

GEOLOGY FOR ENVIRONMENTAL PLANNING IN MARION COUNTY, INDIANA

Special Report 19



State of Indiana
Department of Natural Resources
GEOLOGICAL SURVEY

SCIENTIFIC AND TECHNICAL STAFF OF THE GEOLOGICAL SURVEY

JOHN B. PATTON, State Geologist
MAURICE E. BIGGS, Assistant State Geologist
MARY BETH FOX, Mineral Statistician

COAL AND INDUSTRIAL MINERALS SECTION

DONALD D. CARR, Geologist and Head
CURTIS H. AULT, Geologist and Associate Head
PEI-YUAN CHEN, Geologist
DONALD L. EGGERT, Geologist
GORDON S. FRASER, Geologist
DENVER HARPER, Geologist
WALTER A. HASENMUELLER, Geologist
NELSON R. SHAFFER, Geologist
PAUL IRWIN, Geological Assistant

DRAFTING AND PHOTOGRAPHY SECTION

WILLIAM H. MORAN, Chief Draftsman and Head
RICHARD T. HILL, Geological Draftsman
ROGER L. PURCELL, Senior Geological Draftsman
GEORGE R. RINGER, Photographer
WILBUR E. STALIONS, Artist-Draftsman

EDUCATIONAL SERVICES SECTION

R. DEE RARICK, Geologist and Head

GEOCHEMISTRY SECTION

R. K. LEININGER, Geochemist and Head
LOUIS V. MILLER, Coal Chemist
MARGARET V. GOLDE, Instrumental Analyst
JOSEPH G. HAILER, Geochemist/Analyst
ROGER S. McCAY, Electronics Technician

GEOLOGY SECTION

ROBERT H. SHAVER, Paleontologist and Head
HENRY H. GRAY, Head Stratigrapher
N. K. BLEUER, Glacial Geologist
EDWIN J. HARTKE, Environmental Geologist
JOHN R. HILL, Glacial Geologist
CARL B. REXROAD, Paleontologist

GEOPHYSICS SECTION

MAURICE E. BIGGS, Geophysicist and Head
ROBERT F. BLAKELY, Geophysicist
JOSEPH F. WHALEY, Geophysicist
JOHN R. HELMS, Driller
SAMUEL L. RIDDLE, Geophysical Assistant

PETROLEUM SECTION

G. L. CARPENTER, Geologist and Head
ANDREW J. HREHA, Geologist
BRIAN D. KEITH, Geologist
STANLEY J. KELLER, Geologist
DAN M. SULLIVAN, Geologist
JAMES T. CAZEE, Geological Assistant
SHERRY CAZEE, Geological Assistant
WILLIAM E. HAMM, Geological Assistant

PUBLICATIONS SECTION

GERALD S. WOODARD, Editor and Head
PAT GERTH, Sales and Records Clerk

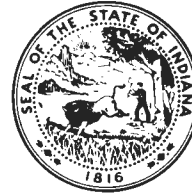
AUTHORS OF THIS REPORT: Hartke, Ault, and Bleuer are staff geologists of the Indiana Geological Survey, Bloomington; Austin is a staff geologist of the New Mexico Bureau of Mines and Mineral Resources, Socorro; Becker is a former staff geologist of the Indiana Geological Survey and now retired; Herring is a staff geologist of the Amax Coal Co., Indianapolis; and Moore is an exploration geologist of the Corley Ginther Oil Corp., Tulsa, Okla.

Geology for Environmental Planning in Marion County, Indiana

By EDWIN J. HARTKE, CURTIS H. AULT, GEORGE S. AUSTIN, LEROY E. BECKER,
N.K. BLEUER, WILLIAM C. HERRING, *and* MICHAEL C. MOORE

ENVIRONMENTAL STUDY 15

DEPARTMENT OF NATURAL RESOURCES
GEOLOGICAL SURVEY SPECIAL REPORT 19



PRINTED BY AUTHORITY OF THE STATE OF INDIANA
BLOOMINGTON, INDIANA: 1980

STATE OF INDIANA
Otis R. Bowen, *Governor*
DEPARTMENT OF NATURAL RESOURCES
Joseph D. Cloud, *Director*
GEOLOGICAL SURVEY
John B. Patton, *State Geologist*

For sale by Geological Survey, Bloomington, Ind. 47405
Price \$2.50

Contents

	Page		Page
Introduction	1	Ground-water resources—Continued	
Geology	3	Quality	24
Unconsolidated deposits	3	Contamination potential	24
Bedrock	7	Crushed-stone resources	25
Engineering geology	10	Potential resources	25
Properties of near-surface uncon-		Sources of aggregate	25
solidated materials	10	Sources of limestone and dolomite	
Glacial tills	10	for chemical uses	27
Granular materials	11	Mining methods, economics, and	
General foundation and construction		environmental considerations	28
conditions	12	Favorable locations for future quarries	
Surface-water resources	12	and mines	30
Historical and physiographic back-		Clay-material resources	32
ground	12	Sand and gravel resources	33
Management	14	Definition and description	33
Water quality	14	Reserves	41
Flow regulation	14	Disposition of waste materials	42
Drainage	14	Sanitary landfills	42
Ground-water resources	14	Septic systems	46
Present usage	15	Storage lagoons for liquid wastes	47
Availability	15	Subsurface waste injection	50
Development potential	15	Selected bibliography	51
Principal Pleistocene aquifer	19	Glossary	53
Bedrock aquifers	19		

Illustrations

	Page
Plate 1 Geologic cross sections through the unconsolidated deposits of Marion County, Indiana	In pocket
Figure 1 Map of Marion County showing surficial geology	2-3
2 Map of Marion County showing thickness in feet of glacial drift	4
3 Map of Marion County showing bedrock geology	5
4 Cross section showing configuration of the land surface and arrange-	
ment of bedrock units	6-7
5 Map of Marion County showing topography of the bedrock surface	8
6 Generalized geologic column of the sedimentary bedrock formations	
underlying Marion County	9
7 Map of Marion County showing average annual flow rate in major streams	13
8 Map of Marion County showing generalized interpretation of potential	
yield from ground-water sources	16-17

Illustrations

	Page
Figure 9 Map of Marion County showing the potentiometric surface of the principal Pleistocene aquifer	18
10 Hydrogeologic cross sections showing aquifer distribution and potentiometric surfaces in the unconsolidated and bedrock materials	20-21
11 Map of Marion County showing susceptibility of aquifers to contamination from surface sources	22-23
12 Sand and gravel pit and limestone and dolomite quarry of the American Aggregates Corp. at 96th Street	30
13 Sand and gravel pit and limestone quarry of the American Aggregates Corp. at Harding Street	31
14 Map of central Indiana showing quarries supplying crushed limestone and dolomite to Marion County (August 1978)	32
15 Map of Marion County and surrounding counties showing major glacial outwash channels and active (1979) and abandoned gravel pits	37
16 Histograms showing size distribution of sand and gravel in Marion County	38
17 Composite section showing the complex nature of unconsolidated deposits at the American Aggregates Corp. plant on South Harding Street	39
18 Map of Marion County showing geologic suitability for sanitary landfilling	44-45
19 Map of Marion County showing geologic suitability for environmentally acceptable septic systems	48-49

Tables

	Page
Table 1 Range of characteristics of near-surface till units below depth of 6 feet	11
2 Quality of ground water in Marion County	24
3 Mineral-resource potential of limestones and dolomites in Marion County	26-27
4 Some comparisons of open-pit and underground mining for limestone and dolomite	29
5 Sand and gravel resources in counties surrounding Marion County (August 1978)	34-36
6 Active sand and gravel operations in Marion County (January 1979)	40
7 Summary of physical tests of commercial gravel deposits in Marion County and nearby counties, 1965-66 and 1973-74	42-43

Geology for Environmental Planning in Marion County, Indiana

By EDWIN J. HARTKE, CURTIS H. AULT, GEORGE S. AUSTIN, LEROY E. BECKER,
N.K. BLEUER, WILLIAM C. HERRING, and MICHAEL C. MOORE

Introduction

Marion County is the center of a large and rapidly growing urban-industrial complex in the heartland of Indiana. The boundaries of the county and of Indianapolis, the state capital, are the same as a result of the UNIGOV concept. The rapid growth of Indianapolis and its suburbs makes effective land-use planning important for Marion County. This report is designed to provide information, based on the geologic setting of the area, that can be used for effective and environmentally sound development of the county.

Marion County, with 792,299 inhabitants (1970 census), is the most densely populated county in Indiana. As late as 1954, when the population was about 600,000, it also led the state in agricultural income. Since that time urban sprawl has consumed a large part of the prime farmland in the county. According to projections (Indiana Department of Commerce, Economic Research Division, 1969), growth pressures will continue as the county reaches an expected population in 1985 of more than 1 million.

Development pressures caused by the growing population create a great need for readily available natural resources and at the same time strain the capacity of the geologic materials in the area to receive and purify wastes. A basic knowledge of the geology of the county and of geologic applications to land-use planning can minimize this stress and point the way to the most efficient and ecologically sound use of the local resources.

Marion County, because it is in the area surrounding the confluence of Eagle Creek, White River, and Fall Creek, has the geologic and mineral-resource potential to support a high level of urban-industrial development. Geologic processes associated with the glacial activity that produced these streams have endowed the area with readily available and

abundant sand and gravel and ground water. Crushed stone, another material needed for construction, is also available. The characteristics of the surface materials and topography present few construction problems, and surface-water supplies are abundant. Because no earthly resource is limitless, however, discretionary development must be practiced to contain growth within an acceptable level and to protect essential resources.

The geology of Marion County, which the information presented in this report is based on, is described only briefly; emphasis is on interpretation of the areal and subsurface geology and its applications with regard to land-use suitability and mineral-resource potential. A detailed geologic report on Marion County is available from the Indiana Geological Survey (Harrison, 1963a).

Data used in compiling this report were collected from the files of the Indiana Geological Survey, the Division of Water, the State Highway Commission, and the U.S. Department of Agriculture Soil Conservation Service. Additional field exploration and laboratory analyses were undertaken to fill gaps in existing data. The maps and other illustrations are of necessity generalized because of the size of the area (more than 400 square miles). The maps are not designed to be used to evaluate individual sites but are meant to be used as: (1) a guide for locating areas in which specific site evaluations will be most useful; (2) a guide to the areas most likely to contain usable resources; and (3) a guide to avoid the areas that present the most serious environmental hazards.

Maps in this report are reductions of more detailed work copies that are on file and available for use at the Indiana Geological Survey. Survey personnel are also available to explain further and amplify information in this report.

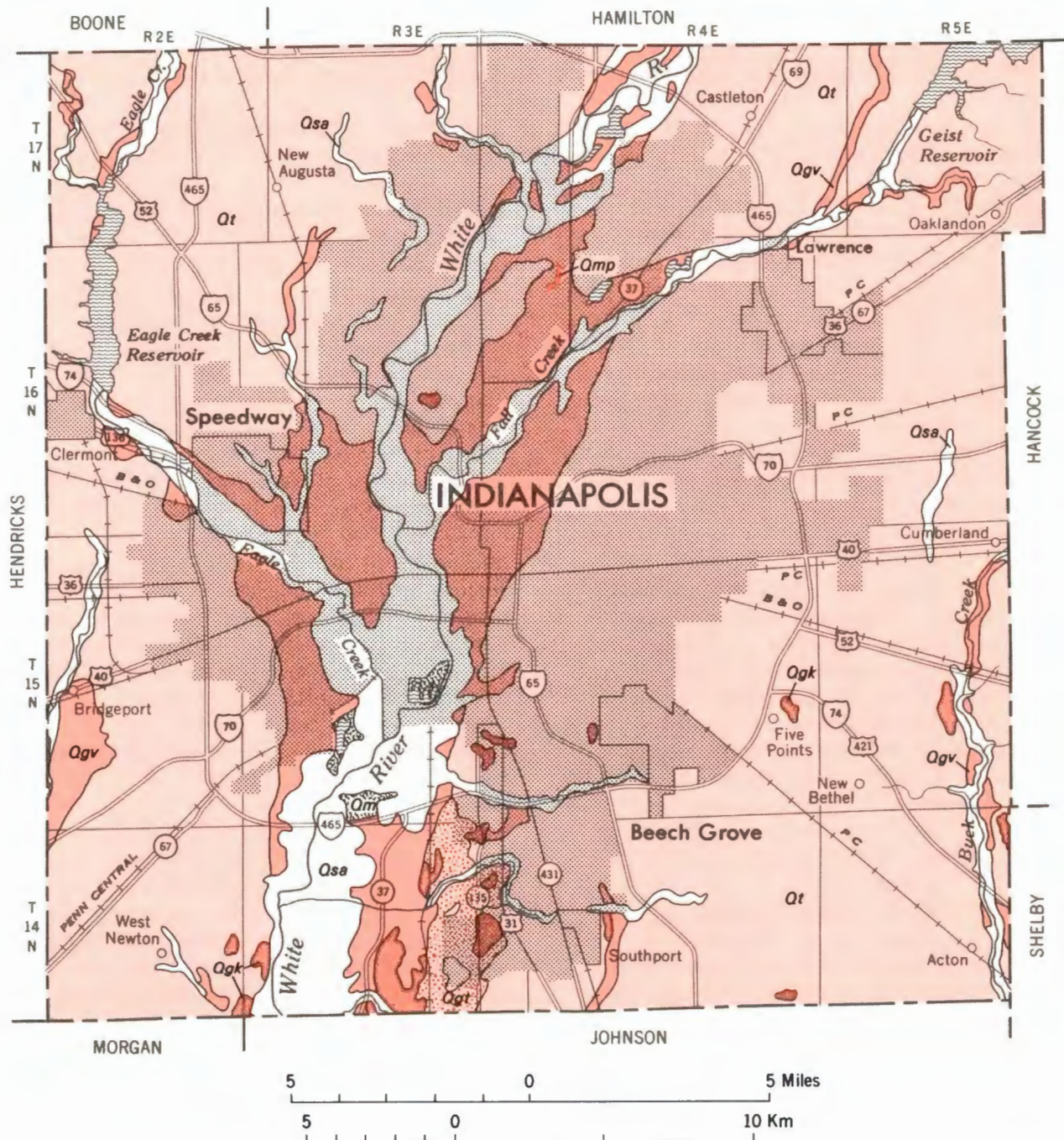


Figure 1. Map of Marion County showing surficial geology. From Indiana Geological Survey Regional Geologic Maps 1 and 7.

EXPLANATION



Modified land

Land extensively modified by excavation for limestone or gravel. Small areas not shown



Silt, sand, and gravel

Deposits of present streams; includes associated slopewash and swamp deposits



Muck and peat

Paludal and lacustrine deposits



Gravel, sand, and silt

Deposits of meltwater streams. Valley-train deposits as partial valley fill



Gravel, sand, and some silt

Hummocky patches of ice-contact stratified drift



Sand, gravel, and till

Undifferentiated ice-contact stratified drift and till with hummocky topography



Till

Mostly loam till. Till sheets of low relief

Geology

UNCONSOLIDATED DEPOSITS

The thick unconsolidated materials (*glacial drift*)¹ that everywhere form the surface of Marion County (fig. 1) were deposited during three glacial ages. Dating from earliest to youngest, they are: Kansan, Illinoian, and Wisconsinan. Only Wisconsinan materials are known to be exposed at the surface. Recent *alluvium* derived from erosion of the glacial materials forms a thin cover on the drift in the stream valleys. Thickness of the glacial drift ranges from less than 15 feet to more than 300 feet (fig. 2). The drift is thin in the southwest and thickest in the northeast and has local variations throughout the county. Because of its widespread distribution and generally great thickness and good bearing capacity, nearly all construction projects in the county are accomplished in the drift.

The broad upland areas are underlain by a pebbly *loam till* of the Trafalgar Formation. The lower areas, particularly the valleys of Eagle Creek, White River, Fall Creek, and Buck Creek, are rimmed with sand and gravel *outwash* terraces formed during the melting of the last (Wisconsinan) glacier. Small patches of gravel (*kames*) dot the upland till surface in the southern part of the county, and larger deposits, glacial crevasse fillings in the form of mounds or ridges, provide scenic topographic relief in the south-central Glens Valley area. (For a detailed map and discussion, see Harrison, 1963a.)

Soil associations are closely related to the basic geology, but detailed soils mapping (U.S. Department of Agriculture Soil Conservation Service, 1978) also reflects drainage, slope, and small-scale characteristics of modern erosion and deposition.

The geology of the unconsolidated deposits beneath the surface is much more complex than that of the surface. (See geologic cross sections and generalized geologic column, pl. 1.) The Cartersburg and Center Grove Till

¹Geologic and other technical terms that are italicized are explained in the glossary.

