HYDROGEOLOGIC ATLAS OF AQUIFERS IN INDIANA

U.S. GEOLOGICAL SURVEY
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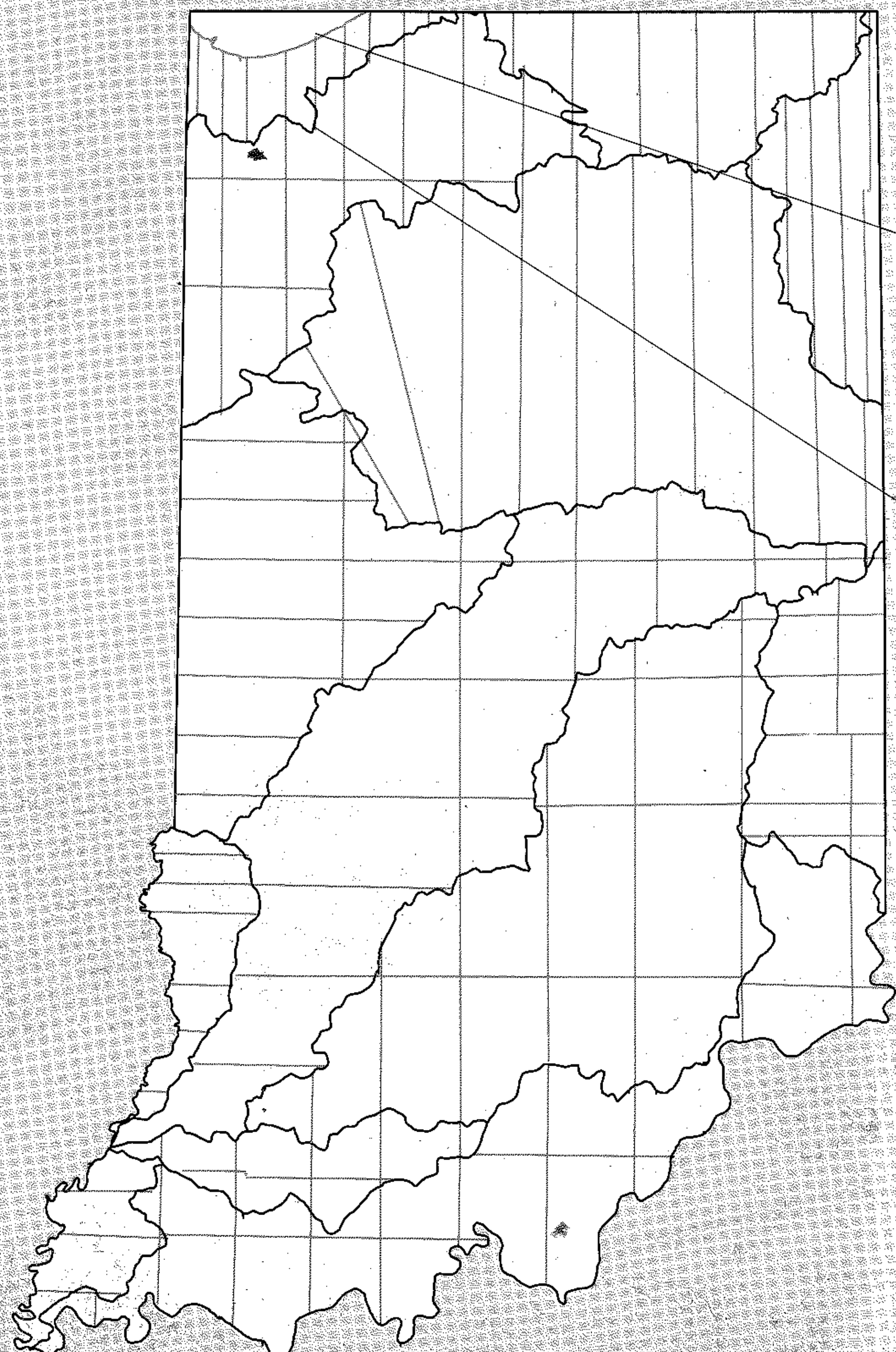

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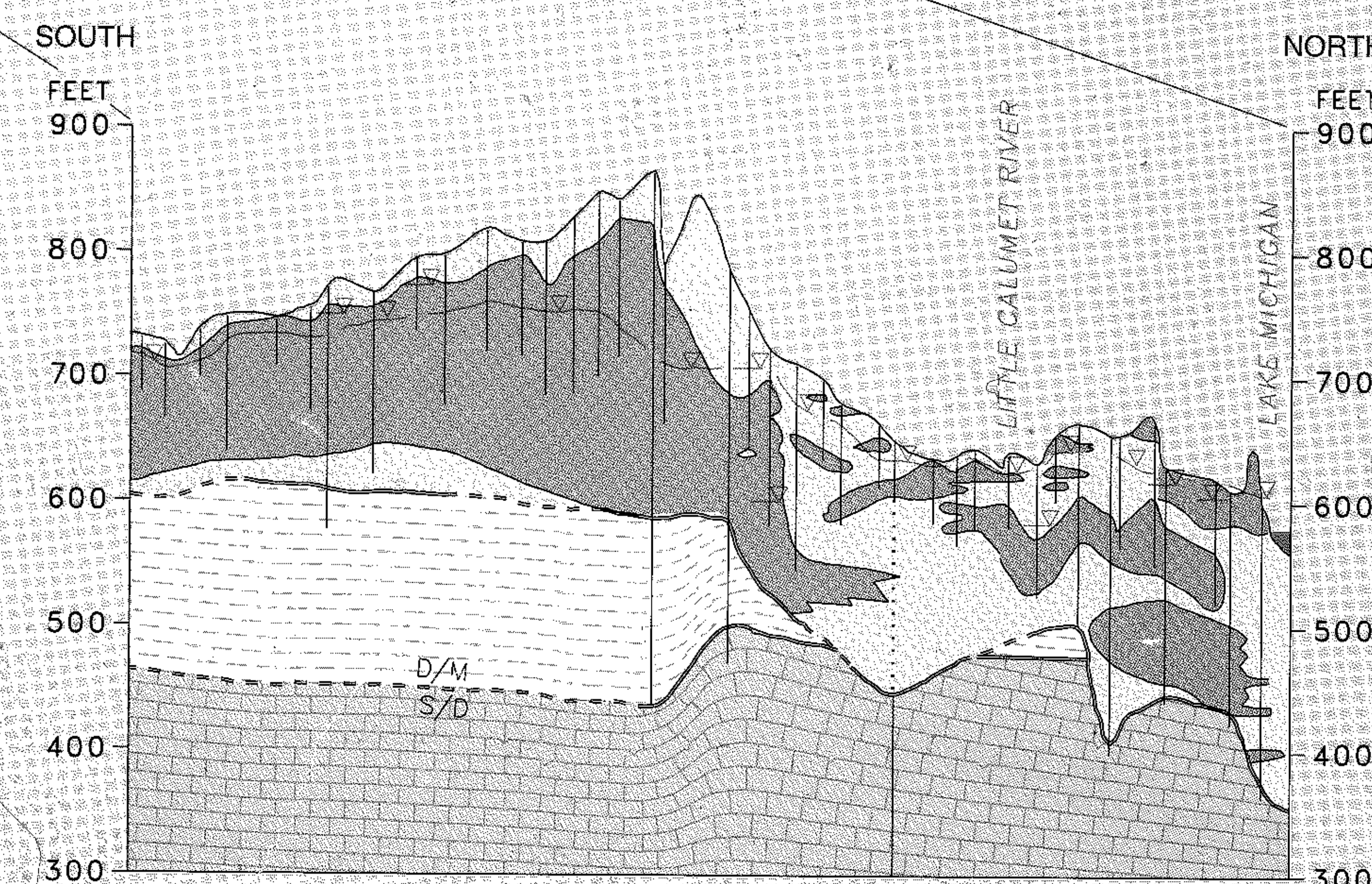
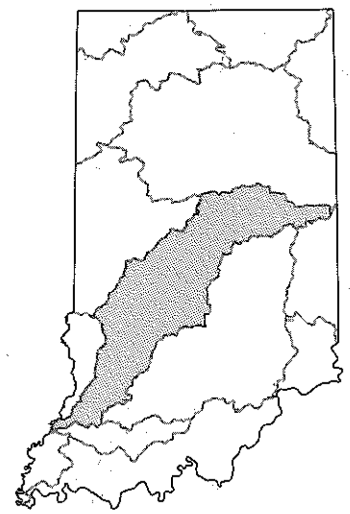




WHITE RIVER BASIN

By Mary E. Hoover and James M. Durbin

General Description

The White River basin spans nearly the entire width of south-central Indiana. The basin, as defined in this report, includes the areas from the headwaters of the White River in Randolph County to the confluence with the Wabash River in Knox County, but does not include the basin of the East Fork White River (fig. 1). The White River basin encompasses 5,603 mi^2 in 27 counties and includes all or large parts of the following counties: Boone, Clay, Davies, Delaware, Greene, Hamilton, Hendricks, Knox, Madison, Marion, Monroe, Morgan, Owen, Putnam, Randolph, and Tipton. Principal cities within the basin are Anderson, Greencastle, Indianapolis, Linton, Martinsville, Muncie, Spencer, Washington, and Winchester (fig. 54).

Previous Studies

Because a large proportion of Indiana's population resides within the White River basin, many studies have been completed on ground water and characteristics of the aquifers that control ground-water availability. A series of reports by the U.S. Geological Survey describes the ground-water resources of five counties within the northern part of the basin: Madison (Lapham, 1981), Delaware (Arihood and Lapham, 1982), Hamilton and Tipton (Arihood, 1982), and Randolph (Lapham and Arihood, 1984). The authors of these studies examined the hydrogeology of the White River basin within each respective county and modeled expected yields given a variety of pumping schemes, geohydrologic characteristics of the aquifers, and locations of induced recharge.

Other studies that focused on northern counties in the basin include reports on the hydrogeology of Delaware County (Hoggatt and others, 1968), Madison County (Wayne, 1975), Marion County (Herring, 1976), and Hamilton County (Gillies, 1976). The study by Gillies (1976) included modeling of an aquifer system adjacent to the White River near Carmel, Ind., and evaluation of the effects of continued and increased production from the aquifer. Studies of the outwash aquifer along the White River in Marion County (Meyer and others, 1975; Smith, 1983) focused on the characteristics of the aquifer and modeling of the hydrology and water availability for Indianapolis. The outwash aquifer along the White River in Johnson and Morgan Counties was studied by Bailey and Imbrigiotta (1982) to estimate the geometry and hydraulic characteristics of the aquifer and to establish the nature and extent of the hydraulic connection between surface and subsurface hydrology. Watkins (1965) appraised the ground-water resources and effects of a proposed reservoir on the hydrology of the Big Walnut Creek watershed in parts of Putnam, Hendricks, and Boone Counties.

Another series of reports published by the Indiana Department of Conservation, Division of Water, in cooperation with the U.S. Geological Survey, describes the ground-water resources of a number of southwestern Indiana counties within the White River basin. Studies were done in Greene County (Watkins and Jordan, 1961), Clay County (Watkins and Jordan, 1962), and Owen County (Watkins and Jordan, 1963); the authors published well logs, delineated which lithologies were aquifers, and evaluated ground-water availability. Other reports published by the Indiana Department of Natural Resources, Division of Water, for Clay and Vigo Counties (Cable and others, 1971) and Greene and Sullivan Counties (Cable and Robison, 1973) refined the work done previously in those counties and expanded the research to include data on water quality. A report by Barnhart and Middleman (1990) detailed the hydrogeology and ground-water quality of Gibson County. A report by Wangsness and others (1981) summarized available hydrologic data for an area that includes the lower half of the White River basin downstream from Gosport, Ind. (fig. 54). The report includes surface-water, ground-water, and water-quality information. A Master's thesis by Thomas (1980) detailed the aquifer potential and characteristics of the Mansfield Formation within Clay County.

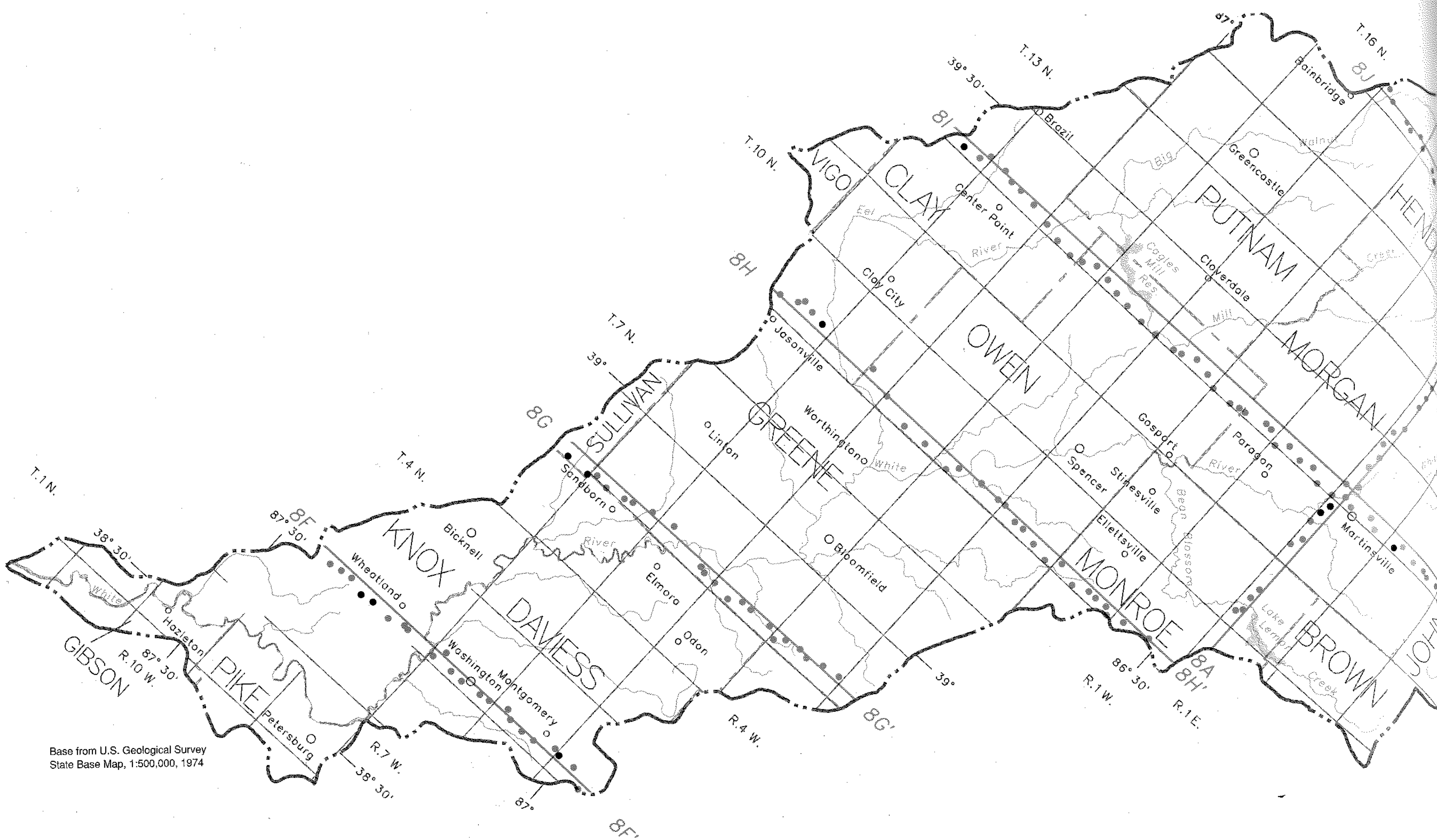
A ground-water study that describes the hydrogeology of the entire White River basin was done by Nyman and Pettijohn (1971). The report is a brief description of the important aquifers in the basin, and includes information on well yields and potential yields, ground-water quality, and ground-water discharge to the major streams in the basin. A major study by the U.S. Geological Survey is currently (1991-97) being done for the White and East Fork White River basins as part of the National Water-Quality Assessment Program. The study will assess the water quality of the surface- and ground-water resources of the White and East Fork White River basins (Jacques and Crawford, 1991).

