Geology for Environmental Planning in Monroe County, Indiana

By EDWIN J. HARTKE *and* HENRY H. GRAY

ENVIRONMENTAL STUDY 21

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INTRODUCTION

Monroe County is in south-central Indiana about 35 miles south of Indianapolis, the state capital (fig. 1). Its shape approximates a rectangle, and its longest dimension is abut 24 miles from north to south. The area of the county is about 412 square miles.

Monroe County is one of the most rapidly growing counties in Indiana. The population was 101,000 in 1982 (U.S. Census Bureau, 1984), and it is projected to reach 108,600 in 2000 (Division of Research, 1983). Most of the population is concentrated in and around Bloomington and Ellettsville. The population of Bloomington and of the county is increased by 30,000 Indiana University students during the normal school year. The student population falls to about 13,000 during the summer.

Monroe County has a continental temperate climate. This area is typically hot and humid during July and August. The daily average high temperature is 85°F, but temperatures occasionally approach a maximum of 105° to 110°F (Visher, 1944). Winters are cold and damp. The average minimum daily temperature is 23°F, but December-January-February temperatures can drop below -20°F. The spring and the fall are generally comfortable, but the weather is subject to extreme fluctuations throughout the year.

According to records maintained by the Indiana University gaging station, the average annual precipitation is about 44 inches, which is spread relatively evenly throughout the year. Much spring and summer rain falls during thunderstorms, some of which bring damaging winds. Seasonal snowfall averages about 8 inches per year, but much more may fall during a severe winter.

Monroe County was established by an Act of the General Assembly in 1818, but the modern boundaries were not set until 1836 (Greene, 1880). The first permanent settlement in the area that was to become Monroe County was in 1816 in the confines of the present city of Bloomington. Early settlers arrived from Grant County and Clark County, Ind., and from Kentucky.

When the first white settlers arrived, Monroe County was magnificently wooded with white and yellow poplar, white, red, black, and chestnut oak, white and black walnut, ash, cherry, chestnut, beech, hickory, elm, sycamore, black and sweet gum, sassafras, and dogwood (Greene, 1880). A large part of the forest was wastefully destroyed during the original clearing. By 1880 most of the good timber had been removed, not for lumber but for farmland.

The virgin woodland soils initially produced excellent crops, but yields soon fell because of reduced fertility and erosion (Thomas and others, 1981). Much of the marginal land that was cleared early has since been abandoned and salvaged by natural reforestation.

Woodland, the largest single land use in Monroe County, covers about 45 percent of the county. Farming is the second major land use; about 20 percent of the county is in cropland and 15 percent is in pasture. Rapid growth in population (greater than 20-percent increase from 1972 to 1984) is placing great pressures on both agricultural and woodland resources. In addition, part of the county landscape has been effectively removed from beneficial use through crushed-stone and dimension-stone quarrying.

This report is designed to present general information to planners, government officials, and the public to assist them in the orderly development and use of the natural mineral resources of Monroe County. It is also a useful guide to more detailed information that is required for specific projects involving earth materials. This is not a definitive, detailed work but is a preliminary estimate of the land-use suitability and mineral resources of the county. For example, the maps are approximations and the boundaries shown on them are gradational, but in nearly all areas more detailed information is available at the Indiana Geological Survey. Data sources

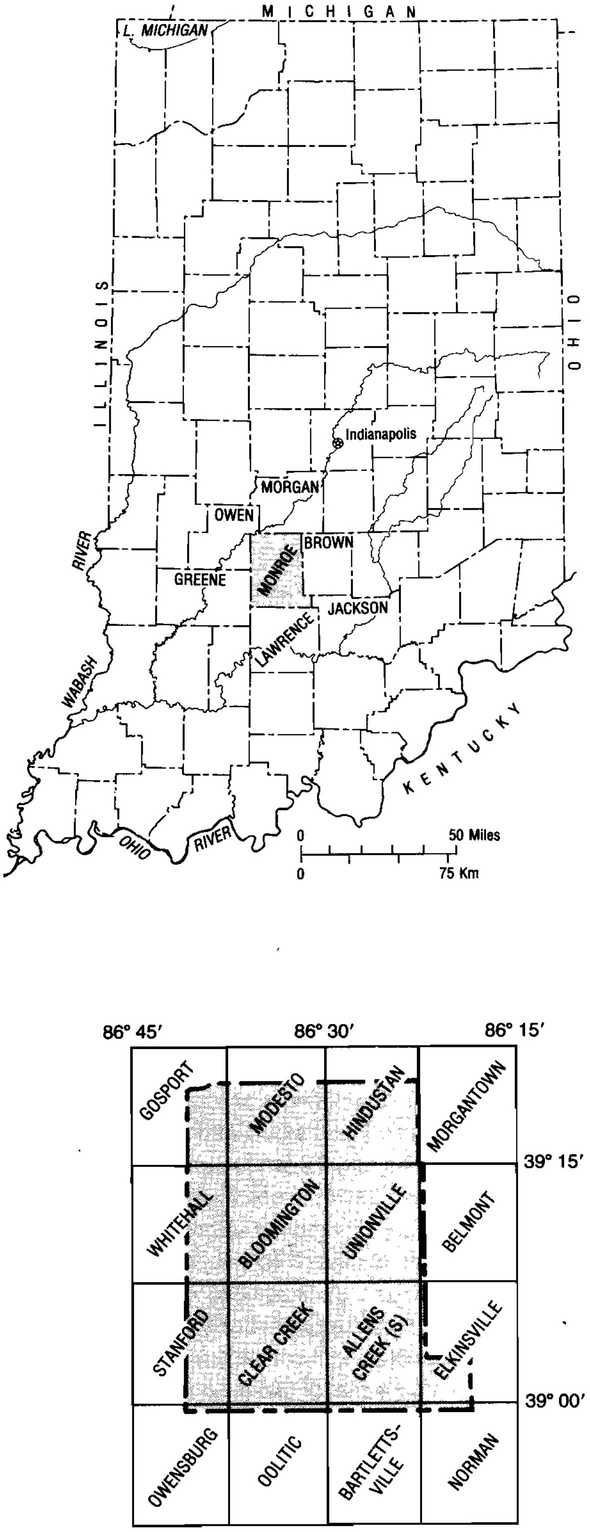


Figure 1. Map of Indiana showing the location of Monroe County and an index to U.S. Geological Survey topographic-map coverage.

for this study include field-investigations, auger borings, seismic surveys, oil- and water-well logs, and published and unpublished reports.

GEOLOGY

GEOLOGIC STUDIES

The geology of Monroe County has been studied for many years. The area surrounding Bloomington has been the locus of many faculty and student studies since geology was first taught at Indiana University in 1853. Since 1919 the State Geologist has been a faculty member at Indiana University, and since 1947 the Indiana Geological Survey has been on the University campus.

The earliest geologic report on Monroe County was prepared by Greene (1880). A second general geologic discussion by Beede and others (1915) covered the Bloomington area. The famous dimension stone, which is generally known as Indiana Limestone and is the basis for the most important mineral industry in Monroe County, was discussed by Hopkins and Siebenthal (1897) and by Siebenthal (1908), and a map showing the extent of the building-stone deposits was prepared by Logan and Esarey (1928). All of these investigators were members of the University faculty, staff of the Geological Survey, or both.

More recently, the Mt. Carmel Fault, a significant structural feature that traverses the county (fig. 2), was mapped by Melhorn and Smith (1959), and urban geology of the Bloomington area was discussed by Gates (1962). Soils of the county were mapped and described by Thomas and others (1981), and a further report on building stone was written by Patton and Carr (1982). Besides these maps and reports, there are dozens of lesser studies and numerous comments on the geologic features of Monroe County in more extensive works, such as in Malott's (1922) classic report, "The Physiography of Indiana."

TOPOGRAPHY

The landforms of Monroe County can be grouped into three topographic regions. These are parts of larger areas in Indiana that were described many years ago and given names by Malott (1922). The northern and eastern parts of the county (fig. 2) are part of the Norman Upland, an area of steep rocky hills and narrow ridgetops. A central belt about 6 miles wide from Stinesville through Bloomington to Harrodsburg is part of the Mitchell Plain, a plain that in many places has abundant sinkholes (fig. 2) and that typically has moderate slopes except where large streams, such as Clear Creek, have cut deep valleys. In southwestern Monroe County, hills that have broad ridgetops and typically moderate slopes are part of the Crawford Upland.

Distinctions between these regions can be seen on topographic maps (fig. 3) but also are apparent on the ground at many places. Driving eastward from Bloomington on State Route 46 (Nashville Road), one leaves the broad slopes of the Mitchell Plain and enters the Norman Upland near the intersection of S.R. 446 (Knight Ridge Road). Slopes break off sharply on both sides of the highway as the road runs a sinuous ridgetop course for about 3 miles before descending steeply to the valley of Stephens Creek. Not everywhere, however, is the contrast so clear. For example, S.R. 45 northeast of Bloomington follows a gradually narrowing ridgetop along which no clear-cut topographic boundary between the Mitchell Plain and the Nomran Upland can be discerned, and plateaulike areas in the Norman Upland north of Beanblossom Creek and west of S.R. 37 have many features of the Mitchell Plain.

Westward from Bloomington following S.R. 48 (Whitehall Pike), one crosses the Mitchell Plain in a straight line to Oard Road, $2^1/2$ miles west of S.R. 37. From there in a series of curves and grades the road ascends about 50 feet through rolling hills typical of the Crawford Upland and passes through a topographic saddle into the valley of a tributary to Richland Creek. The prominent hills west of the Monroe County Airport are part of the escarpment that separates the Crawford Upland from the Mitchell Plain. In Monroe County this boundary is quite clear from its southernmost point about 3 miles southwest of Harrodsburg to its northernmost point about 4 miles west of Ellettsville.

Many of the terrain types designated as map units on plate 1 and in table 1 are associated with one or another of these topographic regions. For example, units "tr," "k," and "ls" are typical of the Mitchell Plain, unit "s" is widespread in the Norman Upland, and unit "h" makes up much of the Crawford Upland. But some map units are found in more than one physiographic region. The Crawford Upland includes some areas of unit "k," and unit "tr" caps some of the ridgetops in the Norman Upland.

More than half of Monroe County—about 52 percent of the area of the county—is in the Norman Upland, 33 percent is in the Mitchell Plain, and the remaining 15 percent is in the Crawford Upland.

BEDROCK

The topography of Monroe County primarily represents the passive response of the various underlying bedrock formations to agents of erosion. Each of the three physiographic regions described above has its characteristic underlying bedrock type (fig. 4). The bedrock formations are all late Paleozoic in age; that is, they date from a few hundred million years ago. They were deposited in ancient seas and streams, along shorelines, in deltas, or in open shallow clear-water seas that were probably similar to those around the Bahamas or off the Florida coast today. After the soft sediments were deposited, they were lithified by compaction and cementation, and then they were gently uplifted and tilted slightly toward the southwest. Erosion since has beveled the rocks, so that younger formations crop out in the western part of the county and older formations crop out in the eastern part (fig. 4).

Capping the hills around Kirksville, the youngest rocks in Monroe County are beds of sandstone and shale a few feet thick that belong to the Mansfield Formation of the Raccoon Creek Group (Pennsylvanian) (fig. 5). These rocks contain a thin coalbed that was mined for local use many years ago, but the bed is too thin and too irregular in distribution to be economically attractive at present.

Lying beneath the Mansfield Formation and making up the bedrock of most of the Crawford Upland are beds of sandstone, shale, and limestone that belong to the Stephensport and West Baden Groups (Mississippian) (fig. 4). These, along with the Mansfield Formation, underlie map unit "h" (pl. 1 and table 1). Gentle to moderate slopes with soils 3 to 15 feet thick form on these rocks. The upland soils are loamy, but on the slopes the soils are stony, and in many places ledges of sandstone and limestone crop out. The stony soil moves slowly downhill by a process known as soil creep, and in some areas it forms an apron over limestone bedrock to form map unit "hl." Units "h" and "hl" are restricted to the southwestern part of the county and to a large extent define the area of the Crawford Upland.

The Mitchell Plain in the Bloomington area is underlain by limestone assigned to the Blue River and Sanders Groups (Mississippian) (fig. 4). Three of the formations included in these groups are economically important. The Paoli and Ste. Genevieve Limestones, which crop out along the west edge of the Mitchell Plain and in valleys in the Crawford Upland,

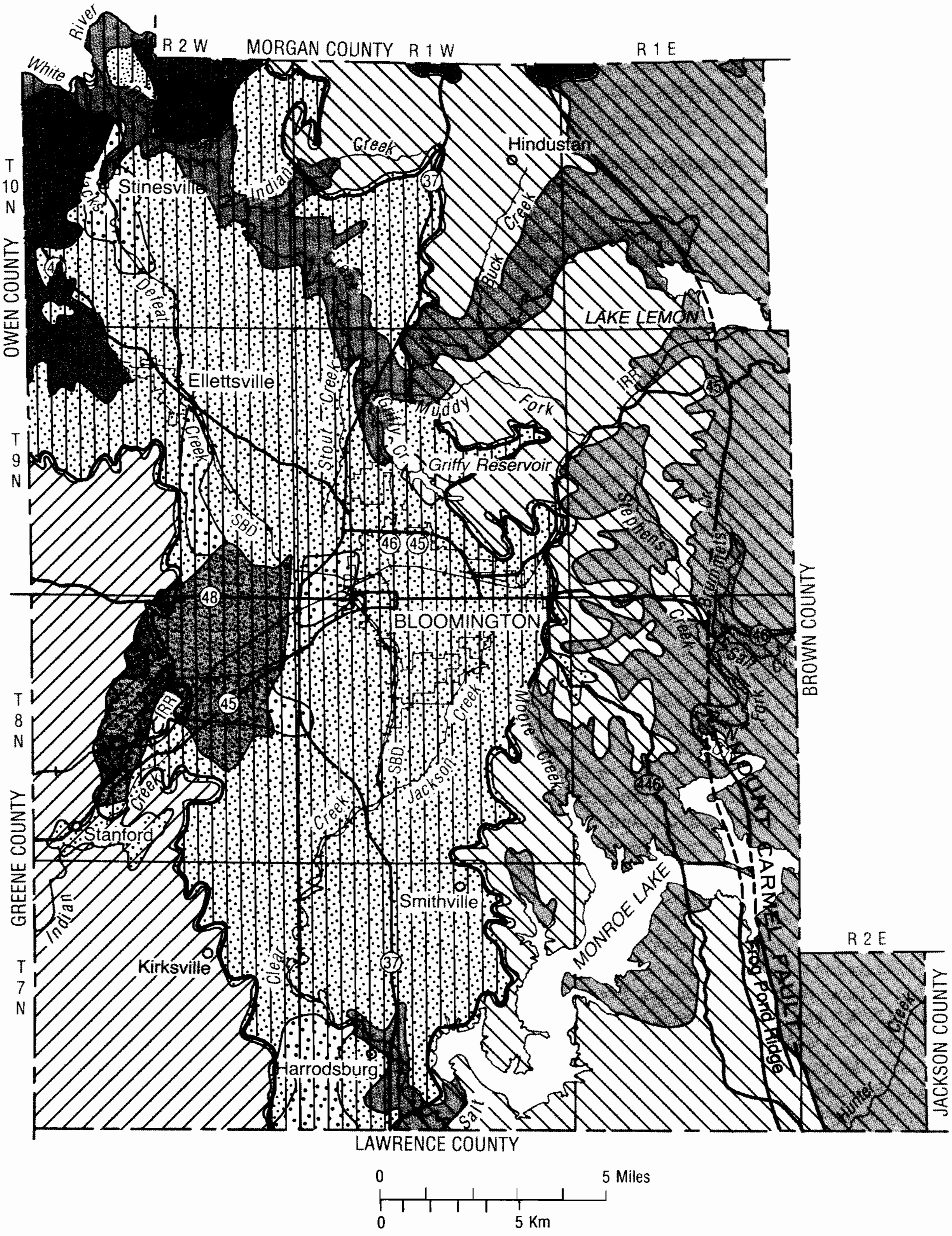


Figure 2. Map of Monroe County showing approximate boundaries of physiographic provinces and contrasting landforms. Red stipple pattern indicates areas of dense sinkholes (more than 25 mappable per square mile), and stippled gray shaded pattern indicates areas where drainage is mostly underground through solution channels.

EXPLANATION

Boundary of physiographic provinces

Crawford Upland

Mitchell Plain

Norman Upland

Rolling loess, till, and outwash upland/valley

Flood plains and low terraces

Rolling dunes

Rolling limestone plain

Steep to rolling sandstone, siltstone, and limestone upland

Steep siltstone and sandstone upland

Steep limestone, siltstone, and sandstone upland

Areas of dense sinkholes
(more than 25 mappable per square mile)

Areas where drainage is mostly
underground through solution channels

Nearly level lakebed

are the principal source of aggregate and agricultural stone in the county, and the Salem Limestone yields the famous building stone and is also a source of specialty high-calcium limestone. Most of the quarries (pl. 1) are in these three formations. A few abandoned quarries were formerly operated in the Harrodsburg Limestone on the east edge of the Mitchell Plain.