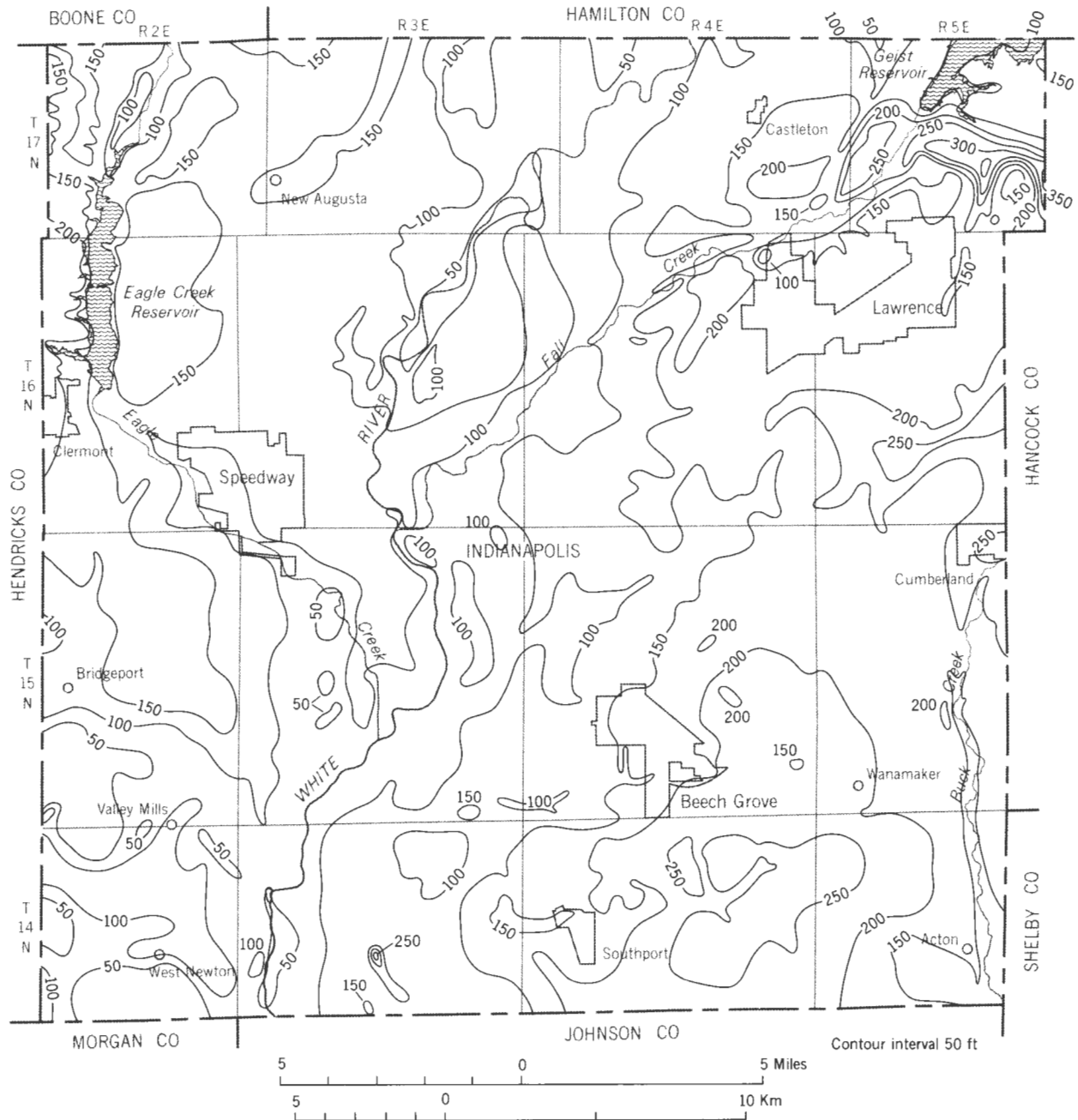


Figure 2. Map of Marion County showing thickness in feet of glacial drift.

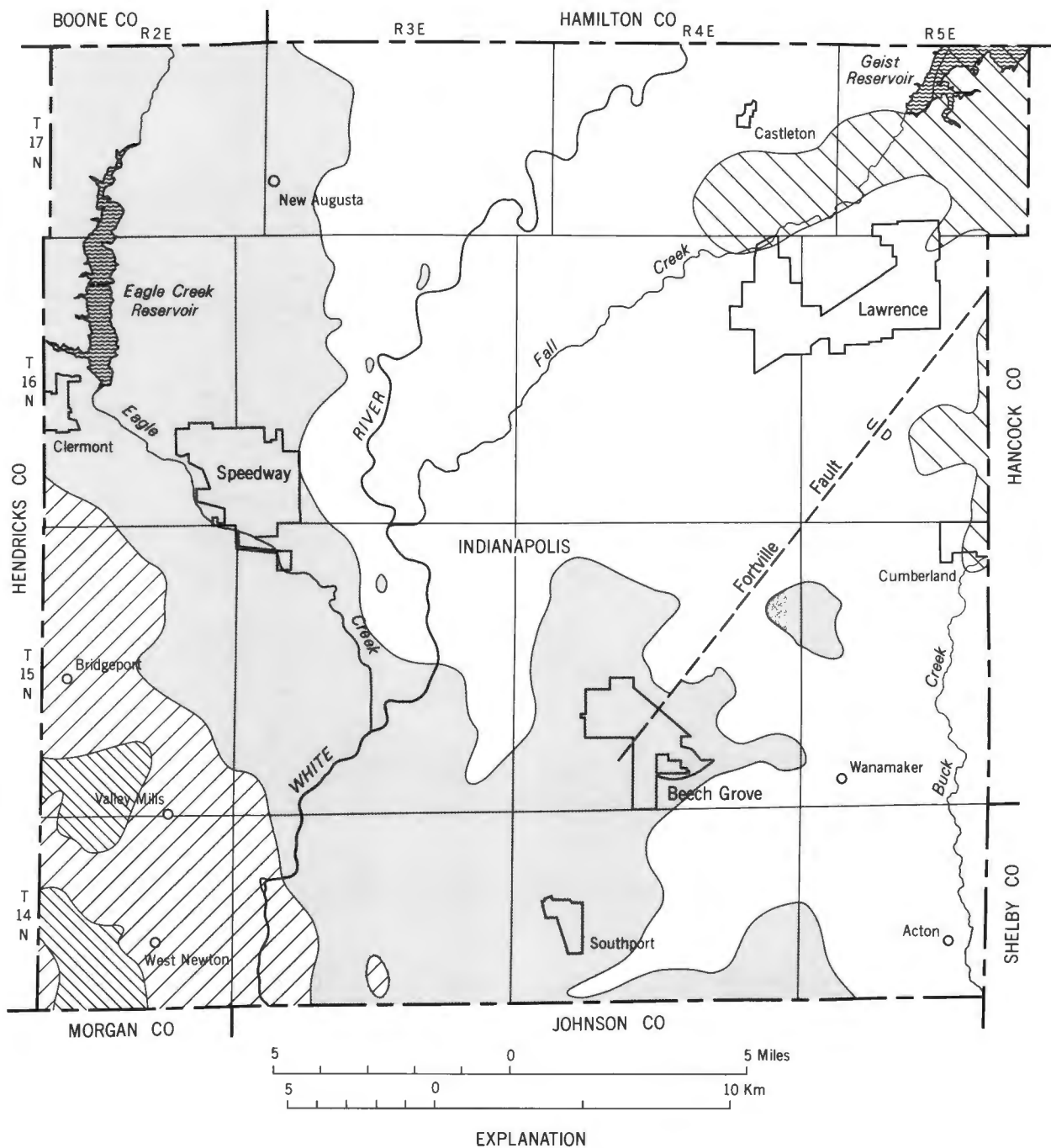


Figure 3. Map of Marion County showing bedrock geology.

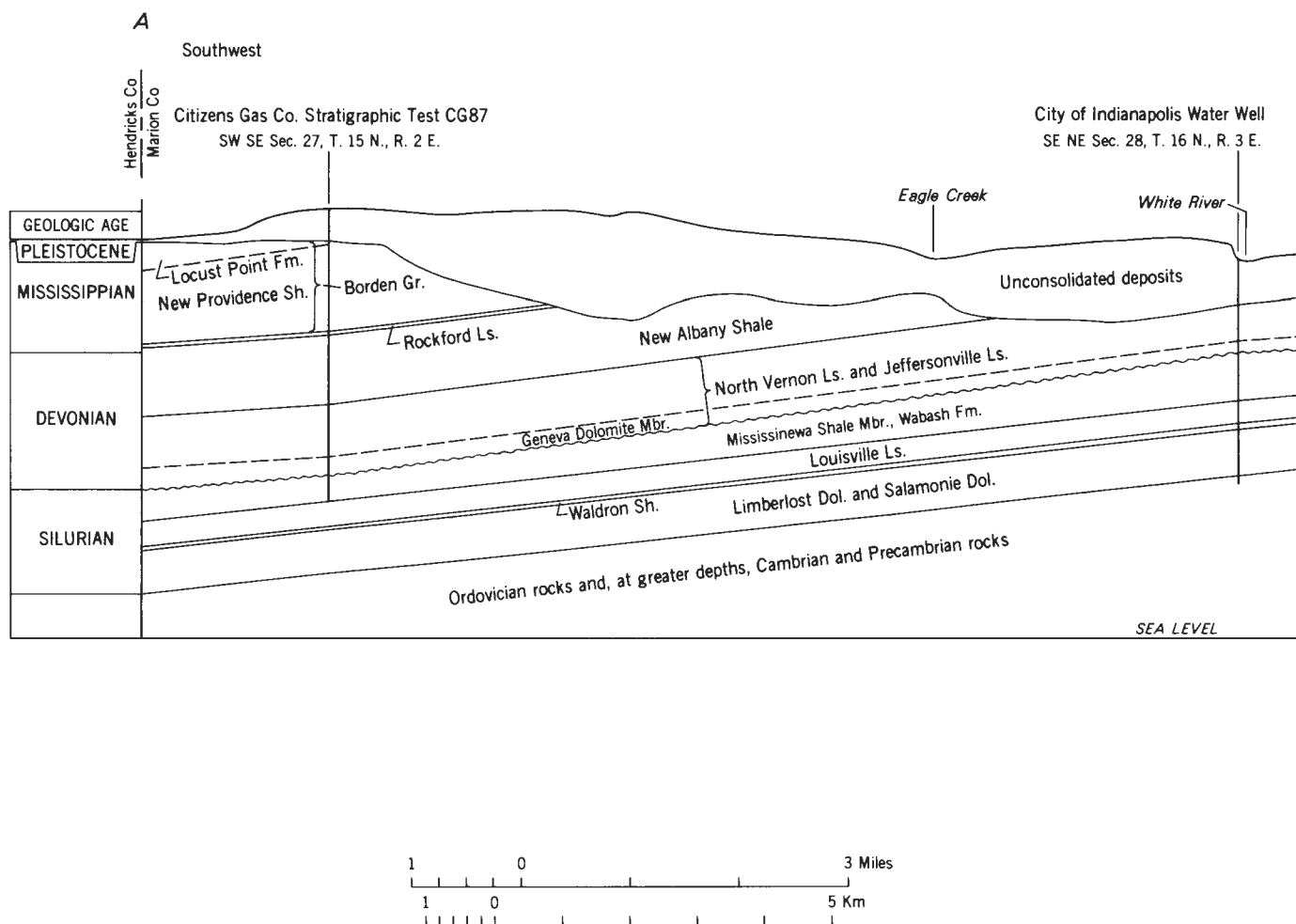


Figure 4. Cross section showing configuration of the land surface and arrangement of bedrock units.

Members,² commonly separated by thin lenses of sand, gravel, or silt, make up the upper 50 feet or so of the upland areas. Older tills, sands, and gravels are present farther below the surface of the upland areas and are encountered only in water wells and other

deep borings. These older tills interfinger with the sand and gravel below the surface of the lower lying terrace areas along the major streams.

²The descriptive terms Shelbyville and Champaign drifts of Harrison (1963a) have been replaced by the more proper rock-stratigraphic terms Center Grove Till Member and Cartersburg Till Member of the Trafalgar Formation (Wayne, 1963). The rock-stratigraphic terms are used in this report. They correspond to the original names as follows:

Harrison (1963a)	Wayne (1963); this report	
Champaign drift	Cartersburg Till Member	Trafalgar Formation
Shelbyville drift	Center Grove Till Member	
Illinoian drift	Jessup Formation	
Kansan drift		

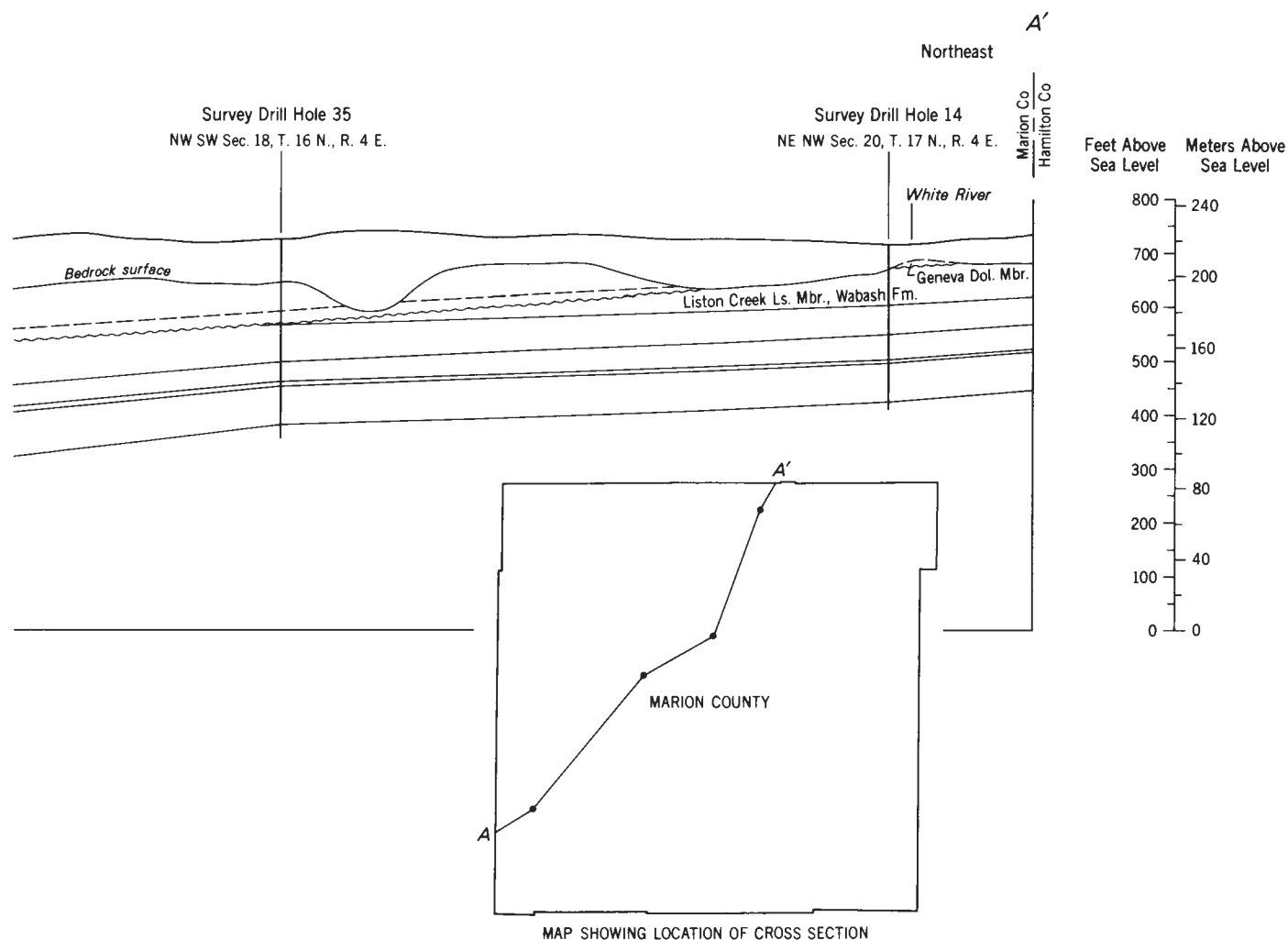


Figure 4—Continued

Although the nature and distribution of unconsolidated materials in the subsurface can be documented only in a general manner, knowledge of them can play a significant role in many urban problems and planning endeavors, including studies relating to ground water, waste disposal, *aggregate* exploration and production, and engineering for foundation construction.

BEDROCK

The sedimentary rocks that form the old, eroded bedrock surface (fig. 3) beneath Marion County represent three geologic systems: Silurian, Devonian, and Mississippian. These rocks form nearly planar layers (fig. 4) that slope gently to the west.