In addition to written reports, various ground-water-availability maps have been published. The Indiana Department of Natural Resources, Division of Water, has published maps that delineate major aquifers along with recorded and potential well yields in the following counties: Morgan (Heckard, 1965), Johnson (Uhl, 1966), Madison (Steen, 1970), Hamilton (Herring, 1971), Marion (Herring, 1974), and Boone (Steen and others, 1977). Ground water availability maps have been completed for the entire state of Indiana by Bechert and Heckard (1966) and Clark (1980).

Physiography

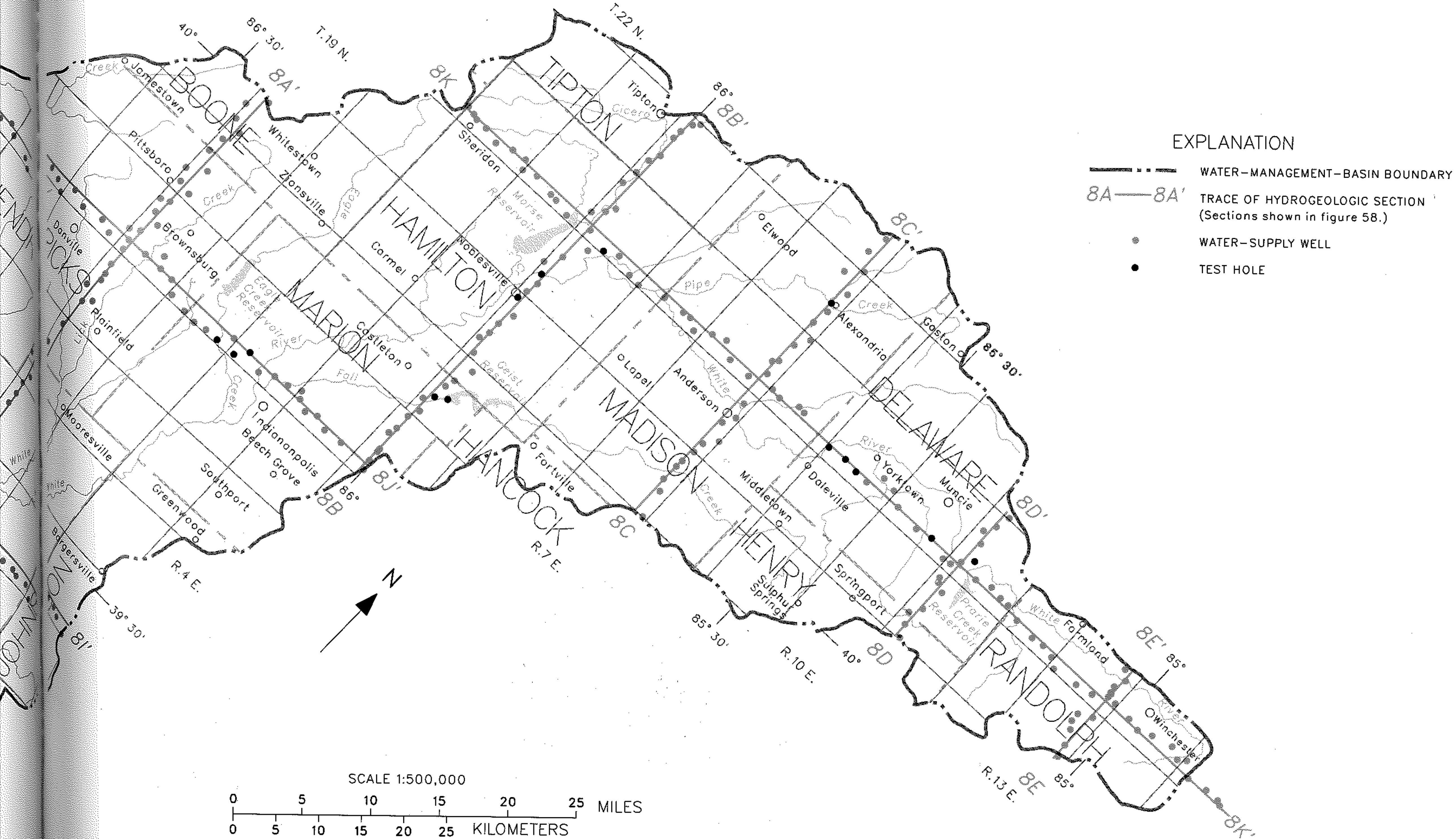
The topographic relief across the White River basin is about 750 ft. The highest point, about 1,200 ft above sea level, is in Randolph County in the eastern part of the basin. The lowest point, about 450 ft above sea level, is in Gibson County in the southernmost part of the basin.

The basin lies within five physiographic units as defined by Malott (1922) and later refined by Schneider (1966) (fig. 55). The northern half of the basin is in the Tipton Till Plain. This plain of low relief is composed of thick glacial deposits that obscure the underlying bedrock topography. The Norman Upland, of which only a small part of the northernmost extent is within the basin, is characterized by narrow, flat-topped divides and deep V-shaped valleys; local relief is typically 125 to 250 ft. The Norman Upland is well drained by a strongly developed dendritic stream pattern. The Mitchell Plain in the White River basin, which in most places is less than 7 mi wide, occupies a narrow strip in the central part of the basin. The Mitchell Plain is a westward-sloping plain composed of limestones. The limestones are subject to karst development and they form numerous sinkholes into which some streams "disappear". The karst development in the White River basin is not as extensive as karst development further south in the State. The Crawford Upland is a westward-sloping plateau developed in interbedded sandstones, shales, and limestones capped by resistant sandstones. Differential erosion in this region has created a deeply dissected upland in which local relief is as much as several hundred feet. The Crawford Upland is about 25 mi wide and is adjacent to, and west of the Mitchell Plain. The Wabash Lowland is the southernmost physiographic unit in the basin. This unit is a broad lowland underlain by nonresistant siltstones and shales, which have been eroded by repeated glaciations into a subdued landscape.



Base from U.S. Geological Survey
State Base Map, 1:500,000, 1974

Figure 54. Location of section lines and wells plotted in the White River basin.


EXPLANATION
WATER-MANAGEMENT-BASIN BOUNDARY
8A——8A' TRACE OF HYDROGEOLOGIC SECTION (Sections shown in figure 58.)
WATER-SUPPLY WELL
TEST HOLE
SCALE 1:500,000
0 5 10 15 20 25 MILES
0 5 10 15 20 25 KILOMETERS
N
BOONE
HAMILTON
TIPTON
MARION
HANCOCK
MADISON
DELAWARE
HENRY
RANDOLPH
Jamestown
Whitestown
Zionsville
Pittsboro
Brownsburg
Danville
Plainfield
Mooresville
Indianapolis
Beech Grove
Southport
Greenwood
Bargersville
Carmel
Castleton
Sheridan
Noblesville
Tipton
Cicero
Elwood
Alexandria
Gaston
Lapel
Anderson
Fortville
Middletown
Daleville
Yorktown
Muncie
Springport
Sulphur Springs
Farmland
Winchester
Morse Reservoir
Geist Reservoir
Eagle Creek Reservoir
Prairie Creek Reservoir
8A
8A'
8B
8B'
8C
8C'
8D
8D'
8E
8E'
8J
8K
8K'
8I'
T.19 N.
T.22 N.
R.4 E.
R.7 E.
R.10 E.
R.13 E.
40°
86° 30'
86°
85° 30'
85°
39° 30'

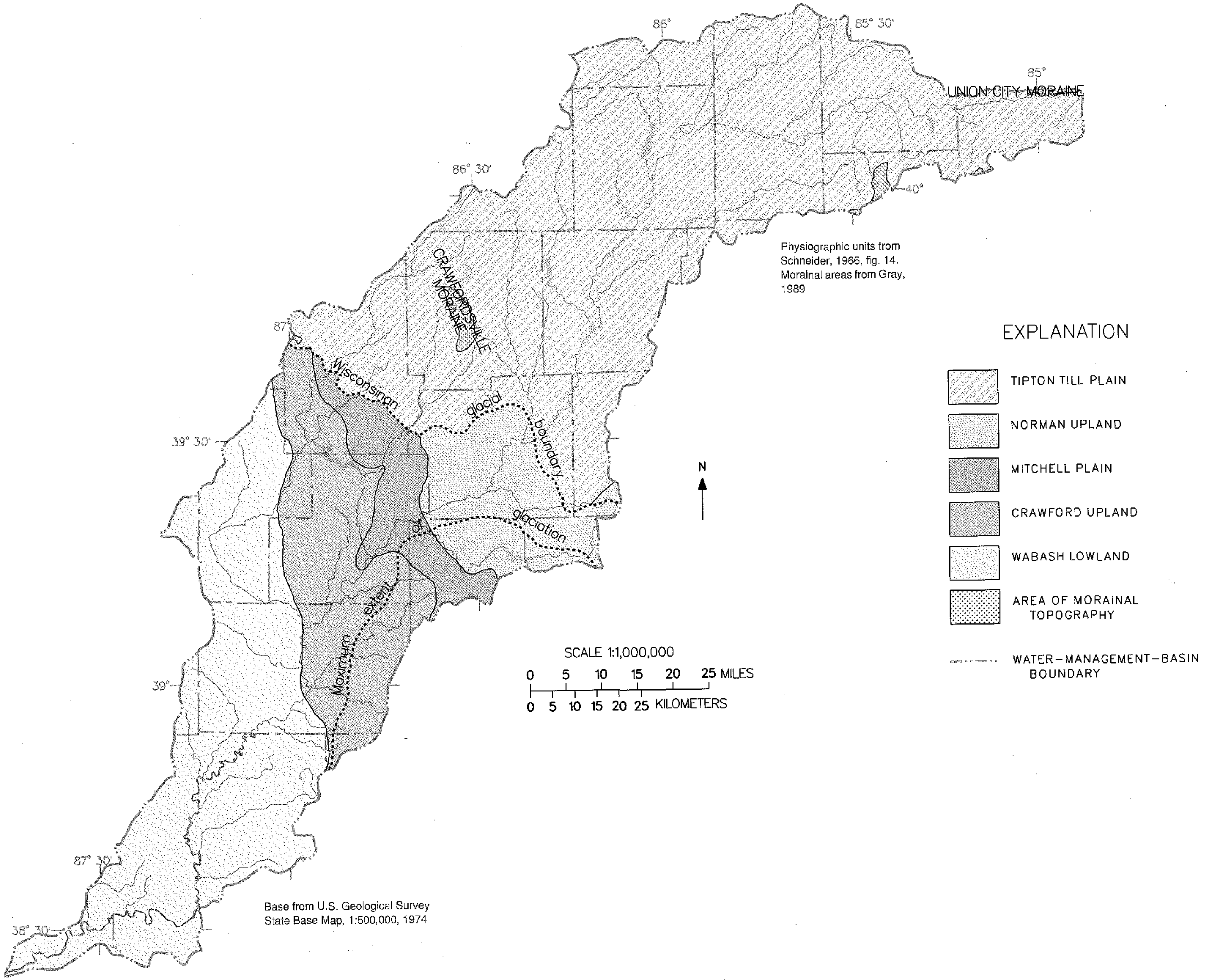


Figure 55. Physiographic units, moraines, and extent of glaciation in the White River basin.

Surface-Water Hydrology

The White River provides the major drainage within the basin; average discharges of the river are 208 ft^3/s near Muncie in Delaware County and 11,850 ft^3/s near Petersburg in Pike County (Arvin, 1989). Several large tributary drainage basins are within the White River basin (fig. 54). The Eel River tributary, in the southwestern part of the basin, has the largest drainage area (830 mi^2) of any tributary to the White River in the White River basin. Other tributaries whose drainage areas are greater than 100 mi^2 include Fall Creek, Eagle Creek, Big Walnut Creek, White Lick Creek, Mill Creek, Pipe Creek, and Cicero Creek. These tributaries are perennial streams and, depending upon climatic and aquifer conditions, are either recharge sources or discharge outlets for ground water.

A number of streams have been artificially dammed to form water-supply reservoirs. Principal reservoirs include Morse, Geist, Eagle Creek, Cagles Mill, and Prairie Creek Reservoirs.

Geology

Bedrock Deposits

The White River basin overlies two major structural features known as the Illinois Basin and the Cincinnati Arch (fig. 4). Bedrock strikes north-northwest, generally dipping gently to the southwest into the Illinois Basin; however, in the northeastern part of the basin where the Cincinnati Arch is present, bedrock dips northward toward the Michigan Basin, as shown in sections 8C–8C′, 8D–8D′ and 8E–8E′ (fig. 58). Successively younger rocks are exposed in the basin from east to west (fig. 56). Rocks of Ordovician age are exposed on top of the Cincinnati Arch in the northeastern part of the basin (fig. 56). To the west, rocks of Silurian, Devonian, Mississippian, and Pennsylvanian age are present at the bedrock surface either as subcrops where covered by unconsolidated materials or as outcrops where exposed in unglaciated areas or along some of the large streams (fig. 56). Erosional unconformities between the Silurian and Devonian contact and the Mississippian and Pennsylvanian contact are significant. Preglacial stream systems have eroded and dissected the entire bedrock surface, removing large amounts of Paleozoic rocks from the crest of the Cincinnati Arch and creating deep bedrock valleys (fig. 7). Examples of these valleys can be seen in most of the hydrogeologic sections (fig. 58).

The Fortville Fault and the Mount Carmel Fault, each about 50 mi long, transect the basin. The Fortville Fault strikes north-northeast from Marion County through Hancock and Madison Counties (fig. 56). The southeastern block of the fault is downthrown. The Mount Carmel Fault strikes north-northwest from Washington County through Lawrence and Monroe Counties (fig. 56). Only the northernmost 10 mi of the Mount Carmel Fault is within the basin.

Ordovician rocks of major lithostratigraphic significance in the White River basin are part of the Maquoketa Group. The Maquoketa Group is as much as 80 percent shale that is interbedded with limestone. The proportion of limestone increases toward the east in the White River basin (Shaver and others, 1986, p. 88).