The most definitive map unit of the Mitchell Plain is map unit "tr" (pl. 1), on which most of Bloomington is built and which covers about 38 percent of the Mitchell Plain in Monroe County. This unit defines those parts of the plain that have generally gentle slopes. It is characterized by relatively thick soils that have two distinctive layers: an upper layer of windblown silt that is about 3 feet thick where it has not been reduced or removed by erosion (loess; see description under map unit "lo") and a lower layer of stone and plastic red clay known as terra rossa or "red earth." This material forms over limestone bedrock where slopes are not steep. It is partly a residual material derived from solution of the underlying limestone and partly a transported material derived from overlying rocks by erosion and stream transport.

The limestone surface beneath unit "tr" is highly irregular, a result of the solubility of limestone, and in some places there are numerous crevices that are deeply filled with rock rubble and red clay. Deeper in the limestone, open crevices and channelways that are yet another result of solution carry water occasionally, frequently, or constantly, depending on the season of the year, the topography, and the position with respect to nearby streams and springs that are outlets for the underground water. A few closed surface depressions called sinkholes are found within areas of unit "tr" especially adjacent to areas of unit "k" or near the steep slopes of unit "ls" along deeply entrenched streams.

Areas of karst—a type of topography that is formed by dissolution of limestone (as in Monroe County), dolomite, or gypsum and that is characterized by closed depressions, caves, and underground drainage—are also typical of the Mitchell Plain and are mapped as map unit "k" (pl. 1). Some karst areas are also found along the east edge of the Crawford Upland in places where limestone is the dominant bedrock. Many sinkholes in these areas are active and have one or more obvious openings through which surface water drains quickly into an underground system of joints, crevices, and caves. Karst features are formed by the differential solution of carbonate bedrock by percolating ground water. These features are most prominent in the St. Louis

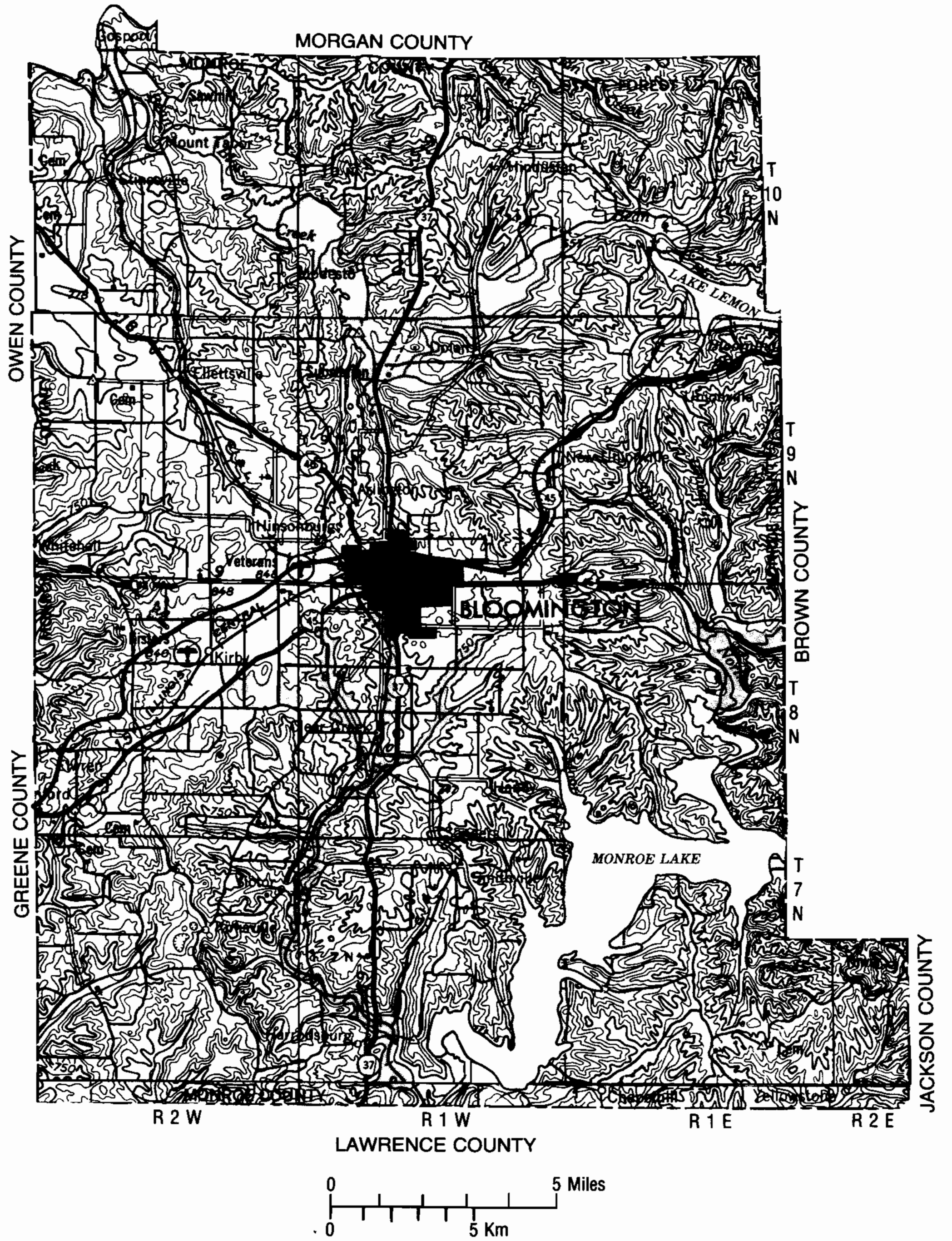


Figure 3. Map of Monroe County showing surface topography (50-foot contour interval), surface-drainage divide (solid red line), and flood-prone areas (red shaded areas). The base and topographic contours are from the U.S. Army Map Service (1954).

and Ste. Genevieve Limestones because they are mostly thin bedded and have extensive joint systems. The Harrodsburg, Salem, and Paoli Limestones, all of which appear at the bedrock surface in the Mitchell Plain, also exhibit some karst development. Topographically the area is characterized by its irregular, somewhat rolling relief and by abundant, variably sized closed depressions.

Unconsolidated deposits in the karst area range from a thin veneer to as much as 30 feet in thickness.

The deposits generally consist of terra rossa that directly overlies the limestone. Variously colored silt and clay layers (loess and [or] colluvium) lie above the residuum. In most places the surficial layer is a thin (2 inches to 2 feet) blanket of loess. The karst area in Monroe County is discussed in more detail later in this report.

A third map unit (pl. 1) that is also characteristic of the Mitchell Plain is unit "ls." This unit includes areas of moderate to steep slopes that are commonly adjacent to deeply incised streams and that have only a thin stony soil over limestone bedrock. Some areas of this unit also occur in the Crawford Upland and at the foot of the escarpment separating that topographic region from the Mitchell Plain. Because the bedrock is limestone, there is subterranean drainage in parts of unit "ls"; active sinkholes, many springs, and numerous outcrops and ledges of limestone occur in this unit. Unit "ls" covers about 27 percent of the Mitchell Plain in Monroe County and is especially widespread in the valley of Clear Creek southwest of Bloomington.

Many ridges in the Norman Upland are capped by limestone, and unit "tr" also occurs there on some of the broader ridgetops; unit "ls" occurs where the ridgetops are narrow or where slopes adjoining the ridgetops are steep. A related unit, "lc," occurs in small areas beneath steep slopes and limestone outcrops, where slabs of limestone have gradually moved downhill to form an apron over the underlying siltstone bedrock. Areas of unit "lc" are small and are restricted to the west margin of the Norman Upland.

Map unit "ss," which occupies most of the Norman Upland in Monroe County, is characterized by steep slopes, narrow ridgetops, and thin stony soils. Bedrock that belongs to the Borden Group is siltstone (fig. 4), and outcrops of siltstone are common, especially in creek banks and on the narrow floors of small steep flumelike ravines. Historically, soils of unit "ss" have been subjected to severe erosion as a result of logging and agricultural practices of the past 150 years. Most of this area is again forested. Areas of unit "sm" are generally similar but have more moderate slopes and somewhat thicker soils.

Rocks of the Borden Group are notoriously poor yielders of ground water, and before many residents of the Norman Upland had centralized rural water systems they depended on cisterns for water supplies. But the coming of adequate central water systems to this area has been a mixed blessing, because the thin soils and steep slopes of map unit "ss" are not conducive to proper operation of septic-tank leach fields.

UNCONSOLIDATED DEPOSITS

Although bedrock exposures are numerous in Monroe County, over most of the area of the county the bedrock is covered either by soil that is more or less related to the underlying bedrock, as in the units described above, or by thicker deposits of materials laid down within the past few hundred thousand years by sedimentary processes such as stream action or glaciation (fig. 6). These deposits are classified as unconsolidated to distinguish them from bedrock. They are not cemented or compacted into indurated rock but are composed of more or less cohesive aggregates of particles ranging from gravel to clay in size. They are described below in approximate order of decreasing age.

Map unit "ti" is till that was deposited by glaciers perhaps as long as 500,000 years ago. These glaciers, which were probably among the first to invade Indiana, reached at least as far south as Ellettsville and Hindustan, but their once-extensive deposits have been eroded, so that only small remnants remain, principally in the Stinesville and Mt. Tabor area. The till left behind by these glaciers is a nonstratified mixture of particles of all sizes, from boulders to clay, and is not more than 15 feet thick in most places. The total area covered by unit "ti" in Monroe County is less than 2 square miles. Considerably more widespread is unit "tl," in which the deposit of till is only about 5 feet thick and is underlain by red clay, the terra rossa of unit "tr" described above. Bedrock beneath unit "tl" is limestone.

Small areas in northwesternmost Monroe County are occupied by two map units that are mostly sand. These are unit "ds," windblown sand in dune form along the margin of the White River valley, and unit "os," sand deposited by meltwater from the glaciers just described. Sand of unit "ds" is thin and has only a weakly developed soil because it is relatively young; sand of unit "os" fills a former valley of Beanblossom Creek, has a well-developed red soil that indicates considerable age, and is as much as 100 feet thick in the deepest part of the old valley.

Unit "lo" is composed of thick windblown silt known as loess. About 20,000 years ago, the most recent glaciers to affect this area occupied northern and central Indiana and advanced as far south as Martinsville. Great quantities of meltwater released from these glaciers carried a vast amount of sand and gravel down the White River valley. The volume of meltwater reached a maximum each year in late summer and early fall; by midwinter the streams were dry, and winds whipped dust from the barren expanses of sand and gravel. Dune sand was deposited near the

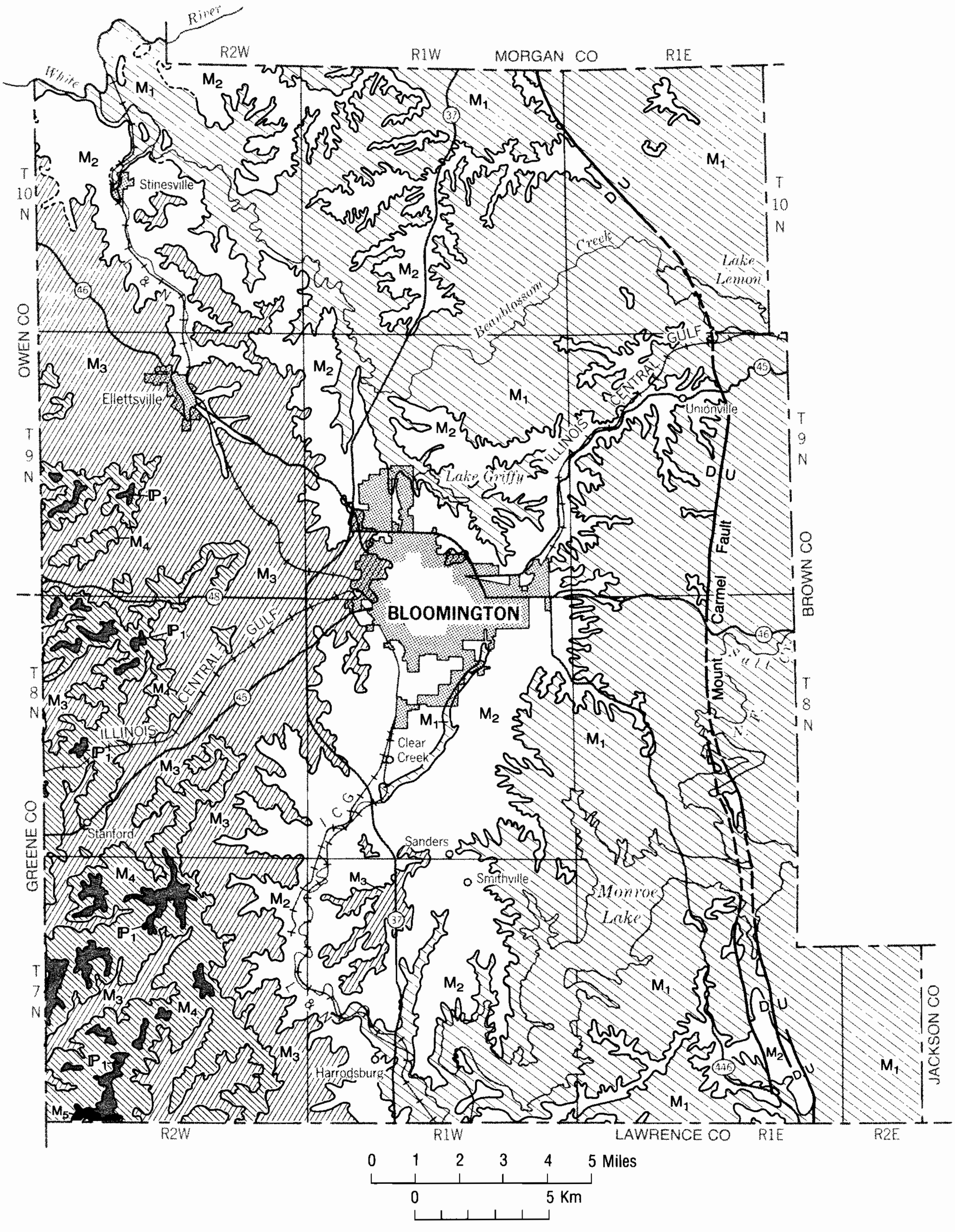


Figure 4. Map of Monroe County showing bedrock geology. From Gray and others (1970) and Gray and others (1979).

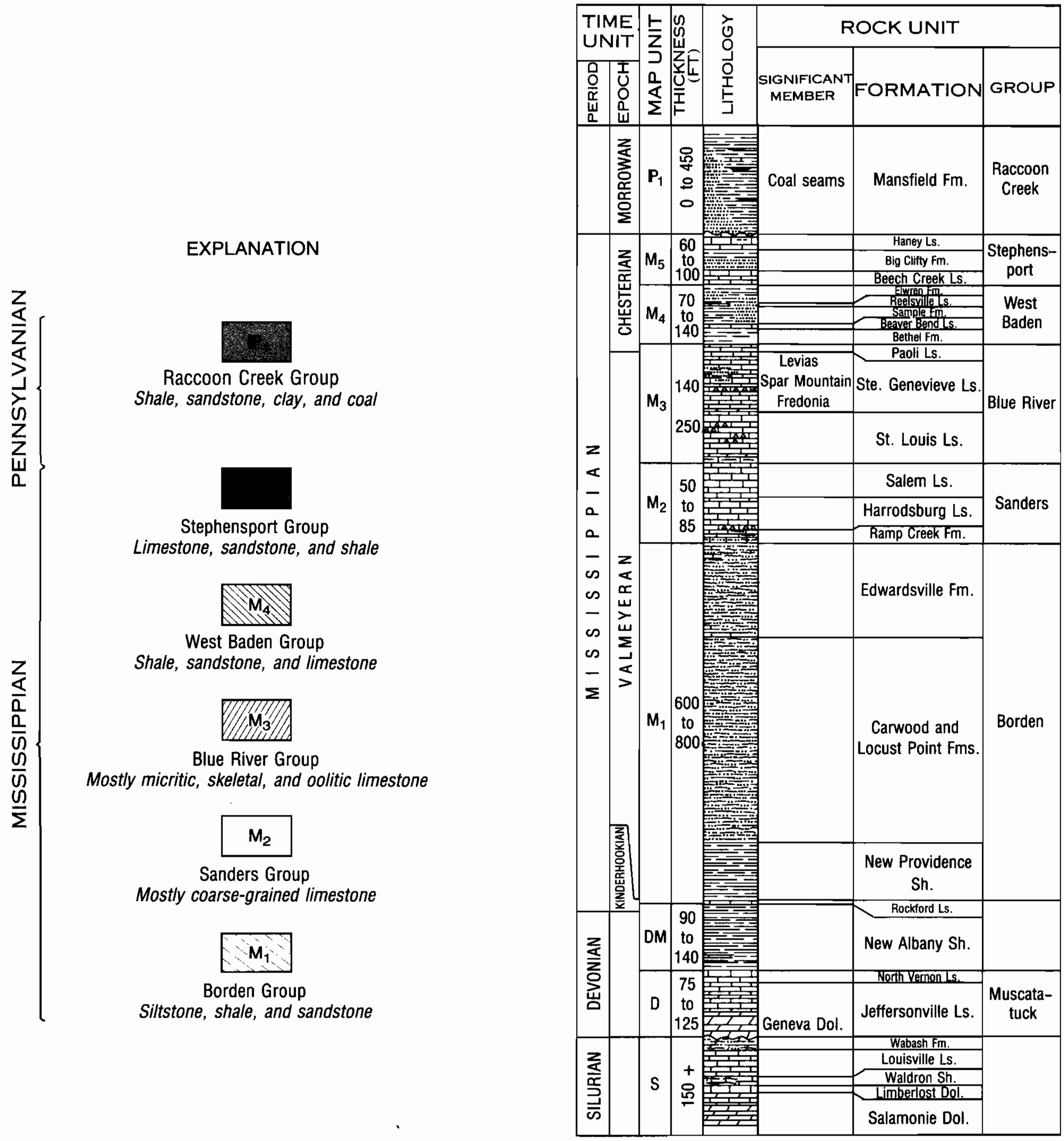


Figure 5. Columnar section showing the upper part of the stratigraphic column beneath Monroe County.

valley edge (map unit "ds"); the finer particles were carried farther and were deposited as a blanket of silt over the entire landscape.