Therefore, increasingly older material appears at the bedrock surface in an easterly direction. The oldest of the bedrock materials are the Silurian limestone and shale which appear at the bedrock surface in scattered areas in the extreme eastern and northeastern parts of the county (fig. 3). The Silurian was a period of marine reef building. Therefore, the sequence of regularly bedded limestones and shales that constitute the Silurian System may be interrupted by dolomitic reef rock of complex structure. Devonian rocks consisting of dolomite, limestone, and shale form the bedrock surface under more than 75 percent of the county in a wide northwest-southeastward-trending band. The southwest corner of the county is underlain by Mississippian rocks

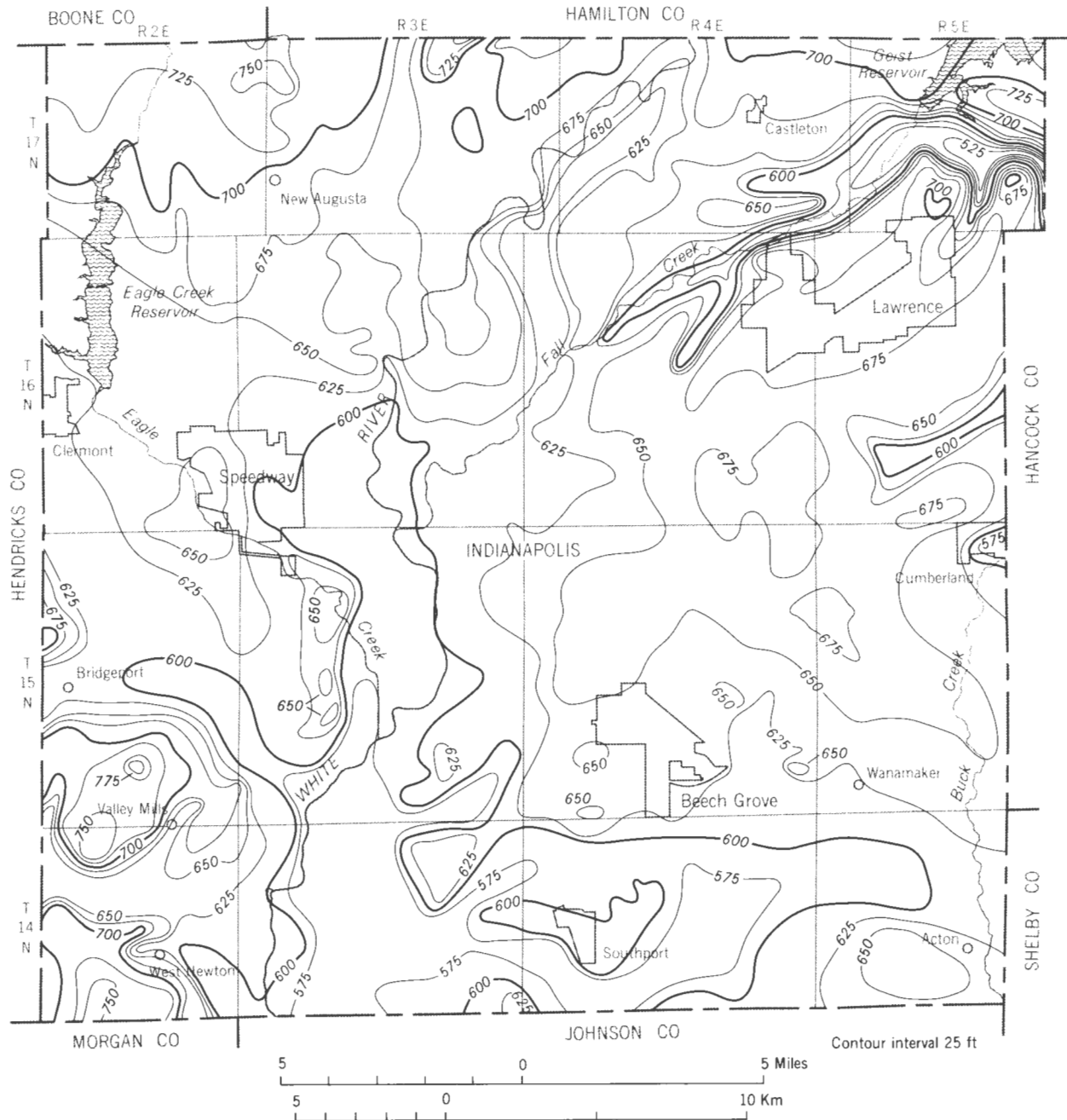


Figure 5. Map of Marion County showing topography of the bedrock surface.

System	Rock unit		Composition	Thickness (ft)	Remarks
Mississippian	Borden Group		Sandstone, siltstone, and shale	0- 50	Present only in the southwest. Aquifer suitable for domestic and farm use. Not suited for liquid-waste injection.
	Rockford Limestone		Limestone		
Devonian	New Albany Shale		Shale	0-250	Present only in the west and south.
	North Vernon Limestone		Limestone		Not present in the northeast. Moderately productive aquifer. Not suited for liquid-waste injection.
	Jeffersonville Limestone	Vernon Fork Member	Dolomite		
		Geneva Dolomite Member	Dolomite		
Silurian	Wabash Formation	Liston Creek Limestone Member	Cherty dolomitic limestone	0-200	Contains reefs (Huntington Lithofacies). Moderately productive aquifer. Not suited for liquid-waste injection.
		Mississinewa Shale Member	Calcareous shale and argillaceous limestone		
		Louisville Limestone	Dolomitic limestone		
		Waldron Shale	Shale		
		Limberlost Dolomite	Dolomitic limestone		
		Salamonie Dolomite	Dolomite and dolomitic limestone		
		Brassfield Limestone	Limestone		
Ordovician	Maquoketa Group		Shaly limestone	~1,500	Aquifer and liquid-waste injection potentials unknown.
	Trenton Limestone		Dolomitic limestone		
	Black River Limestone		Limestone		
	Glenwood Shale and Joachim Dolomite		Shale, siltstone, and dolomite		
	Knox Dolomite		Dolomite	~1,700	
Cambrian	Davis Formation		Siltstone, shale, and limestone	~100	
	Eau Claire Formation		Shale	~700	Potential confining unit for liquid-waste injection.
	Mount Simon Sandstone		Sandstone	~1,200	Unit with greatest potential for satisfactory liquid-waste injection.

Figure 6. Generalized geologic column of the sedimentary bedrock formations underlying Marion County.

consisting primarily of siltstone, shale, sandstone, and thin limestone of the Borden Group.

Depth to the bedrock surface ranges from less than 15 feet to more than 300 feet (fig. 2). This great range in depth is due in part to irregularities of the present land surface and in part to the uneven surface of the bedrock (fig. 5). The entire sedimentary rock sequence (fig. 6) underlying Marion County ranges in thickness from about 5,100 feet in the west to about 4,500 feet in the east and includes rocks of the Ordovician and Cambrian Systems that do not reach the bedrock surface. (See fig. 4.) This series of sedimentary rocks rests on Precambrian granitic basement rock.

The sedimentary rocks have little bearing on construction-related environmental problems, because they are buried under the thick unconsolidated materials. They are, however, a present source of ground water and crushed stone and are a potential source of clay materials. In addition, as urban and industrial growth applies more and more pressure on available surface space, subsurface bedrock excavations can provide additional storage or working areas in which a minimum of energy is needed for climate control. A more detailed description of the bedrock geology is available in Harrison (1963a).

Engineering Geology

The information presented here has been compiled from the records and through the courtesy of the Division of Materials and

Tests and the Division of Design, both of the Indiana State Highway Commission, and of the Division of Water, Department of Natural Resources. The bulk of the raw data was collected from structural boring records acquired since 1960 by the interstate-highway system. For additional geologic background data and cross sections, see Harrison (1963a, geology), Leonards and Altschaeffl (1960, soils engineering), and Herring (1976, ground water).

PROPERTIES OF NEAR-SURFACE UNCONSOLIDATED MATERIALS

GLACIAL TILLS

Consistency values³ of weathered upland till material at depths less than about 6 feet are highly variable; although generally of medium to stiff consistency, the till is dry and hard in places. Values for most engineering characteristics of the uppermost several feet differ greatly and are dependent on variations in soil type and associated drainage. Information regarding the distribution and character of surface soils is available in the Soil Survey of Marion County by the U.S. Department of Agriculture Soil Conservation Service (1978).

³Consistency or *relative-density* data are now most readily available in records of split-spoon borings made to 30- to 50-foot depths for many interstate-highway structures in the Indianapolis area. N, or blow count, represents the number of blows by a 140-pound weight falling 30 inches that are necessary to drive a standard split-spoon sampler 1 foot. The table below is exemplary.

Relative density of sand		Strength of clay		
Penetration resistance N (blows/ft)	Relative density	Penetration resistance N (blows/ft)	Unconfined compressive strength (tons/ft ²)	Consistency
0- 4	Very loose	< 2	< 0.25	Very soft
4-10	Loose	2- 4	0.25-0.50	Soft
10-30	Medium	4- 8	0.50-1.00	Medium
30-50	Dense	8-15	1.00-2.00	Stiff
> 50	Very dense	15-30	2.00-4.00	Very stiff
		> 30	> 4.00	Hard

From Terzaghi and Peck, 1948.

Table 1. Range of characteristics of near-surface till units below depth of 6 feet¹

Parameter	Range (pct)	Mean (pct)	Standard deviation (pct)	Number
Grain size				
Sand	24- 62	46	10	34
Silt	12- 52	31	7	34
Clay	8- 37	22	6	34
Atterberg limits				
Liquid limit	7- 36	21	5	33
Plastic limit	10- 21	13	3	33
Plasticity index	2- 16	8	4	33
Shrinkage limit	11- 18	12	2	31
Classification				
AASHO ²	A-4 to A-6 (clay loam to sandy loam)			
Unified	CL			
Natural moisture content	6- 25	14	4	65
Moisture-density relationships				
Dry density	126-129	127	1.8	4
Moist density	139-142	140	1.3	4
Optimum moisture	10- 11	11	.5	4

¹ Compiled from records of augered roadway borings of Indiana State Highway Commission projects: I-465-4(107), 4(108)135, 4(91)113, 4(105)122, 4(106)127, I-65-3(71)100. Tests were performed according to AASHO specifications. Grain-size variations, particularly, are somewhat greater than are to be expected in the near-surface till units. The grain size of the near-surface till generally can be expected to be in the loam to sandy loam range.

² AASHO, American Association of State Highway Officials.

The consistency of the surface till unit (Cartersburg Till Member) (pl. 1) below a depth of about 6 feet is most commonly stiff to very stiff. The Cartersburg Till Member may become hard at a depth of about 10 to 15 feet or in the basal few feet of the unit, where a sand or gravel unit separates it from the Center Grove Till Member below. The notable increase in consistency values into the hard range, however, appears to correspond in most places to a change in geologic material to more highly *overconsolidated* (compacted) Center Grove till (pl. 1). This change of material is commonly marked by a thin sand or silt bed. In most other engineering respects, the Center Grove Till Member is similar to the overlying Cartersburg Till Member. Consistency values in and below this lower unit generally increase as borings penetrate deeper into even more highly overconsolidated older

tills. The primary basis of Harrison's (1963a) correlation of till units in Marion County was engineering data on the degree of consolidation of glacially overridden silts. The measurements of the consistency of subsurface till units now available in engineering borings aid in extending these correlations over much of the county.

Other engineering properties (table 1) of the surficial till vary within relatively narrow ranges. The grain size of the near-surface till generally can be expected to be in the loam to sandy loam range; variations of other properties are minor.

GRANULAR MATERIALS

Sand and gravel beds (Atherton Formation) sandwiched between till units are commonly dense to very dense. Thicker continuous accumulations of granular materials in stream

terraces, as throughout downtown Indianapolis, are commonly medium dense to dense in their top 10 to 20 feet but grade into dense and very dense material with depth. Grain size and gradation are quite variable, although the materials are most commonly classified as sand with a varying admixture of gravel. Silty clay and similar materials overlying sand or gravel in the lower terraces are of soft to stiff consistency.

GENERAL FOUNDATION AND CONSTRUCTION CONDITIONS

The subsurface materials of Marion County (pl. 1) generally provide excellent foundation for most structures, except as modified locally by surface-soil condition, overall drainage, and *water-table* position. But the sand and gravel beds within the tills, some within the Cartersburg Till Member but most persistently those separating the stiff till of the Cartersburg Till Member from the hard till of the Center Grove Till Member, may necessitate some dewatering and (or) protection from slumping for large excavations. Bedrock and tills of hard consistency are at sufficient depth throughout the county that they present few excavation problems. Thick bodies of sand in lowland terraces will necessitate use of dewatering schemes and caissons for deep excavation in some places, depending on the position of the water table.

Surface-Water Resources

HISTORICAL AND PHYSIOGRAPHIC BACKGROUND

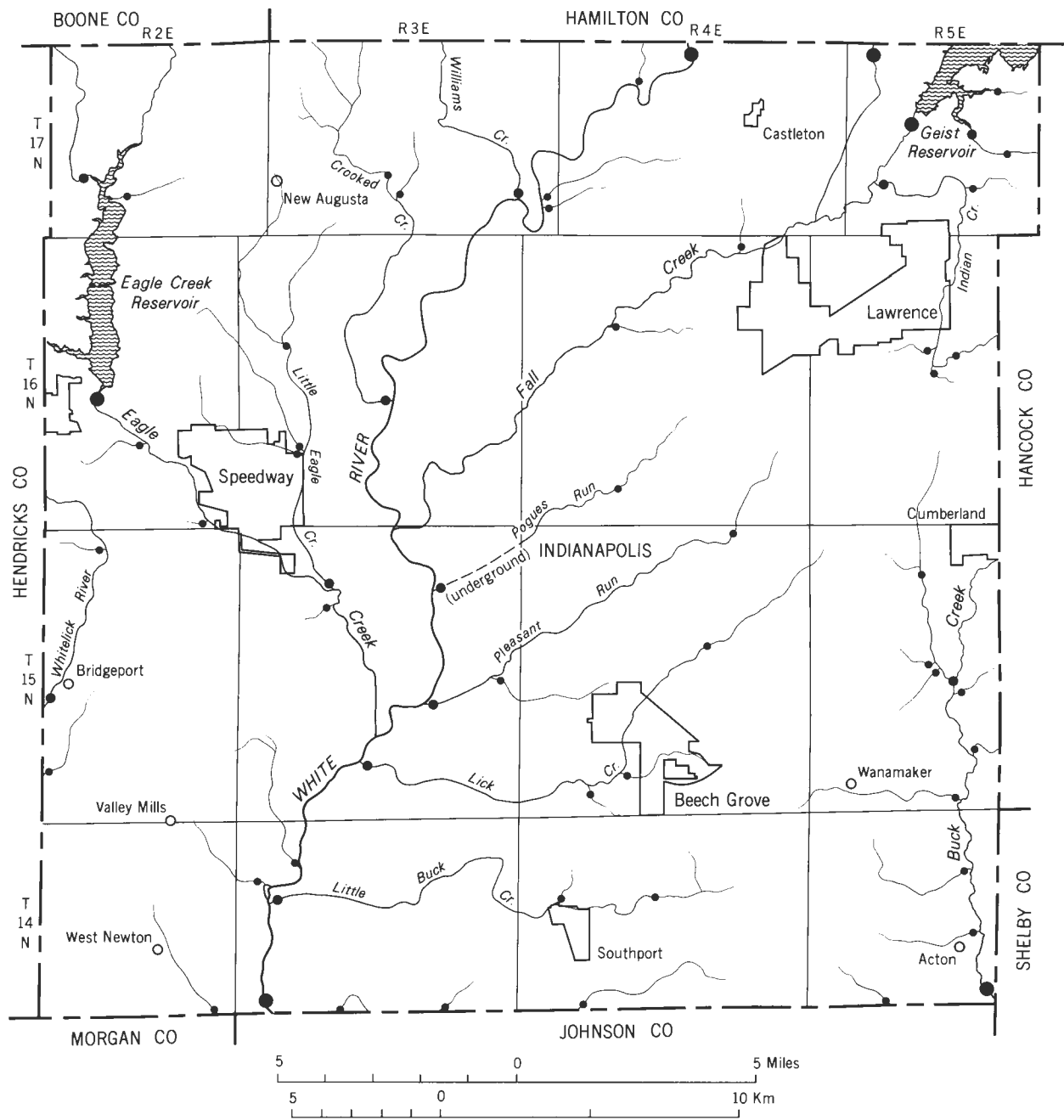
The surface-water regime found by the first white settlers in Marion County was significantly different from that of today. In 1816, when Indiana was admitted to the Union and land was donated to the state for the new capital, the area was covered with stands of hardwood. The poorly drained uplands were dotted with ponds and marshes, and the streams maintained substantial flow even during periods of drought. These conditions changed drastically as farmers cut and burned the timber, dredged streambeds, and drained the uplands. The loss of the water-storage capacity of the forests and marshes created conditions that led to the drying up of streams during periods of drought. The loss of

storage also contributed to direct runoff and increased flood intensity. The addition of reservoirs, Geist in the 1940's, Morse in the 1950's, and Eagle Creek in the 1960's, has somewhat stabilized flow by reducing flood intensity and increasing minimum flow in Eagle Creek, Fall Creek, and White River. Flow in the tributaries is not controlled, however, and flooding is still a real danger in the flood plains of these streams. Modern development patterns, including the construction of subdivisions, extensive road systems, and industrial and shopping centers, have magnified the flooding problem by decreasing holding capacity of the soil and increasing direct runoff.

Indianapolis, the principal water user in Marion County, relied entirely on ground water for its water needs until 1904. Since that time surface water has played an increasingly important role. Surface water is one of the most valuable resources in the county. It is an essential part of the water-supply system, liquid-waste removal process, and recreational facilities.

Marion County lies in the Wabash River drainage basin and the gently rolling physiographic province called the Tipton Till Plain (Malott, 1922). The drainage pattern is *dendritic*, and all streams except Buck Creek, which is in the southeastern part of the county, are tributaries of White River. The major streams flow through outwash-filled valleys in which the water table is high and the internal drainage good. The sloping areas of till, the stream terraces, and the valley walls are dissected and well drained. There are, however, areas of low relief within the upland tills that have poorly developed internal and surface drainage and that as a result pond during wet weather.