Silurian rocks within the basin include the Brassfield Limestone, the Cataract Formation, the Salamonie Dolomite, and the Salina Group. The Brassfield Limestone, which is less than 10 ft thick in most places, interfingers with shales and dolostones of the Cataract Formation (Shaver and others, 1986, p. 20). The Salamonie Dolomite is a fairly pure dolostone that is about 50 ft thick in the central part of the State (Shaver and others, 1986, p. 180-132). The Salina Group contains the Pleasant Mills Formation and the Wabash Formation, both of which are composed of limestone and dolostone interbedded with shale members (Gray and others, 1987). Both the carbonate rocks and the shales are of variable thickness (Shaver and others, 1986, p. 114-116, 163-165).

Devonian bedrock consists primarily of dolomitic carbonate rocks (Muscatatuck Group) or shale (New Albany Shale). The Muscatatuck Group can be as much as 250 ft thick, but it is probably no thicker than 50 to 60 ft in the White River basin. The New Albany Shale, which is Devonian and Mississippian in age, is composed of dark carbonaceous shales (Shaver and others, 1986, p. 101) and is 85 to 150 ft thick within the White River basin.

Rocks of Mississippian age include the Borden, Sanders, Blue River, West Baden, and Stephensport Groups. The Borden Group ranges in thickness from 485 to 800 ft and consists of the New Providence Shale, the Spickert Knob Formation, and the Edwardsville Formation. The New Providence Shale, overlying the New Albany Shale, is composed predominantly of shale. The Spickert Knob Formation grades upward from a silty shale to a massive siltstone but includes some sandstone and limestone. The Edwardsville Formation consists of siltstone, sandy shale, and sandstone interbedded with minor limestones (Shaver and others, 1986, p. 18-19).

The Sanders and Blue River Groups consist of well-bedded and dense limestones that contain thin shale beds. Where limestone crops out or is covered by thin unconsolidated materials, it commonly is highly karstic and contains numerous sinkholes and caves. The thickness of the Blue River Group in outcrop within the basin ranges from 150 to 240 ft; in the subsurface, thickness may exceed 350 ft (Shaver and others, 1986, p. 16-17). Thickness of the Sanders Group is variable, ranging from 120 to 150 ft (Shaver and others, 1986, p. 136).

The West Baden Group is a mixture of sandstones, siltstones, shales, and mudstones, interbedded with thin limestone lenses; outcrop thickness is 100 to 140 ft and subsurface thickness is as much as 260 ft in Gibson County (Shaver and others, 1986, p. 167). The Stephensport Group is composed of equal parts of shales, sandstones, and limestones. Because of the erosional unconformity between the Mississippian and Pennsylvanian rocks, outcrops of the Stephensport Group are generally less than 50 ft thick and are absent in many places throughout the White River basin (Gray and others, 1987). The subsurface thickness of the Stephensport Group ranges from 130 to 230 ft (Shaver and others, 1986, p. 151).

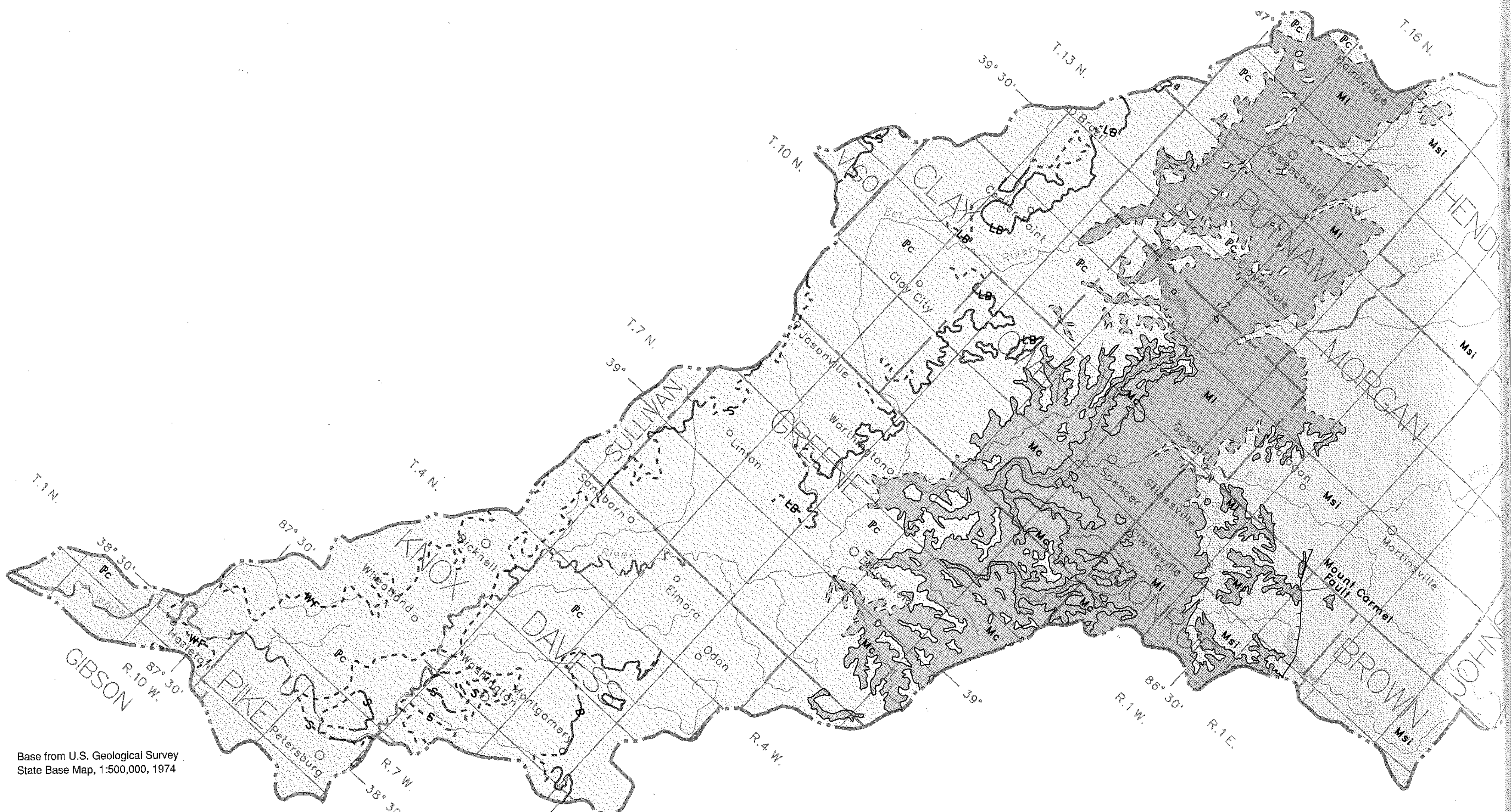
Rocks of Pennsylvanian age within the White River basin include the Raccoon Creek, Carbondale, and McLeansboro Groups. These three groups are dominated by shales, but sandstones, siltstones, limestones, clays, and coal also are major components. Within the Raccoon Creek Group are the Mansfield, Brazil, and Staunton Formations. The Mansfield Formation, which can be as much as 300 ft thick, is mostly sandstone in the lower part of unit but contains increasingly more shale upward in the unit (Shaver and others, 1986, p. 87). The Brazil Formation is characterized by the lack of traceable beds; it is composed primarily of shale, sandstone, underclay, and coal, which have a combined thickness of 40 to 90 ft (Shaver and others, 1986, p. 21). The Staunton Formation consists of 75 to 150 ft of sandstones, shales, thin, areally limited coal beds, and minor limestone lenses (Shaver and others, 1986, p. 149-150). The Carbondale Group includes the Linton, Petersburg, and Dugger Formation. The Linton Formation consists of sandstones, shales, limestones and coal; it is typically about 80 ft thick but ranges from 60 to 162 ft in thickness (Shaver and others, 1986, p. 80). The Petersburg Formation consists of 40 to 120 ft of shale, fine-grained sandstone, and coal, including the Springfield Coal Member (Coal V) (Shaver and others, 1986, p. 112). The Dugger Formation contains several coal members and beds of limestone, shale, and clay, and ranges in thickness from 73 to 185 ft (Shaver and others, 1986, p. 39). The Shelburn, Patoka, and Bond Formations of the McLeansboro Group are present in the far southwestern corner of the basin. The McLeansboro Group is more than 90 percent shale and sandstone, but has small amounts of siltstone, limestone, coal, and clay (Shaver and others, 1986, p. 86). The West Franklin Limestone, a thin but persistent marker bed, is present within the Shelburn Formation (fig. 56).

Unconsolidated Deposits

Nearly all of the White River basin is covered by unconsolidated deposits, most of which were deposited by continental ice sheets. During the Pleistocene, continental ice sheets consisting of numerous lobes advanced into Indiana at least three times and deposited glacial sediments (Wayne, 1966, p. 21). These three glacial advances occurred during the Wisconsinan, Illinoian and pre-Illinoian glacial stages (in order from most to least recent). Thicknesses of deposits range from less than 25 ft in the southern part of the basin to as much as 400 ft in the northern part of the basin, although most of the unconsolidated deposits in the basin are from 50 to 150 ft thick (fig. 57). Glacial sediments, including outwash sand and gravel, from all three glacial stages filled preglacial stream valleys and created buried bedrock valleys (Bleuer, 1989). The location of these buried bedrock valleys is shown in figure 7.

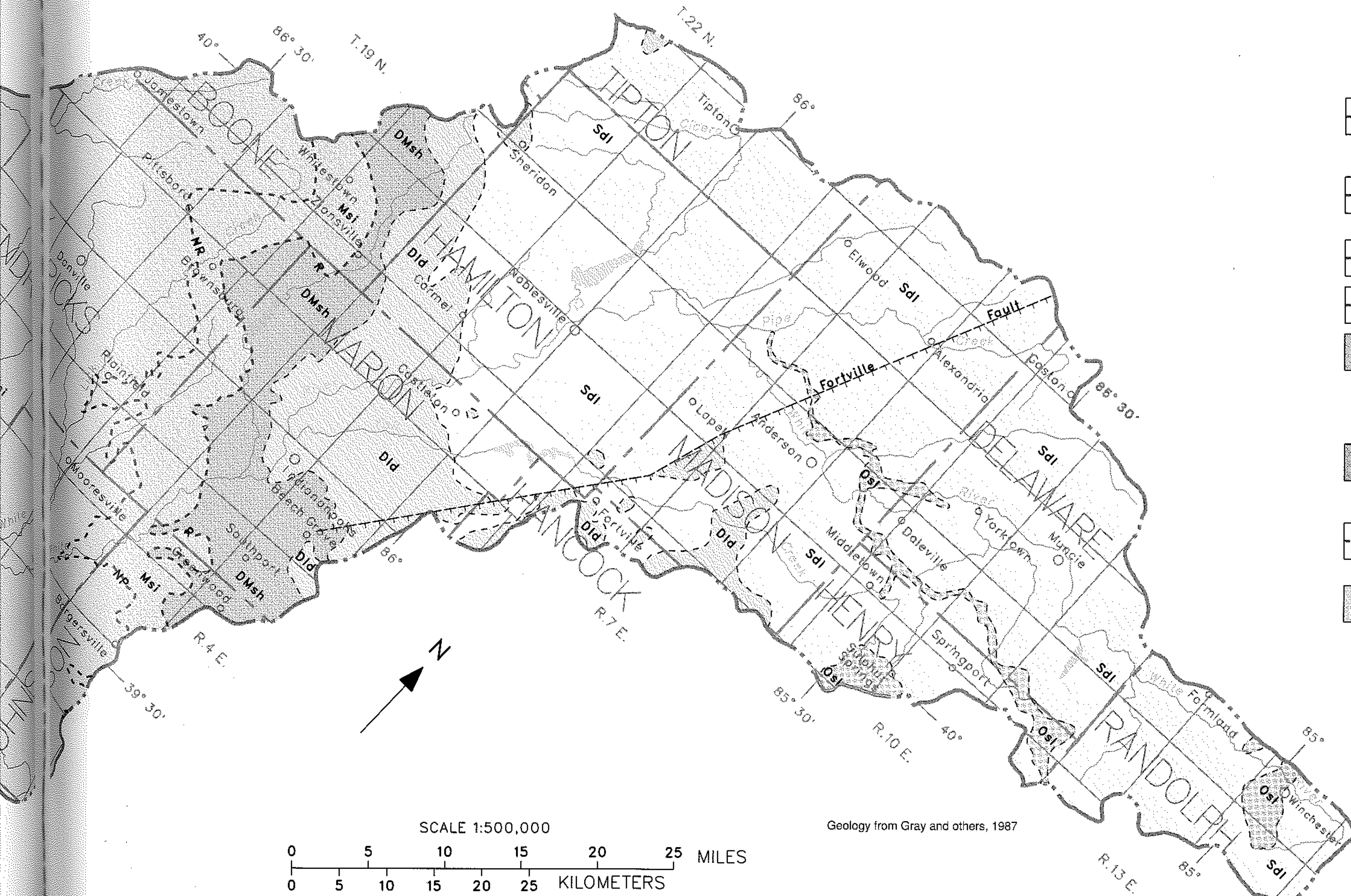
Exposures of pre-Illinoian deposits are rare in the White River basin, and little information on the nature and extent of these deposits is available. During the Illinoian Age, ice covered as much as 80 percent of Indiana. Illinoian deposits are exposed throughout the southern half of the basin. These Illinoian deposits are predominantly loam tills that are heavily dissected; few morainal systems have been delineated. Pre-Illinoian and Illinoian glacial sediments are included in the Jessup Formation (Gray, 1989).

Overlying Illinoian and pre-Illinoian deposits are Wisconsinan glacial materials. During Wisconsinan glaciation, the Lake Michigan Lobe and Erie Lobe covered the upper one-third of the White River basin (fig. 8) and deposited extensive terminal and recessional morainal systems. Only small segments of these systems, the Union City and Crawfordsville Moraines (figs. 3 and 55), are within the boundary of the basin. The northern one-half of the basin is covered by thick ground moraine, which is composed of loamy tills interbedded with thin, discontinuous to continuous layers of stratified sand and gravel. Outwash that was transported south from the Wisconsinan glaciers filled in many of the large stream valleys beyond the glacial boundary, as well as valleys within the Wisconsinan glacial limits. During all of the glacial stages, the landscape was covered by windblown deposits to some degree; these deposits consisted chiefly of loess (windblown silt) and localized dune sand.



Base from U.S. Geological Survey State Base Map, 1:500,000, 1974

Figure 56. Bedrock geology of the White River basin.