Loess is actually the most widespread surface deposit in Monroe County, and most soils in the county are developed in the loess that caps other soil

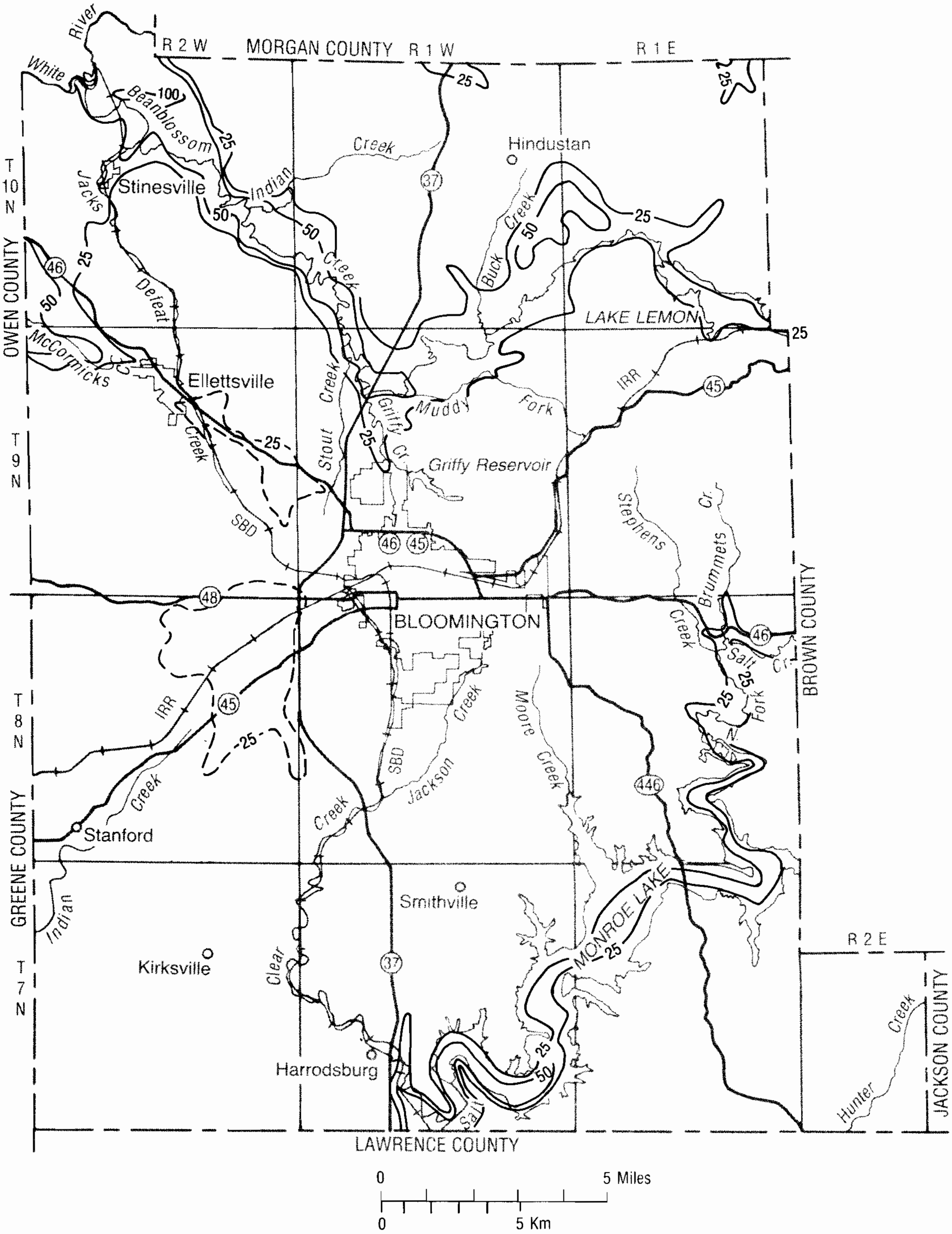


Figure 6. Map of Monroe County showing the thickness of unconsolidated materials. The contour interval is 25 feet. The dashed line encloses areas in which the thickness mostly exceeds 25 feet.

materials. It is mapped as unit "lo" only where the loess is thick (6 feet or more) and where it is therefore the dominant surficial material. Its importance in the other map units is commented on in table 1.

In most places where the loess is thick, such as in the Flatwoods region northwest of Ellettsville and in the industrial area on the west side of Bloomington (fig. 6), unit "lo" lies in low areas of the landscape, and much of the silt in those areas may have washed down from the hills nearby, probably shortly after deposition, because those hills were only sparsely vegetated at the height of glacial activity and loess deposition. But such an origin cannot apply to the area of unit "lo" east of Bloomington along S.R. 446 (Knight Ridge Road). Perhaps the loess blanket all over Monroe County was originally more than 6 feet thick and erosion has reduced it to a present maximum thickness of about 3 feet in most areas. Certainly erosion during historical time has significantly reduced the loess thickness in many areas. When the loess cover is gone (and it is already gone in many severely eroded areas), the consequences to land use will be severe, because the underlying soil materials lack the inherent fertility, tilth, and drainage characteristics of loess.

Most of the areas mapped as unit "lo" are somewhat poorly drained, but still they include much of the best cropland in Monroe County. In the area west of Bloomington the silt is about 6 to 12 feet thick and overlies red clay and limestone. In the Flatwoods region the loess overlies beds of glacial till and other unconsolidated deposits, and bedrock is at depths as great as 70 feet in that part of the Flatwoods that is in Monroe County (fig. 6).

The remaining two map units that show the distribution of the unconsolidated deposits are confined to the valleys. Unit "a" is alluvium, the sediment deposited by present streams; unit "t" is remnants of a complex of deposits that once filled the valleys to a higher level than that of the present bottoms. These remnants are in the form of terraces that stand above the present valley floor.

The valleys of Beanblossom and Salt Creeks have probably been partly filled and partly reexcavated many times. Some of the older fill (unit "t") now preserved as terrace remnants is outwash sand associated with meltwater from the older glaciers described above. These older glaciers extended into headwater areas of these two creeks, and meltwater from these glaciers deposited the sand. Terraces in Beanblossom valley as far downstream as Lake Lemon and in Salt Creek valley as far downstream as the dam that impounds Monroe Lake are at least partly composed of outwash sand. Terraces in Beanblossom valley around Dolan and at the sanitary-landfill site on Anderson Road are primarily silt and clay and are lake deposits that probably date from the time when a glacier blocked the mouth of Beanblossom Creek or from the time when the outwash sand of unit "os" filled the mouth of the old valley and diverted the creek, which then excavated the narrow valley at Mt. Tabor. Other terraces, especially in the valleys of the smaller creeks, are stream deposits of local materials that were washed from adjacent slopes.

In most of the smaller valleys map unit "a" is silty, sandy, and stony; is about 6 to 10 feet thick; and lies directly on bedrock. In the larger valleys most of unit "a" is stratified or layered silt, and beneath the alluvial silt, which is commonly 10 to 15 feet thick, are silt and sand of mixed origin. Some of this underlying material is a stream deposit, but in lower parts of Beanblossom and Salt Creek valleys much of the valley-fill material is silt and clay, a slackwater lake deposit associated with sand and gravel outwash deposits that now partly fill the valleys of the White River and the East Fork White River. At the mouth of Beanblossom Creek these deposits are sandy throughout. In Beanblossom valley from Mt. Tabor to the mouth and in Salt Creek valley from the dam to the Monroe County line, these deposits are more than 70 feet thick and lie on siltstone bedrock of the Borden Group.

MINERAL RESOURCES

Early settlers in Monroe County depended largely on farming and the forests for their needs, but in the middle to late 1800's the influx of people and their increased demands for construction materials brought about the development of natural resources in the county.

An iron-ore furnace of 1840 vintage was one of the first commercial mineral-resource developments in the county. Other resources that were developed in the 1800's were dimension stone, crushed stone, sandstone (for grindstones), lime, clay, and coal. A small oil and gas field was discovered in 1929, and minor production continues to the present. The production of iron ore, grindstones, lime, clay, and coal was minor and short lived.

Only limestone (for dimension stone), high-calcium limestone (for glass flux), and crushed stone (for construction, agricultural lime, and livestock feed) are being mined on a large scale. A small amount of oil and gas is also being produced.

IRON ORE

In 1840 an iron-ore furnace was in operation in Indian Creek Township (Shannon, 1906; Wayne, 1970). Iron was produced from ironstone concretions in Pennsylvanian rocks and highly siliceous banded ore found in small deposits that were between a few inches and a few feet thick. Part of the ore processed through this furnace was mined along Indian Creek, but most was brought from eastern Greene County. Charcoal was produced from the surrounding forests, and limestone (for flux) was brought from the surrounding hills. The furnace, which produced about $1^1/_2$ tons per day, was shut down after several years because the ore deposits were too small.

CRUSHED STONE

Crushed stone has been quarried in the county since the first improved road (commonly described as gravel) was constructed in 1880. Abundant quarryable limestone is available near the surface in much of the county (fig. 6), and an early account (Shannon, 1906) showed that small quarries, scattered through the central and western parts of the county (fig. 6), were operated in the Harrodsburg, Salem, and St. Louis Limestones. The transportation cost of crushed stone has always been an important factor in the use of stone as a road-metal resource, and therefore quarries were generally located near the improved roads on which the crushed stone was to be placed. As late as 1900 there were 865 miles of public roads in Monroe County but only 165 miles of improved roads (Shannon, 1906).

In 1987 there was only one crushed-stone quarry in operation in Monroe County. The Bloomington Crushed Stone Co., Inc., was operating a quarry in the Paoli, Ste. Genevieve, and St. Louis Limestones about 4 miles west of Bloomington (Ault and Carr, 1985). Crushed stone from this quarry was used for construction, agricultural lime, and in powder form for filler and for animal feed.

Standards for crushed stone are much higher today than they were about 1900. It is therefore no longer possible to indiscriminately open small quarries at points of need. Limestones of the Blue River Group, primarily the Paoli and Ste. Genevieve Limestones in Monroe County, have the chemical and physical properties necessary for premium crushed-stone aggregate (Carr and others, 1978). They are exposed along an irregular belt that runs through the western and southwestern parts of the county (fig. 4). Bedding thickness generally ranges from 4 to 12 inches, but a few beds may exceed 7 feet.

The Paoli Limestone is about 20 feet thick in Monroe County. It contains beds of oolitic limestone, but the location of these beds is unpredictable from one locale to another. The Paoli also typically contains some undesirable sandstone and shale beds near its middle and its base.

The Ste. Genevieve is about 100 feet thick in Monroe County. It consists primarily of sound and durable limestone, but it does contain beds and lenses of siltstone, shale, and chert that must be wasted.

Crushed limestone has been applied to several others uses: (1) air-pollution control by fluidized bed combustion, (2) control of coal-mine dust in underground mines, (3) filter stone in sewage-disposal plants, (4) flux stone for steel production, (5) mineral wool, (6) railroad ballast, and (7) glass.

HIGH-CALCIUM LIMESTONE

Several sources of high-calcium limestone are at or near the surface in Monroe County. The Harrodsburg, Salem, Paoli, and Ste. Genevieve Limestones have sufficiently thick sections of 95 percent or more $CaCO_3$ to be quarried for high-calcium limestone. These units all crop out at or near the surface in the Mitchell Plain (fig. 2).

High-calcium lime is used mostly for flux in steel production or as agricultural lime. But high-calcium Salem limestone is being mined in northwestern Monroe County near Stinesville for use in glass manufacture. This underground operation was opened by cutting a horizontal shaft into the face of an abandoned quarry.

CEMENT

Most raw materials (limestone, shale, clay, quartz sand, sandstone, gypsum, and anhydrite) needed to produce portland cement are available in or near Monroe County. The major chemical constituents of cement that are derived from the raw materials listed above are lime, silica, alumina, and iron oxide.

Low-magnesium limestone is the lime source that is used most. The Ste. Genevieve, Paoli, and Salem Limestones (Blue River and Sanders Groups), which lie in a north-south belt through the west-central part of the county (coincident with the Mitchell Plain) (fig. 4), are generally chemically suitable for use in cement. Shale or underclay is generally used as the silica and alumina source. Shale is abundant in rocks of the Borden Group that lie in the eastern part of the county (fig. 4). Borden rocks are also iron rich in places and may rate consideration as a potential source of iron oxide.

DIMENSION STONE

Monroe County is in the heart of the dimension-stone belt (fig. 7). The Salem Limestone, the major dimension-stone source rock, lies at or near the surface in a northwest-southeast swath that passes through the west-central part of the county. The outcrop area is as much as 5 miles wide, and the overburden, which consists mostly of residuum and loess, is generally thin (less than 15 feet).

The Salem Limestone contains diverse lithologies, but the building-stone facies consists of calcarenite that is light gray to bluish gray, massive, granular, even grained, porous, and crossbedded (Patton, 1953). It is generally a pure limestone that consists largely of small fossils and fossil fragments. The Salem is more than 80 feet thick in places, but most quarries contain less than 60 feet of usable stone. Its lack of prominent bedding planes and its nearly uniform strength, both with and across the grain, make the Salem a uniquely desirable dimension stone. It exhibits three principal color categories: gray, buff, and variegated (mixed gray and buff). Much of the building stone may also be classified as high-calcium limestone because the calcium carbonate content exceeds 95 percent and the requirements for other constituents are generally met. A facies of impure lithology (silty, argillaceous, and dolomitic) occurs most commonly above the building-stone facies, but in places it is within and beneath the building stone.

The building stone was at one time said to be oolitic (Siebenthal, 1908), but true ooliths are nearly absent from the Salem Limestone. Some zones contain fossils and fossil fragments coated with concentric layers of calcite, but these coatings are generally less than 20 percent of the radius of the particles (Patton and Carr, 1982).

The same properties that make the Salem Limestone an ideal building stone disqualify it for most crushed-stone uses. Because it is a high-calcium limestone, it is, however, possible to use the waste as a source of chemical limestone.

Building stone is presently removed only by quarrying, although underground removal is technically feasible and is practiced elsewhere in the world. Future land-use considerations and diminishing reserves may improve the outlook for underground operations.

The original Monroe County Courthouse, constructed in 1819, was probably the first commercial application of the Salem Limestone (Hopkins and Siebenthal, 1897). The building was brick, but the foundation, window sills, and lintels were stone. The first recorded quarry began operation near Stinesville in 1827 (Hopkins and Siebenthal, 1897), but the Salem was little used until railroads arrived on the scene. The dimension-stone business began to assume commercial importance with the opening of the Hunter district in 1891 just northwest of Bloomington (Hopkins and Siebenthal, 1897). This was the first large-scale quarrying operation in the area. Since that time the Salem Limestone from the Bloomington-Bedford district has dominated the dimension-stone market for American domestic limestone (Patton and Carr, 1982). The Salem Limestone was formerly a popular building stone throughout the eastern United States, particularly in New York and Washington, D.C. The magnitude of the dimension-stone industry is evidenced by numerous abandoned quarries (fig. 7 and pl. 1). The building-stone industry was the major employer in Monroe County from the latter part of the 1800's until World War II. The Indiana Geological Survey has in its files records of 127 quarries in Monroe County, only five of which have been filled. Most of these quarries are small; 77 of them are less than an acre in area.