Both Indianapolis and Speedway rely on surface water as their principal water source. Indianapolis draws its supply from White River and Fall Creek. Flow in each of these streams is determined by controlled release of water from reservoirs. White River is fed by Morse Reservoir, in Hamilton County, and Fall Creek by Geist Reservoir, in northeastern Marion County. Speedway taps Eagle Creek, which flows from Eagle Creek Reservoir in northwestern Marion County. The two cities



EXPLANATION

- Average annual streamflow rate greater than 25 cfs
- Average annual streamflow rate between 5 and 25 cfs
- Average annual streamflow rate between 1 and 5 cfs

Streamflow data taken from "Water Resources Data for Indiana", (1972) for streams with gaging stations. Data for ungaged streams were computed using a local runoff factor based on the flow versus drainage area derived from gaged streams in a nearby, geologically similar area.

Figure 7. Map of Marion County showing average annual flow rate in major streams.

used about 82.8 mgd in 1972 from these three sources. These reservoirs also serve flood-control and recreational purposes.

MANAGEMENT

Surface water is managed through the use of reservoirs, levees, holding-infiltration ponds, ditching, stream maintenance, and erosion and quality (effluent-discharge) control. The major environmental considerations in surface-water management are: (1) water quality, (2) flow regulation, and (3) drainage.

WATER QUALITY

The maintenance of an acceptable level of water quality depends on control of contaminant discharge, maintenance of some minimum base-level flow, and control of erosion runoff. Contamination results from both point and area sources. Point sources include industrial and municipal wastes, and area sources may include sanitary landfills, septic-system fields, and agricultural fertilizers and pesticides. The base flow in a nonreservoir-fed stream is determined by the regional ground-water level, but that of the major streams in Marion County can be controlled by reservoir discharge. Natural surface-water quality is a reflection of ground-water quality plus dilution by surface runoff. Because surface water moves much more rapidly than ground water, it is much more variable in quality. Ground-water temperature varies within a small range, but surface-water temperature may range from freezing to more than 90° F. Water quality can best be controlled by maintaining a reasonably high flow rate to provide for dilution and self-purification and by minimizing the quantity of contaminants.

FLOW REGULATION

Flow regulation, or the maintenance of an adequate base-level flow and flood control, is a factor important to water supply, quality control, flood protection, and recreational usage. Flow is regulated by controlling discharge from reservoirs and by constructing levees that will increase carrying capacity. Flow is hindered by construction within the *flood plain* and by restrictive bridgeworks and culverts. For example, Pogues Run flows

through a box culvert under the downtown business section of Indianapolis. The culvert will not carry peak flood flow, and the excess floodwater flows overland through the downtown area.

Another aspect of flow regulation is related to surface-construction projects. Parking lots, roadways, and buildings reduce infiltration and increase runoff. Agricultural ditching and tiling also increase surface flow. All the above factors, but not flood-control reservoirs, combine to increase maximum flood level and to reduce base flow level. Average annual streamflow for the larger perennial streams ranges from less than 1 cfs (cubic foot per second) to more than 25 cfs (fig. 7). Flood-plain information, including the expected magnitude of floods, has been studied by the U.S. Army Corps of Engineers and is available for the following streams: Pogues Run, Pleasant Run, and Bean Creek (Flood Plain Information, 1970b); Lick Creek and Little Buck Creek (Flood Plain Information, 1971a); Little Eagle Creek (Flood Plain Information, 1971b); and Crooked Creek and Williams Creek (Flood Plain Information, 1970a).

DRAINAGE

Poor drainage conditions may be either natural, as with upland tills, or construction related. Drainage of upland tills can be improved by tiling and ditching. Such drainage, however, could add to the flooding problem and should be planned cautiously. Construction-related drainage problems involve inadequate culverts and bridges as well as other obstructions constructed on the flood plain. Anything constructed on the flood plain that reduces its cross-sectional area will increase the flood level.

Ground-Water Resources

Ground water, water beneath the earth's surface and within the zone of saturation, along with previously discussed surface water, is one of the most abundant natural resources in Marion County. It is also a resource that is essential to continued development in the area. Ground water has decreased in relative importance to the city since the early 1900's

and is now used only as a supplement or reserve. Industrial and domestic users, however, continue to rely heavily on ground water. With proper development and management, ground water can help meet the increasing water-supply demands of this growth-oriented community. There are limitations to water availability, however, that should be considered when planning for the future of the area. For a detailed review of ground-water resources in Marion County the reader is referred to Herring (1974, 1976), McGuinness (1943), and Meyer, Reussow, and Gillies (1975).

PRESENT USAGE

Ground-water usage in Marion County (1974) is estimated to be about 60 mgd (million gallons per day). This includes water pumped from thousands of domestic wells, hundreds of industrial wells, and dozens of municipal wells. Total ground water used is as follows: (1) industry, 29.0 mgd; (2) domestic, 9.0 mgd; (3) municipal, 7.6 mgd; (4) commercial, 4.3 mgd; (5) institutional, 3.5 mgd; and (6) irrigation, 1.5 mgd. Industrial facilities, the largest users of ground water, are concentrated in the central part of the county and tap the most productive *aquifers* of the area. Domestic use of ground water is also quite high; about 100,000 people rely on private wells scattered throughout the county.

Water discharged from major sand and gravel operations and quarries in the White River valley and from other pits, building-construction sites, and sewer-construction projects scattered throughout the county are excluded from the water-usage figures. The exact amount of water being discharged by these dewatering operations is not known; during 1972, however, an estimated 23 mgd was being pumped into White River by major sand and gravel operations alone.

AVAILABILITY

The availability of ground water depends primarily on geologic and meteorologic conditions. Favorable conditions include: (1) a permeable surficial material that will permit ready infiltration of precipitation, (2) a thick coarse-grained or otherwise highly permeable

geologic unit (aquifer) at some depth below the seasonal low water table, and (3) sufficient rainfall.

Ground water in Marion County is available from unconsolidated materials, primarily sand and gravel in the glacial drift, and from bedrock, mostly Silurian and Devonian limestone and dolomite. The most prolific source is the thick layer of sand and gravel of Pleistocene age in the glacial outwash in and adjacent to the White River flood plain.

Marion County has relatively large areas of flat-lying permeable alluvium, outwash, and kame materials that permit high infiltration rates. Along the major stream valleys the outwash extends to some depth beneath the surface to form an excellent aquifer. The Silurian-Devonian carbonate rocks lying at the bedrock surface and immediately beneath the outwash have undergone extensive solution-channel development and also constitute a good aquifer. Sand and gravel lenses within the till and the Silurian-Devonian carbonate rocks that lie beneath till (as opposed to outwash) are also aquifers but are not as prolific. Rainfall in the Marion County area exceeds *evapotranspiration*, thereby providing the excess water required to recharge the aquifer systems.

DEVELOPMENT POTENTIAL

The development potential or potential yield of an aquifer (fig. 8) depends on aquifer coefficients (*transmissivity*, *hydraulic conductivity*, and storage), aquifer thickness, areal extent, water levels (fig. 9), and recharge. On the basis of the above factors, the potential yield from ground-water sources in Marion County is an estimated 94 mgd (Meyer, Reussow, and Gillies, 1975). This yield can be achieved through location of wells and well fields in accordance with accepted hydrogeologic methods.

An aggressive program of artificial recharge and sound aquifer management could substantially increase the potential ground-water yield. An aggressive program includes the construction of holding ponds to permit the spreading of water over the land surface and for better infiltration and recharge, the possible use of injection wells so that surface

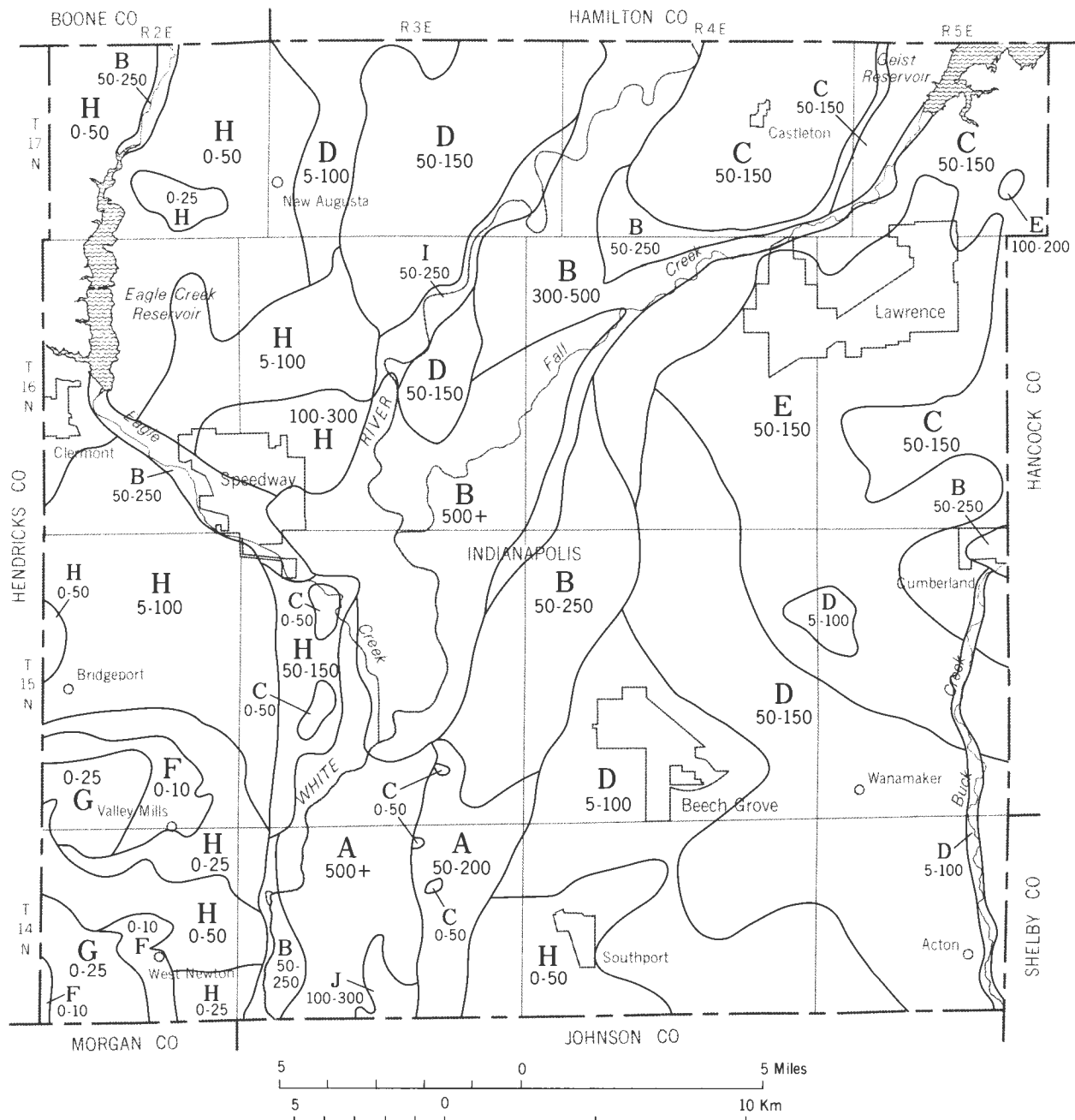


Figure 8. Map of Marion County showing generalized interpretation of potential yield from ground-water sources.

EXPLANATION FOR FIGURE 8

- A Production from thick glacial outwash in stream valleys; greatest potential for ground-water production in the county; sand and gravel wells less than 100 feet deep may produce as much as 3,000 gpm; normal maximum capacity is about 1,500 gpm.
- B Production predominantly from shallow sand and gravel outwash aquifers; wells are generally less than 100 feet deep but may be as deep as 175 feet; bedrock wells in limestone directly beneath outwash are capable of yielding 75 to 250 gpm.
- C Production primarily from sand and gravel aquifers in the till generally less than 100 feet deep; in some areas a bedrock completion may be required.
- D Production from both sand and gravel aquifers in the till and bedrock aquifers; wells in the drift range from 35 to 200 feet in depth, but bedrock wells are more than 120 feet deep.
- E Most wells are completed in limestone bedrock; depth to bedrock in the area ranges from 150 to 210 feet.
- F Very poor ground-water area; the till lacks the necessary sand and gravel formations and the bedrock is nearly impermeable shale.
- G Production from bedrock (sandstone) wells under thin (50 feet) till.
- H Production primarily from sand and gravel aquifers in the till; wells are generally completed at depths between 30 and 100 feet; completion in bedrock may be necessary where sand and gravel are absent.
- I Production may be from thin glacial-outwash materials or from underlying bedrock; in the southern part of the area bedrock wells are usually necessary because the outwash is thin.
- J Production is primarily from kame deposits between 100 and 150 feet thick.

Numbers (5-100) accompanying the above letters indicate the expected range of potential production in gpm from properly completed wells in the outlined area.

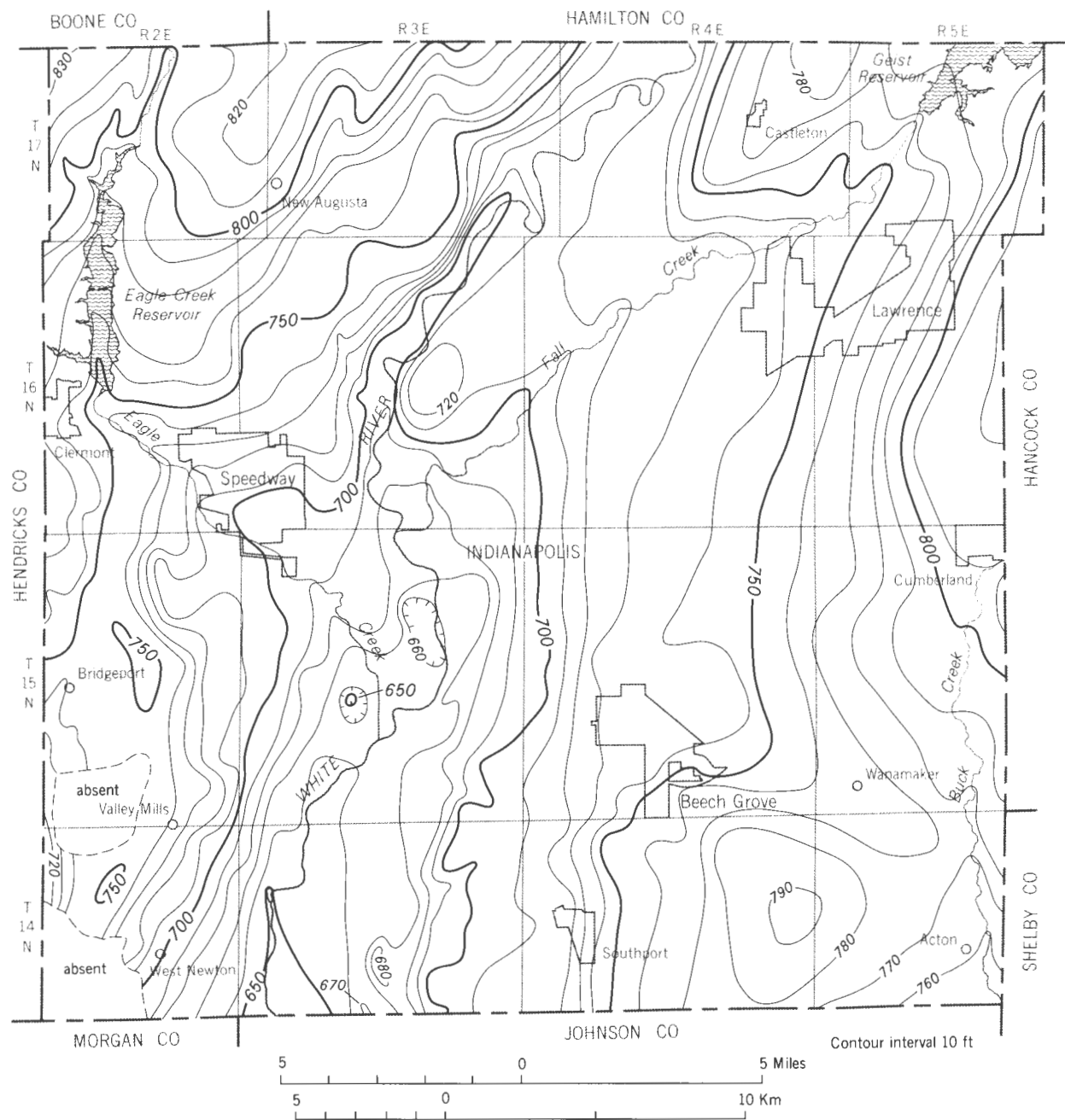


Figure 9. Map of Marion County showing the potentiometric surface of the principal Pleistocene aquifer.

water can be injected into the aquifer during periods of high streamflow, and the use of proper well spacing with controlled pumpage of production wells to avoid overdrafts and obtain the best possible yields.

