near Spring Mill (Guernsey, 1931). Donaldson resided on his property, which was never farmed or timbered, until 1882 when he moved to Alabama. In 1897, Donaldson returned to his native Scotland where he died in September 1898. Because Donaldson never became an American citizen, his property eventually "reverted to the state" and was in the custody of Indiana University from 1903 to 1927.

Dr. Carl Eigenmann (1863–1927), a professor of zoology at Indiana University and the founder/director of Indiana University Biological Stations in the state from 1895 to 1920, was also an important figure in the history of the Spring Mill area. Because of his interest in the development of the northern cavefish found in many of the caves in the area, he established a research laboratory near Donaldson Cave. Basins, or pools, were built in the stream bed near the entrance to the cave and in the west branch of the cave to contain specimens of the fish. At this site, Eigenmann conducted experiments aimed at determining the cause of the cavefish's blindness, and learned that the blindness was a genetically inherited trait.

As early as 1917, the State Park Board of Indiana was interested in developing a park around the then abandoned village of Spring Mill. But it was not until 1927 that the park was actually established. The two individuals who had major roles in the establishment of the park and in the restoration of the village were Richard Lieber and Elma Y. Guernsey.

The restoration of the village of Spring Mill began in August 1928, and the first task undertaken was the repair of the mill. According to Guernsey (1931), in the restoration of the mill, only a small portion of new material was used; he noted that the stone walls, the window frames, except for the sashes, most of the framing material, and much of the machinery were original. The 3-foot-thick walls of the mill are composed of fine-grained limestone characteristic of the St. Louis Limestone. Although the park opened in 1930, the restoration work continued for a number of years. From 1933 to 1940, a Civilian Conservation Corps camp was located at the park and the members of the Corps helped with park work, such as the building of the dam, reservoir, roads, and shelter houses, and with additional restoration work (fig. 8).

Today, Spring Mill State Park consists of the 183.88 acres originally owned by George Donaldson, 539 acres donated by Lawrence County, 295 acres sold by the Lehigh Cement Company to the state of Indiana for one dollar (Guernsey, 1931), plus land that was given to the park by Eliza Turley in 1934. Part of the area formerly owned by George Donaldson is now designated as Donaldson Woods Nature Preserve and contains 67 acres of virgin woods.

The memorial to astronaut Virgil I. "Gus" Grissom is also located within the park. Gus Grissom was born in the nearby town of Mitchell, Indiana, and was the second United States astronaut to go into space. His famous suborbital flight was made on July 21, 1961. In 1966, Gus Grissom, Edward White, and Roger Chaffee were designated as the crew for the Apollo I moon flight. Unfortunately, the three astronauts suffocated as the result of a fire in their Apollo spacecraft during countdown tests at Cape Kennedy in 1967.

Roadlog from Spring Mill State Park to Orleans, Indiana

Return to park entrance and turn right (west) on State Road 60 and retrace route to State Road 37. There turn left (south) for the Lost River part of the trip and continue to State Road 337 in Orleans. For driving directions for the remainder of the trip see the Appendix and Figure 1.

About 3.5 miles south of the junction of State Road 60 and State Road 37, the hills on the right are outliers of the Crawford Upland. Roger's Group, Inc., is quarrying, mostly for scrubber stone, in the Ste. Genevieve Limestone in a small hill at the south end of the hills. An abandoned quarry across the road to the north exposed the upper part of the St. Louis Limestone and the Ste. Genevieve Limestone (both Middle Mississippian), the Chesterian Paoli Limestone, and about 28 feet of the overlying Bethel Formation.

Lost River Drainage Basin

Introduction to Lost River

The Lost River drainage basin is one of the classic karst areas of the United States, and is renowned for its unique karst character. The pioneering geologic work of Indiana University professor Clyde A. Malott first brought scientific acclaim to this area. Malott's work in the area spanned a period of over 25 years from the late 1920s to the early 1950s. Before the advent of modern topographic mapping, he painstakingly constructed detailed field maps for his work with plane table and altimeter. He proposed the name "karst valley" as a generic term for the dry valley areas having pirated surface-water courses that he saw in the western part of the Lost River area. Without the benefit of fluorescent tracers, Malott correctly identified areas where karst ground-water movement crossed beneath surface drainage divides. The Lost River area has been the subject of numerous additional hydrologic investigations. A synthesis of these will be presented later in this guidebook.

The area's uniqueness is recognized by the National Park Service, and contains three registered national natural landmark karst features: Tolliver Swallow Hole (point of interest on the field trip route), Wesley Chapel Gulf (Stop 5), and the Orangeville Rise (Stop 6). Other prominent karst features include large caverns, swallow holes, and a 22-mile-long meandering dry bed channel downstream of the principal river sink.

The unique character of the Lost River area is also recognized by Indiana environmental protection rules. Lost River and all surface and underground tributaries are rated as an exceptional use stream under the provisions of Indiana Administrative Code 327 IAC 2-1-3(a)(6). Such waters are deemed to provide unusual aquatic habitat, be an integral feature of an area of exceptional natural beauty or character, or support unique assemblages of aquatic organisms. By rule, all waters designated for exceptional use shall be maintained without degradation.

Lost River (Plate 2) lends itself to division into three segments. The upper eastern segment appears as a normal surface-flowing stream crossing the eastern part of the Mitchell Plateau. The middle segment makes clear the reason for the river's name as it is marked by loss of water to subterranean drainage. The downstream western segment carries a normal surface flow in a partially filled, entrenched valley flowing through the Crawford Upland. The distance traversed by the middle segment, as the crow flies, is only about 7 miles. The area of this segment of the stream exhibits a wide variety of karst features and is an area of complex subsurface drainage in which other areas may flood when subterranean routes fill (fig. 13).

The meandering, dendritic pattern of Lost River (Plate 2) is inherited from an antecedent Tertiary stream that crossed structure down-dip rather than along strike. During later Tertiary time, a surface of very low relief allowed the accumulation of thick clays (terra rosa, in part) and other weathering products derived in small part from the weathering of the Middle Mississippian limestones that now are at the surface of the Mitchell Plateau and in larger part from the products of the breakdown of the Chesterian shales, sandstones, and limestones responsible for the present elevation and ruggedness of the eastern part of the Crawford Upland to the west. The boundary between the Mitchell Plateau and Crawford Upland is marked by the prominent Springville Escarpment (Plate 1), which has a deep reentrant into the upland along the valley of Lost River.

The highest point along the drainage divide at the headwaters of present-day Lost River is just over 900 feet and indicates the level of the Late Tertiary surface of low relief on which the antecedent stream flowed. Downcutting into this surface and a somewhat lower surface marked by local areas of upland gravels was activated by Pleistocene lowering of base level. Some current topographic levels relate to the glacial and interglacial stages.

A lower base level for the lower segment of the river resulted in episodes of major downcutting and deep entrenchment followed by filling with colluvial, alluvial, and lacustrine deposits. The lower segment of the river begins geographically at the picturesque Orangeville Rise (Stop 6), a National Natural Landmark, but the Rise of Lost River proper is just downstream. The lower perennial segment of Lost River continues a meandering course generally west-southwest to the East Fork of White River.