Geology from Gray and others, 1987

EXPLANATION

IPc	PENNSYLVANIAN COMPLEXLY INTERBEDDED SHALE AND SANDSTONE, WITH THIN BEDS OF LIMESTONE AND COAL-- Composed of the Racoon Creek and Carbondale Groups and the Shelburn, Patoka, and Bond Formations of the McLeansboro Group
-WF-	WEST FRANKLIN LIMESTONE MEMBER OF SHELBURN FORMATION
- - S - -	SPRINGFIELD COAL MEMBER (COAL V)
- - B - -	BUFFALOVILLE COAL MEMBER
-LB-	LOWER BLOCK COAL MEMBER
Mc	MISSISSIPPIAN COMPLEXLY INTERBEDDED SHALE, SANDSTONE AND LIMESTONE-- Composed of the West Baden and Stephensport Groups
Ml	MISSISSIPPIAN LIMESTONE-- Composed of the Sanders and Blue River Groups
-NP-	TOP OF NEW PROVIDENCE SHALE
Msl	MISSISSIPPIAN SILTSTONE AND SHALE WITH MINOR SANDSTONE AND DISCONTINUOUS LIMESTONE-- Composed of the Borden Group
- - R - -	ROCKFORD LIMESTONE
DMsh	DEVONIAN AND MISSISSIPPIAN SHALE-- Composed of the New Albany Shale
Dld	DEVONIAN LIMESTONE AND DOLOMITE-- Composed of the Muscatatuck Group
Sdl	SILURIAN DOLOMITE AND LIMESTONE-- Composed of the Wabash and Pleasant Mills Formations, and the Salamonie Dolomite, Cataract Formation, and Brassfield Limestone
Osl	ORDOVICIAN SHALE AND LIMESTONE-- Composed of the Maquoketa Group
⊥⊥⊥⊥	NORMAL FAULT-- Hachures on downthrown side. Dashed where approximately located
– – ——	GEOLOGIC CONTACT-- Dashed where approximately located
▬ ▪ ▪ ▬	WATER-MANAGEMENT-BASIN BOUNDARY

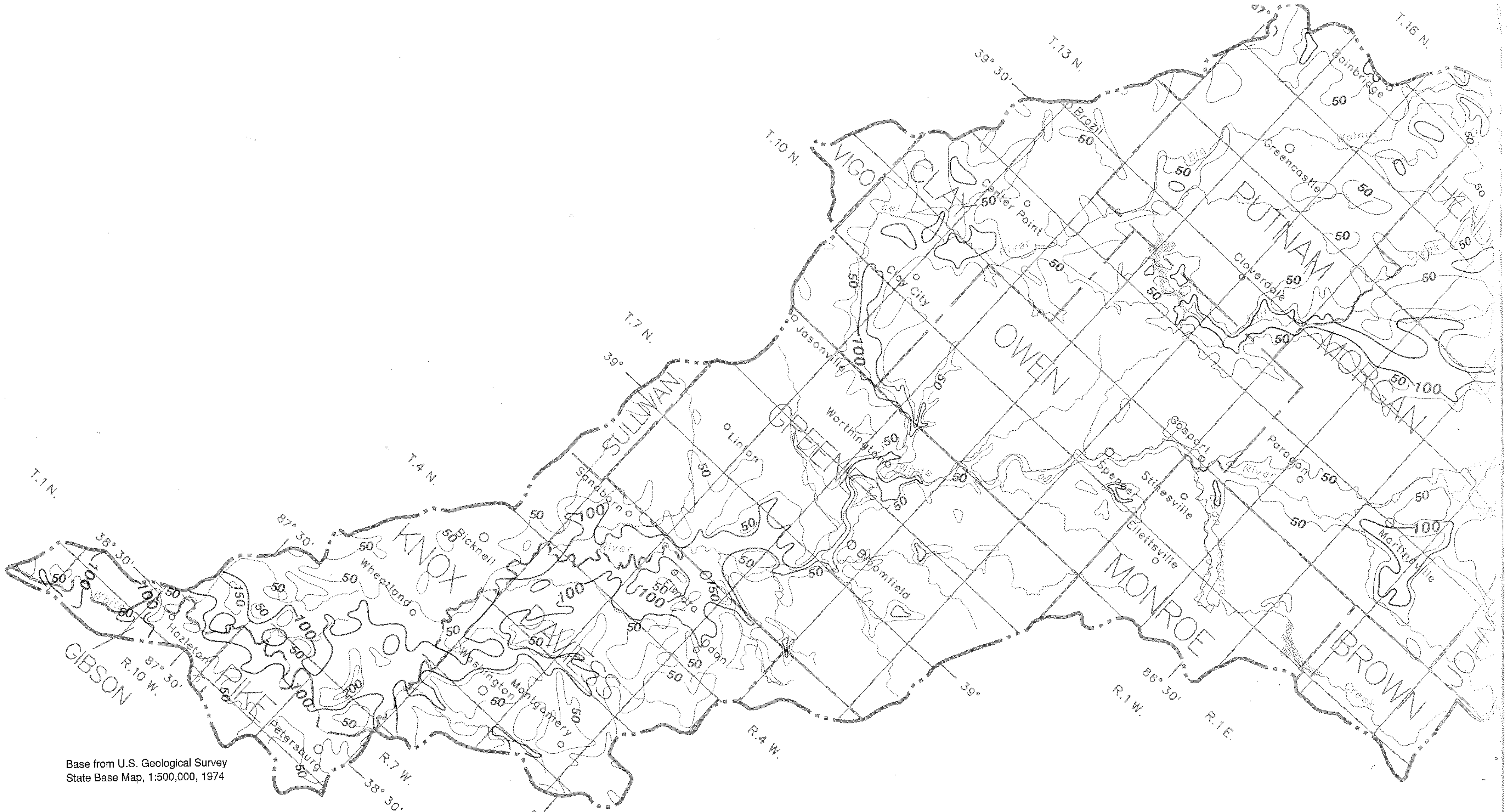
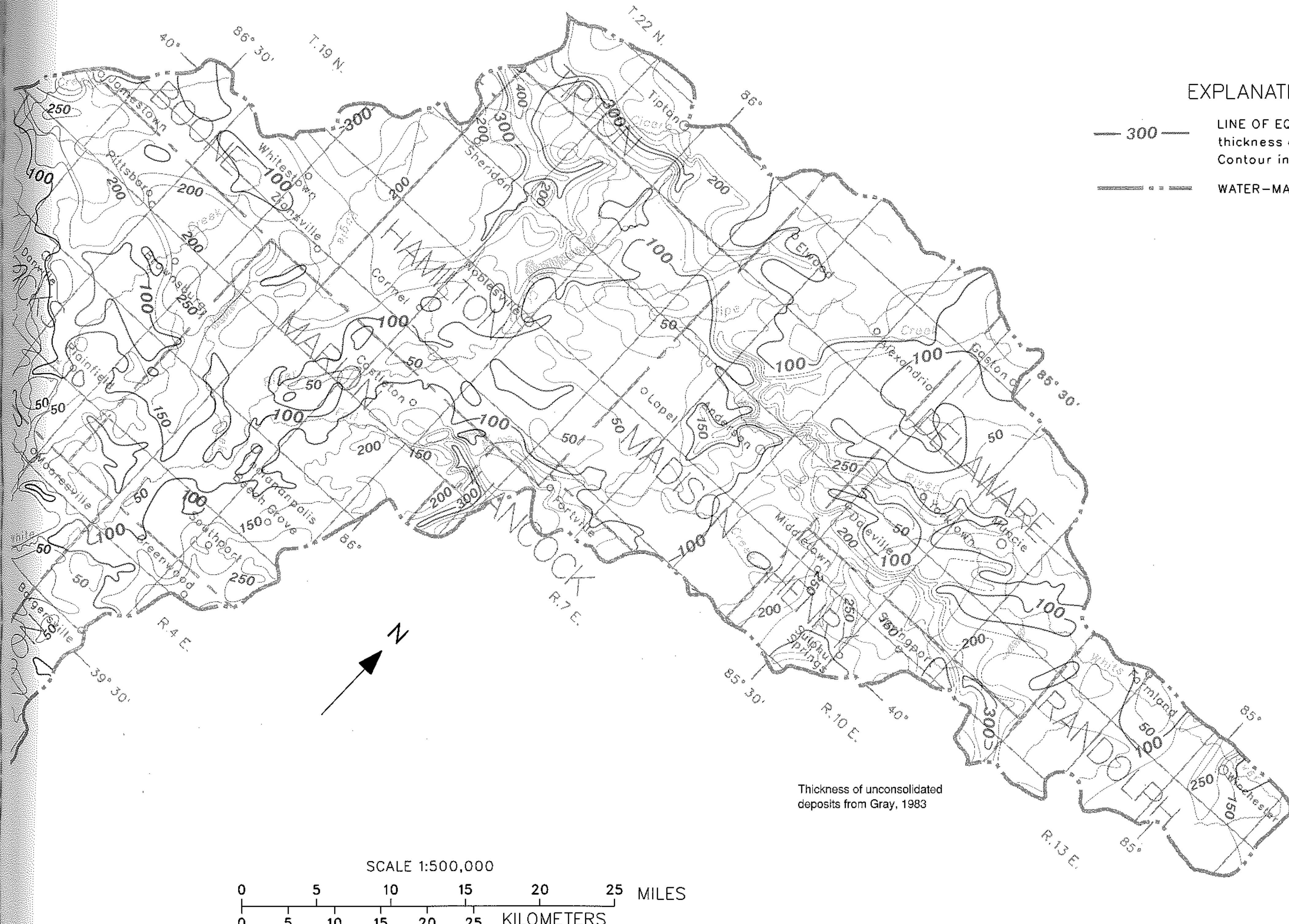


Figure 57. Thickness of unconsolidated deposits in the White River basin.

EXPLANATION

—300— LINE OF EQUAL THICKNESS--Shows thickness of unconsolidated deposits. Contour interval 50 feet

— · · — WATER-MANAGEMENT-BASIN BOUNDARY



Thickness of unconsolidated deposits from Gray, 1983

Aquifer Types

The hydrostratigraphy of the White River basin is shown in 11 hydrogeologic sections (fig. 58). Hydrogeologic sections 8A–8A′ to 8E–8E′ are oriented south-north, and hydrogeologic sections 8F–8F′ to 8K–8K′ are oriented west-east (fig. 54). The typical spacing between hydrogeologic sections is about 18 mi, the exception being the spacing between 8D–8D′ and 8E–8E′, which is only 12 mi. The total length of the 11 hydrogeologic sections is about 410 mi. In all, 354 well logs were used to draw the sections. These well logs were plotted at an average density of one well log every 1.2 miles (fig. 54).

Throughout the northeastern one-third of the basin, the principal aquifers are buried continuous sand and gravel where the drift is greater than 25 ft thick, carbonate rock (limestone and dolostone) where drift is thin, and surficial sand and gravel near major streams (fig. 59). Where the glacial deposits are thick, the depth of wells ranges from 50 to 400 ft and averages 150 ft (Bechert and Heckard, 1966, p. 108-109). The carbonate bedrock aquifer in the northeastern one-third of the basin is Late Ordovician, Silurian, and Devonian in age. Wells in these rocks are as deep as 150 ft (Lapham, 1981, p. 16), but only the upper 100 ft is generally considered to be permeable (Cable and others, 1971).

Throughout the central one-third of the basin, principal aquifers include surficial, buried, and discontinuous sand and gravel; an upper weathered zone in siltstone and shale, and a carbonate bedrock aquifer (fig. 59). The characteristics of the sand and gravel aquifers are the same as those in the northeastern one-third of the basin. The siltstone-shale aquifer is used only where no other aquifer type is available. Water production from these normally low-yield rock types is from a zone of enhanced permeability created by weathering and fracturing of the shale and siltstone. Water produced from the carbonate bedrock aquifer is from Mississippian limestones.

The principal aquifers in the southwestern one-third of the basin are surficial sand and gravel; sandstone; complexly interbedded sandstone, shale, limestone, and coal; and carbonate rock (fig. 59). Surficial sand and gravel along large streams is the only productive sand and gravel aquifer in the southwestern one-third of the basin. Yields from all bedrock aquifers in the area are low (less than 20 gal/min). Sandstone aquifers are present in Pennsylvanian rocks, aquifers in the complexly interbedded materials are present in Late Mississippian and Pennsylvanian rocks, and carbonate bedrock aquifers are present in Mississippian rocks. Physical characteristics and some common or stratigraphic names for aquifer types within the basin are summarized in table 10.

Unconsolidated Aquifers

Surficial Sand and Gravel Aquifers

Surficial sand and gravel aquifers are restricted to the major river valleys throughout the basin (fig. 59) and can be seen in sections 8A–8A′, 8B–8B′, and 8F–8F′ to 8I–8I′ (fig. 58). In instances where an entire valley is filled from bedrock to land surface with sand and gravel (as shown in section 8A–8A′ (fig. 58) along the White River near Martinsville), the valley was mapped as surficial sand and gravel aquifer. The entire thickness of sand and gravel may not represent a single, continuous deposit but rather is an area of stratigraphic and hydraulic connection between the surficial and buried sand and gravel. The surficial sand and gravel consists of Wisconsinan and older glaciofluvial or fluvial sand and gravel and minor windblown deposits in the form of dune sands (Thornbury, 1950; Barnhart and Middleman, 1990; Gray, 1989). The dune sands, found in the southern part of the basin, may be a local source of water for shallow domestic wells, but these sands are generally considered insignificant as aquifers (Watkins and Jordan, 1961; 1962).

The areal extent of the surficial sand and gravel aquifer in the southern part of the basin is greater than that in the northern part; however, the demands on the aquifer in the north are much greater than in the south because of its use by the municipalities of Muncie, Anderson, and Indianapolis, and by nearby industries. Authors of previous studies have agreed that the "outwash" aquifers that underlie the major streams are the most productive aquifers in the basin (Watkins and Jordan, 1961, 1962; Lapham, 1981; Arihood, 1982; Arihood and Lapham, 1982; Lapham and Arihood, 1984). In the southern part of the basin, where the surficial sand and gravel aquifer is used for small-town and domestic supplies, it has not been developed to its full water-producing potential.