COAL

Coal, although not a commercially important mineral resource in Monroe County, was mined at one time on a small scale in the southwestern part of the county near Kirksville. The record of the first coal mine in Monroe County dates back to about 1890, when a small drift mine was opened in the southeast quarter of section 4 in Indian Creek Township. The mine was closed after several tons of coal were removed and the roof collapsed. This mine was reopened in 1917 after an exploratory boring showed a 6-foot bed of coal. The 1917 mine operated as a shaft mine. Coal produced in this mine was low in ash and sulfur and high in fixed carbon and Btu value. The mine operated for only a short time and on a small scale because the extent of the thick coal was limited. Small strip mines later operated in the same area. These too have long been closed. The lowermost Pennsylvanian rocks, which are the coal-bearing rocks, crop out in southwestern Monroe County (fig. 4) only at or near the ridgetops.

CLAY

Halloysite, a porcelainlike clay mineral made up of an irregular sequence of kaolin layers, was found at several places along the ridge between Clear Creek and Indian Creek in southwestern Monroe County

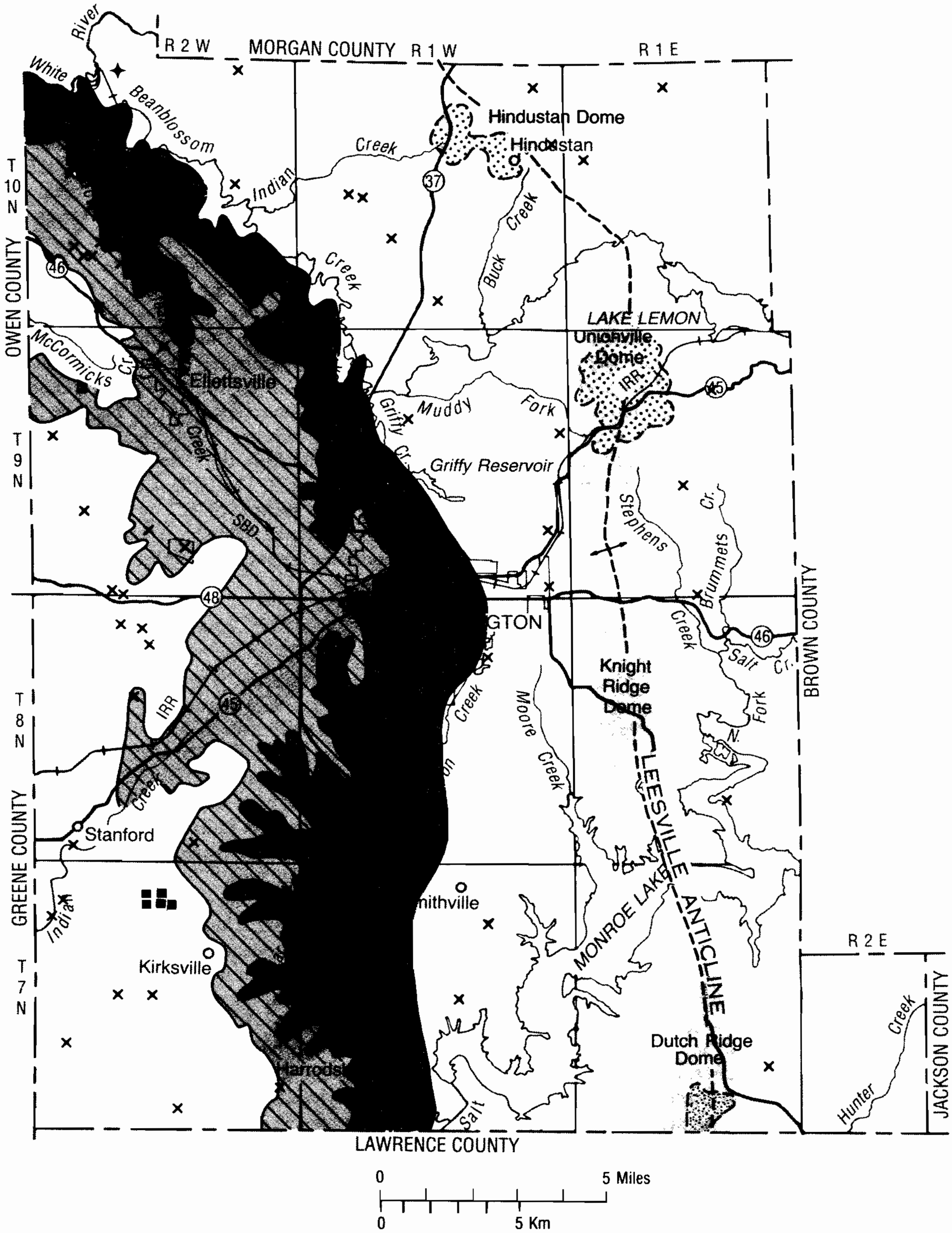
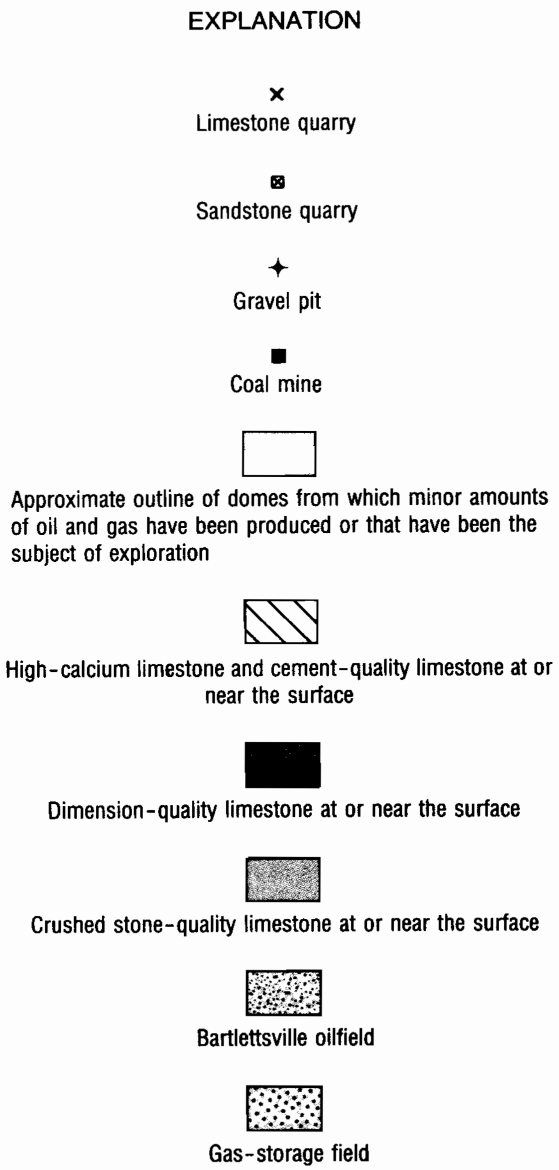


Figure 7. Map of Monroe County showing mineral and hydrocarbon extraction sites and approximate outlines of the areas most likey to contain exploitable mineral resources.



(Logan, 1918). Halloysite occurs just below sandstone of the Elwren Formation in the West Baden Group. According to Logan (1918) small pits were dug at several places along the outcrop of the clay, but none became commercially successful. Logan believed, because of the number and the thickness of outcrops and the findings of an exploratory tunnel, that there was a then-marketable quantity of the clay. Halloysite reserves are probably not sufficient to support a large-scale commercial operation today, but small-scale production of this white porcelain clay may be possible.

OIL AND GAS

Oil and gas have had little impact on the economy of Monroe County. Only minor amounts have been produced, and there appears to be little potential for significant development. Conditions necessary for entrapment of significant quantities of hydrocarbons—a source rock, a porous host rock, an impermeable cap rock, and some structural or stratigraphic trap (such as a dome, a fault, or an unconformity)—do not appear to exist other than along the axis of the Leesville Anticline (fig. 6) and the approximately parallel Mt. Carmel Fault.

Four domes lie along the north-south Leesville Anticline in Monroe County (fig. 7). Two of these, the Unionville Dome and the Dutch Ridge Dome (Melhorn and Smith, 1959), have yielded minor amounts of oil and gas.

Logan (1922) predicted the possible presence of oil and gas in the Unionville area. His prediction proved to be correct, for the first well drilled near Unionville in 1929 was a successful gas producer. The Unionville Field, a term used to define a distinct hydrocarbon trap, coincides with the structural feature called the Unionville Dome (probably a drape structure covering a Silurian reef) (fig. 7). An estimated $1\frac{1}{2}$ billion cubic feet of gas was produced from the Unionville Field before it was converted to a gas-storage reservoir in 1954 (Melhorn and Smith, 1959). Gas was produced from the upper part of the Muscatatuck Group (Middle Devonian) at a depth between 750 and 900 feet beneath the surface. Two more recent and deeper wells in the Trenton Limestone (Ordovician) completed about 1,750 feet beneath the surface are presently (1987) producing small quantities of oil.

The Bartlettsville Field, another small field in the southern part of the Dutch Ridge Dome (fig. 7) in the southeast corner of the county, was opened in 1951 and has produced abut 55,000 barrels of oil (Carpenter and Keller, 1986). Oil production in the

Bartlettsville Field is also from the Trenton Limestone at a depth of about 1,700 feet beneath the surface. Total production from this field in 1985 was only 506 barrels.

The two nonproducing domes have not been thoroughly explored but appear to have little potential for significant oil or gas production.

Few deep wells have been drilled outside the Leesville Anticline, and these have, with one known exception, been dry holes. This exception, a minor noncommercial gas producer, was drilled on a farm just north of Bloomington. This well has produced only enough gas to meet the needs of the farm on which it was drilled.

WATER RESOURCES

DEVELOPMENT

Because water is an essential everyday need, it is one of our most important resources. Most early settlements developed around sources of surface or ground water, but communities in Monroe County as they have grown have been forced to develop water supplies because of the lack of adequate natural sources of supply.

Monroe County is in an area that has abundant rainfall but does not have large, naturally existing, readily available water resources. The geology consists of bedrock that is mostly slowly permeable and of thin fine-grained unconsolidated materials that are mostly poor ground-water sources. The limestone that underlies the Mitchell Plain is an exception to this generalization, because where it is jointed and has been subjected to extensive solution it may produce sufficient water for domestic and farm use. The subsurface elsewhere in the county is not entirely barren; some wells suitable for domestic use are completed in the Crawford Upland. But the hilly terrain and low-permeability surficial soils and bedrock (pl. 1 and table 1) of the eastern and western parts of the county cause precipitation to run off rather than infiltrate and percolate to the water table. Surface water is therefore abundant only during periods of heavy rainfall, and ground water is a significant resource for few projects more ambitious than domestic or farm wells.

The same geologic and physiographic factors that result in a poor natural water supply provide favorable conditions for development of manmade surface-water reservoirs in parts of the county. The deep, narrow, and steep valleys, the low-permeability soils and bedrock (pl. 1 and table 1), and the sparse population in the eastern part of the county (Norman Upland) made development of sizable reservoirs possible. These reservoirs also cover some of the best farmland in the county. Abundant solution features in the carbonate rocks of the Mitchell Plain make the central part of the county unsuitable for large reservoirs.

The potential for developing significant additional surface- or ground-water supplies for Monroe County is small. Each of the major drainage basins capable of producing a useful reservoir has already been developed.

Bloomington, the only city and the largest water user in the county, developed its first central water supply from wells in the limestone that underlies the city. This source was soon outgrown, and the city was forced to construct a series of ever-larger reservoirs. The first, constructed west of the city in the karst limestone, failed to hold water because of the many subsurface drainage routes at that locale. The second was at Leonard Springs, southwest of Bloomington. A third and successful reservoir (Griffy Reservoir) was developed north of Bloomington. When the supply available from Griffy Reservoir was outgrown in about 20 years, Lake Lemon was constructed, but its supply was outgrown within about 10 years. Bloomington and much of Monroe County now rely primarily on a larger reservoir, Monroe Lake, which is referred to locally as Lake Monroe. Bloomington still (1988) draws some water from Griffy Reservoir, but it is strictly a supplemental source.

Some farm and rural domestic supplies are derived from wells, springs, ponds, and cisterns, although a major part of rural Monroe County is supported by rural water systems. The rural systems purchase water from the city of Bloomington. Where public water is not available, water is a severe problem for many rural homeowners because of the unavailability of sufficient good-quality ground water, particularly in the eastern part of the county. Some homes and farms must use cisterns, springs, and ponds that are easily contaminated and are reliable only if maintained by adequate and regular precipitation.

GROUND WATER

OCCURRENCE

Ground water is defined as all free water beneath the earth's surface and includes subsurface water in the zones of saturation and aeration. All pore spaces (voids) in the saturated zone are filled with water, but pore spaces in the zone of aeration are filled partly with water and partly with air. Except where the water table (the top of the zone of saturation) lies at the earth's surface, a single zone of aeration typically overlies a single zone of saturation. A water table may not exist where the zone of saturation is capped by impermeable strata. Where this is so, the water is confined, and water in a well penetrating the permeable saturated zone will rise above the base of the confining impermeable strata.

To be considered a resource, ground water of acceptable quality must be available to wells in useful quantities. Therefore, rock strata that are both porous and permeable and that have sufficient thickness and areal extent must be present beneath the top of the zone of saturation. Strata that meet these criteria and that are saturated and capable of supplying useful quantities of water to wells are called aquifers.

Water wells are completed both in bedrock and in unconsolidated material in Monroe County. But because the unconsolidated material is thin over much of the county, most wells are completed in bedrock. Primary porosity (porosity developed during rock formation) and permeability are low in most of the bedrock formations in the county. The permeability of solid limestone, shale, and even many fine-grained sandstones is generally quite low because pore spaces are small and poorly interconnected. Water flow through bedrock is therefore primarily through fractures and bedding planes. Fracture and bedding-plane porosity and permeability are secondary features formed after the rock has solidified. Joints (fractures without displacement) are the normal type of fractures in Monroe County. Joints are normally planar and mostly occur in subparallel sets that are intersected at an angle by a second subparallel set. They generally tend to be vertical features and may extend deep into the subsurface. Both the abundance and the magnitude of joints and solution features decrease significantly beneath about 150 to 200 feet. Earth scientists can recognize joints on the surface at many places by examining aerial photographs or by onsite reconnaissance. Because joints are normally vertical, water wells should be drilled on or as close as possible to these features. Production is typically as much as an order of magnitude greater in a vertical joint system than in solid rock.

That ground water is not a plentiful resource in Monroe County is abundantly clear. The earth materials that underlie the eastern and western parts of the county are not generally conducive to the storage or transmission of large quantities of water. The surficial unconsolidated material except for the valley-fill and terrace materials is too fine grained and thin to be a significant ground-water source. Bedrock that underlies the area is also fine grained and has low permeability for the most part. Exceptions are the carbonate rocks (Sanders and Blue River Groups) that appear in the west-central part of the county and that have secondary porosity. Water in the shallow carbonate rocks, some of which have considerable secondary porosity and permeability, is subject to contamination and has short residence time (the water-table level fluctuates widely), and water in deeper bedrock, more than about 250 feet, is generally too highly mineralized to be useful.

Ground water is the tenuous source of supply for some rural residents, particularly in the western half of the county. Much of the area is underlain by carbonate bedrock that, as described earlier, has extensive shallow solution-enlarged joints and bedding planes that transmit limited quantities of water to most wells completed in this material. A limited supply of ground water is also generally available to wells drilled in the interlayered shale, siltstone, sandstone, and limestone of mostly low permeability that underlie the far southwestern part of the county. The sandstone beds appear to be the best aquifers in this sequence. Wells are rarely successful in the tight siltstones of very low permeability that underlie the eastern part of the county. The occasionally successful well in the east is generally developed by chance in random sandstone aquifers that have limited areal and vertical extents or in rare joint systems in the siltstone.

SANDERS AND BLUE RIVER ROCKS

Adequate domestic supplies and in some locales small commercial supplies are normally available in the west-central part of the county where carbonate rocks that are a part of the Mitchell Plain crop out at the bedrock surface and are sufficiently thick. In the area of the Mitchell Plain the limestone is less than 100 feet thick in many places and is underlain by shale. Wells finished in the shale generally produce less than 1 gpm (gallon per minute) (fig. 8). Wells finished in the limestone (where it is more than than 50 feet thick) are generally better producers.

Most of the shallow carbonate rocks in Monroe County have been subjected to significant solution of joint and bedding-plane surfaces. Wells that intersect these solution features in the zone of saturation are typically capable of producing more than 10 gpm. Because carbonate rocks that underlie the county have little intergranular permeability, wells that do not penetrate joints or solution features may be dry or produce little water.