In the middle segment of Lost River the thick clay-rich overburden was stripped away, exposing limestone and allowing the karstification that produced the present complex-surface–subterranean-drainage relations and the north-south-trending sinkhole plain having as many as 1,022 sinks in a square mile. During this time, the middle segment was entrenched into bedrock and there was a general westward migration of the Springville Escarpment. The dry bed lies mostly on the Mitchell Plateau but extends a short distance into the Crawford Upland. The farthest downstream part of the middle segment may carry some water independently of the upstream part because it may receive some drainage from resurgences fed from north of the primary drainage.

The change from the middle to the upper river segment to the east occurs near a physiographic change in karst features within the Mitchell Plateau. The upstream segment of Lost River is a normal surface stream flowing in an alluvial valley mostly on thick clays, although in places it is incised to bedrock. It was less affected by lowering of base level and, therefore, karst features are

Figure 13. Historic 1933 photograph of flooded section of the town of Orleans near the terminal swallow hole of a former surface tributary to Lost River. The present underground system is 20 to 30 feet below the surface. From Malott (1952).

greatly subdued under the remaining clay-rich overburden and the younger, thin loess above the clay.

The boundary of the Mitchell Plateau between the clay-covered, gently rolling area generally in the eastern part of the plateau and the active sinkhole plain also is marked by the narrowing of the valley of Lost River (near Observation Point A) and the loss of water underground. As the name implies, during much of the year the principal dry-weather sinks mark the last flowing water, but in times of excess runoff, the water flows down the dry bed from this group of sinks to the next sink; as each subterranean segment fills in turn, the surface flow continues down the dry bed to the next sink or swallow hole. Rarely, water flows the entire 22-mile length of the dry channel.

There are many sinks within the dry channel and a number of side channels. The three major off-channel swallow holes are Stein (Stop 4), Turner, and Tolliver Swallow Holes. The latter is a National Natural Landmark and has been a standard field trip stop for many years. A new owner is prohibiting access. These three swallow holes plus Nicols and Hudelson Caves and Wesley Chapel Gulf (Stop 5), another National Natural Landmark, apparently lie close to the main subterranean route to the Rise of Lost River.

Stampers Creek once was a surface tributary to Lost River, joining it near the principal dry sink; but it and its South Fork became two separate sinking streams during development of the present karst features. Water from Stampers Creek goes to the Rise of Lost River through Wesley Chapel Gulf. On the other hand, although it is in the surface basin of Lost River, water in South Fork of Stampers Creek resurges to the south in Lick Creek outside of the Lost River basin.

Hydrology of Lost River Area

The Lost River area contains the second and third largest springs in Indiana, the Orangeville Rise and Rise of Lost River (Plate 2), respectively (Powell, 1961a). These springs may be viewed as the terminal discharge points of two large karst ground-water basins that underlie the Mitchell Plateau and adjacent parts of the Crawford Upland in the Lost River drainage basin. The combined discharge of these two springs, located about 0.75 miles apart in sections 6 and 7, T. 2 N., R. 1 W., form the headwaters of the downstream portion of Lost River below the dry bed section (fig. 14). Recharge to the ground-water basins occurs through autogenic sinkhole recharge on the Mitchell Plateau, and from allogenic fluviokarst recharge from numerous sinking streams on the Mitchell Plateau and dry “karst valley” areas of the Crawford Upland.

The Lost River area has been the subject of several geologic and hydrologic investigations (Malott, 1952; Murdock and Powell, 1968; Bassett, 1976; Bayless and others, 1994; and Earth Tech, 1995).

Ground-water tracing investigations over a period of about 30 years have delineated the ground-water basins of the Orangeville Rise (see Stop 6) and the Rise of Lost River, and have aided in understanding their subterranean flow characteristics. Tracer test results in the field trip area, compiled from various published and unpublished sources, are shown in Plate 2. The subterranean drainage systems are hydrologically complex. Surface drainage basins and subsurface ground-water basins are not necessarily correlative. Surface streams such as Lost River, Stampers Creek, Mt. Horeb Drain, and Flood Creek at Orleans sink at multiple swallow holes along their channels. The swallow holes and subsurface conduits of both basins have limited capacity. When the subsurface conduits fill, the surface water bypasses upstream swallow holes and flows downstream in the surface channels to the next downstream swallow hole. After very large storm events, storm water rises or overflow springs may discharge subsurface water into the lower reaches of the Lost River dry bed, and bypass the downstream portions of the subsurface flow systems. Estevelles, alternately acting as rises and swallow holes, exist at a number of locations in the Lost River area.

A number of large karst drainage systems in the area are habitat for the state-endangered northern cavefish (*Amblyopsis spelaea*) (fig. 6).

Orangeville Rise Ground-Water Basin

The basin of Orangeville Rise is the more extensively studied of the two ground-water basins of Lost River. Ground-water-tracing results suggest that the Orangeville Rise ground-water basin is about 50 square miles in extent (Plate 2). The northeastern boundary of the basin is roughly coincident with the route of State Road 37 near Mitchell. Areas north and east of the basin are tributary to the springs at Hamer Cave and at Donaldson Cave in Spring Mill State Park. North of Mitchell, subsurface flow is conveyed to Bluespring Caverns and the East Fork of White River (Plate 2).

Malott (1945) suggested that ground water beneath a wide, dry valley extending west of Mitchell along the route of State Road 60 drained southward to Lost River and northward to the East Fork of White River. The

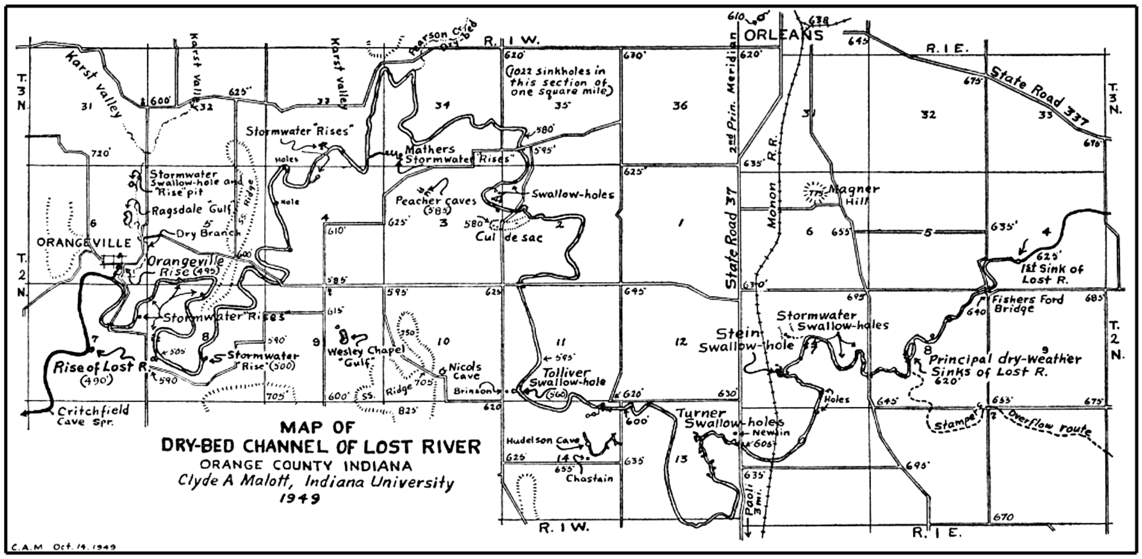

Figure 14. Map showing major named features in the area of the dry-bed segment of Lost River. From Malott (1952).