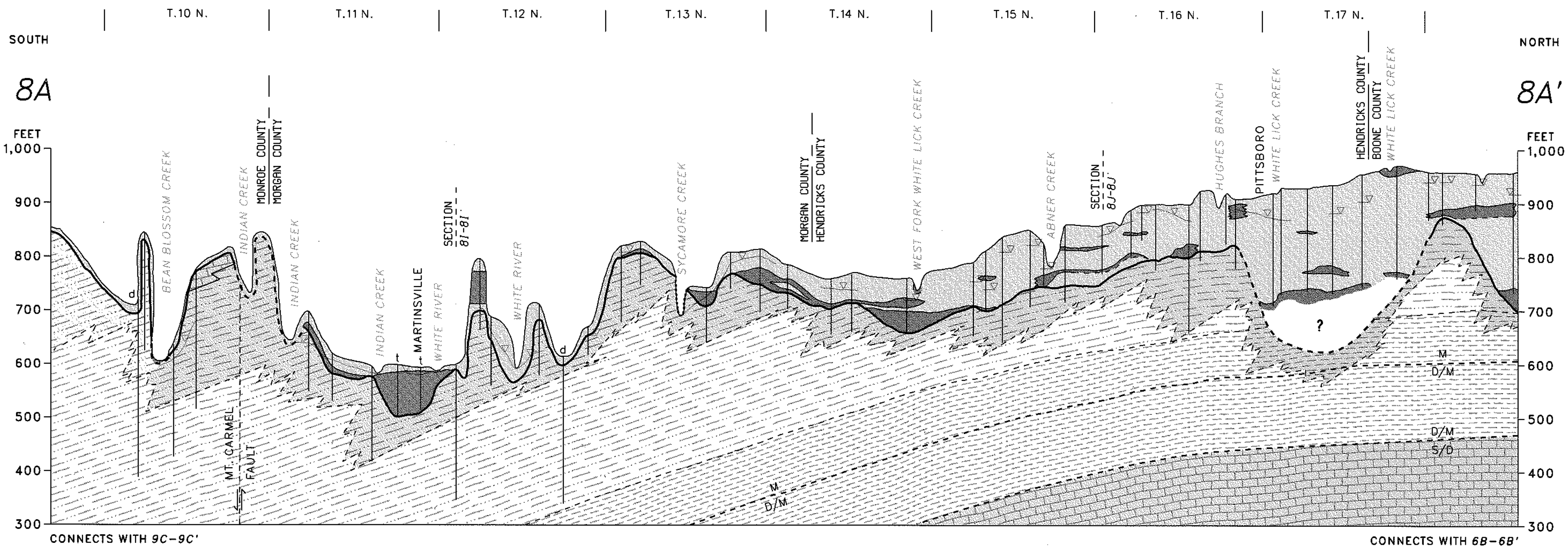
The surficial aquifer is generally unconfined along rivers (see section 8B–8B′ along the White River and Fall Creek, fig. 58). In places, the aquifer is hydraulically connected to buried sand and gravel aquifers that extend beneath the river, as shown in section 8D–8D′ (fig. 58) (Gillies, 1976, Smith, 1983). Recharge to the aquifer is from direct infiltration of precipitation and, at times, from the streams. The streams are connected hydraulically to the aquifer, usually gaining water from it; however, during drought or heavy pumping nearby, the streams can function as recharge sources for the aquifer (Gillies, 1976).

The thickness of the surficial sand and gravel aquifer ranges from 10 to more than 150 ft. Within the northern one-half of the basin, where the outwash aquifers have been studied extensively, the water table is generally within 10 ft of the surface. Saturated thickness, which ranges from 10 to 110 ft, depends on bedrock relief and thickness of the aquifer (Meyer and others, 1975; Smith, 1983). Hydraulic conductivities for the surficial sand and gravel aquifer range from 24 to greater than 1,500 ft/d (Arihood and Lapham, 1982; Smith, 1983). Well yields range from 10 to 2,000 gal/min (Meyer and others, 1975; Gillies, 1976; Smith, 1983; Barnhart and Middleman, 1990).

Buried and Discontinuous Sand and Gravel Aquifers

Buried and discontinuous sand and gravel aquifers have similar origins and exhibit similar characteristics, and therefore, are discussed here together. The major difference between the two aquifer types is that buried sand and gravel aquifers are thicker and areally more extensive than the discontinuous sand and gravel aquifers. Buried sand and gravel aquifers, used in the northern one-half of the White River basin (fig. 59), can be seen in sections 8A–8A′ to 8E–8E′ and in section 8K–8K′ (fig. 58). Discontinuous sand and gravel aquifers, used in the middle one-third of the White River basin (fig. 59), can be seen in section 8A–8A′ (northern one-third), 8I–8I′ (eastern one-quarter), and 8J–8J′ (western one-half) (fig. 58). The two aquifer types were deposited as outwash-plain deposits, valley fill in pre-Illinoian valleys, thin sheets of stratified drift, and small pockets of coarse-grained glaciolacustrine sediment (Watkins and Jordan, 1961, p. 6; Watkins and Jordan, 1962, p. 6; Watkins and Jordan, 1963, p. 6; Meyer and others, 1975, p. 7-9; Gillies, 1976, p. 4; Lapham, 1981, p. 10-31; Arihood, 1982, p. 8-23; Barnhart and Middleman, 1990, p. 9). Where buried sand and gravel deposits are continuous, they can be sources of large amounts of water. Discontinuous sand and gravel deposits tend to have low water yields; well contractors commonly drill through these deposits to obtain higher yields from the bedrock sources below (Watkins and Jordan, 1962, p. 6; Barnhart and Middleman, 1990, p. 9).

The buried and discontinuous sand and gravel aquifers are usually confined by layers of low-permeability till (see section 8A–8A′, fig. 58) (Watkins and Jordan, 1962, p. 6-7; Arihood and Lapham, 1982, p. 10-25). In some locations, the buried or discontinuous sand and gravel aquifers are contiguous with surficial sand and gravel aquifers along the major streams; together, the aquifers form a complex hydrogeologic system as shown in section 8C–8C′ (fig. 58) (Gillies, 1976, p. 9; Meyer and others, 1975, p. 9-16).



EXPLANATION

- SAND AND GRAVEL
- UNCONSOLIDATED NONAQUIFER MATERIAL
- LIMESTONE AND DOLOSTONE
- SHALE
- SANDSTONE
- COMPLEXLY INTERBEDDED SANDSTONE, SHALE, AND LIMESTONE
- LIMESTONE AND SHALE
- SILTSTONE AND SHALE, WITH MINOR SANDSTONE AND DISCONTINUOUS LIMESTONE
- COMPLEXLY INTERBEDDED SANDSTONE, SHALE, AND MINOR LIMESTONE AND COAL
- BEDROCK AQUIFER
- BEDROCK AQUIFER--Potential unknown
- BEDROCK NONAQUIFER
- ? NO DATA
- BEDROCK SURFACE--Dashed where approximately located
- CHRONOSTRATIGRAPHIC BOUNDARY--Dashed where approximately located
- LITHOLOGIC CONTACT--Dashed where approximately located
- COAL SEAM--Dashed where approximately located
- GENERALIZED POTENTIOMETRIC SURFACE--Dashed where approximately located
- WELL--All well data are projected to trace of section. Dotted where data are incomplete
- FAULT--Arrows show relative displacement
- BASE OF UPPER WEATHERED BEDROCK
- ? LITHOLOGIC BOUNDARY UNKNOWN
- t TEST HOLE--Not drilled for water supply
- d DRY HOLE
- IP PENNSYLVANIAN
- M MISSISSIPPIAN
- D DEVONIAN
- S SILURIAN
- O ORDOVICIAN

DATUM IS SEA LEVEL
VERTICAL SCALE GREATLY EXAGGERATED

0 5 10 MILES
0 5 10 KILOMETERS

Figure 58. Hydrogeologic sections *8A–8A′* to *8K–8K′* of the White River basin.

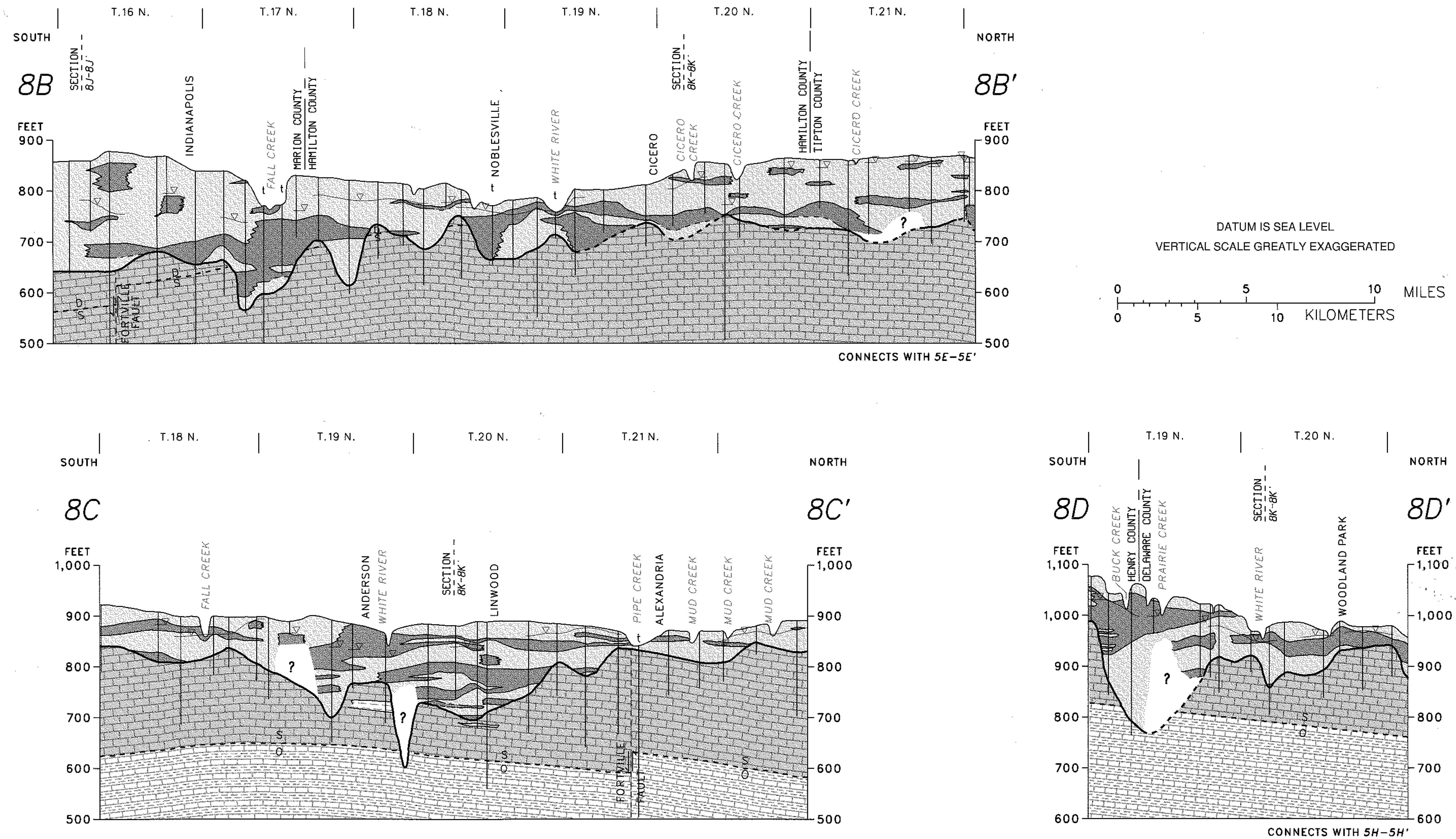
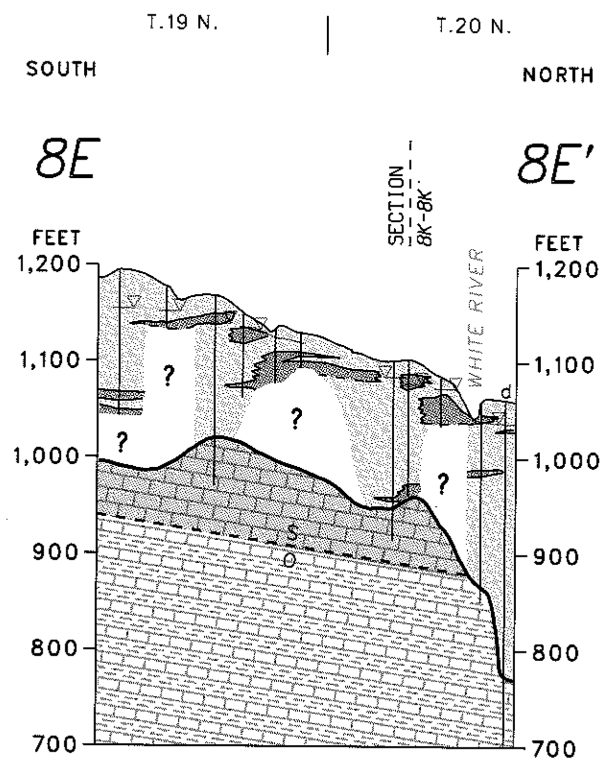
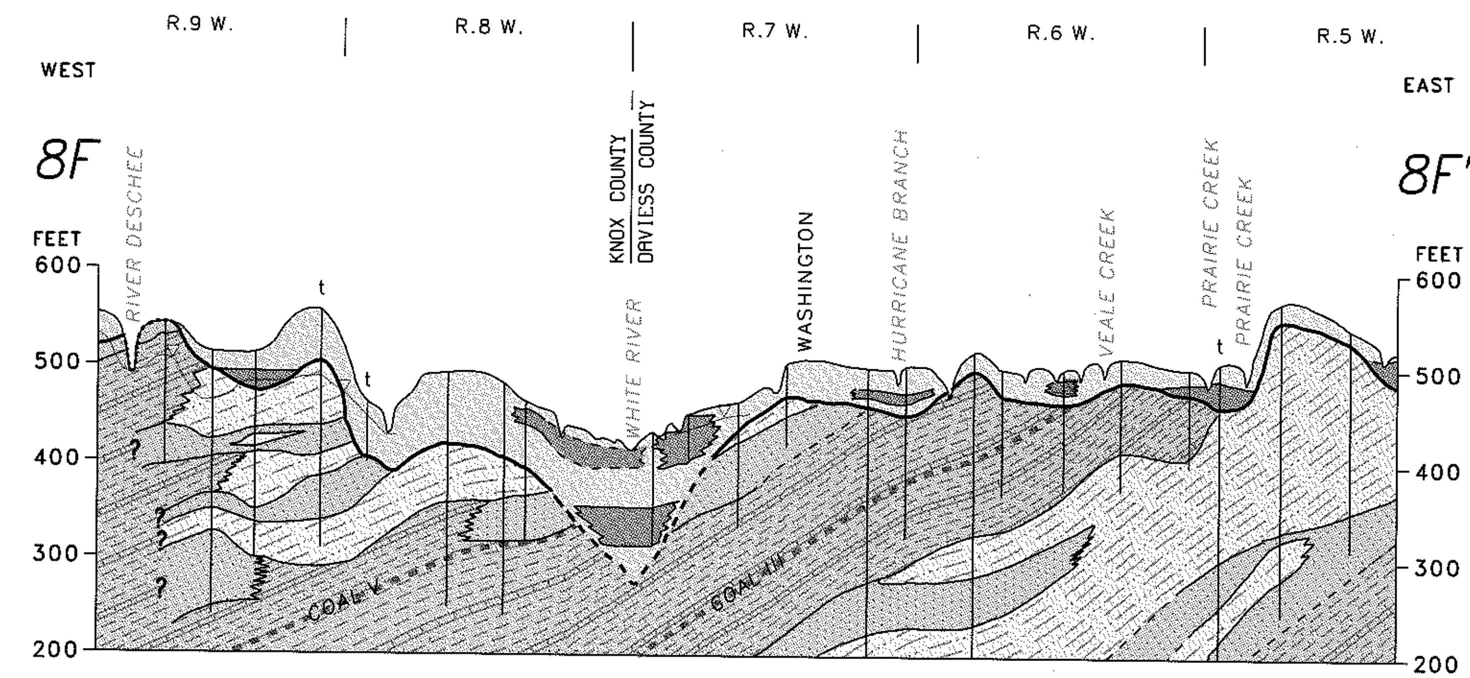
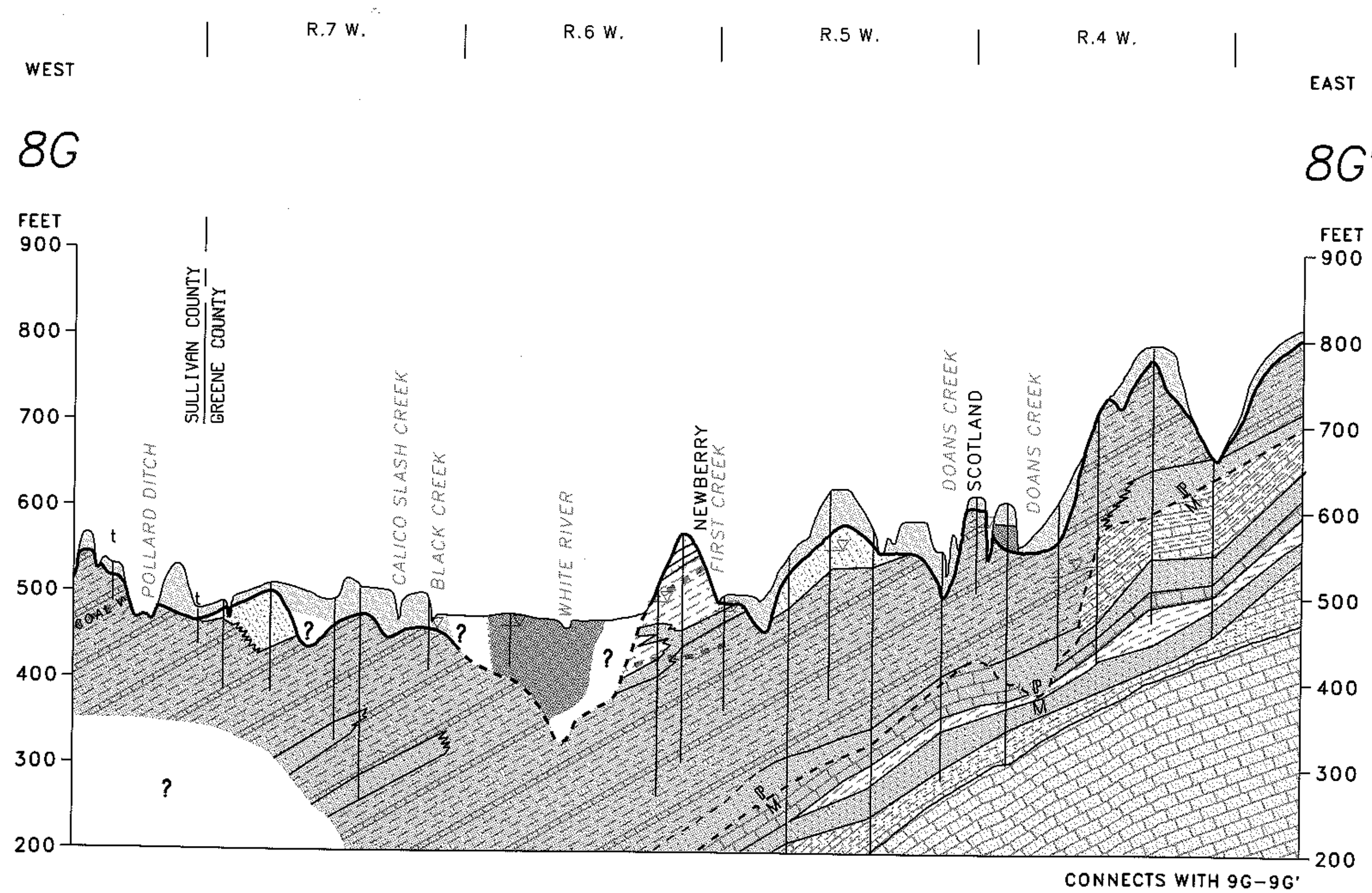