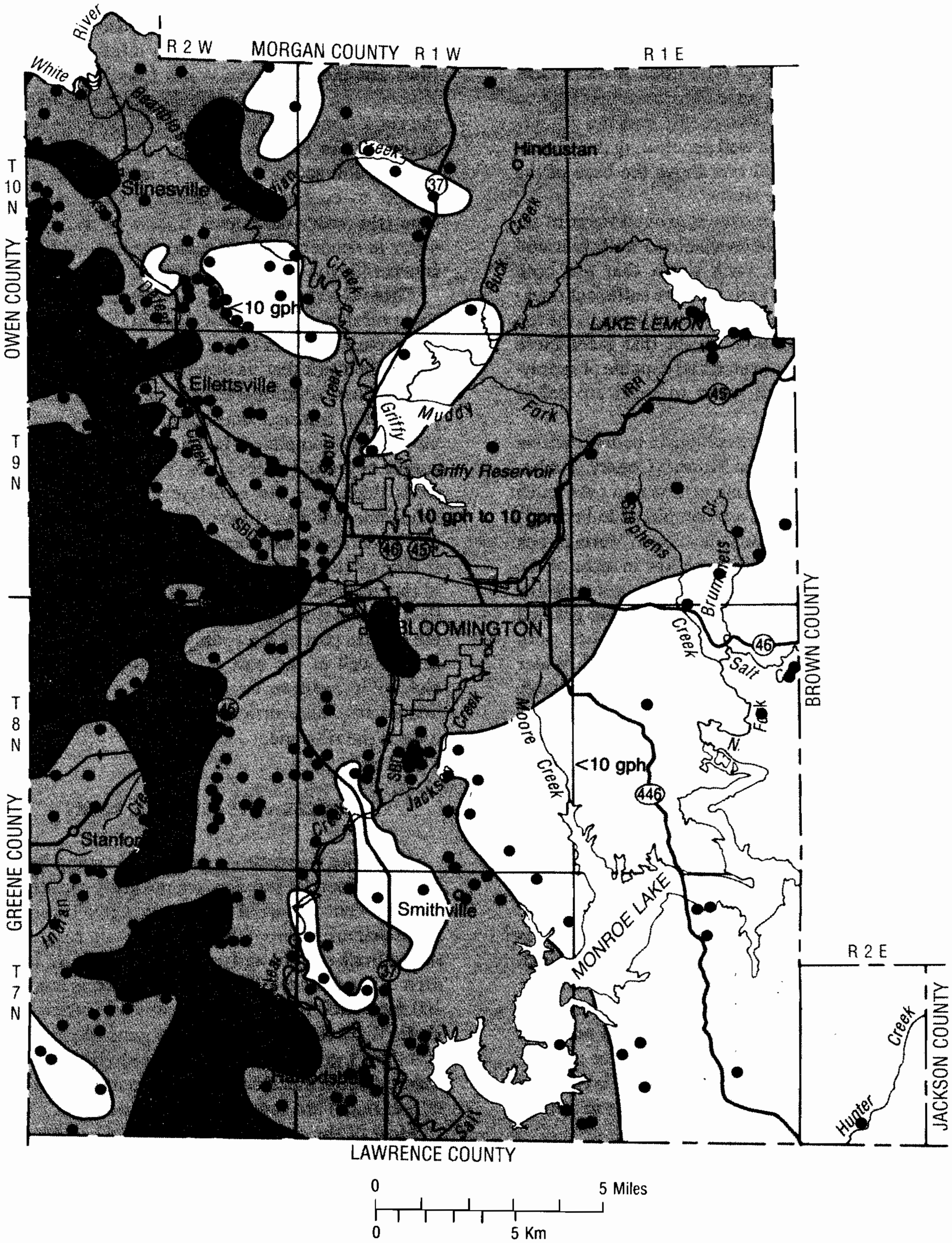


Figure 8. Map of Monroe County showing trends in ground-water production according to production from existing wells. The sparsity of data for the eastern part of the county greatly reduces the reliability of the map in that area.

EXPLANATION

● Datum points

Less than 10 gph

10 gph to 10 gpm

More than 10 gpm

Depth to the static water level (fig. 9) in the carbonate bedrock largely depends on the topography. The static water level is relatively constant in a particular aquifer system; therefore, its depth is greater on ridgetops and less in valleys. Depth to the static water level is one of the factors that determine storage capacity of the well and the specifications of the pump needed to draw water from the well.

Because of the nature of ground-water flow in the carbonate rocks, little purification takes place. Organic and inorganic wastes placed on the thin soils or in leaky sinkholes above the carbonate bedrock find their way, almost unaltered, into the zone of saturation and from there to pumping wells. A large percentage of the surface-derived contaminants will remain at or near the water table or will flow through joint systems above the water table and emerge again at the surface in a spring somewhere downgradient. Because ground-water contamination in the area of the Mitchell Plain (fig. 2) is likely, precautions should be taken by all users.

Most wells developed in the limestone of the Mitchell Plain are less than 150 feet deep, but in some locales they are between 150 and 250 feet deep (fig. 10). Shallow wells are generally successful in bottom lands, but ridgetop wells may be as much as 250 feet deep because of the above-mentioned relationship between topography and the static water level.

PENNSYLVANIAN AND CHESTERIAN ROCKS

The Pennsylvanian and Chesterian (Mississippian) rocks that form much of the surface in southwestern Monroe County are generally adequate sources of ground water (fig. 8) for domestic wells. These erosion-resistant rocks form the ridges and hillsides in this rugged part of the Crawford Upland. Because of their high topographic position, the total water-bearing thickness of these rocks is not great. The sandstone and limestone horizons are typically the most productive ground-water sources, but shale and coal also yield adequate supplies in some wells. As is true with most rock wells, all permeable water-bearing formations penetrated by the drill contribute to the water supply, because the wells are typically cased only a few feet into competent rock.

The static water level is deep under most of the Crawford Upland and is especially deep (generally more than 150 feet) in areas in the extreme southwestern part of the county (fig. 9). Where the Pennsylvanian rocks are thin and wells are completed in the underlying Mississippian carbonate rocks, production is generally satisfactory for domestic use (more than 1 gpm) (fig. 7).

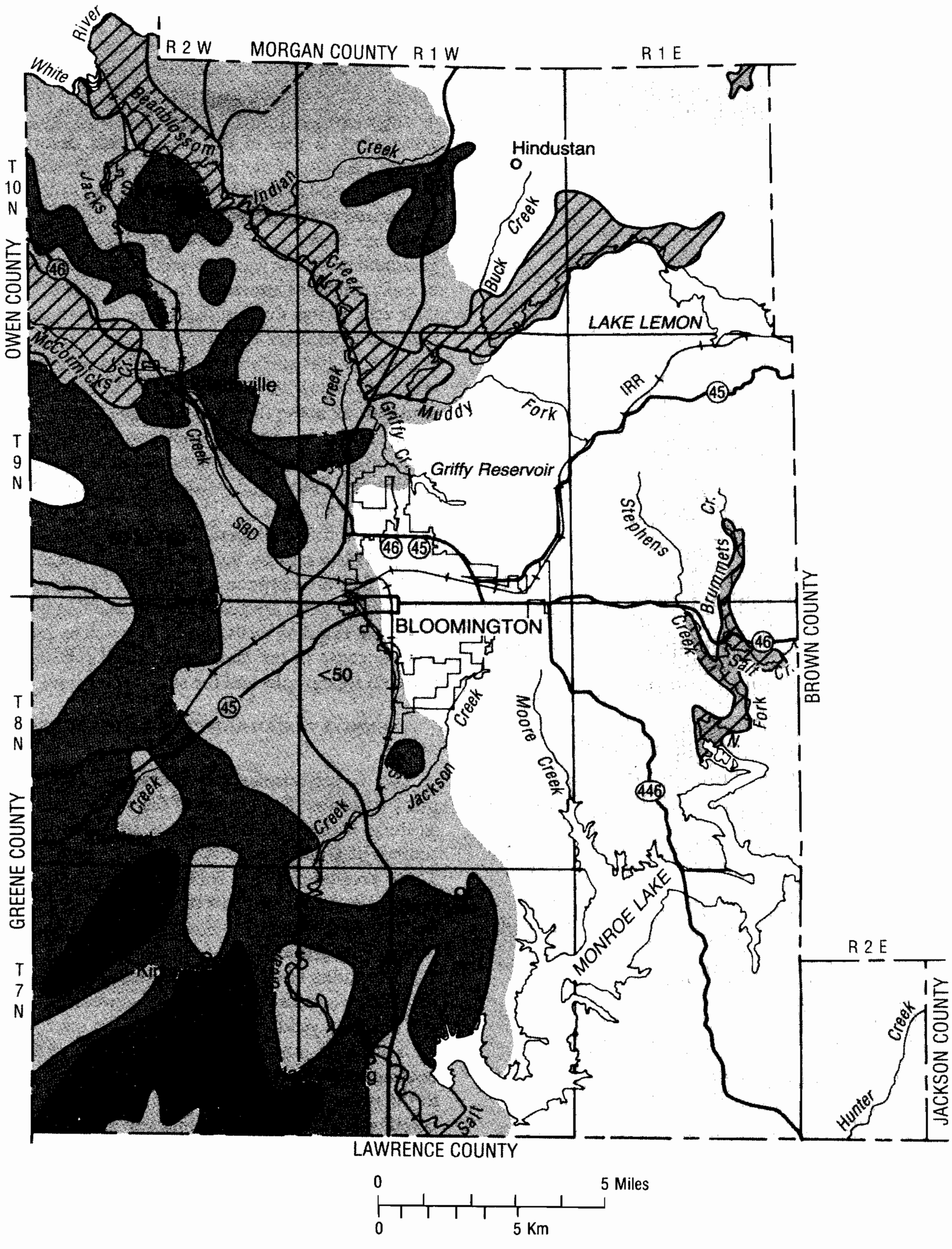


Figure 9. Map of Monroe County showing the approximate depth to the static water level in existing wells.

EXPLANATION

Less than 50 feet beneath the surface.

50 to 150 feet beneath the surface.

More than 150 feet beneath the surface.

Data too sparse and variable to evaluate.

Most wells completed in unconsolidated material.

BORDEN ROCKS

Aquifers are rare in the Borden rocks that underlie the Norman Upland in eastern Monroe County. The sedimentary materials that form these bedded strata are generally too fine grained, have too few joints, and are too well cemented to act as aquifers. Infrequent and unpredictable sand lenses that lie within the Borden are capable of providing water for domestic use. These are apparently channel sands and occur unpredictably. Individual domestic water supplies in the area underlain by Borden rocks east of a north-south line through Bloomington are derived mostly from manmade surface impoundments, such as reservoirs, ponds, or cisterns.

UNCONSOLIDATED MATERIALS

Pleistocene (glacial) and Holocene (postglacial) materials may provide adequate domestic water supplies in some areas, specifically in stream valleys and in much of the Flatwoods region. The water table is generally shallow (mostly less than 10 to 20 feet) in the productive unconsolidated materials (fig. 9).

The valley of Beanblossom Creek was filled mostly with glacially derived materials, as described earlier in this report, some of which are coarse grained and permeable and are able to transmit usable quantities of water. Other stream valleys containing coarse-grained material that may be sufficiently thick to yield water for domestic wells are Brummett Creek, Robertson Creek, Salt Creek, and Honey Creek. The Flatwoods region, which is drained by McCormicks Creek, also has significant thicknesses of sand in some places.

The best source of information on the availability of ground water at a specific locale in Monroe County is a reliable well driller who is familiar with the area. A second opinion is desirable, and one may wish to contact the Department of Natural Resources, Division of Water, or the Geological Survey for this purpose.

SURFACE WATER

Monroe County is within the White River drainage basin. The northern part of the county drains into the White River principally through Beanblossom Creek. The southern part drains into the East Fork White River through Hunter Creek, Salt Creek, and Indian Creek. The drainage divide between the White River and the East Fork White River follows a tortuous route through the county.

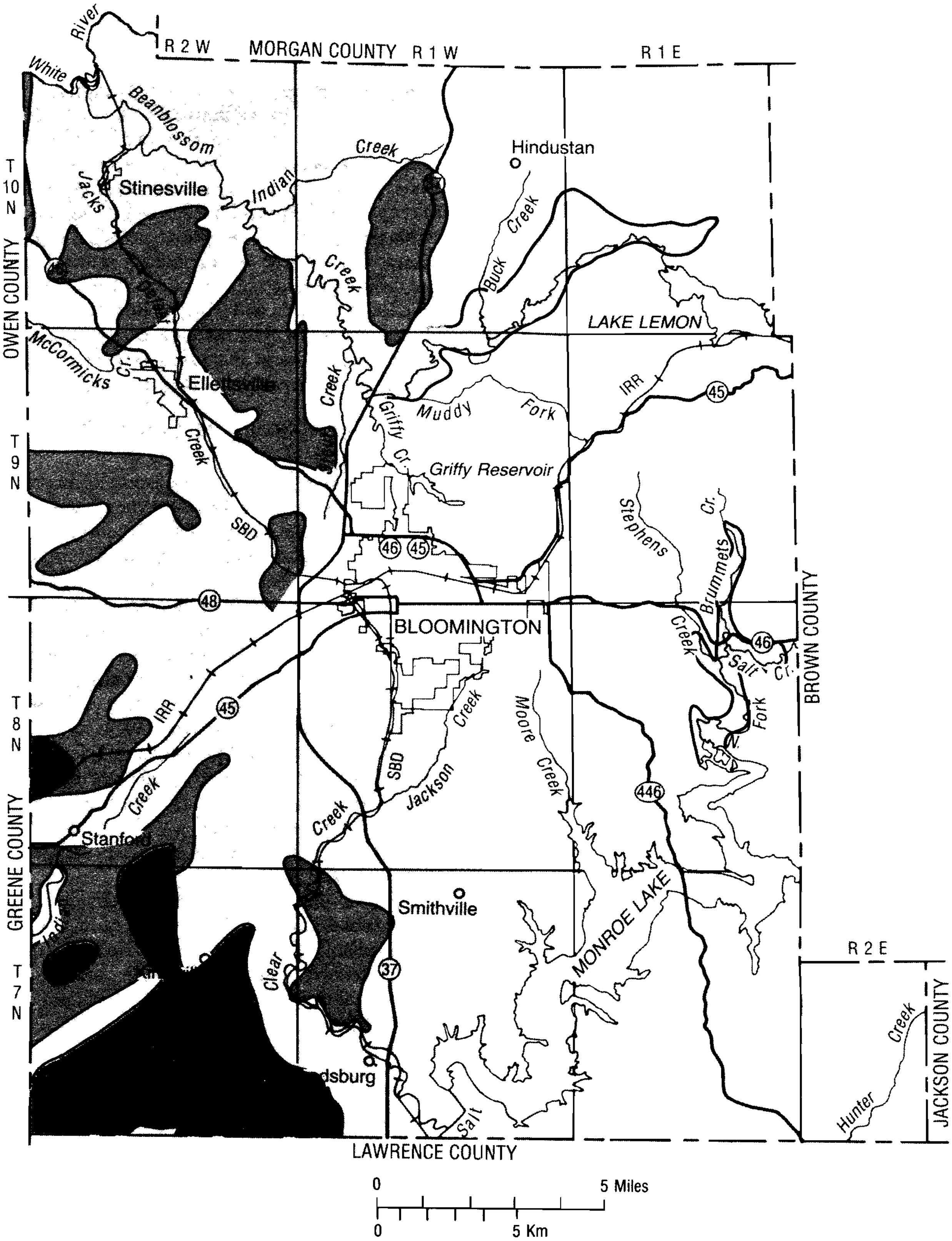


Figure 10. Map of Monroe County showing trends of typical completion depths of most water wells. The wells are normally shallower in valleys and deeper on ridgetops within the map units. The data are too sparse and variable to map in the eastern part of the county.

EXPLANATION

Less than 150 feet beneath the surface.

150 to 250 feet beneath the surface.

More than 250 feet beneath the surface.

From a point just south of Lake Lemon on the eastern border of the county the divide is approximately coincident with S.R. 45 almost to the east edge of Bloomington. From Bloomington westward, the divide follows approximately the line of the Illinois Central Gulf Railroad (fig. 3). The divide is indistinct in the area of the Mitchell Plain because much of the drainage flows into subterranean routes that may not be controlled by surface-drainage divides.

Three significant reservoirs are part of the surface-drainage system in the county: Monroe Lake, Lake Lemon, and Griffy Reservoir. Monroe Lake was created in 1964 after the construction of a U.S. Army Corps of Engineers dam on Salt Creek about 10 miles south and east of Bloomington and 25.9 miles upstream from the junction of Salt Creek and the East Fork White River. The Monroe Lake watershed encompasses about 482 square miles, much of which is woodland. The lake-surface area at the low-flow regulation pool level of 538 feet MSL (above sea level) is 16.8 square miles. The flood-control pool level is 556 feet MSL, and at this level the surface-water area is 28.8 square miles. Monroe Lake was constructed primarily for flood control and low-flow augmentation in Salt Creek and the East Fork White River. Because the lake is situated on nearly impermeable Borden rocks, leakage is insignificant. The secondary uses of Monroe Lake are recreation, fish and wildlife propagation, and water supply.