floor of this enigmatic valley contains numerous sinkholes and swallow holes, and is herein referred to as the "Beaver Creek Karst Valley" (Plate 2). In the geologic past, the Beaver Creek Karst Valley was a major tributary to lower Beaver Creek. Karst development beneath the valley floor has diverted drainage into subterranean solution conduits, and today no through-flowing perennial stream exists in the valley. Runoff into the valley from the adjacent sandstone and shale-capped hills and ridges soon disappears into swallow holes in the valley floor. Examination of the Georgia, Indiana, U.S. Geological Survey 7.5-minute topographic quadrangle map reveals at least eight separate surface watersheds in the Beaver Creek Karst Valley. Each of these watersheds drains to individual swallow holes. Some sinking streams contain multiple swallow holes that serve as overflow routes during various flow conditions. Many swallow holes are choked with sediment and rafted vegetative debris that accumulates in chaotic piles. A few swallow holes drain into open bedrock crevices, some of which are cavern entrances.

Throughout the eastern part of the Beaver Creek Karst Valley, fluorescent dye-tracing investigations for the Indiana Department of Transportation (Earth Tech, 1995) indicate southward drainage to Orangeville. Subsurface flow paths as long as 6.9 miles have been documented. In this area, the Orangeville ground-water basin is bounded to the north by drainage to Bluespring Caverns and other large karst springs located along the entrenched East Fork of White River. The ground-water basin boundary is drawn along a prominent topographic divide. Although no tracer tests have been conducted in the area north of the divide, numerous cave streams in the area indicate northward flow toward the White River.

Farther west, the middle reaches of the Beaver Creek Karst Valley drain southward to Sulphur Spring on Sulphur Creek (Plate 2). The Sulphur Spring ground-water basin, a 19-square-mile area, forms a portion of the western boundary of the Orangeville ground-water basin. The Sulphur Spring ground-water basin is interesting in its own right as ground-water recharge is derived almost exclusively from fluviokarst systems in the Crawford Upland.

The Sulphur Spring system is bounded to the north by smaller ground-water basins draining to the East Fork of White River via Hooper Spring and Blindfish Spring, both located north of Huron. The Sinks of Beaver Creek at Huron are known to be tributary to Hooper Spring. Under high-flow conditions, water in the extreme western portion of the Beaver Creek Karst Valley spills across the Sulphur Spring ground-water divide to emerge in the lower Beaver Creek channel above the Beaver Creek sinks. Earth Tech (1995) documents an interesting high-flow dye trace from "Feature 4 Sink" (Plate 2) in the extreme western part of the Beaver Creek Karst Valley that was recovered at both Sulphur Spring and at Hooper Spring, 8.6 miles to the north.

Ground-water movement is dominated by rapid flow in branchwork karst conduit systems. Treated wastewater from the Town of Orleans wastewater treatment plant (WWTP) is discharged directly to a sinkhole, and flow times to the Orangeville Rise of less than 25 hours have been documented (Bassett, 1976). Yet these apparently very efficient conduits have insufficient hydraulic capacity during peak flow periods. High-flow traces to the Orangeville Rise conducted by both Earth Tech (1995) and the U.S. Geological Survey (Bayless and others, 1994) have detected dye in the lower reaches of Dry Branch (Plate 2, location DBR) and in the dry bed channel of Lost River above the Orangeville Rise (Plate 2, location LRB). These traces document the presence of storm water rises, or overflow springs, connected to the Orangeville Rise underflow resurgence. The Mather Storm Water Rises are a cluster of such overflow springs. Dye detected in the dry bed channel (Plate 2, location LRB) during a tracing from Salkfeld Swallow Hole in the Orleans area by Bayless and others (1994) probably emerged at the Mather Rises (Plate 2). The presence of a large, deep spring alcove at the Mather Rises suggests that these features may have at one time been a major underflow spring discharge point.

The Mather Rises are not the only significant overflow springs in the area. Five pounds of eosine dye was injected into Feature 20 Swallow Hole in the eastern part of the Beaver Creek Karst Valley during high-flow conditions in April 1995 (Plate 2). The dye was detected in charcoal elutant at Orangeville Rise indicating a straight-line flow distance of approximately 6.9 miles. The dye was also detected above background fluorescence on charcoal detectors placed in Dry Branch north of Orangeville (Plate 2, location DBR), and in the dry bed of Lost River above the Orangeville Rise (Plate 2, location LRB). Both of these detections were at relatively low concentration but were well above background and confirmed from multiple dye detectors. Inferred dye flow paths are shown on Plate 2. Possible resurgences for the dye in the Dry Branch include Ragsdale Gulf and a small wet weather rise north of Ragsdale Gulf. Dye detected at Lost River bridge may have resurfaced at storm water rises along the dry bed located by Malott (1952) and shown in Plate 2.

These tracer results indicate that overflow springs above the Orangeville Rise "leak" ground water back to surface channels during high-flow events. Further, the trace from Feature 20 Swallow Hole in the Beaver Creek Karst Valley indicates that *multiple* high-flow storm-water routes and widely separated overflow springs may exist for a given drainage conduit. The presence of alternate storm-water overflow routes via alternate surface or subsurface drainage channels necessitates the evaluation of karst drainage systems, such as those of the Lost River region, with respect to both low-flow and storm-water flow conditions.

The southern boundary of the Orangeville Rise basin is not well defined by dye-tracing data but must certainly lie somewhere between the Mather Rises and Wesley Chapel Gulf (Stop 5) where drainage is known to be toward the Rise of Lost River (Plate 2). The meandering Lost River dry bed must cross the drainage divide at least twice in the last few miles of its course. Numerous storm water rises occur in this reach of the dry bed.

Continuous flow records made at the Orangeville Rise during the 1973 to 1974 period indicate a minimum base flow of about 9 cubic feet per second (Bassett, 1976). By dividing the minimum observed base flow by the ground-water basin size (50 square miles) obtained from tracer test investigations, a normalized base flow value of 0.18 cubic feet per second per square mile may be obtained. This value is in good agreement with normalized base flow values tabulated for similar karst ground-water basins by Quinlan and Ray (1995). The normalized base flow value for Orangeville would thus appear to have some utility in estimating the drainage area of other springs in the Indiana karst where tracer test information is lacking but where discharge measurements may be made.

Discharge from the Orangeville Rise appears to be effectively limited to about 180 cubic feet per second (Bassett, 1976). During high-flow conditions, normally dry storm-water rises upstream from Orangeville discharge large volumes of excess storm water back to the surface and effectively short circuit the lower reaches of the Orangeville conduit system. The Mather Rises (Plate 2) appear to be among the largest of these overflow springs.