Figure 58. Hydrogeologic sections *8A–8A'* to *8K–8K'* of the White River basin—Continued.


T.19 N.
T.20 N.
SOUTH
NORTH
8E
8E'
SECTION 8K-8K'
FEET
1,200
1,100
1,000
900
800
700
WHITE RIVER


R.9 W.
R.8 W.
R.7 W.
R.6 W.
R.5 W.
WEST
EAST
8F
8F'
FEET
600
500
400
300
200
RIVER DESCHEE
KNOX COUNTY
DAVIESS COUNTY
WHITE RIVER
WASHINGTON
HURRICANE BRANCH
VEALE CREEK
PRAIRIE CREEK
PRAIRIE CREEK
COAL V
COAL VII


R.7 W.
R.6 W.
R.5 W.
R.4 W.
WEST
EAST
8G
8G'
FEET
900
800
700
600
500
400
300
200
POLLARD DITCH
SULLIVAN COUNTY
GREENE COUNTY
CALICO SLASH CREEK
BLACK CREEK
WHITE RIVER
NEWBERRY
FIRST CREEK
DOANS CREEK
SCOTLAND
DOANS CREEK
CONNECTS WITH 9G-9G'

Recharge of buried and discontinuous aquifers is probably by infiltration of precipitation through the confining layers. Recharge rates reported by most of the studies of the White River basin were calculated from baseflow and static-water-level data (Lapham, 1981; Arihood and Lapham, 1982; Arihood, 1982; Lapham and Arihood, 1984). Such data can be used to determine recharge rates for buried or discontinuous aquifers if the aquifers are hydraulically linked to the stream. However, this linkage is not the case for many of the buried aquifers some distance from the surficial "outwash" aquifers, such as those shown in section 8K–8K′ (fig. 58). Because most of the buried and discontinuous aquifers are not regionally extensive, they have not been studied in detail; no information regarding recharge rates is available, other than average areal recharge rates for a particular modeled region. Arihood and Lapham (1982) calculated average areal recharge rates to the buried and discontinuous aquifers of 2 in/yr, or approximately 5 percent of the total precipitation, for a modeled region in the upper part of the White River basin.

The thickness of the buried and discontinuous sand and gravel aquifers ranges from 5 to 50 ft in most of the counties in the northern part of the basin (Lapham and Arihood, 1984, p. 11). Reported hydraulic conductivities of the confined buried and discontinuous aquifers range from 200 to 390 ft/d (Cable and others, 1971; Meyer and others, 1975). Many hydrologic studies in the northern part of the basin were based on the assumption that the average hydraulic conductivities of the buried and discontinuous sands and gravels were similar to those of the surficial sands and gravels, namely 433 ft/d (Arihood and Lapham, 1982; Lapham and Arihood, 1984; Lapham, 1981). Well yields of buried and discontinuous aquifers typically range from 10 to 250 gal/min (Herring, 1971, 1974).

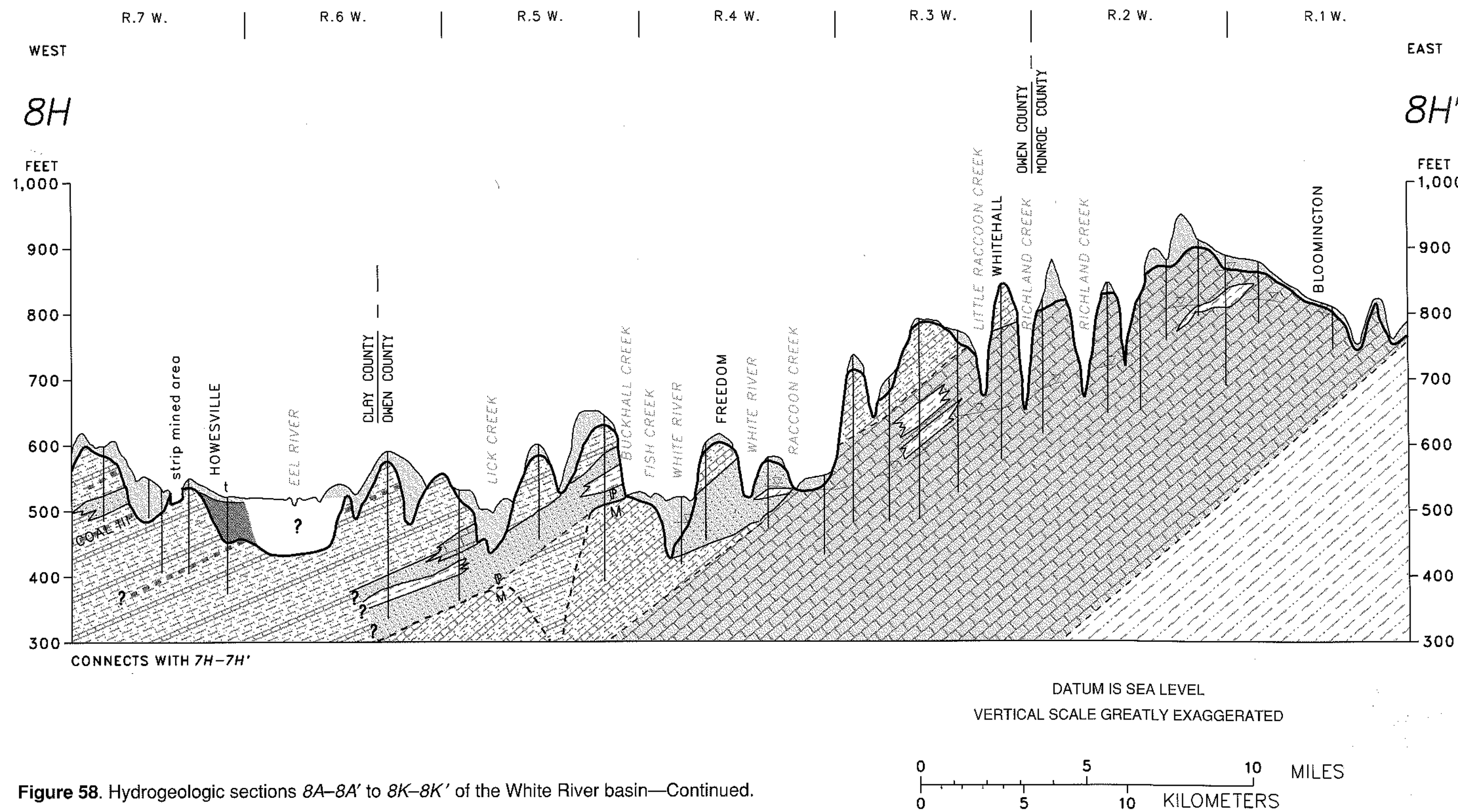


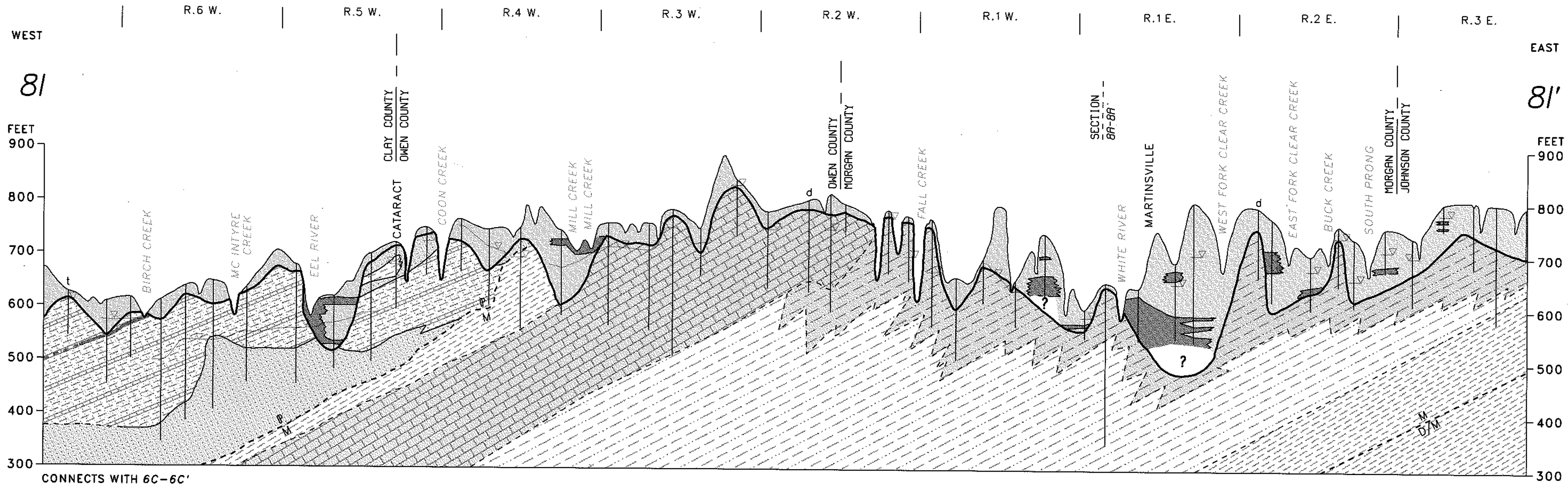
Figure 58. Hydrogeologic sections *8A–8A′* to *8K–8K′* of the White River basin—Continued.

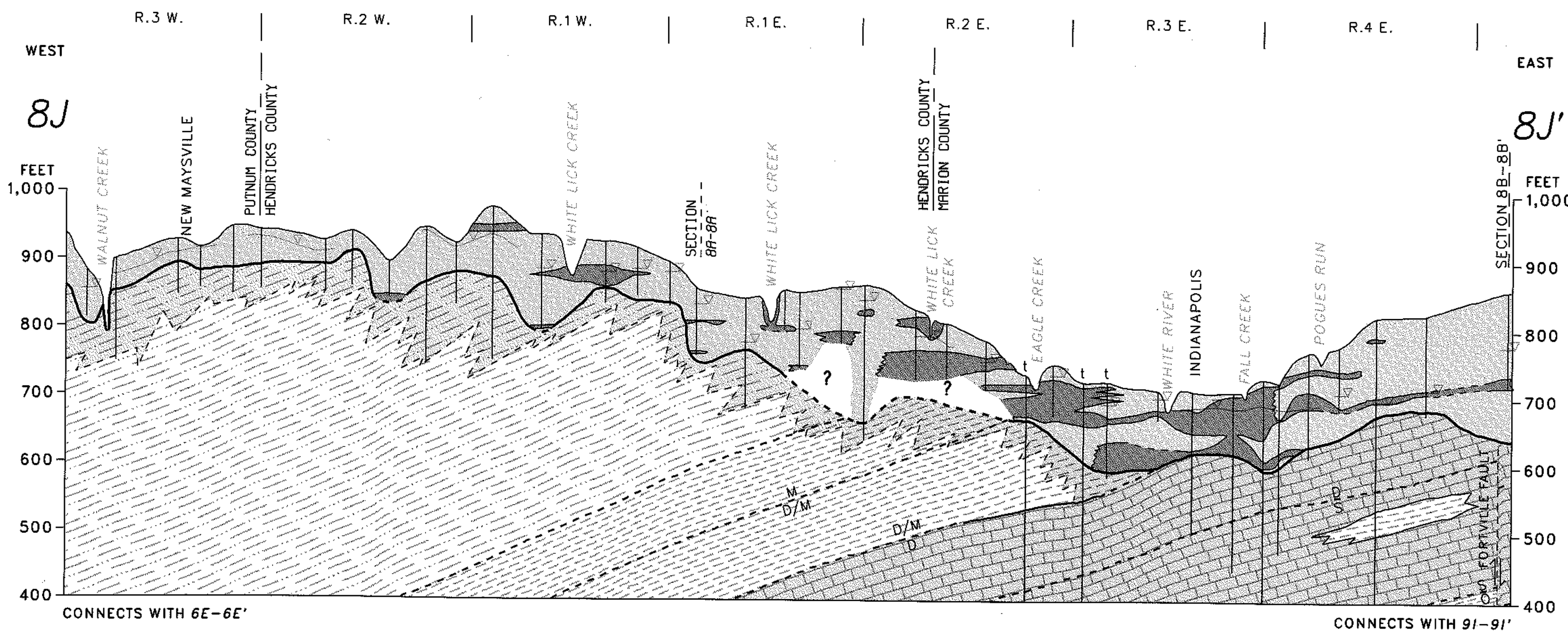
Bedrock Aquifers

Carbonate Bedrock Aquifers

Carbonate bedrock aquifers are present in the northern one-third of the White River basin and in a north-south band that is about 15 to 20 mi wide near the middle of the basin (fig. 59). Carbonate bedrock aquifers are shown in all hydrogeologic sections (fig. 58) except section 8F–8F′.