Lake Lemon was created in 1953 when an earthen dam was constructed on Beanblossom Creek about 9 miles northeast of Bloomington. The Lake Lemon dam regulates flow from a largely forested drainage basin of 70.2 square miles. The spillway is at 630 feet MSL, and at this elevation the lake covers about 2.25 square miles. Flood control, low-flow augmentation, and water supply were the primary-design functions of Lake Lemon, but the lake is also used for recreation. Lake Lemon has not been used as a water-supply source since the completion of Monroe Lake. Lake Lemon does remain a potential source of additional water, but heavy reliance on it during late summer and early fall, a period of low flow in Beanblossom Creek, may jeopardize recreational uses. Because water from Lake Lemon is picked up for treatment in Beanblossom Creek about 8 miles below the dam, high suspended-sediment loads during periods of extreme discharge may create filtration problems.

Griffy Reservoir, about 1 mile north of Bloomington, is held by an earthen dam on Griffy Creek. The dam was constructed in 1924 by the Bloomington Water Co. for the sole purpose of developing a reliable water supply for the city. Griffy Reservoir, modified in 1944 by raising the height of the dam, has a surface area of about 110 acres at its recreational pool elevation of 635 feet MSL (Jones and others, 1984). Maximum water depth is 31 feet at the dam, but mean depth is only 10 feet. The mostly wooded drainage basin covers about 5,000 acres. Griffy is presently used (1988) as a supplemental source of water by the city of Bloomington. Griffy has supplied only a small percentage of the water needs of the city since the completion of Monroe Lake.

Each of the successful reservoirs is situated on impervious rocks of the Borden Group (Mississippian) in the central part or the eastern part of the county. In fact, much of the western part of the county is unsuitable for reservoir construction because of the permeable nature of the karstic carbonate bedrock.

The construction of small farm ponds is possible throughout the county if care is taken to avoid the solution features of the north-south, centrally located Mitchell Plain (fig. 2). The unconsolidated materials (residuum and colluvium) that overlie the bedrock are nearly impermeable and where they are sufficiently thick will serve well as dam and bed material for small ponds.

As noted above, the two through-flowing streams, Beanblossom Creek and Salt Creek, are impounded by major reservoirs. The larger tributaries to Beanblossom Creek are Jacks Defeat Creek, Indian Creek, Stout Creek, Griffy Creek (with reservoir), Muddy Fork, Buck Creek, and Honey Creek. Jacks Defeat Creek, the largest of these tributaries, heads on the karst area just northwest of Bloomington and flows northward past Ellettsville and from there past Stinesville to Beanblossom Creek. The nature of flow in Jacks Defeat is such that it ceases to flow through much of its reach during extended dry periods but floods from south of Ellettsville to its mouth 2 miles north of Stinesville during periods of intense rain (fig. 3).

Brummett Creek, Stephens Creek, Moore Creek, North Fork Salt Creek, and Clear Creek are the major tributaries of Salt Creek. All but Clear Creek drain the rugged terrain west and southwest of Bloomington. Clear Creek drains the Mitchell Plain south of Bloomington.

The streams that meander through Monroe County are normally quite tranquil, but snowmelt and heavy rainfall that occur in late winter and early spring often send a number of these streams cascading into their flood plains. Because surface drainage is controlled by topography, landscape, geology, climate, and vegetation, hydrologic conditions vary throughout the county. Steep slopes and low-permeability soils promote runoff rather than infiltration over much of the county, whereas dense vegetation, especially green deciduous forests, delay and reduce the intensity of runoff. Flood potential is therefore greatest during winter and early spring when the ground is frozen (impermeable) and before the vegetation emerges. Because woodlands and other vegetation are important inhibitors of flooding, clear cutting of forests and construction of homesites or other structures on hillsides facilitate runoff and increase flood intensity.

Damage to structures and crops and loss of life are obvious flood hazards, but floods create less spectacular and longer lasting problems as well. High-energy floodwaters carrying large amounts of suspended sediment that is deposited in the flooded areas and in lakes and reservoirs reduce the water-storage capacity and shorten the lives of the lakes and reservoirs. Any activity that decreases erosion protection, such as clear cutting, construction, or poor agricultural practices, contributes not only to erosion but also to flood and siltation.

Two types of floods occur in Monroe County. High-intensity short-duration storms cause flash floods that have high peak flow, high velocity, short duration, and relatively small volume flow. Flash floods are most damaging to narrow flood plains and small channels that have little reserve carrying capacity. Prolonged rainfall or the melting of heavy-snow accumulations are, on the other hand, typified by floods with large peaks, low velocities, and long runoff periods. The latter type of flood may entirely cover the wide flood plains of Beanblossom and Salt Creeks.

Detailed flood information is available for parts of the county drained by Beanblossom Creek (U.S. Army Corps of Engineers, 1974) and Clear Creek and Jackson Creek (U.S. Army Corps of Engineers, 1976). These creeks have flooded during all seasons of the year, but the main flood season is late winter and spring. An Intermediate Regional Flood (100-year return period) would result in inundation of roads, bridges, agricultural areas, and many residences in the flood plains (fig. 3).

A U.S. Corps of Engineers study in 1974 showed that a major part of the flood plain of Beanblossom Creek would be subject to inundation during an Intermediate Regional Flood. The land subject to flooding would be mostly agricultural but would include some residences, storage buildings, and private and public utilities.

Jackson Creek drains the east side of Bloomington, and Clear Creek drains the west. The two creeks meet about 2 miles south of the city. A few miles farther south, Clear Creek empties into Salt Creek just below the Monroe Lake dam. The areas along these two creeks that would be flooded by the projected Intermediate Regional Flood would be mostly agricultural but would include residences, roads, bridges, and some commercial facilities. Flooding along Jackson Creek might extend into the Ridgemede addition, and flooding along Clear Creek would involve much of its flood plain in the southern part of Bloomington and parts of the village of Clear Creek (U.S. Army Corps of Engineers, 1976).

The flood problem must also be considered in the karst area east of Bloomington and near the Monroe County Airport. All drainage in parts of these areas is diverted to the subsurface. Because subsurface channels in most locales are not sufficiently large or their openings are not sufficiently dense to carry sudden deluges, water backs up at the surface entrances and causes localized flooding.

DISTURBED AREAS

Man's activities have altered a substantial part of the landscape in Monroe County (fig. 7 and pl. 1). Careless agricultural practices in the late 19th and early 20th centuries removed soil nutrients, denuded much of the landscape, and resulted in erosion and the replacement of mature forests with scrub brush and weed trees. Proper management, primarily in state and federal forests, has reclaimed part of this land but has not replaced the top soil. The organic-rich top soils formed in geologic time and destroyed in a decade or two of abuse will not reform for millenia.

Limestone quarries, mostly abandoned and mostly small (less than half an acre), dot much of the Mitchell Plain. Some early quarries (mid-1800's) were worked by hand with horses and were quite small. Many of these workings were on outcrops that are now weathered and almost unrecognizable. Some smaller quarries have been filled naturally by plant growth, weathering, and sediment infilling.

The major problem that must be overcome to reclaim a quarry is the recovery of sufficient material to fill the deep excavation. A dimension-stone quarry—and many quarries in Monroe County are that kind—creates an additional problem. It produces large volumes of essentially useless and extremely large rubble. The rubble, in the shape of large prismoids, generally occupies an area as large as the pit and is not reclaimable except at great expense.

According to field reconnaissance by the Indiana Geological Survey, about 125 quarries have disturbed about 550 acres of land in Monroe County (fig. 7). Five of these quarries have been filled, and residences or businesses have been constructed on three of these reclaimed sites. Many abandoned quarries are eyesores, and some are health hazards because they have been used as dumps for everything from large machinery to household and industrial wastes. The large irregular blocks left as waste and the deep precipitous banks of the water-filled excavations are dangers to the unwary.

Some quarries can be effectively reclaimed to a greater or lesser extent without returning the land to its original contours and can be adapted to practical beneficial uses. Reclaimed abandoned quarries are being used as swimming pools, fishing ponds, sunken gardens, and scenic ponds. As already mentioned, some smaller quarries have been filled and built on.

Other sizable disturbed areas in the county include the Anderson Road Landfill, the three major reservoirs, numerous farm ponds, and all other construction associated with rural and urban life.

SANITARY-LANDFILL SUITABILITY

Sanitary landfills are permanent storage sites for society's wastes. As such, they should hold wastes not only out of sight but also out of biospheric circulation. Recycling is the best solution to the waste-disposal problem, but at this time recycling does not appear to be economically practical. Therefore, the selection of a safe, secure landfill site is of great importance.

The major threat to the environment posed by land disposal of wastes is the entry of harmful leachates into ground or surface water. Other complications associated with land disposal include vector (rodent, insect, etc.) control, dust and blowing trash, and odors. Meteorologic, geologic, and topographic conditions largely determine the amount and the type of leachate hazard that will be encountered at each individual landfill site. Because abundant rainfall in Monroe County ensures that a significant amount of leachate will be produced, it is imperative that the most geologically and topographically suitable site be found.

Large parts of Monroe County are unsuited for sanitary landfills because of steep slopes, lack of cover material, high water table, flood potential, or cavernous limestones (fig. 11). The prominence of each of these factors is determined by the geology (pl. 1) and the geomorphology (fig. 2) of the county.

The consolidated rocks, siltstones, shales, and sandstones of the Borden Group that underlie the Norman Upland in the eastern part of the county (fig. 4) generally have low permeability. Few water wells are successfully completed in Borden rocks, and those wells that are completed find only a little water

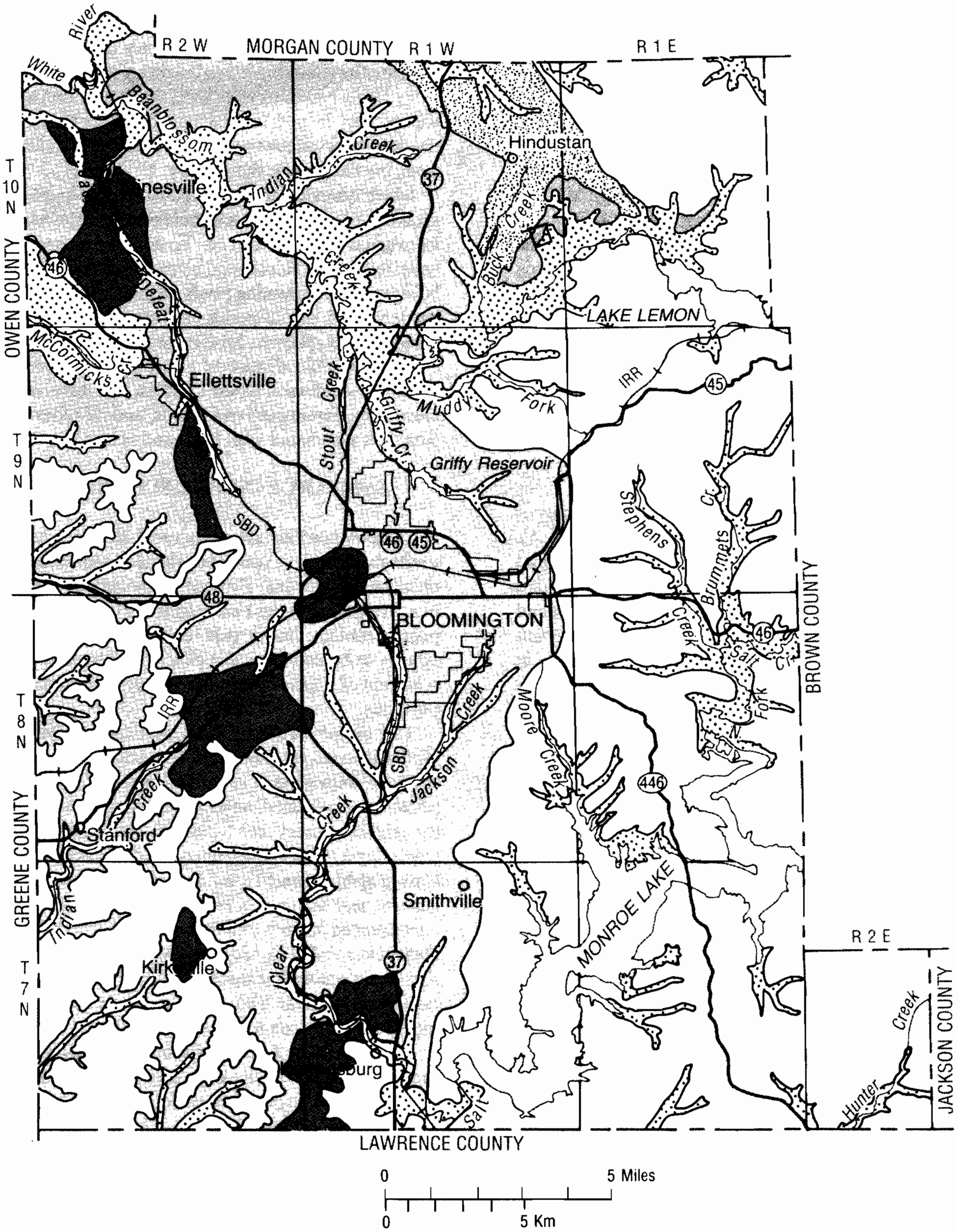


Figure 11. Map of Monroe County showing suitability for sanitary landfills. The location of the active county landfill is outlined in red.

EXPLANATION FOR SANITARY-LANDFILL SUITABILITY

1 Unsuitable. Shallow limestone bedrock with a thin covering of fine grained residual soils and loess. The thickness of the unconsolidated materials is typically 5 to 15 feet. Much of the bedrock is marked with joints and fractures that have been subject to enlargement by solution. Ground water contamination is a distinct possibility in this area.

2 Unsuitable. Flood plains composed mostly of alluvium and some outwash in floodways of Beanblossom, Salt, and Robertson Creeks. Materials are largely coarse grained (silt, sand, and some gravel) and moderately to highly permeable in part. Parts of the floodway are subject to periodic flooding, and the water table is mostly very high (within 10 feet of the surface). Therefore, ground water and surface water are easily contaminated in these areas.

3 Unsuitable. Area of relatively shallow karst limestone that has slight to moderate slopes. Ground water is highly subject to contamination because of thin cover and channel flow within the limestone.

4 Certain areas may prove to be suitable. This area contains a mix of thick (as much as 115 feet) fine and coarse grained water-and ice-deposited unconsolidated materials, mostly silt and sand. Parts of the area are underlain by low-permeability silt, and other parts are underlain largely by high-permeability sand. Ground water contamination potential is high in the areas underlain by sand, but the predominantly silt areas may provide adequate ground water protection for area-type landfills.

5 May be suitable in part but requires thorough evaluation. Stream and lake deposits (terraces) that are mostly fine grained (silt and clay with some sand). The material is relatively thick (more than 60 feet in some areas) and mostly above modern flood level. Because of the low permeability and paucity of aquifers in this material, ground water contamination is unlikely. Surface water contamination by leachate seepage from the toe of a landfill may present problems, however.

6 Suitable only if proper engineering precautions are taken. Shallow siltstone bedrock with moderate relief and a thin (5 to 15 feet) cover of silt. The same cautions apply as for category 8 except that slopes are less steep, and surface water contamination may be less of a problem.

7 Suitable only if proper engineering precautions are taken. Shallow siltstone, shale and sandstone bedrock with a thin (5 to 25 feet) cover of mostly fine grained residuum and loess. Relief consists of relatively steepsided ridges and valleys with a minimal amount of relatively flat surface area on the ridgetops. Potential for surface water contamination is high; potential for ground water contamination in the mostly fine grained materials is relatively low; shallow sandstone aquifers, however, may be subject to contamination.

8 Suitable only if proper engineering precautions are taken. Highly irregular, incised upland with steep slopes, a system of ridges and valleys. Bedrock is low-permeability siltstone that contains little readily accessible water. Cover is generally thin (15 to 25 feet in valley bottoms and 5 to 10 feet on ridgetops and slopes). Surface water contamination is likely, but the limited ground water supply should be protected by the abundant fine grained materials that lie above the producing zones in the bedrock. Although not naturally well suited for landfilling, specially designed sites may prove to be successful.