Lost River Ground-Water Basin

The Lost River Rise ground-water basin is considerably less studied than the Orangeville basin. The Rise of Lost River is located on private property south of Orangeville, and emerges from a deep mud-lined channel immediately adjacent to Lost River. Flow measurements at the rise are difficult, but continuous flow measurements at Orangeville and at a gauge below the Rise of Lost River during 1972 and 1973 clearly indicate that the base flow of the Rise of Lost River is less than that of the Orangeville Rise.

The Lost River Rise receives drainage directly from sinkholes on the Mitchell Plateau as well as from a considerable surface catchment area in the upper portion of the Lost River watershed. This surface catchment area includes at least 52 square miles above the principal sinks of Lost River and 33 square miles above the sinks of Stampers Creek and other smaller sinking streams in the eastern part of the Lost River watershed. The Rise of Lost River also drains approximately 23 square miles of sinkhole plain and associated surface catchment area located below the principal sinks.

From the principal sinks to Lost River Rise, Lost River flows through subsurface solution conduits a straight-line distance of 7.0 miles. The flow route passes a short distance north of Tolliver Swallow Hole (point of interest), an overflow sink point, where a short section of the underground route was mapped by Malott (1952) (fig. 15). The underground flow route continues to Wesley Chapel Gulf (Stop 5) where dye injected at the principal sinks of Lost River was observed (Murdock and Powell, 1968) (Plate 2). Scuba divers have followed a 10-foot-high by 30-foot-wide submerged conduit of Lost River 300 feet upstream around the north side of the Wesley Chapel Gulf (Clarence E. Dillon, personal communication, 2000). A large storm water overflow cavern extends west from the gulf (fig. 16). Several storm-water rises noted by Malott (1952) in the lower reaches of the dry bed channel west of Wesley Chapel Gulf may be overflow discharge points for the Rise of Lost River, but this has not been definitely established. No subsurface hydraulic connection has been found between the Orangeville Rise and the Rise of Lost River.

The Rise of Lost River is one of the most remarkable karst features of the Lost River area. Where the underground course of Lost River may be observed at Tolliver Swallow Hole and Wesley Chapel Gulf (figs. 15 and 16), the conduit flow system appears to be developed at relatively shallow depth. Malott (1952) estimated that the lowest level of the explored cavern at Wesley Chapel Gulf occurs at about 515 feet above mean sea level. This point in the cavern is located about 1.9 miles east of the Rise of Lost River. The elevation of the Rise of Lost River is about 480 feet above mean sea level.

In the 1970s, cave divers descended a vertical slot opening in the Rise of Lost River to a depth of 160 feet. A large horizontal conduit was discovered at the bottom of the slot at an elevation of about 320 feet above mean sea level (fig. 17). Why does the Lost River conduit system, known to be at relatively shallow depth for most of its length, make an apparent deep phreatic loop in the final two miles of its course? None of the other large karst springs in Indiana are known to extend to such depth. Perhaps the flow of underground Lost River enters the vertical slot somewhere near the top and the flow, in fact, is not that deep. If so, then how did the slot form in the first place? One possible explanation is that the Rise of Lost River may be a modified mineral spring "vent" that discharges ground water from deep in the limestone strata. A number of mineral springs do occur in the West Baden and French Lick area a few miles to the southwest.

The St. Louis Limestone in the area is known to contain beds of anhydrite ($CaSO_4$) and gypsum ($CaSO_4 \cdot 2 H_2O$) (French and Rooney, 1969). Anhydrite and gypsum are relatively soluble rocks that readily dissociate in ground water to produce sulfate. Krothe and Libra (1983) and Tweddale (1987) note that $\delta^{34}S$ sulfur isotopic values in the mineral spring samples closely match values associated with the gypsum in the lower part of the St. Louis Limestone and strongly suggest that the gypsum is the source of the sulfate in the ground water. In certain areas, then, this mineral water circulates back to the surface from depth, presumably along preferential fracture zones. The lower part of the St. Louis Limestone is as much as 150 feet thick in the area near Shoals, Indiana, and gypsum and anhydrite beds occur throughout this sequence (Jorgensen and Carr, 1973).

In 1996, at a location about 5 miles south of the Rise of Lost River (SE¼, NW¼, NE¼, Section 1, T. 1 N.,

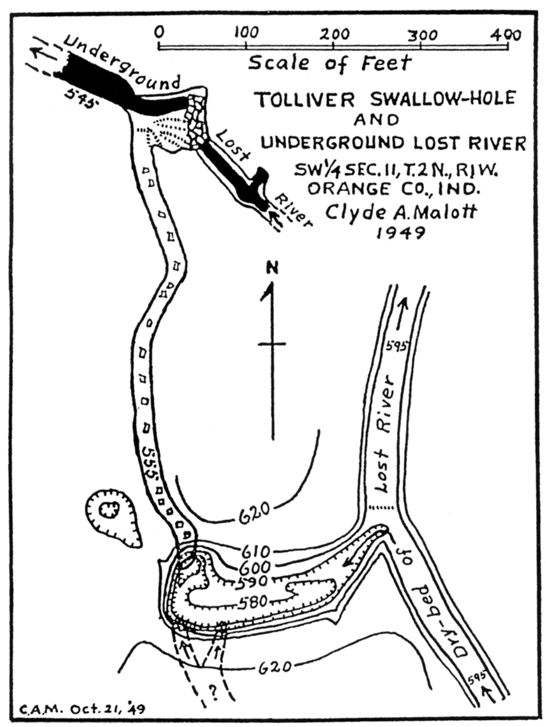

Figure 15. Sketch map of Tolliver Swallow Hole. From Malott (1952).