PRINCIPAL PLEISTOCENE AQUIFER

The greatest development potential exists in the principal Pleistocene aquifer, an extensive system of sand and gravel deposits in the White River valley. This aquifer, which has all the requirements (continuity, thickness, recharge potential, and permeability) for prolific ground-water production, also extends to the east and west beneath the glacial-till cover (fig. 10). Recharge to the aquifer is very good because the soil cover is relatively permeable and allows a substantial amount of precipitation to percolate downward into the underlying aquifer. A perennial stream, White River, transects the area and is hydraulically connected to the aquifer, thereby providing substantial induced infiltration. The aquifer is near the surface, and the topography and present land use in much of the area are such that an extensive and effective artificial recharge system of canals, trenches, pits, or wells could be constructed. In places, particularly where it lies beneath a cover of till, the aquifer is divided into two units by a relatively thick and extensive till layer (fig. 10). In the White River valley and in the lower reaches of Eagle Creek and Fall Creek, the saturated sand and gravel deposits range from 30 to more than 80 feet in thickness and constitute the most productive area of the principal Pleistocene aquifer (fig. 10).

Much of the present ground-water withdrawal takes place in the northern section of the aquifer; little development has been directed toward the southern part.

BEDROCK AQUIFERS

The most productive bedrock-aquifer system in the county is composed of the limestone and dolomite formations of Silurian and Devonian age. These formations behave hydraulically as a single aquifer (fig. 10). The most productive zone is in the upper 100 feet in areas where it was once exposed at the bedrock surface. The greatest amount of

solution development has occurred in this zone.

The Silurian-Devonian aquifer exhibits considerable variability in its ability to transmit water to wells. For example, in the western and southern parts of the county, where the aquifer is overlain by younger shales of Devonian and Mississippian age, the potential yield is much less than in the rest of the county, where it is overlain by glacial drift. The shales greatly retard the downward percolation of water and decrease the potential for solution-channel development and other processes that would permit rapid recharge of the aquifer.

On the other hand, the potential yield in the Silurian-Devonian aquifer in those areas where it is overlain by valley-train and outwash-plain deposits of sand and gravel is quite good. Not only has the bedrock been exposed to surficial weathering and more rapid solution-channel development, but it is also exposed to constant recharge from the overlying sand and gravel. Individual well yields of several hundred gallons per minute are common in these areas.

Where the Silurian-Devonian aquifer is overlain by glacial till, as in much of eastern Marion County, well yields are generally about one-half as great as where sand and gravel overlie the aquifer. One prominent exception is in the small well field of the town of Lawrence, where some wells are capable of producing 1,000 gpm. Apparently a relatively high degree of jointing and (or) solution-channel development has occurred there.

The potential yield of the New Albany Shale of Devonian-Mississippian age is very limited. Few wells are completed in this formation, which is as thick as 125 feet, because it has a relatively low yield and because more water can usually be found either above or below it. Where the New Albany Shale underlies the younger Borden siltstone and shale, it has a very low permeability and yields almost no water to wells. Where the New Albany lies immediately beneath the glacial drift, it is somewhat more highly jointed and weathered, and, consequently, the yields to wells tend to be higher. Nevertheless, many wells are dry and some

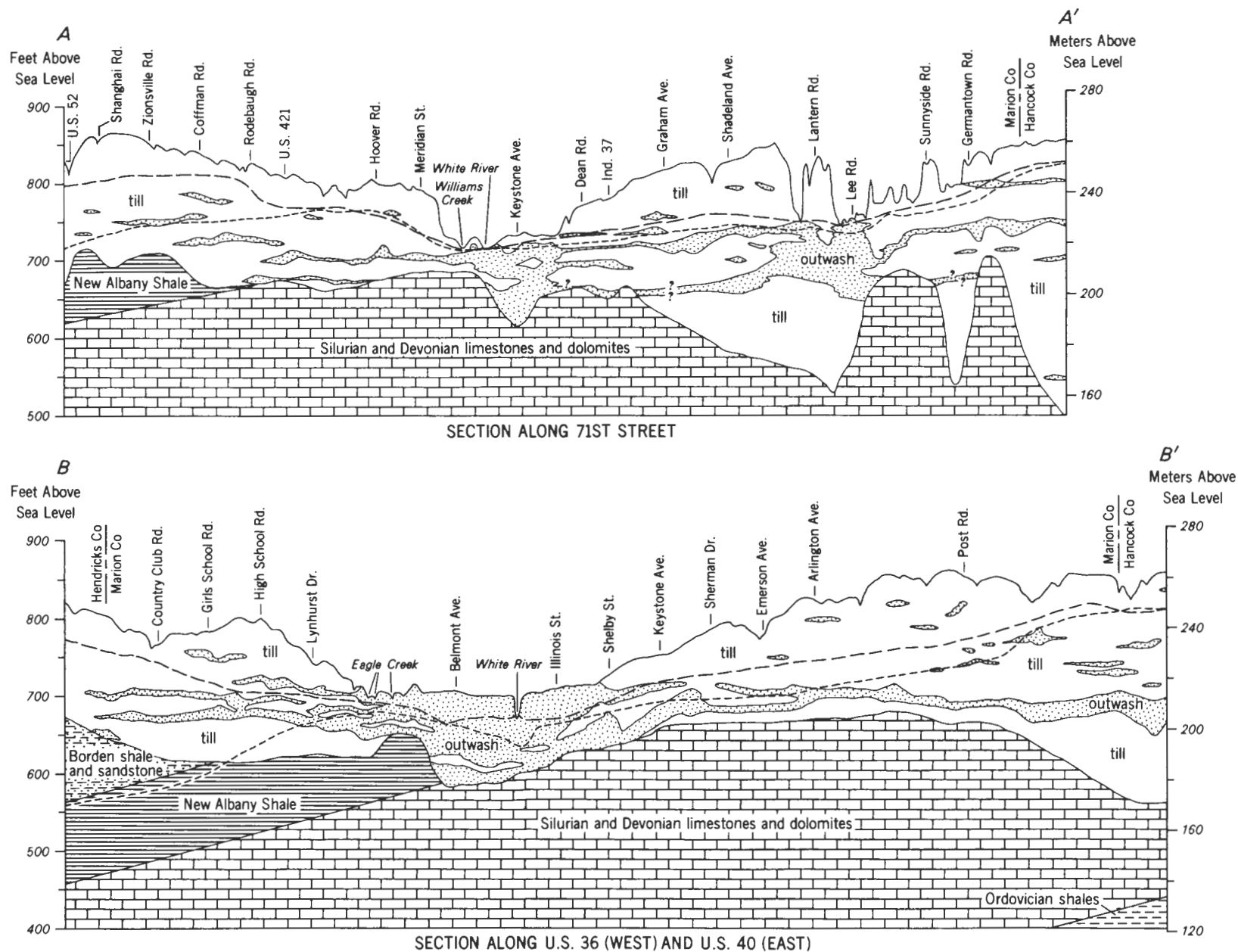


Figure 10. Hydrogeologic cross sections showing aquifer distribution and potentiometric surfaces in the unconsolidated and bedrock materials.

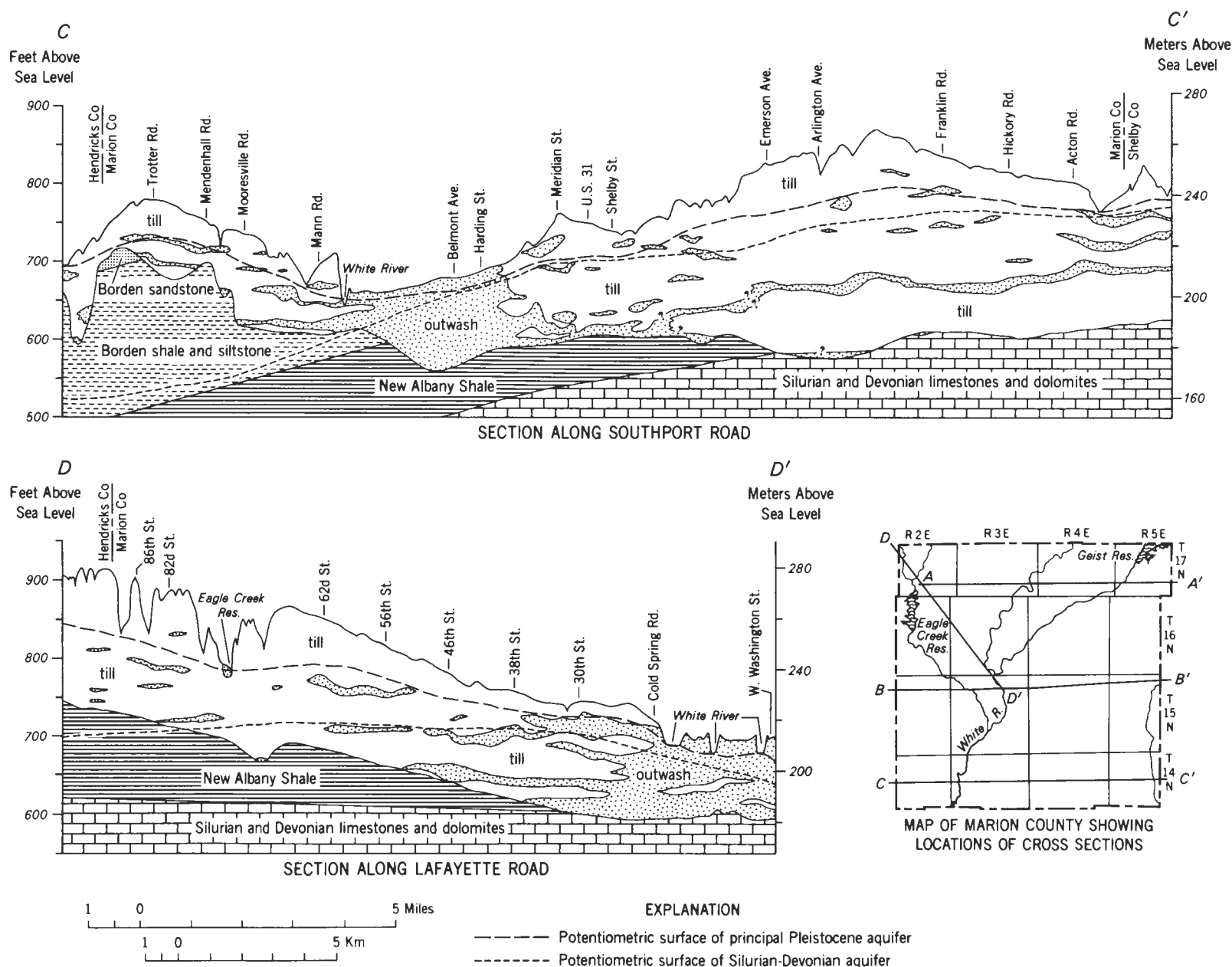


Figure 10—Continued

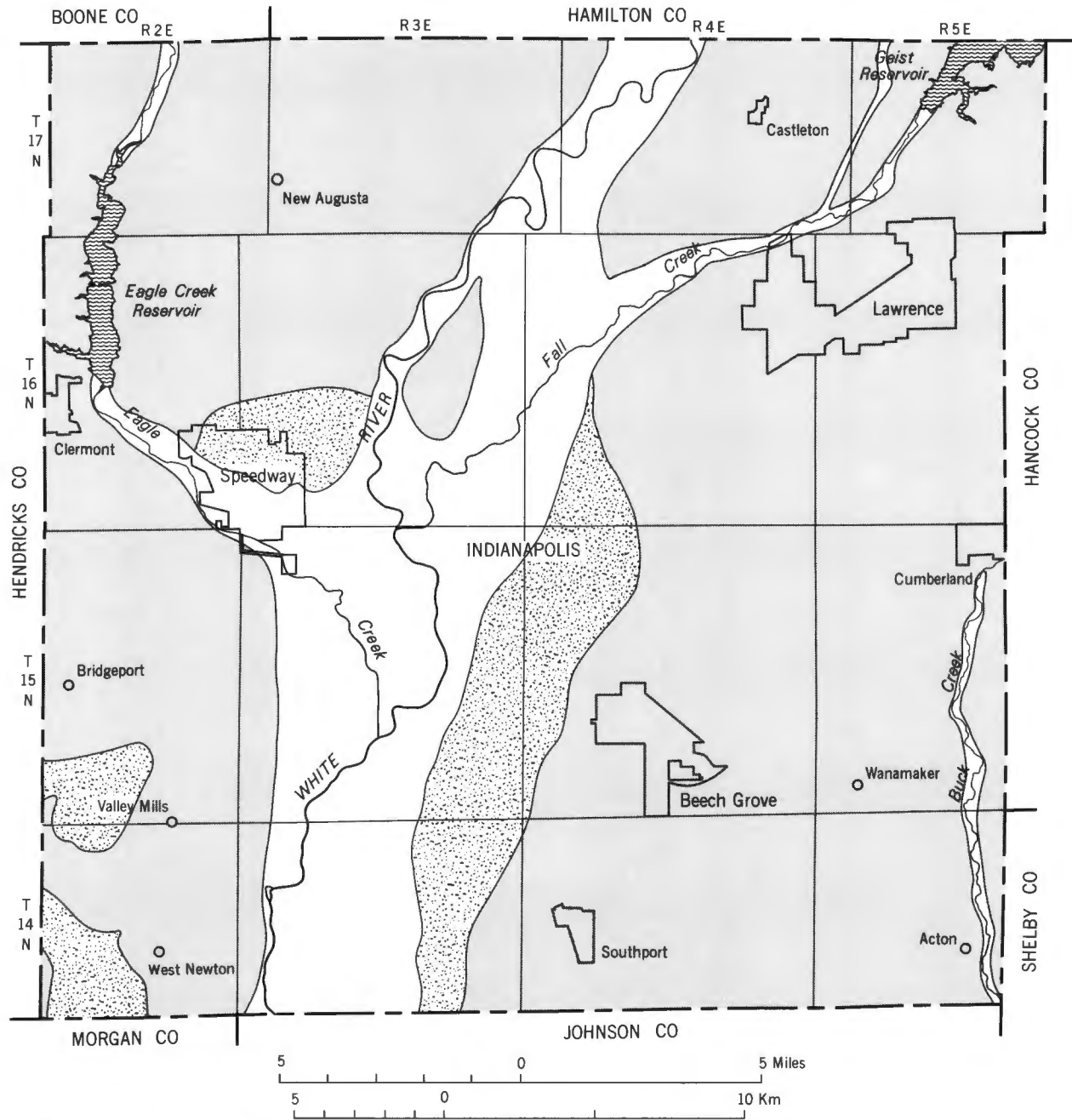


Figure 11. Map of Marion County showing susceptibility of aquifers to contamination from surface sources.

EXPLANATION FOR FIGURE 11



Little if any natural barrier exists to stop the downward migration of contaminants into the permeable outwash of the principal Pleistocene aquifer; no liquid wastes or solid wastes that produce leachates should be disposed of in these areas; a possible exception may be the use of treated sewage effluent for agricultural purposes.



Caution should be applied in locating waste-disposal sites in these areas; in many places there is less than 30 feet of soil above a local-use aquifer.



Surface disposal of wastes on these glacial-till uplands does not generally pose a major threat to aquifers; certain contaminants, such as chlorides and cyanides, however, can migrate hundreds of feet through glacial clays and contaminate even the deep aquifers; potential disposal sites must be examined to determine the possible existence of local aquifers that may be affected.

Table 2. Quality of ground water in Marion County¹

Quality parameter	Sand and gravel aquifers		Silurian-Devonian limestone aquifer	
	Range	Average	Range	Average
pH	6.9 – 8.1	7.5	7.2 – 8.3	7.6
Hardness	250 – 875	394	210 – 1017	382
Calcium	50 – 172	98	43 – 186	80
Magnesium	17 – 50	32	22 – 58	36
Sodium	3 – 60	24	13 – 180	42
Iron	0 – 4.8	1.7	0.1 – 4.5	1.7
Manganese	0 – 0.2	0.06	0 – 0.75	0.09
MO alkalinity	256 – 450	315	284 – 350	321
Bicarbonate	289 – 432	375	304 – 476	385
Chloride	2 – 63	18	1 – 212	30
Sulfate	0 – 261	73	0 – 319	57
Fluoride	0 – 1.4	0.4	0.2 – 3.0	0.9
Nitrate	0 – 3.7	1.0	0 – 8.5	2.5
Specific conductance	522 – 1180	736	520 – 1320	749
Total dissolved solids	296 – 767	476	273 – 946	464

¹ All units are milligrams per liter except pH and specific conductance. Specific conductance units are micromhos per centimeter. Hardness and MO alkalinity are expressed as CaCO₃.

others contain noticeable amounts of hydrogen sulfide gas, or sulfur water as it is commonly called.

Little water is available to most wells from the shales and siltstones of the Borden Group. Dry holes are common except where a local sandstone unit yields water at a relatively shallow depth in two areas in the southwestern part of the county (fig. 10).

QUALITY

Ground water in Marion County contains calcium bicarbonate, iron, and moderate concentrations of total dissolved solids and may be classified as hard to very hard. Water quality in the bedrock and sand and gravel aquifers is similar except in the southwestern part of the county where the aquifers are separated by shale. In that area the bedrock aquifer may have considerably higher concentrations of sulfides, chlorides, and total dissolved solids. The averages and ranges of chemical parameters of ground water are shown in table 2. Some of these analyses

reflect the effects of waste disposal and cooling-water recirculation.