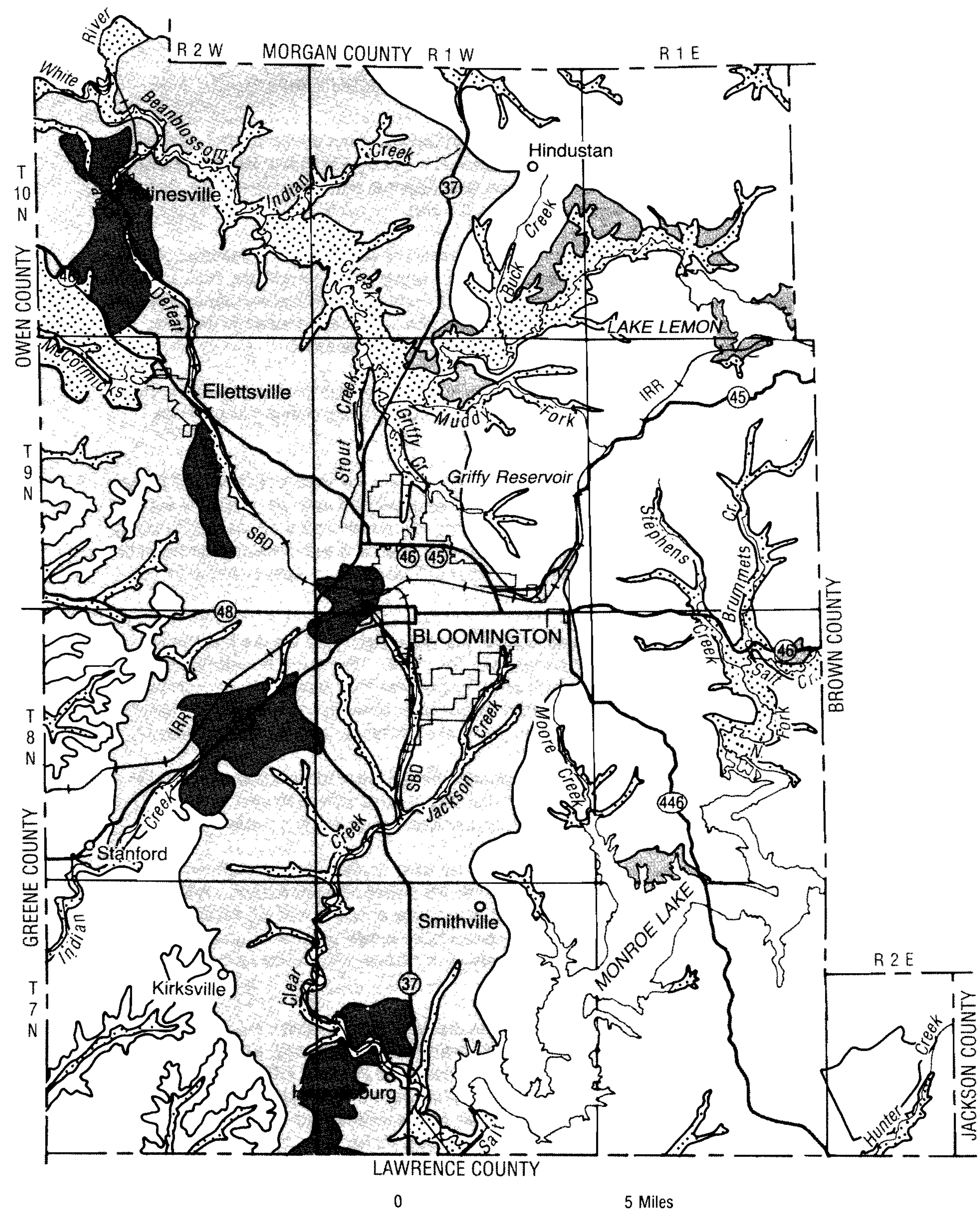


Figure 12. Map of Monroe County showing suitability for septic systems.

EXPLANATION

Generally unsuitable. karst area of shallow limestone that has been subjected to extensive solution activity. Soil cover is thin and most drainage is channeled internally through the limestone bedrock. Contaminants are, therefore, readily introduced into the ground water system.

Mostly unsuitable. Thin, commonly stony soil overlies siltstone and shale on steep slopes. Shallow low-permeability soil and steep slopes are not suitable environments for septic systems because much of the effluent is likely to seep to the surface.

Mostly unsuitable. Flood plains are underlain mostly by coarse grained materials and have high water tables. Susceptible to flooding in part. Ground water and surface water contamination is likely.

Suitable in part. Thin residual soil overlies fine grained bedrock, which is mostly siltstone and shale and some fine grained sandstone that are covered with from 5 to 15 feet of silty and in some places stony soil. Slopes are moderate, and relatively extensive flat areas are on the ridgetops. Ground water is relatively well protected in this area because the water table is deep and most wells are developed in deeper sandstones.

Suitable in part. Thick lake and stream deposits. In some areas unconsolidated material consists mostly of fine grained silt and clay, and in other areas it consists largely of coarse grained sand. Ground water in areas underlain by silt and clay should be well protected; where sand is at or near the surface, however, ground water is subject to contamination.

Suitable in part. Varying thicknesses of generally low permeability soil underlain by Karst area of limestone. The degree of protection of ground water and surface water depends on the thickness and permeability of the local soil cover.

Mostly suitable. Terraces are composed of mostly fine grained stream- and lake- deposited material that is elevated above the adjacent flood plain. Terraces contain as much as 60 feet of unconsolidated material, mostly silt and clay. Low permeability may dictate the use of large tile fields, and some low areas may have a seasonally high perched water table.

in thin beds of fine-grained sandstones. Ground-water contamination by leachate is therefore not a serious threat to human health in this area. But surface-water contamination is an important consideration because of the shortage of cover material and the abundance of steep slopes. Satisfactory landfilling techniques are available for use in this type of setting but may be expensive. For example, a valley-type landfill operating at the head of a valley permits the use of hillside and ridgetop material for cover and facilitates leachate collection and recycling or treatment of the leachate that flows out the toe of the landfill and down the valley. This type of operation essentially fills the head of the valley with successive layers of waste material and in effect shortens the valley. The valley-fill procedure is not recommended where the valley floor is filled with permeable coarse material, such as rock debris and gravel washed from the adjacent ridges. Where the valley fill is permeable, leachate flows into the ground-water system and is not retained at the toe of the fill.

The Mitchell Plain, because it is underlain by karst limestone that has a thin soil cover, provides a generally unsatisfactory environment for sanitary landfilling (fig. 10). The solution-enlarged joints and fractures in the limestone carry contaminants directly into the ground-water system with little dilution or filtration. Thin soil cover, mostly residuum and loess, also provides little protection for ground water because travel time is not sufficient to assure filtration. Leachate produced in a landfill above the limestone will surely contaminate ground and surface water in this area unless costly preventative measures are used.

Topographic features in the western part of the county are similar to those in the east, but the underlying geologic materials are different in part. The topography is that of a deeply dissected upland (Crawford Upland) cut into sandstone, limestone, shale, and coal. Steep slopes and a thin covering of unconsolidated material do not provide conditions amenable to sanitary-landfill operations. In addition, the nature of the bedrock – there are water-bearing beds of limestone and more coarse-grained sandstones than in the Norman Upland – is such that ground water may be subject to contamination. Nearly all water wells in the Crawford Upland are more than 100 feet deep (fig. 9), and most are finished in limestone. Little purification occurs, however, because ground-water recharge in the bedrock is mostly direct (through fractures).

The three major surface drainageways, Beanblossom Creek, Salt Creek, and Clear Creek, and their principal tributaries present generally hazardous conditions for sanitary landfills. Much of the floodplain area of these streams is subject to seasonal flooding, and the water table is near the surface much of the year. In addition, the surficial materials are relatively permeable. The terraces of Beanblossom Creek (fig. 11) are the only possible exception, as they may contain sufficient thicknesses of low-permeability materials to accommodate small sanitary-landfill operations.

It is apparent from the above that little of the land surface in Monroe County is suitable for establishing sanitary landfills. The geologic environment of the county is fragile and easily disturbed and therefore poorly suited for supporting storage of wastes produced by industry or by a large population. Because of the pressure of significant urban and industrial growth in the Bloomington area and the effect that a poorly planned site may have on the environment and on the quality of life, special caution must be used when selecting a site for waste disposal.

SEPTIC-SYSTEM SUITABILITY

The most common type of independent disposal system for household sewage, one not connected to a central sewage-treatment plant, consists of a septic tank and a drain field. This is perhaps the simplest, most convenient, and satisfactory method of sewage disposal within the confines of an individual lot. The system provides for the collection of liquid household wastes in a buried container where scum, grease, and suspended solids are removed from the liquid by gravity. The solids are mostly digested and partly liquefied by bacteria. The resulting, somewhat clarified liquid is passed into a tile field from which it percolates into the soil.

Because the effluent liquid contains significant organic material, it must be further clarified by the soil of the tile field. This soil must be sufficiently permeable to disperse the liquid but not so permeable that the liquid is discharged directly (with insufficient purification) to the ground-water system.

Limiting factors that directly affect tile-field function are soil permeability, water-table level, depth to hardpan or bedrock, slope, annual precipitation, hydraulic loading, character of the wastes, and design of the components. Low-permeability soils dictate the use of large tile fields that reduce effective hydraulic loading, whereas highly permeable soils readily accept effluent but in doing so permit rapid percolation to the ground-water system and provide little purification of the effluent. The annual high water table should be a minimum of 5 feet beneath the base of the trench to prevent the system from backing up or effluent from coming to the surface. Likewise, if impermeable bedrock or hardpan is at or near the base of the tile field, ponding may occur and cause effluent to rise to the surface.

Where the bedrock is highly permeable as is the karst limestone in parts of Monroe County, the effluent may enter the ground-water system directly. Moderate to steep slopes are unsatisfactory sites because effluent is likely to travel to the surface; stability of the hillside is reduced by installing trenches and adding water, and the cost of construction is high. The hydraulic loading is the result of domestic-water management and can be controlled to a certain extent by using water-conservation techniques. Design and size of the tank and tile field should be on the conservative side, and, if possible, a diversion box and an auxiliary tile field should be constructed. The use of two separate fields allows for partial drying and results in the recovery of permeability in the unused field.

It is apparent from the above that a large percentage of the surface of Monroe County is poorly suited or entirely unsuited for septic systems (fig. 12). In the eastern part of the county on the Norman Upland only the ridgetops are suitable. The valley walls are mostly unsuitable because they are too steep, and the bottom lands are mostly unsuitable because of a seasonally high water table and the possibility of seasonal flooding.

The central part of the county coincident with the Mitchell Plain is partly suited for septic systems. Areas where karst bedrock is near the surface are unsuited because of the high potential for ground-water contamination. In places the soil permeability is marginal, and large tile fields are required for preventing saturation and leakage to the surface.

In the western part of the county on the Crawford Upland steep slopes and bottom lands are also mostly unsuitable for septic systems. The nearly flat ridgetops are mostly suitable, but the low permeability of the soil may necessitate the installation of large tile fields.

The Beanblossom valley is suitable for septic systems in part. The seasonally flooded areas and that part of the flood plain affected by a seasonally high water table (within 5 feet of the surface) are unsatisfactory. Terraces that lie adjacent to the valley walls and above the level of the flood plain are mostly suitable because they are generally above flood level and are not normally affected by a high water table. The suitability of the flood plain must be determined on a site-by-site basis.

The suitability of the soils in Monroe County for septic systems is explained in greater detail in the "Soil Survey of Monroe County, Indiana" (Thomas and others, 1981). But the ultimate determination of site suitability must be based on engineering tests of the performance of the materials at a particular location.

GAS STORAGE

Gas-storage facilities are an integral part of the system for distributing natural gas. Excess gas is stored when demand is low and is used to supplement normal pipeline flow during peak use. The most economical and least hazardous means of gas storage is underground in abandoned gasfields or in aquifers or any other geologic formation capable of accepting, holding, and then releasing a large quantity of gas. Underground storage is expedient because impractically large and expensive storage facilities need not be constructed and is less hazardous because handling and storage are less complex and leakage is less likely than if above-ground tank-type facilities are used.

Geologic conditions conducive to practical underground storage are essentially the same as those needed in nature to create a natural oilfield or gasfield. Geologic features that provide conditions for storing natural gas are a sufficiently large dome- or wedge-shaped impermeable cap rock superimposed on a suitably porous and permeable host rock. Natural gas is often stored in depleted gasfields that have been resealed.

Gas is stored underground in Monroe County in the Unionville Dome and the Hindustan Dome about 6 miles northeast of Bloomington (fig. 7). These apparently reef-related domes, which lie adjacent to and west of the Mt. Carmel Fault, appear to be interconnected because changes in gas pressure in one directly affect pressure in the other (R. J. Kuhn, oral communication, April 23, 1985). They are therefore operated as one field—the Unionville gas-storage field. Storage is primarily in the Geneva Dolomite Member of the Jeffersonville Limestone (Devonian) at about 890 feet below the surface and in the Jeffersonville Limestone and the North Vernon Limestone (Devonian) at about 800 feet below the surface. A small amount of gas is also stored in the Trenton Limestone (Ordovician). Total storage capacity in the Devonian rocks is greater than 2,500,000 Mcf, and daily deliverability exceeds 23,000 Mcf. Total storage capacity in the Trenton Limestone is 400 Mcf, and daily deliverability is 2 Mcf.

NATURAL FEATURES

KARST

The karst area of Monroe County (pl. 1), which is mostly coincident with the Mitchell Plain (fig. 2), is marked by sinkholes, sinking streams, caverns, and other features characteristic of karst terrain. There is also a small area of subdued karst in the southeastern part of the county on an outlier of the Harrodsburg and Salem Limestones. An example of karst terrain can be seen at Karst Park near the county fairgrounds just west of Bloomington. Outstanding examples of solution features are also visible along S.R. 37 south of Bloomington where the roadway has been cut into the limestone bedrock.

Parts of the karst area have a particularly high density of large sinkholes. Sinkholes are closed depressions that are formed either by solution of the surficial limestone or by collapse of underlying caves. Large sinkholes have a distinctive appearance on airphotos and on 7.5-minute topographic maps. They appear as dimples on aerial photographs and as short closed contours on topographic maps. Sinkholes range in diameter from less than 10 feet to more than one-fourth mile. One sinkhole-covered area that lies southwest of Bloomington (fig. 13) looks much like the aerial view of a World War I artillery target. Many more sinkholes too small to map at this scale also mark this area.

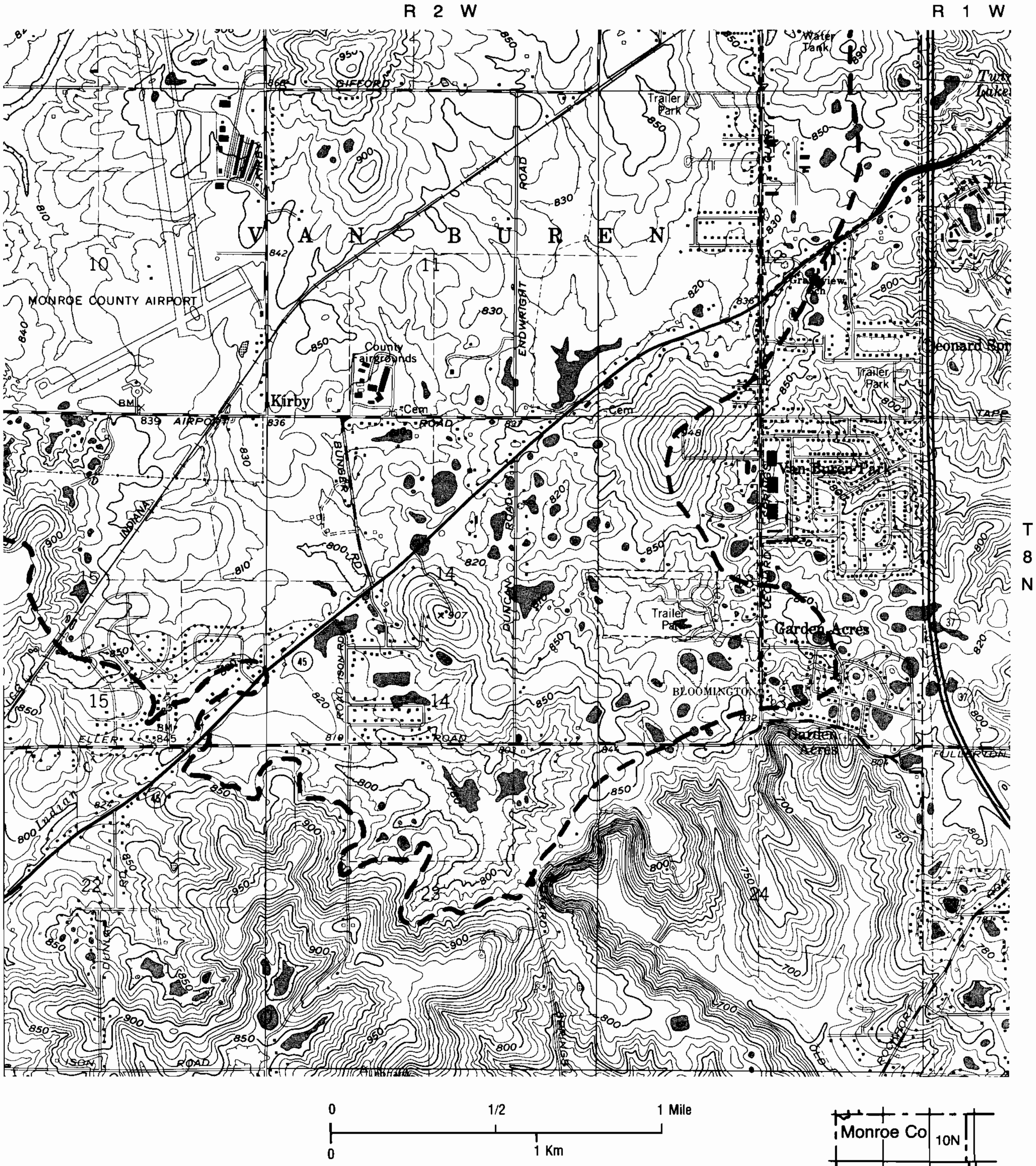
Caverns and sinkholes are formed by the dissolving action of acidic ground water on calcium carbonate as the water percolates through joints and along bedding planes in the limestone. Weak acids are formed when nitrous oxide, sulfur dioxide, and carbon dioxide are dissolved in atmospheric water and greatly concentrated by the addition of carbon dioxide as water percolates through the soil. Acid concentration increases in the soil water because roots and decaying organic matter liberate large amounts of carbon dioxide. Air in organic-rich soil can contain as much as 250 times as much carbon dioxide as atmospheric air (Foster, 1950).