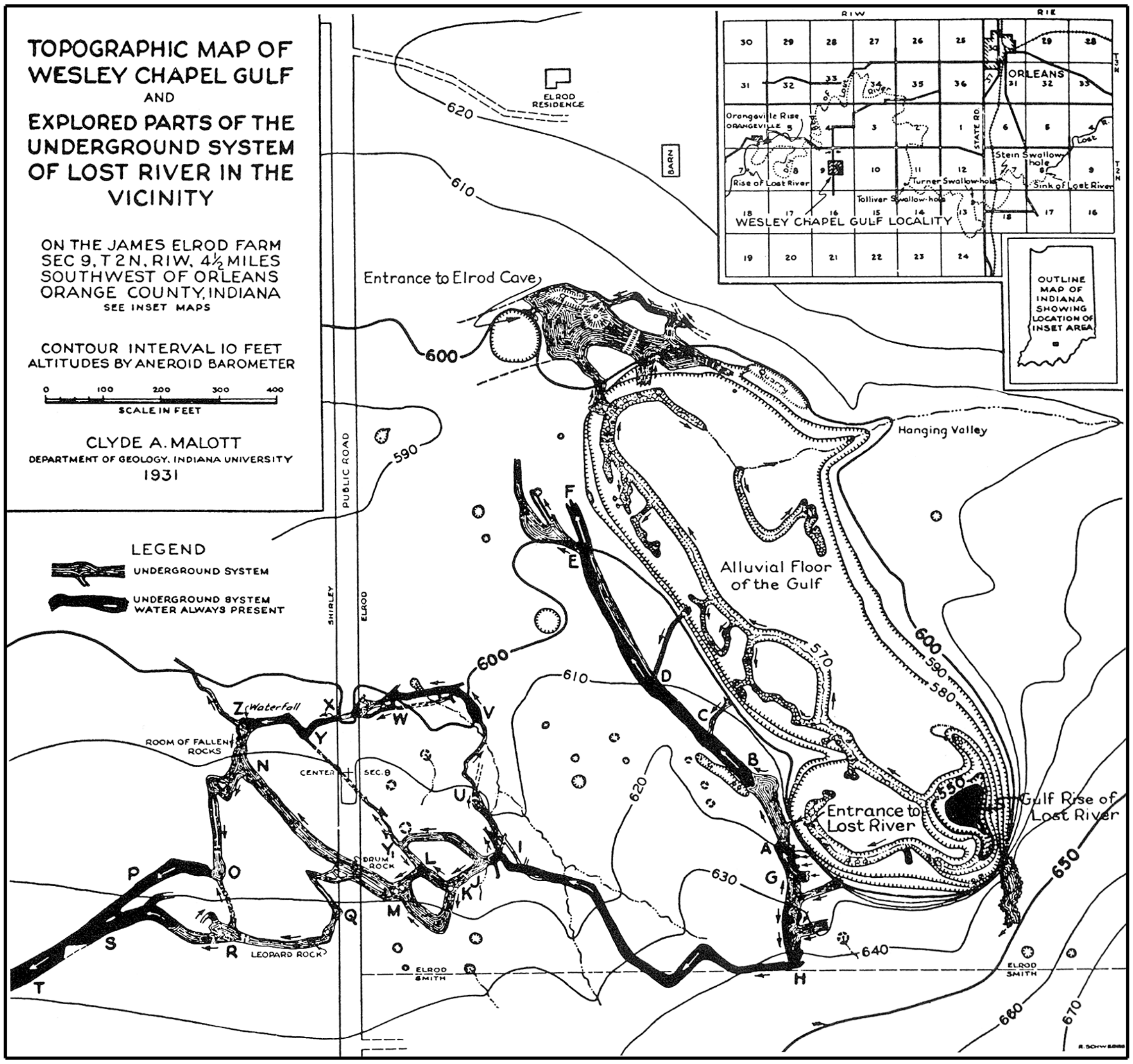

Figure 16. Sketch map of Wesley Chapel Gulf, Stop 5. From Malott (1952).

R. 2 W.), a gas well was drilled to a depth of 1,520 feet. A compensated neutron log of the boring shows several extreme left deviations (very high apparent porosity) in the 202- to 354-foot depth range (333- to 181-foot mean sea level elevation range). The high apparent porosity zones are most likely indicative of bedded gypsum, and gypsum is present in drill cuttings from this interval. The gypsum beds occur throughout an interval of about 152 feet and are particularly prevalent in the lower part.

The renowned Pluto (or Sprudel) water discharging from mineral springs at West Baden and French Lick is natural water containing a very high concentration of sulfate (SO_4). Data from various sources indicate that the sulfate concentration in springs and flowing wells typically ranges from about 1,200 to 2,000 mg/l (milligrams per liter). The Ritter well, a flowing mineral water well on the bank of Lost River at West Baden, drilled to a depth of 388 feet (Cumings, 1912), has a strong sulfur odor and produces mineral water with a sulfate content of 1,600 mg/l (Earth Tech, 1997, unpublished data). Deep domestic water wells in the area commonly produce high-sulfate ground water, similar in composition to the Ritter well and the mineral springs (data in Saines, 1983). The sulfate concentrations allow sulfur-reducing bacteria to thrive in the water. These bacteria chemically reduce some of the sulfate sulfur to hydrogen sulfide, resulting in the characteristic "rotten egg" odor of the mineral water.

It is estimated that the base of the lower part of the St. Louis Limestone occurs at an elevation of about 290 feet at the Rise of Lost River. Thus, stratigraphically, the bottom of the spring vent at 320 feet mean sea level elevation occurs within the gypsum horizon near the base of the St. Louis Limestone, which fits nicely with the possible mineral spring origin for the Rise of Lost River. Ground water slightly below the elevation of the bottom of the Rise is known to contain substantial amounts of sulfate. A water well drilled at a residence 0.5 miles east of the Rise of Lost River produces mineral water having a sulfate content of 1,980 mg/l at a depth of 280 feet (250 feet above mean sea level) (data in Saines, 1983). But limited sampling at the Rise of Lost River indicates that the spring water has a low sulfate content (data in Bassett, 1976). This may not be surprising, however, because the flow of the average mineral spring in the area is only a few gallons per minute, and a large degree of dilution of the mineral water flow would be anticipated. Ongoing dye tracing, cave mapping, and water quality investigations may provide additional insights into the hydrology of the Rise of Lost River and its ground-water basin.

Observation Point A, First Sink

At this point under reasonably normal weather conditions, a slow-moving meandering surface stream flowing in an alluviated valley is visible upstream (east). Here the change in stream morphology is part of the broad physiographic change between the clay-covered, gently rolling part of the Mitchell Plateau to the east and the active sinkhole plain to the west. There is a subdued reentrant here where Lost River crosses this boundary. From this position, the northern leg of the boundary trends northeast-southwest and the other leg is nearly east-west for a little more than a mile before turning southward. The valley here is about 0.3 miles wide, whereas a few miles upstream it is about 0.75 miles wide; downstream it narrows further where "the river begins to downcut even more into a distinct channel below the grade of the Mitchell Plain [Plateau], and loses the morphology of an alluviated valley. The sediment is being carried underground" (Powell and Bassett, 1992).

About 0.25 miles upstream and in the channel is First Sink of Lost River (fig. 14), and the in-channel Blue Hole resurgence is about 0.33 miles farther upstream. The balance between normal surface flow, the spring or springs, and the sink is such that this part of the stream is perennial. About a mile downstream are the principal dry-weather sinks. Although called dry-weather sinks, under normal conditions of precipitation they are a common limit for flowing water. Only under dry conditions of long duration is the First Sink capable of taking the entire flow of Lost River. A short distance upstream from the dry-weather sinks is Miles Cave, one of the easternmost features of the lost part of Lost River.

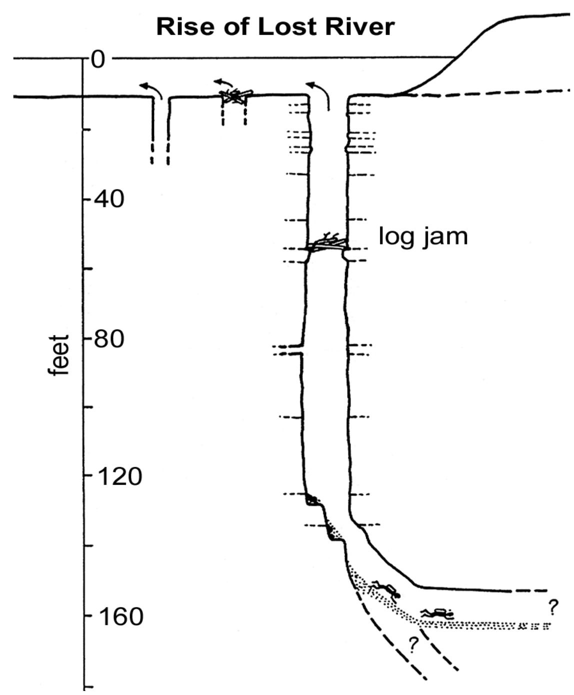

Figure 17. Cross section of Rise of Lost River, Orange County, Indiana. From Quinlan and others (1983).