In the northern part of the basin, Ordovician shales and limestones of the Maquoketa Group are overlain by thick carbonate rock sequences with shale-dominant facies of Silurian and Devonian age (sections 8B–8B′ to 8E–8E′ and section 8K–8K′, fig. 58) (Wayne, 1975, p. 16-17; Lapham and Arihood, 1984). The upper Ordovician rocks of the Maquoketa Group consist of a large proportion of carbonate rock in the northeastern part of the basin (Gray, 1972) and are adequate for domestic water supplies in some places; however, Silurian and Devonian carbonate bedrock aquifers are preferred to Ordovician aquifers as water sources. The Silurian and Devonian carbonate rocks, which are now covered by glacial deposits, were once exposed and underwent some karst development (Wayne, 1966, p. 30). Because the primary permeabilities of the carbonate rocks tend to be low, it is this weathered zone within the carbonate rocks that is most likely to produce significant amounts of water, owing to solution-enhanced bedding planes, joints, and fractures (Lapham and Arihood, 1984, p. 10).


WEST
EAST
8I
8I'
R.6 W.
R.5 W.
R.4 W.
R.3 W.
R.2 W.
R.1 W.
R.1 E.
R.2 E.
R.3 E.
FEET
900
800
700
600
500
400
300
CLAY COUNTY
OWEN COUNTY
OWEN COUNTY
MORGAN COUNTY
MORGAN COUNTY
JOHNSON COUNTY
SECTION 8A-8A'
CATARACT
MARTINSVILLE
BIRCH CREEK
MC INTYRE CREEK
EEL RIVER
COON CREEK
MILL CREEK
MILL CREEK
FALL CREEK
WHITE RIVER
WEST FORK CLEAR CREEK
EAST FORK CLEAR CREEK
BUCK CREEK
SOUTH PRONG
CONNECTS WITH 6C-6C'


WEST
EAST
8J
8J'
R.3 W.
R.2 W.
R.1 W.
R.1 E.
R.2 E.
R.3 E.
R.4 E.
FEET
1,000
900
800
700
600
500
400
NEW MAYSVILLE
PUTNUM COUNTY
HENDRICKS COUNTY
HENDRICKS COUNTY
MARION COUNTY
SECTION 8A-8A'
SECTION 8B-8B'
INDIANAPOLIS
WALNUT CREEK
WHITE LICK CREEK
WHITE LICK CREEK
WHITE LICK CREEK
EAGLE CREEK
WHITE RIVER
FALL CREEK
POGUES RUN
FORTVILLE FAULT
CONNECTS WITH 6E-6E'
CONNECTS WITH 9I-9I'

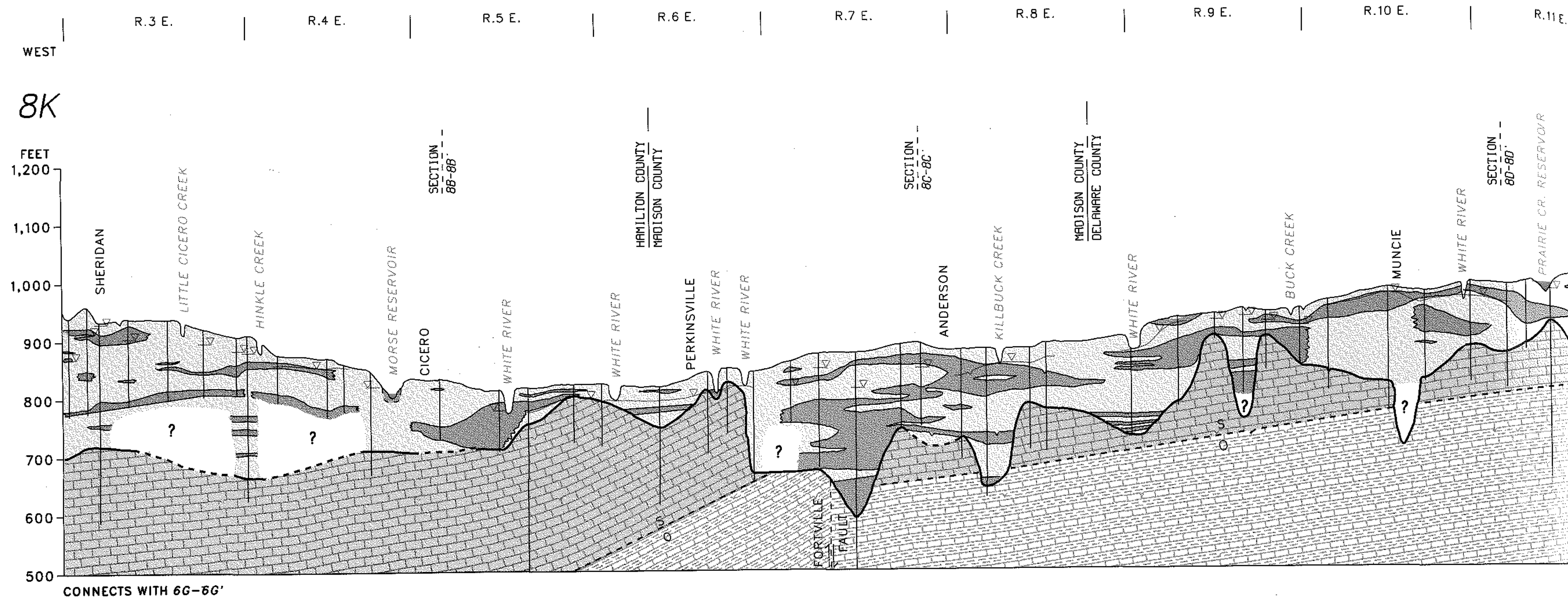


Figure 58. Hydrogeologic sections *8A–8A'* to *8K–8K'* of the White River basin—Continued

DATUM IS SEA LEVEL
VERTICAL SCALE GREATLY EXAGGERATED

0 5 10 MILES
0 5 10 KILOMETERS

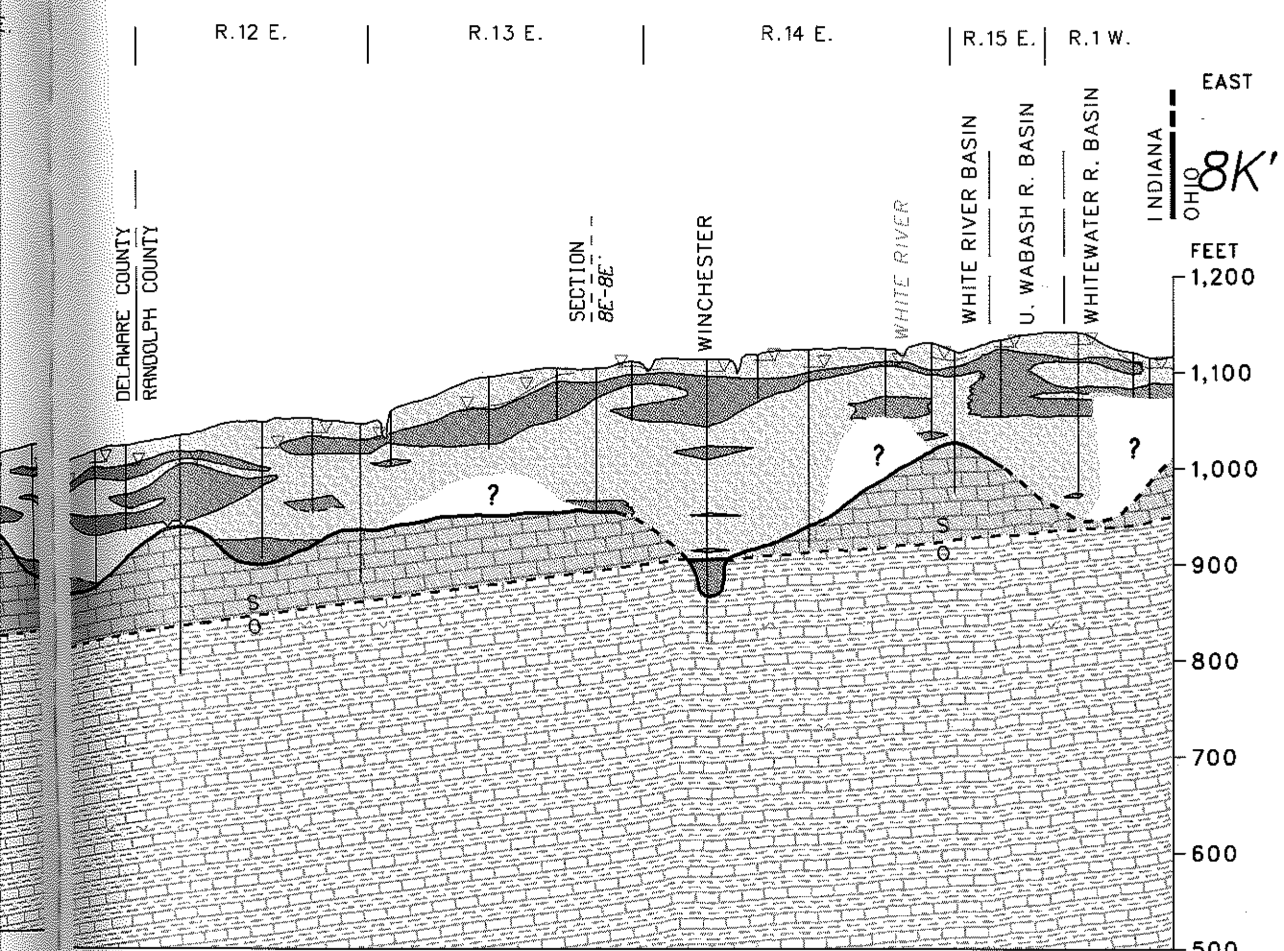
Wayne (1975), in a Madison County report, states that nearly all of the rocks within the Silurian and Devonian Systems will yield water. Specific rock units that are particularly good water producers include the Salamonie Dolomite and the Louisville Limestone (Wayne, 1975, p. 16).

Recharge to the carbonate bedrock aquifers is mostly by infiltration and percolation of rainwater through the overlying glacial deposits. Thicknesses of specific carbonate bedrock aquifers within the Ordovician, Silurian, and Devonian systems range from 40 to 300 ft, but only the upper 150 ft is generally tapped (Arihood, 1982, p. 8). The water-bearing capability of the Silurian and Devonian aquifers is chiefly dependent on the fracture density and degree of weathering. Because of this, the hydraulic conductivity of these aquifers is highly variable. Cable and others (1971) estimated the average hydraulic conductivity of the aquifers to be 13.4 ft/d. Well yields of more than 100 gal/min are possible from these aquifers (Steen, 1970; Wayne, 1975, p. 16).

Other carbonate bedrock aquifers within the basin include the Mississippian Blue River and Sanders Groups. The carbonate rocks are well-cemented, dense, medium-bedded limestones; ground water commonly flows along fractured and weathered surfaces. Intense karst development in the limestone of these groups is common where they are exposed at the surface. Flow of ground water through the fracture and joint systems enhances preexisting avenues of water flow. Recharge of these aquifers is by infiltration of precipitation through thin glacial deposits, exposed bedrock fracture surfaces, and karst terrain. Wells within these aquifers generally yield less than 30 gal/min, and dry holes are not uncommon (Bechert and Heckard, 1966, p. 108-109).

Upper Weathered-Bedrock Aquifer

In the central one-third of the basin, aquifers are developed in an upper weathered zone of the Devonian and Mississippian New Albany Shale and siltstones and shales of the Mississippian Borden Group. This aquifer type is shown in hydrogeologic sections 8A–8A', 8I–8I', and 8J–8J' (fig. 58). The upper weathered zone is a zone of enhanced permeability produced by weathering before, during, and after glaciation. The availability of water in this weathered zone is highly variable and is dependent on the degree of enhanced permeability, the type and thickness of overlying deposits, and the bedrock topography. The dependence on type and thickness of overlying deposits is evident in hydrogeologic section 8A–8A' (fig. 58) where, as glacial deposits thin toward the south, dry wells are increasingly common. Where the aquifer is unreliable, the weathered zone is mapped as "aquifer—potential unknown." This boundary is located near the maximum extent of glaciation (fig. 55 and 59).



The shale-siltstone upper weathered-bedrock aquifer is used primarily for domestic and stock water supplies in areas where no other aquifers are available. The exact thickness of the weathered-bedrock aquifer is unknown but is inferred by the depth of the wells that are completed in it. These depths range from 20 to greater than 200 ft, but the zone of enhanced permeability is generally limited to the upper 150 ft (table 10). Because shales and siltstones are generally considered to be confining units, hydraulic conductivities are thought to be low; owing to secondary permeability caused by weathering, however, the actual value is unknown. Well yields range from 0 to 10 gal/min (Bechert and Heckard, 1966; Clark, 1980).

Complexly Interbedded Sandstone, Shale, Limestone, and Coal Aquifer

In the southwestern part of the basin, laterally discontinuous basal sandstones and to a lesser degree, limestones and coals are the principal aquifers (Cable and Robison, 1973, p. 8-9). These aquifers are contained within complexly interbedded sandstones, siltstones, shales, limestones and coals of Mississippian and Pennsylvanian age. The complexly interbedded sequence is shown in hydrogeologic sections 8F–8F′ to 8I–8I′ (fig. 58). The sections may or may not show individual aquifer units within the complexly interbedded sequence depending on well density and(or) detail of the well logs. The coals and limestones are typically less than 10 ft thick and can serve as useful stratigraphic markers. Shales and siltstones are generally much thicker, but variable in thickness as well.