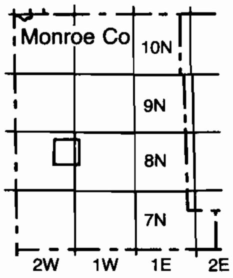
Solution of the limestone is most intense in the zone of the seasonally fluctuating water table because oxygenated, slightly acidic water, unsaturated with respect to calcium and magnesium carbonate, is continually being added to the ground-water system in this area. Because the formation of solution features has been a slow (by human standards) near-surface process and because the presently exposed limestone bedrock has been at or near the surface and undergoing weathering and erosion since late Tertiary time (more than a million years), these features are not necessarily coincident with the modern water table. Some late Tertiary and early Pleisotcene solution activity took place as much as 100 feet below the present water table because the water table was lower at that time, but most of the larger caves in Monroe County are relics of higher erosional levels of the past and happen to be at or above the modern water table. According to information gathered from water-well logs, solution features appear to decrease in size and abundance with depth and are minimal at depths greater than about 200 feet beneath the surface.

The effect of karst development on surface hydrology is most dramatic in the area of the Monroe County Airport. The entire area immediately surrounding the airport is internally drained through a system of sinkholes and blind valleys. Most of the drainage from the blind valleys reappears in nearby drainageways (Clear Creek, Indian Creek, and Richland Creek), but some remains in the ground-water system.

Solution channels and sinkholes that drain the blind valleys are much like the drain in a kitchen sink; they are subject to clogging. The channels and sinkholes occasionally fill with sediment or debris, and when this filling occurs, preciptation can result in surface flooding. Even when free of sediment and other debris, the subsurface drainage system is often not adequate to carry away all the surface flow from prolonged heavy precipitation. Because of potential flooding, erosion and debris control are extremely important in karst areas and especially in blind valleys. The reverse of flooding is also possible, as ponded sinkholes may suddenly develop leaks result-

Figure 13 (*on facing page*). Topographic map of a small part of the Mitchell Plain southwest of Bloomington showing the distinctive features of a typical karst area. Shaded areas indicate mappable sinkholes, but most sinkholes are too small to map at this scale. The area north and west of the heavy dashed line is drained entirely through sinkholes. From the U.S. Geological Survey topographic maps of the Bloomington and Clear Creek Quadrangles (1980a, 1980b).





LOCATION MAP

ing from solution or from increased subsurface transport of fill material.

Although dissolution of limestone is very slow, sinkholes may form rapidly or even catastrophically, or filled sinkholes may wash out without warning. Catastrophic failure involves the sudden collapse of surface material into a subsurface void. This type of collapse is generally caused by the rapid washing into subterranean channels of the material that fills an earlier established sinkhole. Collapse may also result from loss of support for the roof of a shallow cavern or from the addition of weight to the surface above a cavern. There are several potential triggering mechanisms. Sediment-filled sinkholes may wash out because there is a sudden heavy rain or because nearby construction alters surface or subsurface drainage. Roof collapse occurs when support is lost because solution has weakened a cave roof or because the water table is lowered below the level of the roof. Excess weight applied to the surface in the form of water (either ponded or soil water) or some man-made structure can also apply sufficient additional pressure to trigger collapse.

Sinkholes are part of a complex hydrologic system that is subject to unpredictable change. Some sinks fill with debris and accommodate semipermanent ponds, others form swallow holes (direct conduits that carry surface flow to the subsurface), and still others fill with water only during periods of heavy rain.

Irregular bedrock-surface features such as filled sinkholes and grikes (shallow solution-widened joints that are not evident on the surface) can be positively identified only through detailed drilling programs. The formation of subsurface caverns and sinkholes cannot be predicted accurately or controlled, and existing sinkholes are difficult and expensive to fill and stabilize. For these reasons construction in the karst area should be approached cautiously.

Solution in the karst area has resulted, especially in southwestern Monroe County, in numerous caves that are favored by spelunkers (Powell, 1961). A few of these caves are open with the landowner's permission to the public and to educational groups. Unfortunately, many of the caves have been abused by thoughtless or uncaring explorers. The more readily accessible caves now contain litter, and some speleothems (secondary mineral deposits formed in a cave by the action of water) have been removed.

FLATWOODS REGION

The Flatwoods region begins less than 1 mile west of Ellettsville and extends westward into Owen County. It is a low-level basin that is 6 miles long and 2 miles wide and that is mostly surrounded by higher land but has several openings in the peripheral hills. The unconsolidated materials of the Flatwoods region (as much as 70 feet thick) are thicker than those materials in other parts of the county except possibly the terraces of Beanblossom valley.

The Flatwoods is an unusually interesting geologic feature in Monroe County because it was formed behind a glacial-ice dam (Malott and Gray, 1979), which caused a great thickness of glacial till and lacustrine, alluvial, colluvial, outwash, and loess materials to accumulate. Also, there are a number of openings in the rim of the basin through which the ice-dammed lake drained into adjacent valleys (Malott and Gray, 1979).

The material that composes the valley fill in the Flatwoods region was derived from several sources. Melting of the glacial ice that formed the dam produced outwash (deposited by high-energy meltwater pouring from the ice margin) and glacial till (deposited directly from melting ice). Lacustrine deposits formed in the ponded area behind the ice dam, and alluvial material was deposited in the stream valley east of the lake. Finally, alluvial, colluvial, and windblown material has been deposited in the lake since the retreat of the glacier.

The geology of the Flatwoods region is environmentally significant because the outwash sand that was deposited by high-energy glacial meltwater is a significant source of ground water for domestic use, and the organic-rich silty loess and colluvial materials that form the surface provide perhaps the best farmland in the county. A detailed description of the Flatwoods region by Clyde A. Malott was originally published in 1915. Malott's work has been reprinted with some more recent interpretations, illustrations, and documentation (Malott and Gray, 1979).

MT. CARMEL FAULT

The Mt. Carmel Fault has a known length of about 50 miles (Ault and Sullivan, 1982; Melhorn and Smith, 1959; Shaver and Austin, 1972). It extends south by southeast through the Norman Upland from Morgan County to Washington County. In Monroe County the fault trends mostly north-south and cuts through Lake Lemon and the east end of Monroe Lake (fig. 4 and pl. 1). The fault plane is inclined steeply westward, and the downthrown side is to the west. Maximum displacement of as much as 175 feet is evident. The exact time of formation of the fault is unknown, but it probably dates from Mississippian time or later. It has apparently not been active since the beginning of the Pleistocene and has certainly not been active in recent history.

Adjacent to the fault on the west, the downthrown side, is the Leesville Anticline. The fault and the accompanying anticline form one of the largest and most significant geologic structures exposed in Indiana. Four domes lie along the crest of the anticline in Monroe County. Oil and gas have been produced from Devonian and Ordovician limestones in two of these domes, and as discussed above, two are now used for natural-gas storage.

GEOLOGIC HAZARDS

Geologic hazards are those physical circumstances of the geologic environment that may have harmful effects on manmade structures. These harmful effects may be triggered by development. The geologic hazards discussed here are mostly those that are caused or aggravated by man's activities but are also those that are hazards by their very nature. Most landforms and geologic materials are stable in their natural state, but when they are disturbed, they become unstable. For example, only minimal hazards generally result from recreational use of land, but severe hazards may result if the same land is subjected to intense industrial or commercial development. Development that alters a landscape formed through thousands or millions of years of natural processes may aggravate or create a hazard by disturbing the natural equilibrium of the landscape.

The geologic environment of Monroe County is a rather fragile one that presents certain definable hazards to continued development. These hazards are not particularly life threatening, but they can and do affect the quality of life. The more serious geologic problems that may be encountered in all or parts of Monroe County are land slumps or slides, karst sinkholes, irregular bedrock surface, expansive soils, erosion, soils sensitive to freeze-thaw, and the remote possibility of seismic activity (earthquakes).

LANDSLIDES

Small natural landslides are common on the steep hillsides of the Norman Upland in the eastern part of the county. These landslides occur in residual soils that overlie the siltstone bedrock (Borden Group) (pl. 1). Natural landslides are somewhat less common in the western part of the county, but some are evident on the slopes of the Crawford Upland. Downslope movement of soil is a natural phenomenon, but catastrophic movement normally requires some triggering circumstance. Alteration of the natural slope by even the simplest of construction projects can increase slope stress to the failure point. Failure may take place along any zone of weakness. In Monroe County the zone of weakness is normally the zone of weathering just above the bedrock surface, in part because the weathered zone is also generally the most permeable and highly saturated soil zone.

Shear strength is at its lowest when a soil is water saturated. Therefore, any construction that adds weight to or reduces the strength of a critically stable slope or that increases the water content of saturated or nearly saturated unconsolidated materials in a critically stable slope may trigger a slide, especially if zones of weaker, more permeable material separate masses of more competent material.

Because of potential landslides, construction should be restricted on excessive slopes. If construction is essential, however, several factors should be considered: (1) the unconsolidated materials that form slopes should not be weakened by removing material from the toe, (2) internal and external drainage should be provided to prevent saturation or supersaturation of the subsurface, and (3) foundations for heavy structures should be secured by competent bedrock.

SINKHOLES (KARST)

The karst area of Monroe County, mostly the Mitchell Plain but also a small area along Frog Pond Ridge south of the Monroe Lake causeway at the southeastern tip of the conty (fig. 2), presents several hazards to the unwary. Sinkholes, generally cone-shaped depressions, are the major surface expressions in the karst area of Monroe County. Sinkholes are hazards because many of them develop unexpectedly, they are conduits through which toxic substances can enter the shallow ground-water system, and they are subject to plugging and flooding.

Sinkhole formation and the collapse or subsidence of fill material in sinkholes are processes that normally occur naturally in a karst area such as the Mitchell Plain. They develop from changes in precipitation patterns or from natural weathering. Man's activities can also trigger the development or the settling of sinkholes. Sudden collapse at the ground surface may result when the roof of a shallow cavity is stressed by construction on the surface or when buoyant ground water is removed from below.

Sediment-filled sinkholes may undergo slow surface subsidence or empty suddenly as a result of altered surface or subsurface hydrology.

Subsidence of earth fill in an existing sinkhole may be catastrophic or gradual, but roof collapse into a cavern is normally catastrophic. Subsidence of major or minor proportions can be costly, regardless of whether it is triggered by nature or by man. Some examples of structures especially susceptible to damage caused by collapse are highways, railroads, buildings, sewers, gas pipelines, vehicles, farmland, streams, and reservoirs.

The irregular bedrock surface of the Mitchell Plain (fig. 2) is typical of karst areas. Bedrock spires, ridges, and holes caused by solution along joints, grikes, and sinks are hidden by the covering residuum and loess. Cursory subsurface investigations may miss some of these features and underestimate their potential impact on construction projects. Abundant bedrock spires or ridges may make foundation construction uneconomical or may dictate careful planning for buried pipeline routes. Bearing strength of soils in this area may also cause a problem. For example, if one end of a foundation is placed in thin soil above a bedrock ridge and the other end is placed in thick soil over a solution feature, differential compaction or expansion could result in unequal settling of the foundation.

EXPANSIVE SOILS

Expansive soils, those with a shrink-swell potential of more than 3 percent, can cause damage to buildings, roads, and other structures (Thomas and others, 1981). The soils that require special construction considerations in Monroe County are mostly derived from limestone, loess, shale, and outwash. Expansive soils, therefore, lie predominantly in the central and western parts of the county and in the flood plain of Beanblossom Creek. The most expansive soils are developed on shale in the southwestern part of the county and on glacial outwash in the terraces of the Beanblossom flood plain. The loess-covered limestone residuum of the Mitchell Plain and the alluvial terrace material along the valley walls of Beanblossom Creek also produce potentially hazardous expansive soils.

A common effect of expansive soils is cracked, bowed, or collapsed basement walls. If a dry soil of high shrink-swell potential is used as backfill against a basement wall, the soil will expand when wet and exert great pressure on the wall. Cracked walls cause wet basements, and bowed or collapsed walls create serious structural problems.

EROSION

Erosion is a special hazard in Monroe County because a major part of the surface of the county consists of moderate to steep slopes (fig. 3) and because certain types of soils are highly susceptible to erosion. Erosion not only strips away valuable top soil but also causes siltation in cultivated flood plains and contaminates surface water. High suspended-sediment loads in stream waters can also kill fish in streams and lakes and clog stream channels.

A thick cover of vegetation is the best protection against erosion, but construction, agriculture, lumbering, and off-road vehicles are prime contributors to erosion. Construction projects that denude the soils should be designed to control drainage and reduce soil exposure to a minimum. Minimum-tillage methods are advisable on sloping farmland because these methods reduce soil exposure and minimize runoff. Lumbering techniques should be designed to minimize erosion. Clear cutting leaves little protective cover for readily erodible soil. Detailed information regarding erosion and other soil-associated hazards is available in Thomas and others (1981).

Erosion appears to be a more serious problem in the western part of the county than in the eastern part even though slopes are generally steeper in the east. This is probably largely caused by differing land use. Much of the east is forested state and federal land, but the west is in private ownership and is used largely for pasture or crops.

SOILS SENSITIVE TO FREEZE-THAW

Frost action on many soils of the county is a significant environmental factor (Thomas and others, 1981). It is sufficiently severe in some soils to cause cracking of shallow foundations and buckling of road surfaces. Freezing and thawing produce significant volume changes in certain saturated or partly saturated soils and therefore can apply substantial stress to rigid structures.

Soils formed on alluvium, loess, lake sediments, and weathered shale are the soils most sensitive to free-thaw in Monroe County. These soils form the surfaces of the flood plains and terraces of the major streams, they are in a lobate area in the west-central part of the county and in the Flatwoods region, and they cover parts of the ridge and valley complex in the southwest corner of the county. (See Thomas and others, 1981, for a more detailed analysis and location of soils sensitive to free-thaw.)

Certain precautions can be taken to avoid this hazard. For example, foundations should be placed beneath the frostline or should be reinforced to withstand the stresses applied by freeze-thaw action. Construction projects on soils sensitive to freeze-thaw should also provide adequate internal drainage to help minimize problems connected with these soils.

EARTHQUAKES

Monroe County is in a seismically quiet area where earthquakes are rare and the prospects for damaging seismic activity are minimal. The probable return period for a quake of intensity VI (causes slight damage to structures) or greater is 140 years (Blakely and Varma, 1976). The expected source of an earthquake that would produce energy of this magnitude is more than 200 miles to the south near New Madrid, Mo. In fact, as far as earthquakes with epicenters in Indiana are concerned, the state is seismically very quiet. Minor quakes (less than V on the modified Mercalli scale) have occurred in counties that border Monroe (Morgan, Lawrence, and Greene). The latest of these minor quakes occurred in 1931, had an intensity of V, and was centered near Elliston in Greene County. The most recent earthquake felt in Monroe County had its epicenter near Lawrenceville, Ill. This quake had an intensity of V and occurred in 1987. The only recorded earthquake with an epicenter in Monroe County occurred in 1976 beneath Stinesville and had an intensity of III+ on the modified Mercalli scale.

The Mt. Carmel Fault (fig. 4 and pl. 1), which at one time probably caused severe seismic activity in this area, has apparently lain dormant since Mississippian or Pennsylvanian time (about 300 million years ago). Numerous small post-Missourian (Late Pennsylvanian) faults exist in southwestern Indiana about 50 to 75 miles from Monroe County. None of these or any other faults in Indiana are known to be modern earthquake epicenters.

However remote the possibility of a damaging earthquake, the possibility may be sufficient justification for designing construction projects such as hospitals and powerplants that are resistant to earthquake damage.

The minor earthquakes that have had their epicenters in Indiana were probably the result of east-west plate compression and did not cause faulting that can be detected in the sedimentary rocks. The foci of these earthquakes appear to lie deep in rocks of the basement complex.

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