Observation Point B, Dry Bed at Roosevelt Road Bridge

This stop on the bridge over Lost River on Roosevelt Road is for a quick look at the nature of the dry channel of Lost River, assuming, of course, that at the time of the trip the bed is dry, as is usual. Malott (1952) noted three in-channel swallow holes (fig. 18) between here and Stein Swallow Hole, 0.75 miles (as the crow flies) to the west, but in an active karst region like this, previous swallow holes may close and new ones open or old ones reopen. You will cross the dry channel again on State Road 37 before Stop 4.

Stop 4, Stein Swallow Hole

Stein Swallow Hole (figs. 14, 19, 20) (Plate 2) is the farthest upstream of the three major active swallow holes along Lost River, and it is estimated (Malott, 1952) that it accepts about 750 cubic feet of water per second when the channel leading in to it has 7 or 8 feet of water. The swallow hole is about 60 feet wide by 100 feet long and a cliff rises about 20 to 25 feet above the massive log fill. One cannot get down through the logs to the entrance below, but Malott estimated the base water level to be about 20 to 25 feet below the dry-bed level of Lost River. The small swallow hole and sinks generally north of the main swallow hole take water when the large one is overwhelmed, and when the Stein system is full, water continues downstream to the next sink or swallow hole. The swallow hole is about 75 yards west of the dry bed of Lost River, and some water is lost to small sinks in the connecting channel, which is about 120 yards long, before water enters the swallow hole proper. Unlike the dry weather sinks and a multitude of small sinks within or on the edge of Lost River, all three of the major swallow holes are fed by channels and are on the western side of the dry bed.

One explanation for swallow holes outside the channel is that at one time they were boiling springs resulting from subterranean blockage downstream from the swallow holes, the blocking being related to backfilling during interglacial stages. Thus, the original flow that cut the channels was from the springs to the river.

Observation Point C, Overview from Crawford Upland

Here on the Crawford Upland, essentially at the top of the Springville Escarpment (fig. 21), you are about 200 feet above Lost River. The quarry in the outlier of the Crawford Upland just north of Orleans is about 5.5 miles northward, and smaller outliers suggesting pre-Pleistocene surfaces can be observed. This is the southern flank of the westward reentrant of the Lost River in the Crawford Upland, and the northern flank trends more or less north-northeast by south-southwest and then curves nearly north-south above Lost River.

The material that developed into the thick clay cover on the Mitchell Plateau, including terra rosa, came mostly from the shedding of material from Chesterian rocks. Those processes continue, and as the current escarpment slowly retreats, the weathered and eroded products accumulate with a balance between deposition and erosion in a pediment-like form along the flanks of the escarpment. In the area of the Mitchell Plateau to the east that was not greatly affected by karstification, continued weathering with relatively little erosion has resulted in much more developed soil profiles.

Point of Interest, Tolliver Swallow Hole

Tolliver Swallow is the most spectacular of the swallow holes along Lost River. The cliff along the western edge is about 45 feet high (figs. 14 and 15), although the lower portion can be obscured by timber. The surface level of the Mitchell Plateau is 10 to 20 feet higher than the cliff top. The cave entrance at the base of the cliff leads northward to a trunk passage of underground Lost River. According to Powell and Bassett (1992),

Figure 18. Historic 1933 photograph of noisy vortex in the storm waters of the dry-bed channel of Lost River about 100 yards below Roosevelt Road Bridge, Observation Point B. From Malott (1952).

"The recent Fee survey shows that the cave passage drops 35 feet from the bottom of the sink, which is about 60 feet below the Mitchell Plain [Plateau] surface elevation (610 to 620 feet above sea level), placing upstream underground Lost River 95 to 100 feet below the surface at an elevation of about 520 feet above sea level." There is about 25 feet of drop from the dry bed to the cave entrance, and bedrock along this channel has an unusually high westerly dip. Whether this is from solution related to the swallow hole, a local aberrant increase in dip, or some other cause is speculative.

Lost River on the surface has cut to bedrock in this portion of the stream. The diversion into Tolliver Swallow Hole is much more active erosionally than is the downstream surface flow that is limited to periods of major flooding. The diversion, therefore, has cut below the downstream dry-bed level leaving a tread at the juncture. That is, the upstream dry bed of Lost River, where it swings into the channel leading to the swallow hole, is now about 11 feet below the downstream bed. Flood water must not only fill the cave and the swallow

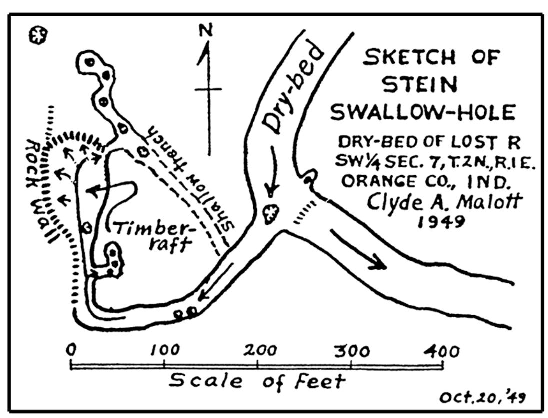

Figure 19. Sketch map of Stein Swallow Hole, Stop 4. From Malott (1952).

hole but must be backed up to a depth of 11 feet in the dry-bedded Lost River before any flood water can flow past Tolliver Swallow Hole down the dry bed.

Stop 5, Wesley Chapel Gulf

Among the many unusual and unique features of the Lost River karst area, Wesley Chapel Gulf is considered the most interesting (figs. 14 and 16). It is the only place in the 7 miles from sink to rise where the underground "Lost River" emerges at the surface, albeit for only a distance of a few feet. It is the prototypical gulf, a large collapse sink having the defining features of a flat alluviated floor, a major spring rising at the southern end, and drainage through a series of many swallow holes into the main Lost River subterranean drainage of which more than 9 miles have been mapped. Standing on the floor of the gulf, one is in a different world surrounded by an oval of cliffs, which ranges from about 25 to 85 feet in height, completely shutting out the surrounding countryside. The 6.1 acres of floor were in crops and pasture before ownership shifted to the U.S. Forest Service. The total area is 8.3 acres having a length and breadth of about 1,200 by 350 feet.

Boiling Spring at the southern end is about 14 feet deep at normal pool level and is nearly azure in color. During storms, however, the water boils up a muddy brown to reddish brown from a solution channel 3 feet in diameter sloping down about 30 feet in a distance of 160 feet to a much larger cave passage leading northeast (Maegerlein, *in* Powell and Bassett, 1992). On occasion, water covers the floor to several feet in depth (fig. 22) and these periods of flooding make it obvious that the floor was formed by alluviation. The spring can carry 4,000 to 5,000 cubic feet per second.