Because aquifers within the complexly interbedded sequences are discontinuous, water-bearing capabilities are variable and can be assessed only on a local basis. These complexly interbedded sequences are therefore mapped as "aquifer—potential unknown" in the hydrogeologic sections and on the aquifer map (fig. 59). Wells finished in the complexly interbedded bedrock are usually not screened but are open throughout the length of the well; it is not always possible, therefore, to identify the unit that is the source of water. Well yields from the complexly interbedded aquifers tend to average about 5 gal/min and rarely exceed 20 gal/min (Bechert and Heckard, 1966, p. 108-109; Cable and Robison, 1973, p. 23). Hydraulic conductivities are probably low also.

Sandstone Aquifers

Most of the sandstones are sheetlike deposits or sinuous channel sandstones (Cable and Robison, 1973) that range from less than 20 to 100 ft. Thin discontinuous sandstones are combined with other shales, siltstones, limestones, and coal deposits and mapped as "aquifer—potential unknown." The more extensive sandstones are shown in hydrogeologic sections 8F–8F′ to 8I–8I′ (fig. 58) where they are mapped as aquifers (fig. 59). These sandstones produce greater yields than do the thin, discontinuous sandstones within the complexly interbedded deposits. The most frequently used sandstone aquifer is the lower Pennsylvanian Mansfield Formation (Thomas, 1980). This sandstone, confined above and below by shales, ranges from 20 to 100 ft in thickness in Clay County (Thomas, 1980, p. 14). Other sandstones that are considered to be aquifers are in the Linton Formation and the Petersburg Formation of Middle Pennsylvanian age (Cable and others, 1971, p. 11). Recharge to these sandstone aquifers occurs where the formations crop out at the surface, primarily in the southern, unglaciated parts of the basin.

Permeability of most of the sandstones is low, and yields from wells that tap any of the relatively continuous sandstone aquifers are correspondingly low; maximum yield is 30 gal/min, and average yield is 10 gal/min (Cable and others, 1971; Cable and Robison, 1973).

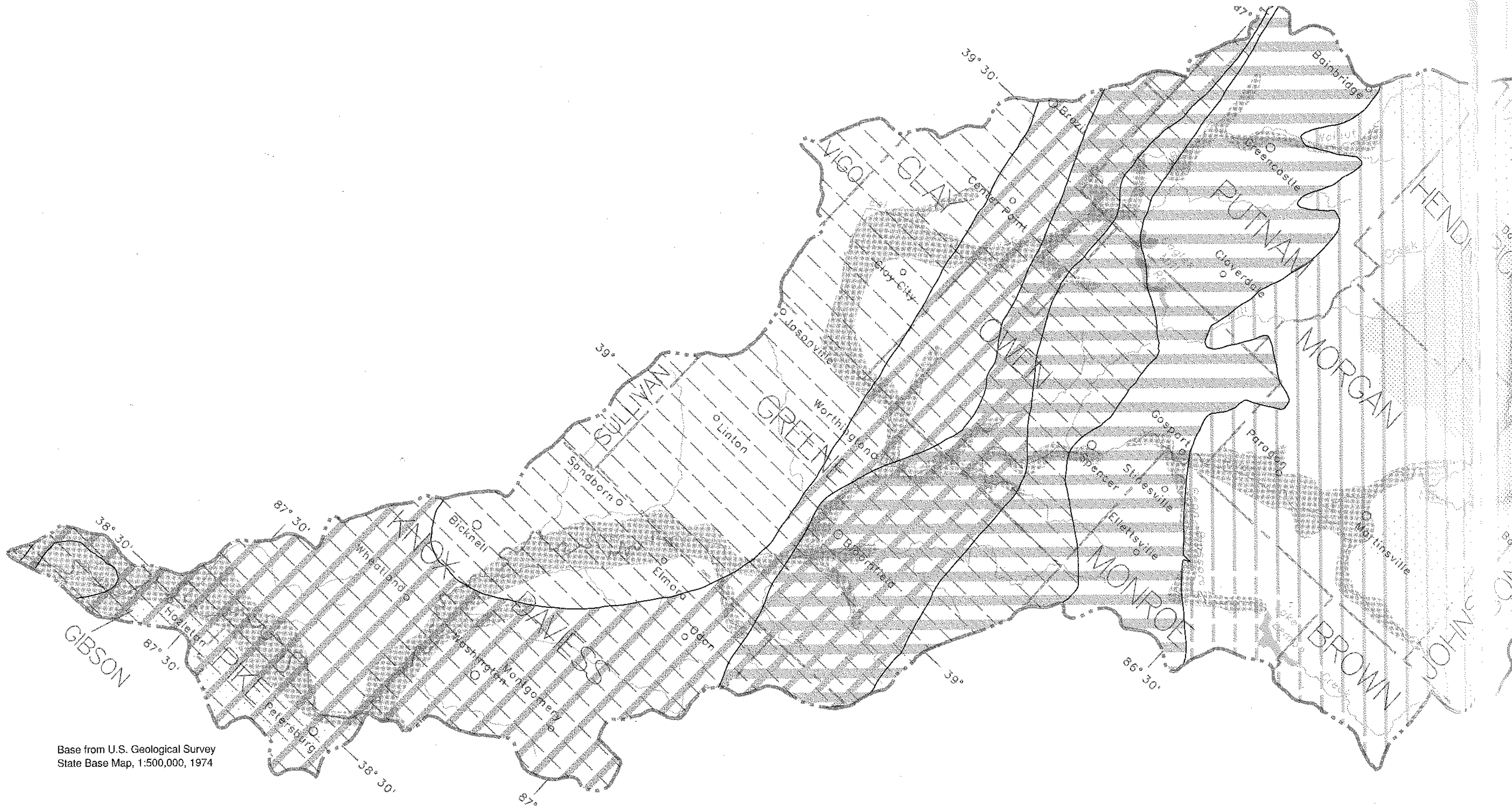
Summary

Several large cities, including Indianapolis, and all or parts of 27 counties lie within the White River basin. The basin contains unconsolidated glacial deposits which overlie bedrock that ranges in age from Ordovician to Pennsylvanian. The unconsolidated deposits consist of clay-rich, loamy, tills interbedded with stratified sand and gravel, as well as sand and gravel deposited as outwash along the major streams. A variety of lithologies are present in the bedrock system. Limestones and shales dominate the rocks of Ordovician, Silurian, Devonian, and early Mississippian age. Almost all sedimentary lithologies are present in the Late Mississippian and Pennsylvanian Systems.

Seven different aquifer types have been identified within the basin: three unconsolidated aquifer types and four bedrock aquifer types. The most productive aquifers are the surficial sands and gravels. Wells completed in this type of aquifer can yield as much as 2,000 gal/min; such wells are major water sources for Indianapolis, Anderson, and Muncie. The surficial sand and gravel aquifers are generally unconfined, are variable in thickness, and have high hydraulic conductivities.

Buried and discontinuous sand and gravel aquifers are commonly used where the drift is thick. The hydrologic character of these aquifers is similar to surficial sand and gravel aquifers, but the aquifer is confined by relatively impermeable till layers.

Carbonate rocks form the primary bedrock aquifer in the northern one-third and the west-central part of the basin. Well yields are moderate to high in the northern part of the basin, ranging from 20 gal/min to greater than 600 gal/min, but recharge rates are probably low because recharge occurs by infiltration and percolation of rainwater through the overlying fine-grained glacial deposits. Yields from the carbonate bedrock aquifer in the west-central part of the basin are lower than in the north, ranging from 0 to 20 gal/min.



Base from U.S. Geological Survey
State Base Map, 1:500,000, 1974

Figure 59. Extent of aquifer types in the White River basin.

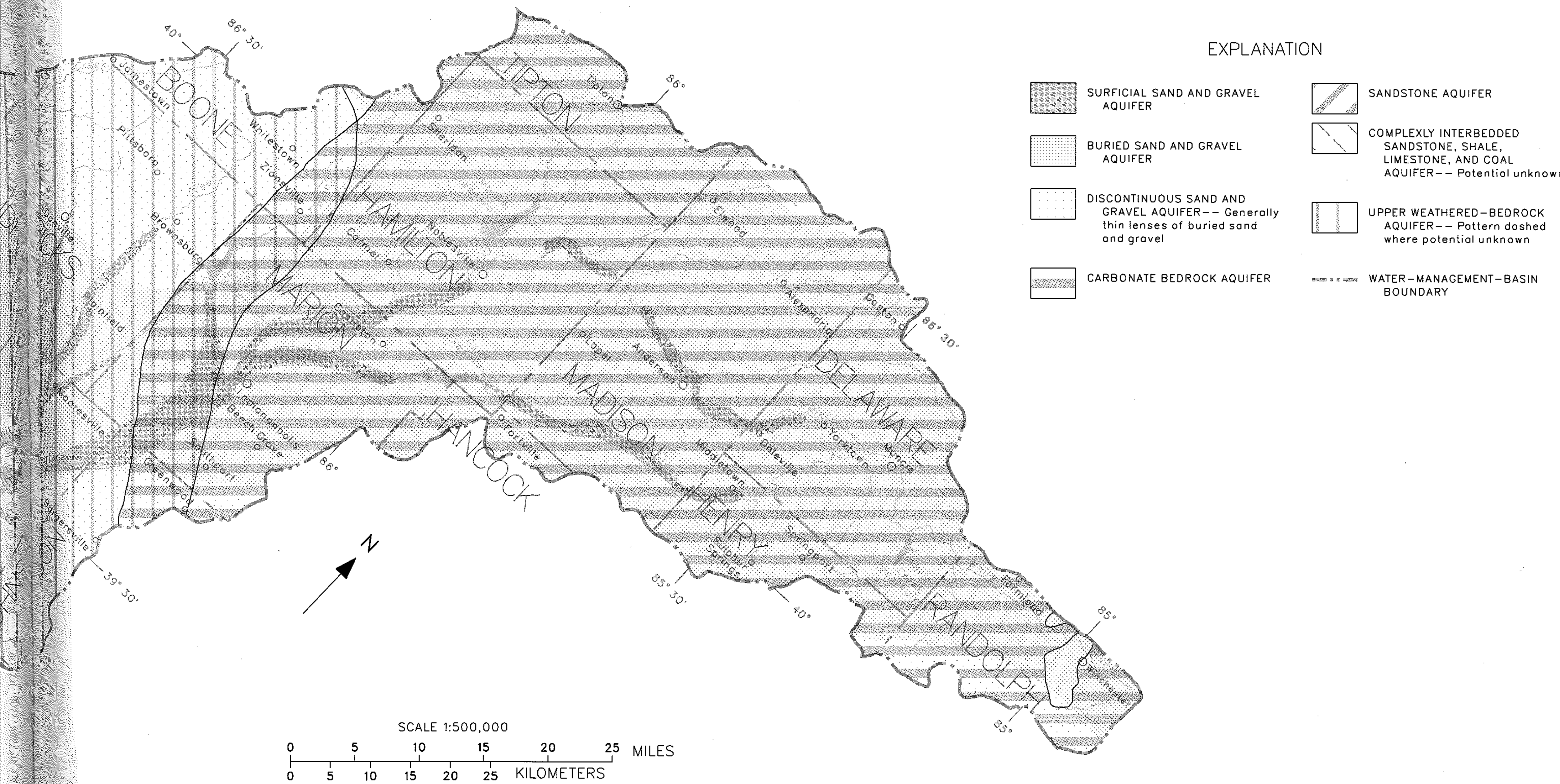

EXPLANATION
SURFICIAL SAND AND GRAVEL AQUIFER
BURIED SAND AND GRAVEL AQUIFER
DISCONTINUOUS SAND AND GRAVEL AQUIFER-- Generally thin lenses of buried sand and gravel
CARBONATE BEDROCK AQUIFER
SANDSTONE AQUIFER
COMPLEXLY INTERBEDDED SANDSTONE, SHALE, LIMESTONE, AND COAL AQUIFER-- Potential unknown
UPPER WEATHERED-BEDROCK AQUIFER-- Pattern dashed where potential unknown
WATER-MANAGEMENT-BASIN BOUNDARY
BOONE
TIPTON
HAMILTON
MARION
MADISON
DELAWARE
HANCOCK
HENRY
RANDOLPH
Jamestown
Pittsboro
Brownsburg
Whitestown
Zionsville
Sheridan
Tipton
Noblesville
Carmel
Castleton
Elwood
Alexandria
Gaston
Lapel
Anderson
Indianapolis
Beech Grove
Southport
Greenwood
Fortville
Middletown
Daleville
Yorktown
Muncie
Sulphur Springs
Springport
Farmland
Winchester
Plainfield
Mooresville
40°
86° 30'
86°
85° 30'
85°
39° 30'
N
SCALE 1:500,000
0 5 10 15 20 25 MILES
0 5 10 15 20 25 KILOMETERS

Table 10. Characteristics of aquifer types in the White River basin
[<, less than; locations of aquifer types shown in fig. 59]

Aquifer type	Thickness (feet)	Range of yield (gallons per minute)	Common name(s)
Surficial sand and gravel	5- 150	[1,2,3]100- 2,000	Outwash, alluvium, valley train[4,5,6]
Buried sand and gravel	5- 90	[1,2,3]50- 300	Interbedded sand and gravel, outwash plain[4,5]
Discontinuous sand and gravel	5- 40	[1,2,5]10- 200	Interbedded sand and gravel, outlier[4,5]
Carbonate bedrock			
Mississippian	[7]150	[1,2]<20	Sanders and Blue River Groups[8]
Devonian	[7]150	[1,2]100- 600	Muscatatuck Group[8]
Silurian	[7]150	[1,2]200- 600	Salamonie Dolomite, Brassfield Limestone, Cataract Formation, and Salina Group[8]
Upper weathered bedrock	[7]150	[1,2]0- 10	Borden Group and New Albany Shale[8]
Complexly interbedded sandstone, shale, limestone, and coal	highly variable[9]	[1,2]5- 20	West Baden, Stephensport, Raccoon Creek, and Carbondale Groups, and Patoka Formation[8]
Sandstone	20- 100	[1,2,10]5- 20	Raccoon Creek Group[8]

[1]Bechert and Heckard, 1966.
[2]Clark, 1980.
[3]Herring, 1971; 1974.
[4]Arihood and Lapham, 1982.
[5]Barnhart and Middleman, 1990.
[6]Watkins and Jordan, 1961; 1962; 1963.
[7]Reported thickness is not total thickness of unit but thickness of unit considered permeable or water bearing.
[8]Shaver and others, 1986.
[9]Water is commonly found in thin beds within complexly interbedded sequence.
[10]Thomas, 1980.

Complexly interbedded rocks of different lithologies are used as aquifers in the southern one-third of the basin, but yields from these aquifers are generally low. The major water producers within the complexly interbedded sequence are thin sandstones but limestones and coals also can produce water.

Relatively continuous sandstone units, mostly within the Pennsylvanian System, such as the Mansfield Formation, are used as aquifers and are mapped as a separate aquifer type. Well yields from sandstone aquifers are slightly higher than from the complexly interbedded aquifers.

In the central part of the basin, the only source of usable quantities of water is a weathered zone within shale and siltstone. These rocks have sufficient secondary permeability to serve as a source of water, but only for small supplies. Well yields range from 0 to 10 gal/min within this aquifer type.

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