CONTAMINATION POTENTIAL

Because the principal Pleistocene aquifer in the White River valley is a prolific source of water, it should be protected from such sources of contamination as landfills, settling ponds, waste-disposal pits, and salt piles. Within this valley the aquifer has little natural protection against contamination. Two of the same qualities that make it a highly productive aquifer (a high water table and a permeable cover material) also leave it highly susceptible to surface-derived contaminants. Additionally, from a hydrologist's viewpoint, the White River flood plain and the rest of the area of glacial outwash containing the principal Pleistocene aquifer (fig. 11) should be protected from developments that obstruct flood flow and that place asphalt, concrete, and other materials above the aquifer, thereby reducing infiltration.

The aquifers beneath the upland till areas have the greatest protection from surface-derived contamination. The high clay-silt content of the till and low water table ensure slow percolation rates and reasonably high *ion-exchange capacity*. Therefore, contaminant concentrations are attenuated as they migrate toward the underlying aquifers.

Ground water and surface water are interrelated and should receive equal consideration and management. Ground-water reservoirs, particularly those in major outwash stream valleys, should be treated as analogous to surface-water reservoirs. Just as it would be unthinkable to contaminate a surface-water reservoir, it should likewise be unthinkable to subject the prolific ground-water reservoirs to such degradation. Land-use policies should be adopted that will provide protection against development or waste-disposal practices that may destroy the future productivity of these underground reservoirs.

Crushed-Stone Resources

Marion County is underlain by a wealth of crushed-stone reserves suitable for many purposes. More than 200 feet of limestone and dolomite of Silurian and Devonian age (table 3) are at or near the bedrock surface under much of the county. These reserves are more than sufficient for the crushed-stone needs of Indianapolis and the surrounding area for the foreseeable future, but mining has been hampered or is impractical because of the high ground-water table and intense land use of the surface in most of the county.

As is true for all natural resources, crushed-stone reserves and requirements are not related to political boundaries. Crushed stone is both exported and imported. Rapid growth in urban areas could greatly curtail locally available reserves because noise and dust are two serious environmental problems associated with crushed-stone production. Naturally, the reserves most easily and economically exploited are being used first. Remaining reserves must be located and protected if construction in the area is to continue to be economically feasible.

The limestone and dolomite can be mined by open-pit methods where the overburden is thin or contains marketable sand and gravel.

Favorable geologic and environmental conditions for open-pit quarries are severely limited, however, and bedrock sources of high-quality aggregate in many areas could be mined only by underground methods.

POTENTIAL SOURCES

Silurian and Devonian limestone and dolomite are the only commercially important sources of crushed stone in Marion County. These strata are found at the bedrock surface in the eastern two-thirds of the county (fig. 3). They dip gently to the west and southwest at 20 to 30 feet per mile and are overlain by younger strata, mostly shale and siltstone of Mississippian and Devonian age, in the western and southwestern third (fig. 4).

The limestone and dolomite are thin or missing in the east and northeast because of preglacial erosion at the bedrock surface. The topography of the bedrock surface is irregular (fig. 5), and the thickness of the *carbonate rock* varies considerably where present at the bedrock surface. More than 300 feet of limestone and dolomite lie beneath younger bedrock in the southwest.

Potential uses for the rock units (table 3) vary because of their differing composition and rock character. Detailed descriptions of the Silurian and Devonian rocks are available at the Indiana Geological Survey. A knowledge of the distribution and thickness of individual rock units is necessary to determine the potential crushed-stone reserves at any location.

SOURCES OF AGGREGATE

Although the largest reserves of carbonate rock suitable for aggregate and possibly chemical uses are in the southwestern part of the county where the rocks are thickest and have not been eroded at the bedrock surface, there are also large reserves of thinner rock strata which could be used for class A aggregate.⁴ In particular, the Louisville

⁴Class A aggregate is the highest quality aggregate specified by the Indiana State Highway Commission. It can be used for any purpose subject to size restrictions for A2 and A3 subdivisions, but it is the only class of aggregate that the state approves for use in concrete and bituminous pavings.

Table 3. Mineral-resource potential of

Rock unit	Thickness and distribution	General rock description
Devonian		
North Veron Limestone	25 to 60 ft; thinner where eroded at bedrock surface; central and southwestern parts of county.	Limestone to calcareous dolomite; a few thin beds of phosphate nodules.
Jeffersonville Limestone	25 to 55 ft; thinner where eroded at bedrock surface; southwestern two-thirds of county.	Limestone to calcareous dolomite, laminated in part; some chert and sandy zones.
Geneva Dolomite Member	20 to 50 ft; thinner where eroded at bedrock surface; southwestern two-thirds of county.	Dolomite, brown, sugary; calcite masses.
Silurian		
Wabash Formation		
Huntington Lithofacies	64 ft thick in SDH 196; identified in a few petroleum tests in Marion County.	Gray reefal dolomite, vuggy and fossiliferous.
Liston Creek Limestone Member	25 to 75 ft; northern half of county.	Rubby dolomite and calcareous dolomite with abundant chert.
Mississinewa Shale Member	45 to 90 ft; thickness variable at eroded Silurian surface; absent from some areas in northeastern part of county.	Dolomite, very clayey and silty.
Louisville Limestone	25 to 45 ft; absent from a few areas in the northeast.	Dolomitic limestone and calcareous dolomite, mottled; contains silt and argillaceous laminations.
Waldron Shale	Less than 7 ft; absent from a few areas in the northeast.	Shaly dolomite.
Salamonie Dolomite		
Laurel Member	35 to 50 ft; may be absent from a few areas in the northeast.	Dolomite and dolomitic limestone; contains shaly bands and chert in places.
Osgood Member	35 to 45 ft; may be absent from a few areas in the northeast.	Dolomite and limestone; abundant chert and shaly zones.
Brassfield Limestone	Less than 12 ft, generally less than 5 ft; may be absent from a few areas in the northeast.	Dolomitic limestone and dolomite; glauconite.

Limestone is widespread and offers the greatest mineral-resource potential of the Silurian rocks in the northeastern part of the county.

The Huntington *Lithofacies*, which refers to reef rock of Silurian age, is a good source for class A aggregate. The Huntington has been identified in Boone County near the northwest corner of Marion County and in drilling samples of a few petroleum tests in Marion County. Some rock sections in the

Liston Creek Limestone Member of the Wabash Formation and in the Limberlost and Salamonie Dolomites may also be suitable, depending on the amount of porous *chert* and other deleterious substances that are common in these rocks. The Liston Creek and Salamonie are good sources for aggregate for use as road metal, in parking lots, and as fill.

The two formations of Devonian age, the North Vernon Limestone and the Jeffersonville Limestone (includes the Geneva Dolo-

limestones and dolomites in Marion County

Potential for aggregate	Potential for chemical use
Source of quality aggregate at American Aggregates Corp. quarry at Harding St.; good potential elsewhere.	Ultrahigh-calcium limestone analyzed in incomplete section in SDH 35; suitable for all chemical uses for limestone.
Good potential for aggregate, although thin cherty zones may not be suitable for concrete, and some laminated zones may have high absorption.	Thin section of high-calcium limestone analyzed at top of formation in SDH 35; sparse data indicate limited chemical value at other locations.
Fair potential for aggregate; generally softer than above formations, but accepted for class A aggregate in southeastern Indiana on basis of past performance.	Possible chemical uses for high-purity dolomite; one analysis at SDH 35 indicates rock is not a high-magnesium dolomite.
Good potential.	Reefal dolomite may be very pure, but carbonate composition is variable in many reefs.
Fair potential; contains white chalky chert that is unsuitable for concrete or bituminous products; used extensively for road metal, base courses, and parking lots.	Variable amounts of chert preclude use for most chemical purposes.
Poor potential; poor to fair durability.	The Mississinewa was used for the production of rock wool in the mid and early 1900's in north-central Indiana.
Good potential; used at 96th St. quarry.	Contains more clay and quartz than is desirable for most chemical products.
Of little significance; thin.	No chemical value.
Fair potential; chert may limit use in concrete and bituminous mixes; shaly bands are deleterious.	Variable amounts of chert and shaly bands limit value.
Poor potential; probably too much chert for use in concrete and bituminous mixes; shaly bands are deleterious.	Variable amounts of chert and shaly bands limit value.
Of little significance; thin.	

mite Member), are potential sources of class A aggregate in southwestern and central Marion County. In the southwest they are overlain by the impermeable New Albany Shale, which acts as a barrier to ground water and makes them and the underlying Silurian rocks choices for underground mining.

SOURCES OF LIMESTONE AND DOLOMITE FOR CHEMICAL USES

Limestone and dolomite can truly be called

basic mineral resources. More than a hundred chemical products ranging from agricultural limestone to cement are produced from them (Lamar, 1961; Rooney, 1970), and a few of these products (burned lime, for example) also have numerous uses.

Many chemical products are obtained from high-calcium limestone (more than 95 percent calcium carbonate) and high-magnesium dolomite (more than 42 percent magnesium carbonate). The extent of these rocks in

Marion County is not well known. The analyses of core samples from Indiana Geological Survey drill hole (SDH) 35, drilled at the Indiana State fairgrounds, indicate that parts of the North Vernon and Jeffersonville Limestones are high-calcium limestones. The areal extent of the high-purity stone at SDH 35 has not been determined, but it would be difficult, if not impossible, to mine because of the concentrated urban land use of the surface at the fairgrounds site.

The Huntington Lithofacies, a high-purity dolomite, has been cored at SDH 196 in Boone County near the northwest corner of Marion County. The composition of the Huntington may be variable, however, and extensive drill testing will be necessary to evaluate the deposit adequately.

Drilling to date indicates that high-purity limestone and dolomite are likely to be confined to Devonian rocks in the central and southwestern parts of the county.

MINING METHODS, ECONOMICS, AND ENVIRONMENTAL CONSIDERATIONS

Crushed stone can be obtained from open-pit quarries or underground mines or from a combination of them. Economic considerations as well as geologic and environmental conditions (table 4) at any one locale will determine which method can or should be used. The quarries of the American Aggregates Corp. at 96th Street (fig. 12) and at Harding Street (fig. 13) are in the Wabash Formation and the Louisville Limestone and in the North Vernon and Jeffersonville Limestones. These quarries supply crushed stone to the Indianapolis market, but much of the class A crushed-stone aggregate used for road building and construction in and near Marion County is shipped from quarries as distant as Bartholomew, Putnam, and Owen Counties (fig. 14). Aggregate of lesser quality is obtained from nearby quarries for use as road metal, in parking lots, and as fill.

Transportation charges are a large part of the high cost of the stone from the distant quarries; trucking charges, for example, can equal the cost of production in as little as 30 miles. The high cost of good-quality crushed-stone aggregate has contributed to the extensive use of sand and gravel for aggregate

near Indianapolis, but the demand for crushed stone is still great. The bedrock sources of class A aggregate that are being developed in the 96th Street and Harding Street quarries will help meet this demand and will replace, to some degree, the use of gravel in concrete.

Rehabilitation of a quarry site after production has ceased is a major environmental consideration. An unreclaimed abandoned quarry is a hazard and an eyesore. Rehabilitation when accomplished concurrently with quarrying can produce a property suitable for wildlife, recreation, or even housing development. Some reclaimed quarries have proved to be more valuable than the stone that was removed.

Underground mines near Indianapolis may now be economically feasible, and if not now, then probably in the future. Although underground mines normally cost more to operate than open-pit quarries, they can be competitive in a market where the cost of aggregate is high (table 4). Such high cost may be the result of high transportation charges from distant quarries, high cost of production in a nearby quarry (usually because of thick overburden), or greater demand for crushed stone than can be supplied from nearby quarries. At least two and probably all three of these economic conditions exist in the Indianapolis market.

Suitable locations for new open-pit quarries in and near Marion County are limited, and reserves of class A stone that can be mined by open-pit methods must eventually be exhausted. An underground mine then would be the nearest and most economical source of quality aggregate. Further, underground mines may be the best answer to the difficult-to-solve environmental and reclamation problems often associated with open-pit quarries in populated areas (Ault, 1974).

Open-pit quarries can perhaps best be rehabilitated for recreational use. Proper landscaping can produce an attractive park with a lake as its focal point. Abandoned underground mines can be used as storage and even work areas. Underground space has the distinct advantage in this time of high energy costs of providing a stable atmosphere with a constant temperature. Therefore, expenses for heating and cooling are minimal. Abandoned

Table 4. Some comparisons of open-pit and underground mining for limestone and dolomite¹

Parameter	Open-pit mining	Underground mining
Areas with greatest potential	Primarily the White River valley where overlying sand and gravel may also be profitably mined.	Western and southwestern sections where the carbonate rocks underlie impermeable shales and siltstones.
Cost	Usually less expensive to operate than underground mine, especially where the overburden is thin.	Usually greater cost than open-pit mining (50 percent or more) and a larger initial capital investment is required.
Surface area needed	Amount of surface area available limits horizontal extent of quarries.	Surface need not be disturbed by underground mining, although some area needed for surface facilities.
Geologic conditions	Only near-surface beds can be quarried.	Deep strata can be mined; mining operations can follow favorable beds.
Efficient use of reserves	All reserves that can be reached can be recovered; large-scale production can be practical.	If pillars of partitions are left, 30 percent or more of the reserves are left behind.
Selective mining	Rock units must be benched and inferior overburden and strata removed to reach higher quality stone.	Highest quality units can be mined directly.
Environmental conditions	Dust and noise from blasting and plant operations may be difficult or expensive to control.	Most operations can be conducted underground.
Safety	Generally safe; only a few men needed to operate quarry and plant.	Historically less safe than open pits.
Weather	May temporarily stop quarry operations.	Unaffected.
Ground water problems	Variable from quarry to quarry; large quantities can usually be pumped out economically.	Excessive water is a difficult problem in underground mines; may be difficult to control.
Reclamation and potential uses	Reclamation of large open pits may be a problem; requires long-range planning; may be used for water-based recreation or possibly water supply.	Subsidence can be a problem with some types of mining; stable environment is ideal for storage; if water removal was a problem in mining, the abandoned cavity may make a good water storage reservoir.

¹Much information for this table was obtained from Rooney and Carr, 1971, p. 8-14.



Figure 12. Sand and gravel pit and limestone and dolomite quarry of the American Aggregates Corp. at 96th Street.

mines, when properly grouted, can also be used to store liquids, such as LPG or storm-water runoff. Storm runoff in many places causes overflow and subsequent bypassing of sewage-treatment plants. Underground storage could permit the detention of excess runoff until it can be properly treated.

If handled properly, both surface and underground aggregate-removal operations can be economically and environmentally profitable.

FAVORABLE LOCATIONS FOR FUTURE QUARRIES AND MINES

Urban and industrial development has covered and is rapidly covering many of the more favorable locations for both quarries and mines. The most favorable location for open-pit quarries is a place where the overburden is thin or contains a salable material. This situation exists in the White River valley where surficial sand and gravel have long been mined. Unfortunately, the

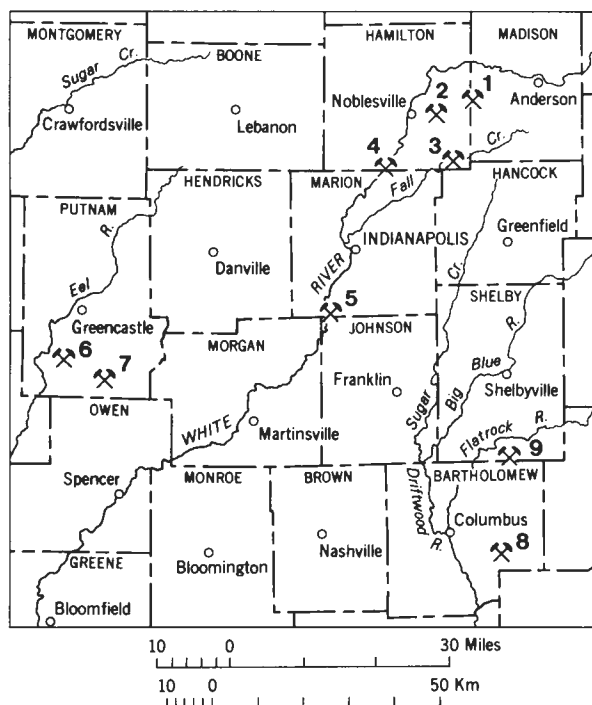


Figure 13. Sand and gravel pit and limestone quarry of the American Aggregates Corp. at Harding Street.

Silurian rock at or near the bedrock surface in the north has marginal quality for aggregate use and much of the White River valley has been urbanized or zoned, so that mining can no longer be considered.

The western part of the county holds the greatest promise for underground mining. Cores from SDH 196 on the northwest side of Indianapolis indicate that almost 100 feet of limestone and dolomite of the Jeffersonville Limestone and the Wabash Formation at a

depth of 291 feet are suitable for class A aggregate. About 50 feet of this interval may be high-purity dolomite, which has several chemical uses. The carbonates are capped here by 100 feet of New Albany Shale, which should provide an effective barrier to ground water from above. Although detailed drill-hole data are not available, similar geologic conditions exist south of this point along the west edge of the county.