A mud-bottomed major outflow channel close to normal pool level leads more or less along the southwestern wall where it ends in a large swallow hole just east of the cave entrance, which is below an overhang of the cliff (fig. 23). The channel has many sinks along its course, but between periods of rain most of the water sinks near the spring. A second, higher-level channel cuts across nearly to the wall a short distance northeast of the cave and continues to circle along the wall to the northern end where it turns back in a southeasterly direction. A large number of soil-pipe sinks also are in the course of this channel.

The Lost River Chert Bed of the St. Louis Limestone (Rexroad, 2000) lies at about the level of the alluvial floor, and the upper boundary with the Ste. Genevieve Limestone is only a few feet above the top of the chert. The cave passages are in the St. Louis; most of the cliff

Figure 20. The western side of Stein Swallow Hole showing timber raft. Photograph by Carl B. Rexroad.

exposure is Ste. Genevieve. It has been suggested that the gulf was formed by the collapse of a network of cave passages (Powell and Thornbury, 1967) or the collapse of two or more sinkholes and subsequent sapping of the walls by collapse into passages underlying the margins of the gulf (Malott, 1952). Passages of Elrod cave, which opens in a sinkhole just northwest of the gulf, underlie the adjacent part of the gulf and apparently drain part of it.

An intermittent, westward-flowing surface stream enters the gulf over a waterfall near its northern end and is a good example of subterranean capture of surface drainage because the topography shows that the stream once continued to the west of the gulf. It retains its surface characteristics to the east where it displays excellent solution-enlarged joints, but weathering and erosion have eliminated most of the evidence of stream flow to the west.

Malott (1952) indicated that the gulf was originally named Shirley Gulf, that the spring was a source of water for the community, and that in 1876 Elrod named it Wesley Chapel Gulf. This does not explain why it is labeled as Elrod Gulf on the 7.5-minute French Lick topographic quadrangle, but the usual explanation is that it was named after a former land owner.

Stop 6, Orangeville Rise

Orangeville Rise (figs. 14 and 24) is the second largest spring in Indiana. Numerous dye traces over a period of 30 years indicate that the subterranean drainage basin of the rise encompasses about 50 square miles and as noted earlier includes wastewater treated by the Orleans treatment plant. The Orangeville Rise is fed by both fluviokarst in the Crawford Upland and drainage from the Mitchell Plateau to the northeast (Plate 2). It is distinct from drainage to the true rise of subterranean Lost River, which is about 0.75 miles downstream and whose water comes mostly from the east from the Mitchell Plateau.

The True Rise of Lost River and the Orangeville Rise are vertical rise cave springs fed through deep, phreatic, bedrock conduits and through 20 to 30 feet of overlying interglacial backfill, which raised ground-water level and resulted in the current artesian springs. The

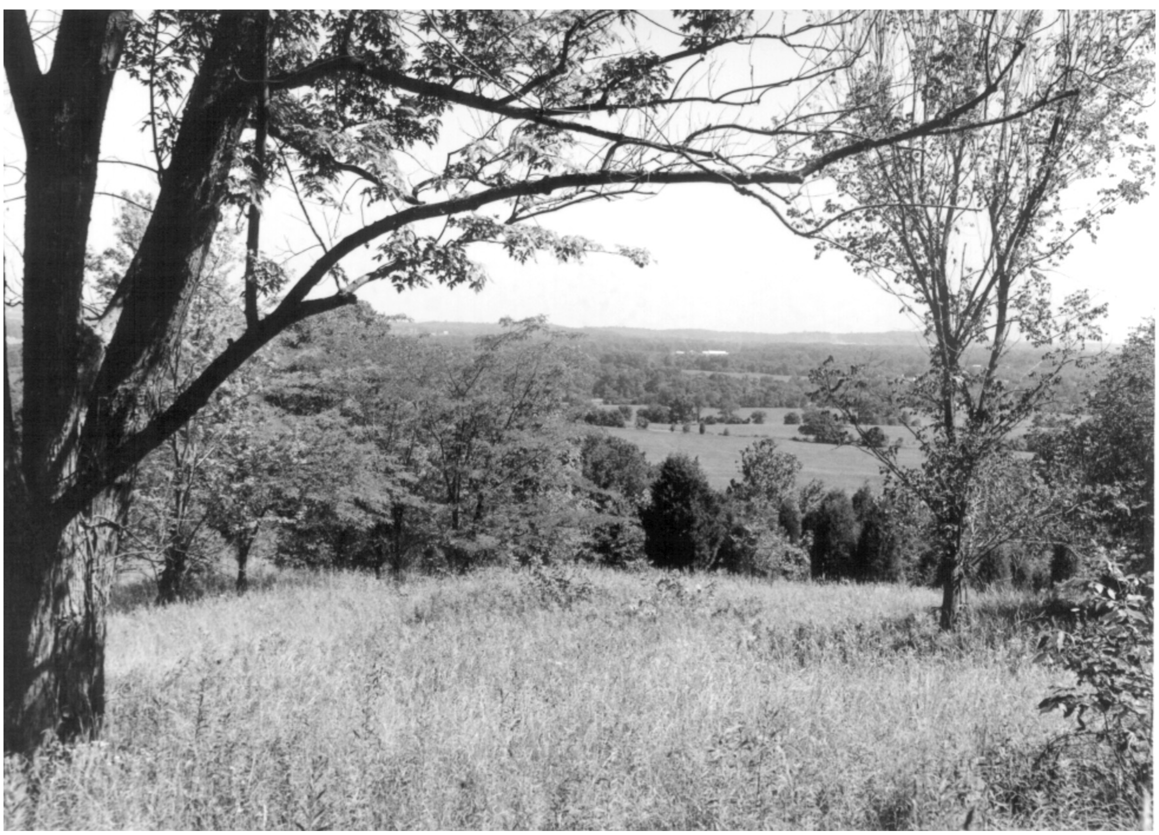

Figure 21. Part of the Mitchell Plateau viewed from the Springville Escarpment at Observation Point C. Photograph by John M. Day.

Figure 22. The southern end of Wesley Chapel Gulf during overbank flooding of "Boiling Spring." Photograph by Samuel S. Frushour.

alcove setting of Orangeville Rise is formed in the Ste. Genevieve Limestone, and in extremely high-water conditions, the level of the spring may rise above the top of the cliff.

Downstream, the complex True Rise of Lost River lies in a deep mud-lined channel immediately adjacent to Lost River. The depth of the rise is exceptional. Divers have descended one slotlike passage 160 feet vertically (Maegerlein, *in* Powell and Bassett, 1992) to an unexplored, presumed nearly horizontal passage, which is stratigraphically in the lower part of the St. Louis Limestone, the interval containing commercial deposits of gypsum, a rock considerably more soluble than limestone.

The Orangeville Rise is designated as a National Natural Landmark, now owned and protected by the Indiana Karst Conservancy.

Figure 23. Cliff overhanging entrance to cave in western wall of Wesley Chapel Gulf. Photograph by John M. Day.

Figure 24. The Orangeville Rise (Stop 6) during a flood stage. Photograph by Samuel S. Frushour.

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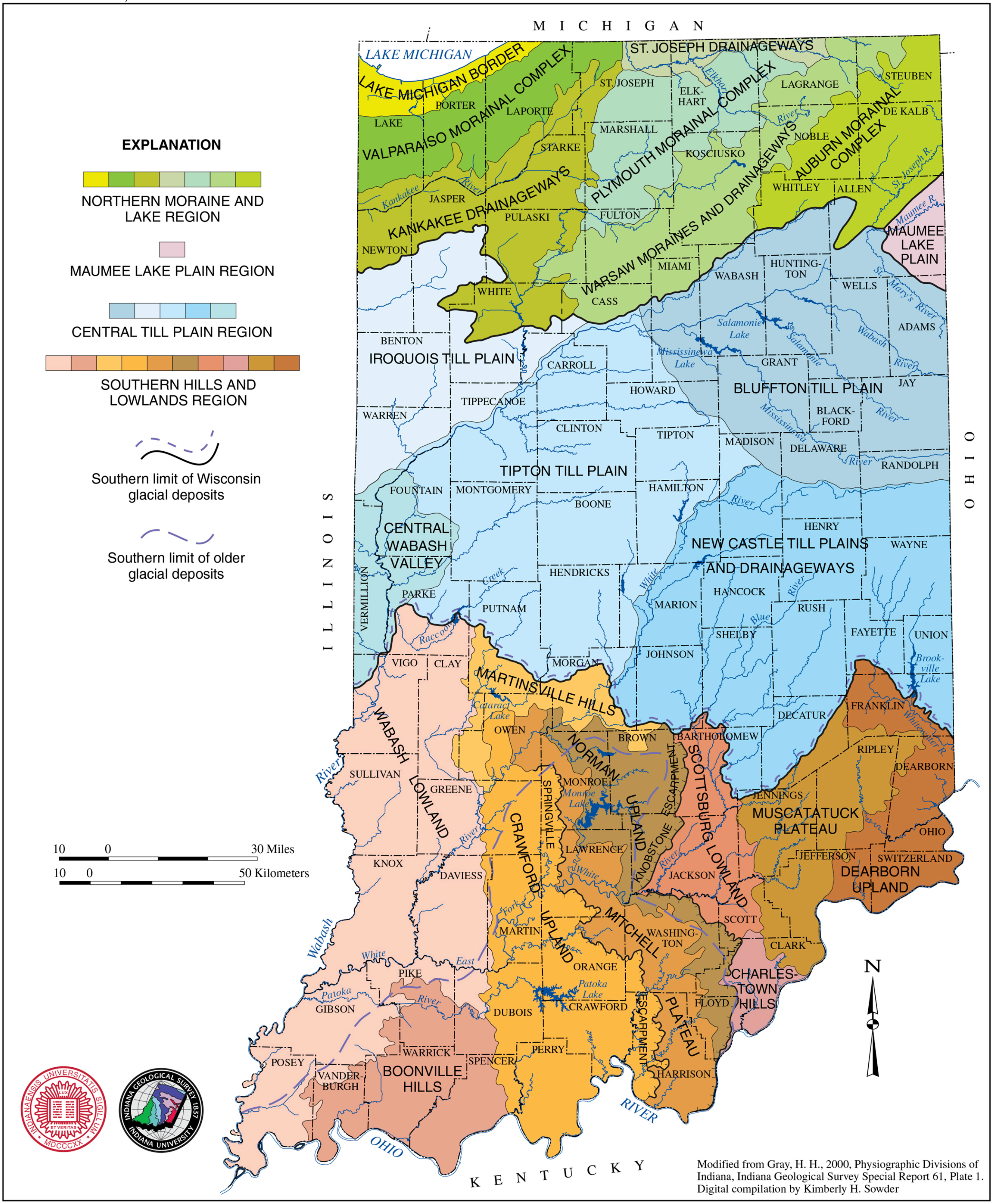
APPENDIX: Driving Instructions

Departing from the Indianapolis metropolitan area, travel south to Indiana State Road 37. Take Indiana State Road 37 south to the intersection of State Road 37 and State Road 60 West near the town of Mitchell, Indiana. Continue south on State Road 37 0.8 miles to State Road 60 East. At the junction of State Road 37 with State Road 60 East turn left (east) and proceed 3.3 miles to the entrance to Spring Mill State Park. Stop 1 at Spring Mill Lake, Stop 2 at Donaldson Cave, and Stop 3 at the Pioneer Village are in Spring Mill State Park.

Return to park entrance and turn right (west) on State Road 60 and retrace route to State Road 37. There turn left (south) for the Lost River part of the trip and continue 4.7 miles to State Road 337 in Orleans. Turn left (east) and in about 1.75 miles turn right (south) on County Road 200 E. Proceed 1.5 miles to Observation Point A where Lost River is visible. Continue about 0.25 miles along the river and turn right (west) on County Road 500 N; go 1 mile to Roosevelt Road (County Road 100 E), turn left (south), and go about 0.75 miles to Roosevelt Road Bridge and Observation Point B.

Continue southward for about 0.75 miles and turn right (west) on County Road 350 N and go about 1.25 miles to State Road 37. Turn right (north) and proceed 1 mile to Reynolds, Inc. Enter, cross railroad right-of-way, and walk south to Stop 4, Stein Swallow Hole. Return to State Road 37 and turn left (south). In 0.5 miles turn right (west) on County Road 400, after 1 mile turn left (south) on County Road 100 W. Keep right at a triangular junction at about 1.5 miles and a few hundred yards farther, make a sharp right turn (westerly). Observation Point C, an overlook, is a little more than 0.5 miles more.

The road goes down a steep hill and turns northeast and north becoming County Road 200 W. Tolliver Swallow Hole will be on the right in 1.5 miles, 1 mile before County Road 500 N. Turn left (west) on County Road 500 N and go 1.5 miles before turning left (south) at Wesley Chapel on County Road 350 W. In 0.25 miles turn left into the labeled parking area for Stop 5, Wesley Chapel Gulf. On leaving Wesley Chapel Gulf return north to County Road 500 N and turn left (west). Follow the road to Orangeville turning left at the T-junction with County Road 500 W, a total of about 2 miles. In Orangeville turn left down the incline and park on the right by the rise, Stop 6. Retrace route to Wesley Chapel and County Road 350 W. Turn left (north) and follow the turns and curves for slightly less than 3.5 miles to a T-junction with County Road 100 W. Turn left (north), go more than 0.5 miles to another T-junction with County Road 700 N. Turn right (east) and drive into Orleans and junction with State Road 37, a little more than 1.25 miles. Turn left (north) and proceed to Indianapolis.



Modified from Gray, H. H., 2000, Physiographic Divisions of Indiana, Indiana Geological Survey Special Report 61, Plate 1. Digital compilation by Kimberly H. Sowder

MAP OF INDIANA SHOWING PHYSIOGRAPHIC DIVISIONS

By Henry H. Gray

2001

PLATE 2

Map Showing Dye Traces in the Bluespring Caverns, Spring Mill Lake, Lost River, and Orangeville Rise Ground-Water Basins

Modified from original map by John L. Bassett, February 2000