Map No.	Company	Quarry location (county)
1	Martin Marietta Aggregates	Madison
2	Stony Creek Stone Co., Inc.	Hamilton
3	Irving Materials, Inc.	Hamilton
4	American Aggregates Corp.	Hamilton
5	American Aggregates Corp.	Marion
6	Martin Marietta Aggregates	Putnam
7	The France Stone Co.	Putnam
8	Meshberger Stone, Inc.	Bartholomew
9	Cave Stone, Inc.	Shelby

Figure 14. Map of central Indiana showing quarries supplying crushed limestone and dolomite to Marion County (August 1978).

Clay-Material Resources

Although Marion County is underlain by large volumes of clay material, no thick shale unit is exposed anywhere in the county except for one outcrop in a quarry in the south. The two youngest clay-rich units, the Borden Group and the New Albany Shale, underlie a relatively thin overburden of surficial materials in southern and western Marion County

(fig. 2). Older clay-rich units within the Silurian and Devonian limestone and dolomite sequence, such as the Mississinewa Shale Member of the Wabash Formation and the Waldron Shale, both of Silurian age, are too thin and (or) too impure to be exploited for their clays in the foreseeable future. Still older shaly rocks, including the Maquoketa Group of late Ordovician age, may be exposed in one of the buried valleys in the northeastern part of the county. These rocks are several hundred feet thick in Marion County but are deeply buried and have little chance of being used. Clay is not being mined in the county at present. There is, however, an active clay pit in Morgan County about 5 miles south of the Marion County line in the above-mentioned Borden rocks.

In Marion County the Borden Group consists of two formations, the Locust Point Formation, which is composed of interbedded clay-rich and clay-poor siltstones, and the underlying New Providence Shale, which is composed primarily of gray-green and red fissile shale. Borden rocks are not exposed in Marion County but are covered with as little as 30 feet of Pleistocene material in the extreme southwestern part of the county. Where they have been deeply eroded by pre- and intra-Pleistocene streams, they may be buried by more than 200 feet of glacial debris.

As much as 200 feet of Borden rocks consisting principally of silt-sized, fine sand-sized, and clay-sized quartz (in decreasing order of abundance) and of illite, chlorite, and mixed-layer clay minerals are present in southwestern Marion County. Although not used in Marion County, Borden rocks are used elsewhere in manufacturing structural clay products. Brick, drain tile, and expanded-shale lightweight aggregate are produced in nearby Morgan County, brick is made in Jackson County, and the Borden is quarried in Fountain County for use as a filler in plastics. The Borden was once used in Clark and Lawrence Counties as a source of alumina and silica in manufacturing cement.

The Locust Point Formation, the younger of the Borden formations in Marion County, lies at relatively shallow depths and occurs at what appears to be the top of buried mesalike

features which dot the edge of a buried shale plain in the southwestern part of the county. The harder clay-poor siltstone ledges which hold up the mesas have been quarried elsewhere in Indiana for use as a decorative building stone. Rustic stone for facing is quarried mostly in Brown and Monroe Counties and is known as Brown County Stone. It is possible that the Locust Point Formation in Marion County could be quarried for similar purposes.

Sand and Gravel Resources

The importance of sand and gravel operations in Marion County and surrounding counties is not limited by the county boundaries and is therefore considered on a regional basis in this report. Each operation serves a particular area, the radius of which is determined by transportation costs, local availability, and demand. Active and abandoned pits in the nine-county area are shown in figure 15. The locations of present production and potential reserves of sand and gravel in the counties adjacent to Marion County are summarized in table 5.

The importance of protecting sand and gravel reserves in growth areas can perhaps best be appreciated when viewed economically. Because sand and gravel are materials high in bulk and low in unit cost, transportation and handling are major cost factors. Transportation becomes the dominant factor when travel distance exceeds about 15 miles. The bulk of the sand and gravel reserves is in the White River valley in and adjacent to Marion County. These reserves are being depleted rapidly by mining and are being covered by commercial, industrial, and urban development. When these centrally located reserves are covered or exhausted, construction costs will increase.

Perhaps development pressures and efficient use of sand and gravel reserves could be satisfied by the programmed usage of areas containing sand and gravel. Sand and gravel removal operations generally result in the formation of lakes. With proper preplanning regarding the disposition of spoil and final grading of the pit, these lakes could serve as the focal point for urban, commercial, or industrial development.

Sand and gravel production in Marion County and surrounding counties (Boone, Hamilton, Hancock, Hendricks, Johnson, Madison, Morgan, and Shelby) amounted to 6.95 million tons in 1973 and had a value of \$9.7 million. More than 200 persons were employed in the operation of the pits, and many more derived a livelihood from transporting these aggregates or handling them at the delivery site. In recent years gravel operators in Marion County have produced more than 10 percent of the sand and gravel mined in Indiana. In addition, gravel has also been imported from neighboring counties. Statewide trends in the quantity and value of sand and gravel produced for the past 15 years have shown a general increase in production and a substantial rise in unit price.

Sand and gravel are common geologic materials, but they are not present everywhere throughout the county. Commercial deposits are found only in association with ancient glacial drainageways, which occupy only about 10 percent of the land surface in Marion County. Changes in market conditions cause the exploitability of many deposits to vary from time to time. Information regarding the availability and location of sand and gravel resources can be found in: Harrison (1963a); Carr (1966); French and Carr (1967); French (1969); Carr and Webb (1970); Carr (1971).

DEFINITION AND DESCRIPTION

The terms sand and gravel refer to materials of specific size classes. Sand ranges from 0.0024 inch to 0.185 inch in diameter and gravel from 0.185 inch to 4 inches. These boundaries are arbitrary, and upper and lower limits do not correspond exactly when used by geologist, civil engineer, agronomist, or the Indiana State Highway Commission.

Virtually all sand and gravel mined in Marion County was deposited by the massive glaciers of Wisconsin age that covered most of the state. (In one pit in Marion County, older gravels of presumed Illinoian age are mined, but these constitute a minor volume of the material taken from the pit.) Because they contain coarse-grained material deposited by fast-flowing glacial meltwater, the deposits beneath terraces are generally the

Table 5. Sand and gravel resources in counties surrounding Marion County (August 1978)

County	Active pits		Potential resources			
	Company and location	Geology	Location	Geology and remarks		
Boone	Mid-State Aggregates, sec. 29, T. 20 N., R. 1 W.	Outwash beneath terraces along Sugar Creek	Sugar Creek valley west of Mechanicsburg	Terraces underlain by outwash; valley fill reaches thicknesses of 90 ft; terraces are seldom more than half a mile wide west of Thorntown.		
	Routh Gravel Plant, sec. 15, T. 18 N., R. 2 E.	Outwash in valley of Big Eagle Creek	Buried channels throughout county	Shallow trenches and segments of stream valleys and eskers are aligned along an azimuth of 235° to 240°.		
			Outwash plain southwest of Lebanon extending toward Jamestown	A broad outwash plain with several abandoned pits which were as much as 25 ft deep.		
			Big Eagle Creek valley	Very limited reserves; encroaching urbanization.		
Hamilton	American Aggregates Corp., sec. 9, T. 17 N., R. 4 E.	Outwash beneath terraces in White River valley	White River valley and associated outwash channels	Thicknesses of more than 90 ft may be found over extensive portions of the old glacial drainageway; sand-to-gravel ratios are on the order of 40/60.		
	Beaver Gravel Corp., sec. 12, T. 18 N., R. 4 E.					
	Irving Materials, Inc., sec. 2, T. 17 N., R. 5 E.	Outwash beneath terraces in Fall Creek valley near Geist Reservoir	Fall Creek valley	Good quality and thicknesses of material, but a reservoir limits area of potential exploitation; deposits are beneath terraces in valley-filling outwash.		
	Martin Marietta Aggregates, sec. 4, T. 17 N., R. 5 E.	Outwash in valley of Mud Creek	Little Cicero Creek valley	Thirty-foot sections of coarse outwash are present, but a reservoir occupies most of the valley.		
	Riverwood Gravel Co., sec. 16, T. 19 N., R. 5 E.	Outwash beneath terraces in White River valley				
	Southard Gravel Co., sec. 35, T. 20 N., R. 5 E.					
	37 Gravel Co., Inc., sec. 3, T. 19 N., R. 5 E.	Outwash in valley of White River				
	U.S. Aggregates, Inc., sec. 13, T. 18 N., R. 4 E.	Outwash beneath terraces in White River valley				

Hancock	Caldwell Gravel Sales, Inc., sec. 28, T. 15 N., R. 8 E.	Outwash in valley of Sixmile Creek	Brandywine Creek valley	Outwash pits are small because local markets are not large, but some mason sand is shipped to Indianapolis and Anderson.
	Leary's Gravel, Inc., sec. 21, T. 16 N., R. 7 E.	Outwash in valley of Brandywine Creek		
	Strubbe Gravel, sec. 28, T. 16 N., R. 7 E.			
Hendricks	U.S. Aggregates, Inc., sec. 14, T. 14 N., R. 1 E.	Outwash beneath terrace in Whitelick Creek valley	Whitelick Creek valley	Outwash-filled valley; best areas for discovery of new reserves are near the southern boundary of the county.
			Mill Creek and Big Walnut Creek valleys	These small valleys contain some outwash that may be mined if demand increases.
Johnson	Central Aggregates, sec. 7, T. 13 N., R. 3 E.	Outwash beneath terrace in White River valley	White River valley	Outwash beneath terraces in this former glacial drainageway may be as much as 90 to 100 ft thick with overburden of 0 to 15 ft; a bed of till 5 to 10 ft thick may separate the outwash in some places; sand content is generally high.
	Jefferson Sand & Gravel, Inc., sec. 33, T. 11 N., R. 5 E.	Outwash in Big Blue and Sugar Creek valleys		
	Shelby Gravel, Inc., sec. 22, T. 11 N., R. 5 E.	Outwash in Big Blue River valley	Big Blue River valley	Fine-grained outwash as much as 40 ft thick fills the broad drainageway now occupied by Big Blue River; only a few square miles in the southeast corner of the county are within this valley.
			Sugar Creek valley	Outwash-filled glacial drainageway; best deposits seem to be at its center.
Madison	Aggregates of Anderson, sec. 18, T. 20 N., R. 8 E.	Outwash in valley of Little Killbuck Creek	White River, Fall Creek, and Killbuck Creek valleys	Outwash in valley fill and beneath terraces.
	Alexander & Sons, sec. 15, T. 18 N., R. 7 E.	Outwash beneath terraces in Fall Creek valley		
	Irving Materials, Inc., sec. 31, T. 20 N., R. 8 E.	Outwash in valley of Killbuck Creek	Various points in southeastern part of county	Kames and eskers are remnants of sub-ice drainage systems; some of these gravel ridges are a continuation of the drainage formerly occupying Killbuck Creek valley.
	Irving Materials, Inc., sec. 15, T. 19 N., R. 8 E.	Outwash beneath terraces in White River valley		
	Ryan, Inc., sec. 21, T. 21 N., R. 7 E.	Outwash in valley of Pipe Creek	Pendleton area	Devonian sandstone might be suitable for glass and specialty sand.

Table 5. Sand and gravel resources in counties surrounding Marion County (August 1978)—Continued

County	Active pits		Potential resources	
	Company and location	Geology	Location	Geology and remarks
Morgan	Aggregates of Anderson, sec. 13, T. 13 N., R. 2 E.	Outwash beneath terrace in White River valley	White River valley	Glacial drainageway that ranges from 1 to 6 miles in width; thicknesses as great as 60 ft may be mined; sand-to-gravel ratio of 60/40 is common; buried trees may be a problem in mining, and some sections of the outwash may have too much chert.
	Hoosier Aggregate Co., sec. 23, T. 13 N., R. 2 E.	Terrace underlain by outwash in White River valley		
	Hopkins Gravel & Sand Co., sec. 26, T. 14 N., R. 1 W.	Outwash in Whitelick Creek valley	Whitelick Creek valley	Outwash beneath terraces may exceed 35 ft; buried trees and lenses of till may cause mining problems.
	Jones Sand & Gravel Co., sec. 8, T. 11 N., R. 1 E.	Outwash beneath terrace in White River valley		
	Morgan County Gravel, sec. 7, T. 11 N., R. 1 W.			
	Waverly Gravel & Concrete Co., sec. 14, T. 13 N., R. 2 E.			
Shelby	Caldwell Gravel Sales, Inc., sec. 2, T. 14 N., R. 7 E.	Outwash beneath terraces in Big Blue River valley	Big Blue River valley	As much as 25 ft of good-quality gravel; 50 percent sand in the north and 90 percent sand in the south; shallow bedrock enhances the possibility of combined gravel pit and quarry.
	Indiana Gravel Div., Construction Products Corp., sec. 29, T. 13 N., R. 7 E.	Outwash in valley of Big Blue River	Brandywine Creek valley	Outwash with high sand content and a little coarse gravel in deposits as much as 30 ft thick.
	Shelby Gravel, Inc., sec. 29, T. 13 N., R. 7 E.		Sugar Creek valley	Broad outwash plain with as much as 35 ft of gravel.
			Flat Rock Creek and Little Blue River valleys	Reserves in outwash are limited because of shallow bedrock.

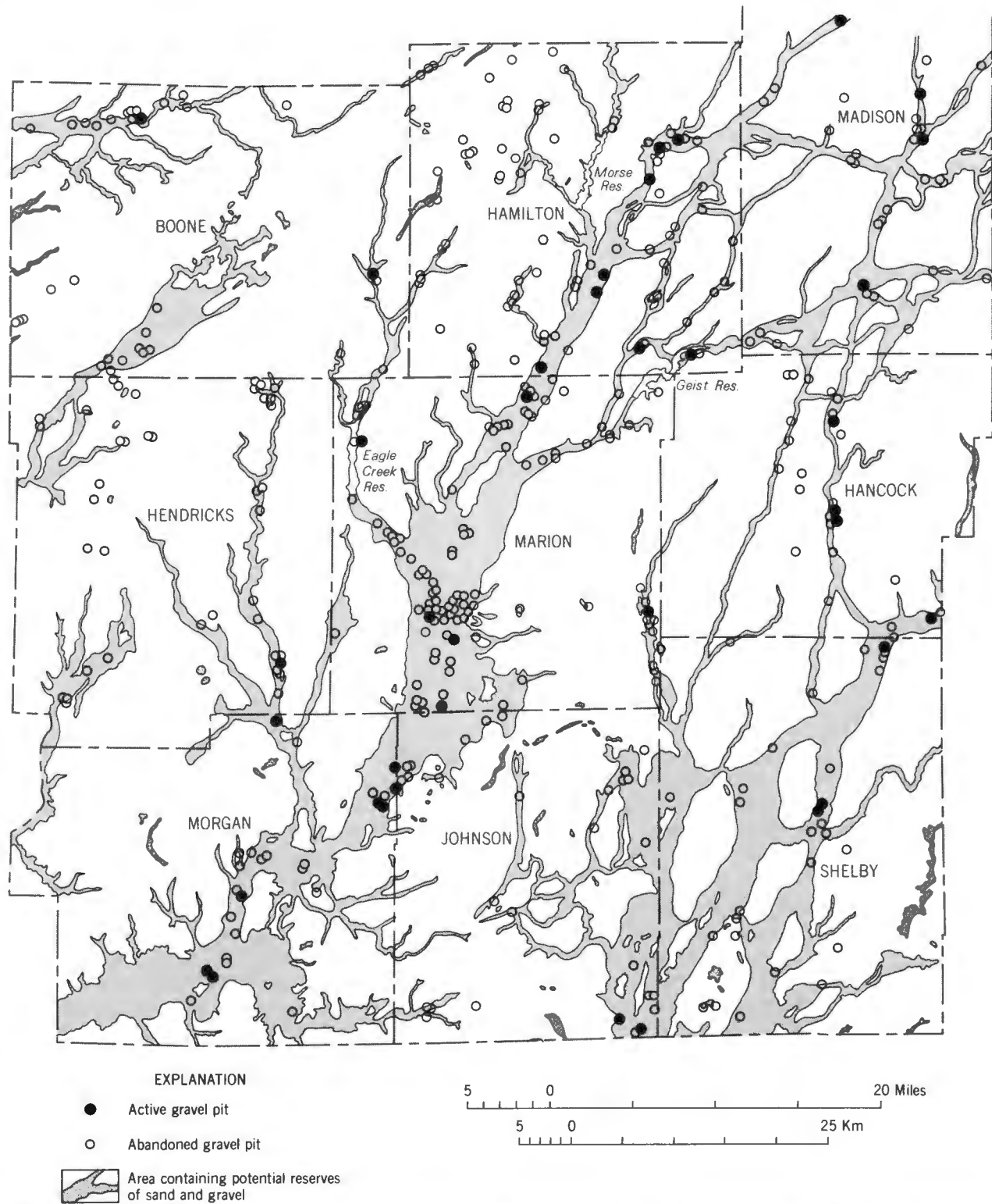


Figure 15. Map of Marion County and surrounding counties showing major glacial outwash channels and active (1979) and abandoned gravel pits.

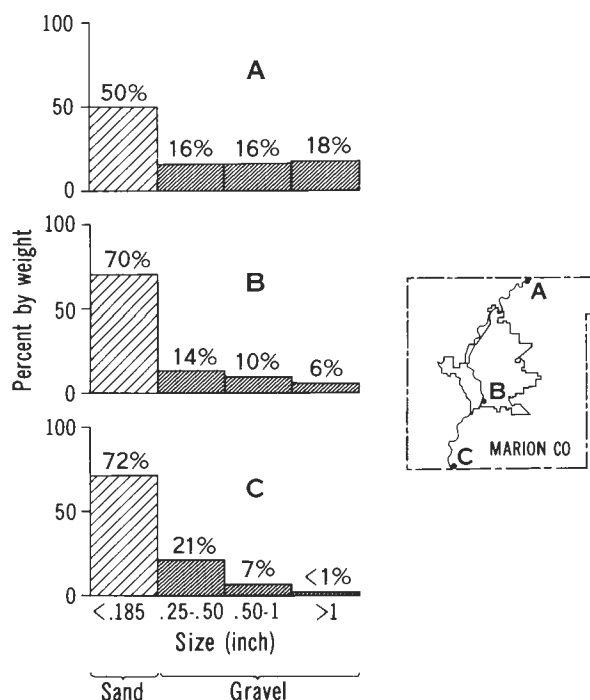


Figure 16. Histograms showing size distribution of sand and gravel in Marion County. From French and Carr (1967).

best sites in which to develop an aggregate supply. There can also be coarse deposits beneath a flood plain, but the materials deposited by White River are too fine grained and contain too much trash, logs, and other debris to have economic potential.

The outwash channels in Marion County and surrounding counties are shown in figures 1 and 15. The gravel in these drainageways is coarser toward the north and toward the centers of the abandoned channels. The channels may contain coarser material than do the margins of the terraces. The change in grain-size distribution in three pits in Marion County is shown in figure 16. A sharp decrease in maximum grain size can take place over a distance of a few miles in the downstream direction.

Kames are also a potential source of sand and gravel, but they do not hold the same prospect for commercial deposits as do the outwash-filled drainageways. Kames commonly contain much silt and clay, and the gradation and composition of the sand and gravel in them are much less uniform than in

the valley-fill deposits. There are, however, some large kames in southern Marion County which have been opened for gravel. If a kame overlies outwash from a prior glaciation, a pit there may be attractive because of the increased total thickness of the deposit. Harrison (1963a) listed the locations of some kames that may contain commercial deposits: secs. 18 and 19, T. 14 N., R. 3 E.; sec. 24, T. 14 N., R. 2 E.; secs. 21 and 28, T. 15 N., R. 5 E.; secs. 25 and 26, T. 15 N., R. 3 E.; sec. 24, T. 15 N., R. 4 E.; sec. 35, T. 15 N., R. 2 E.; secs. 11, 12, and 14, T. 14 N., R. 3 E.

The Indiana State Highway Commission has established specifications for sand and gravel (fine and coarse aggregates) used in road and bridge construction (Indiana State Highway Commission, 1975). The specifications give limits for particle-size gradation and for the content of potentially deleterious materials. The most stringent standards apply to aggregate used in exposed concrete or for road surfacing. Other purchasers use similar criteria. The total content of deleterious material in sand and gravel in Marion County may be as much as 10 to 20 percent, which exceeds the limits for the highway commission's highest quality classification.

The average composition of gravel from two pits in Marion County is 67 percent limestone and dolomite, 15 percent igneous and metamorphic rocks, 8 percent chert, and 10 percent siltstone, sandstone, and shale. The siliceous rock known as chert (flint) may be present in significant quantities (5 to 10 percent) in gravel from Marion County. Chert originates as a precipitate or chemical replacement in limestone or dolomite. Although it is hard and durable, it is an undesirable constituent of aggregate used in concrete. It may react adversely with the cement, and if water enters and freezes in the many pore spaces in some cherts, the rock may break down and pop out of the concrete. Cherts with a specific gravity greater than 2.45 (that is, low porosity) may be accepted for state specification work. Shale and soft siltstone, clay lumps, iron oxide, and wood are other undesirable elements in gravel, but they are easily broken up or scalped off during the washing process. Chert, unfortunately, cannot be so easily removed.

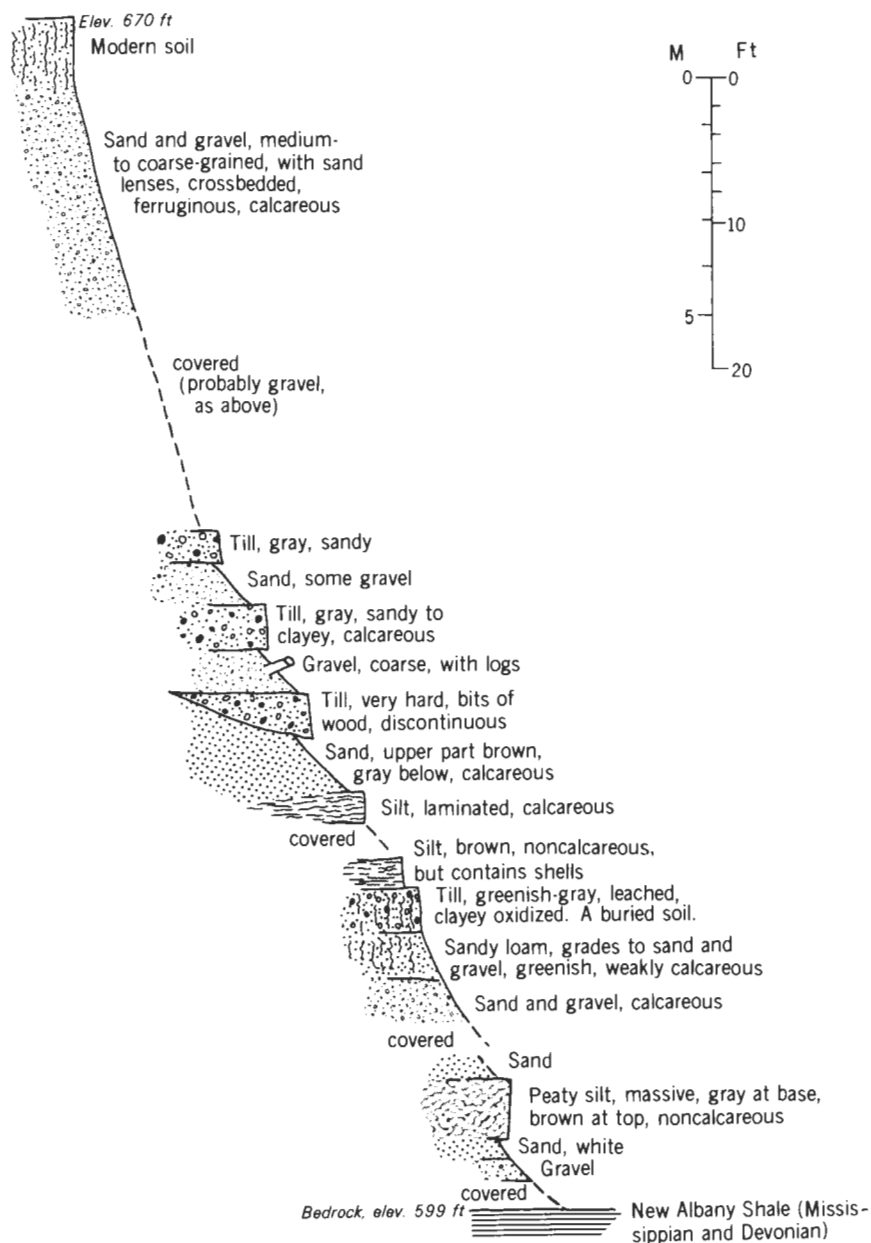


Figure 17. Composite section showing the complex nature of unconsolidated deposits at the American Aggregates Corp. plant on South Harding Street.

The geology of the southern part of the White River sluiceway is complex, as illustrated by the section at the American Aggregates Corp. plant on South Harding Street (sec. 33, T. 15 N., R. 3 E.) (fig. 17).

Undoubtedly, some of the thick glacial outwash shown in the more generalized sections (fig. 10) could be similarly subdivided.

Table 6. Active sand and gravel operations in Marion County (January 1979)

Company	Mailing address	Telephone	Descriptive location	Congressional location	Geology
Allied Aggregates Corp.	P.O. Box 68088, Indianapolis 45331	(317) 293-7020	W. 69th St. and Eagle Creek Reservoir	NE¼ sec. 33, T. 17 N., R. 2 E., Zionsville Quadrangle	Outwash in Eagle Creek valley
American Aggregates Corp.	4200 S. Harding St., Indianapolis 45311	(317) 787-2223	S. Harding St. just north of I-465	W½ sec. 34, T. 15 N., R. 3 E., Maywood Quadrangle	Outwash in White River valley
Martin Marietta Aggregates, Central Div.	P.O. Box 40171 Indianapolis 46240	(317) 849-4642	S.R. 100 at White River	W½ sec. 20, T. 17 N., R. 4 E., Fishers Quadrangle	Outwash in White River valley
Martin Marietta Aggregates, Central Div.	2605 Kentucky Ave., Indianapolis 46241	(317) 244-4460	2605 Kentucky Ave.	SW¼ sec. 21 and NW¼ sec. 28, T. 15 N., R. 3 E., Maywood Quadrangle	Outwash in White River valley
Construction Products Corp., Indiana Aggregates Div.	3211 Senour Rd., Indianapolis 46239	(317) 862-2461	1.5 miles south of U.S. 52 on Buck Creek	W½NW¼ sec. 27, T. 15 N., R. 5 E., Acton Quadrangle	Outwash in Buck Creek valley
Littleton Sand & Gravel	8645 S. S.R. 37, Indianapolis 46241	(317) 888-4362	Just east of S.R. 37 at county line	SE¼ sec. 14, T. 13 N., R. 2 E., Martinsville Quadrangle	Kame in White River valley
Colgate Enterprises	4301 W. Southport Rd., Greenwood 46142	(317) 882-2261	1.5 miles west of S.R. 37 on Wicker Rd.	SE¼NW¼ sec. 20, T. 14 N., R. 3 E., Maywood Quadrangle	Outwash in White River valley
Jones Gravel, Inc.	2646 W. Minnesota Ave., Indianapolis 46241	(317) 247-1558	0.5 mile west of S.R. 67 on Minnesota Ave.	SW¼NE¼ sec. 16, T. 15 N., R. 3 E., Maywood Quadrangle	Outwash in Eagle Creek valley

The beds of till represent separate episodes of ice advance in the geologic history of Marion County. Likewise, each succeeding layer of outwash is evidence of a drastic change in the balance of erosional and depositional forces, and thus the composition and gradation of beds of outwash may differ from the top to the bottom of the section. At the American Aggregates pit these differences, and the presumably great differences in the amount of weathering to which the material has been subjected, result in a higher total chert content for the lowest outwash units.

The major pulses of outwash deposition can be traced throughout the county, especially in association with White River and Fall Creek. Fall Creek carried as much outwash as did the main channel (fig. 10), which was active over a longer period of time. Several tributaries to the main sluiceway (Eagle and Lick Creeks, for example) contributed significant amounts of outwash. The earliest episodes of outwash deposition appear to be confined to the bedrock-valley bottoms. Figure 10 shows that complexity of the deposits increases toward major drainage lines.

RESERVES

Harrison located more than a hundred abandoned pits in Marion County (1963a, pl. 1). The operating sand and gravel pits in Marion County as of January 1979 are listed in table 6 and are shown in figure 15. Outwash deposits from the White River drainageway are mined at all but two small operations. This broad trough full of sand is also the source of aggregates in nearby Hamilton and Morgan Counties.

Harrison (1963a) estimated that the reserves of sand and gravel in Marion County were 1,265 million tons and were concen-

trated in an area of 29.8 square miles. French and Carr (1967) determined that construction of reservoirs, subdivisions, and shopping centers had reduced the available reserves by more than 50 percent. Today the areas containing potentially minable sand and gravel in Marion County are even more restricted. Enlargement of Geist Reservoir by construction of the Highland Dam will eliminate acres of prime reserves in Fall Creek valley in Marion and Hamilton Counties. Some additional reserves in Fall Creek valley have been lost to urban development from 1967 to the present. The expansion of the city during those years has reduced the available gravel supplies from 73d Street to the north county line. Very little minable reserve remains in Eagle Creek valley. The reserves of Buck Creek and Whitelick Creek valleys have been only slightly reduced but were never large. The section of Marion County with the greatest potential for sand and gravel development is the White River valley south of I-465. Here, some of the coarsest material is lacking, but the reserves are great.

The Division of Materials and Tests of the Indiana State Highway Commission performs physical tests on aggregate materials to determine their suitability for road construction. The results of such tests (table 7) show that the quality of gravel produced in Marion County and adjoining counties changed little between 1965 and 1974, although different pits were being worked.

No specialty sand (glass sand, molding sand, refractory sand, etc.) is being produced in Marion County, and there is little reason to expect that any deposit uniquely suited to a special use will be found. But some specialty sand might be derived as a byproduct of an aggregate operation.

Table 7. Summary of physical tests of commercial gravel deposits

Parameter	Apparent specific gravity ¹			Absorption ^{1, 2}			Total chert ^{1, 2}
Year ³	1965-66	1973-74	1973-74	1965-66	1973-74	1973-74	1973-74
Gradation ⁴	No. 5	No. 5	No. 14-2	No. 5	No. 5	No. 14-2	No. 5
No. of samples	14	13	14	14	13	14	15
Minimum	2.72	2.72	2.61	1.3	1.44	.81	1.04
Maximum	2.76	2.75	2.70	2.0	2.15	2.25	6.5
Range	.04	.03	.09	.7	.71	.44	5.46
Mean	2.74	2.74	2.67	1.5	1.78	1.33	4.24
Standard deviation ⁵	.01	.01	.03	.22	.21	.46	1.75

¹Tests were run according to Indiana State Highway Commission specifications. Data were provided by the State Highway Department.

²Units are in percent by weight.

³Results for 1965-66 were published by French and Carr (1967). Data for 1973-74 include information for samples from plants a few miles north of Marion County (Hamilton County) and a few miles south of Marion County (Morgan County).

⁴Sizes specified by Indiana State Highway Commission (1975, p. 469-475). Coarse aggregates: No. 2 ranges from ½ to 2½ in.; No. 5 ranges from ½ to 1½ in.; fine aggregates: No. 14-2 ranges from .003 to 3/8 in.

⁵The standard deviation is a statistical measure of the variability of the sample from the mean (average) value. About 68 percent of the samples fall within one standard deviation of the mean.

Disposition of Waste Materials

The environmentally sound disposition of waste materials is a vital facet in the orderly development of any urban-industrial area. The best possible disposition of wastes is rehabilitation and reuse. Because this is often difficult and (or) uneconomical, the least harmful method of storage or disposal must be used. The following sections are designed to be used as a guide for the most geologically sound disposition of both liquid and solid wastes.

SANITARY LANDFILLS

Because it is a high-density population center, Marion County is faced with an imposing solid-waste disposal problem. Fortunately, there are large areas throughout most of the

county that appear to be geologically suited for sanitary landfills. Geologically suited areas are those in which a thick section of low-permeability unconsolidated material is present, the water table is far below the surface, surface drainage is good, and flooding is unlikely. When a suitable site is selected, an appropriate landfilling method is used, and a predetermined end-use plan is followed, a sanitary landfill can be an environmentally sound project.

Sanitary landfills are necessary, even though they may ultimately contribute to environmental degradation, because they provide the best known interim method for storage of solid waste. The sanitary landfill is an acceptable alternative because an open dump is a health hazard and recycling of

in Marion County and nearby counties, 1965-66 and 1973-74

Chert, less than 2.45 sp gr ^{1, 2}		Soft particles ^{1, 2}		Los Angeles abrasion loss ^{1, 2}		NaSO ₄ soundness loss ^{1, 2}		Acid insoluble ^{1, 2}
1965-66	1973-74	1965-66	1973-74	1965-66	1973-74	1973-74	1973-74	1973-74
No. 5	No. 5	No. 5	No. 5	No. 2	No. 5	No. 5	No. 14-2	No. 14-2
14	10	14	14	14	13	13	14	14
00.0	1.07	0.0	.12	20.4	20.20	2.7	2.16	49.3
1.7	2.95	2.9	3.24	34.7	29.36	10.87	10.8	65.3
1.7	1.88	2.9	3.12	14.3	9.16	8.1	8.2	16.0
.8	2.0	1.8	1.11	24.7	24.88	6.25	5.08	58.81
.14	.62	.56	.8	6.48	2.92	2.29	2.55	5.07

waste is not yet entirely practical. Two major environmental problems attendant even on properly constructed and operated sanitary landfills are the escape of harmful leachates and gases. These problems can be minimized, although not eliminated, by proper planning and operation.

The selection of specific areas within the county for sanitary landfills is beyond the scope of this report. It is possible, however, on the basis of available geologic and hydrologic information, to separate the county with reasonable accuracy into general categories according to relative suitability. The resulting map (fig. 18) serves as a guide for locating sites that will require the least preparation to construct an environmentally

acceptable landfill. It depicts the relative degree of environmental hazard presented by the operation of a conventional landfill with a minimum of preparation in the various geologic conditions encountered in the county. This areal depiction is a generalization because neither the small scale nor available data are sufficient to permit detailed mapping. For example, the small scale does not permit the separation of the smaller flood plains or poorly drained depressions from otherwise suitable upland till areas. There may also be shallow sand and gravel aquifers that are capable of providing local water supplies within the till but that are not indicated by available data. Such aquifers should be avoided.

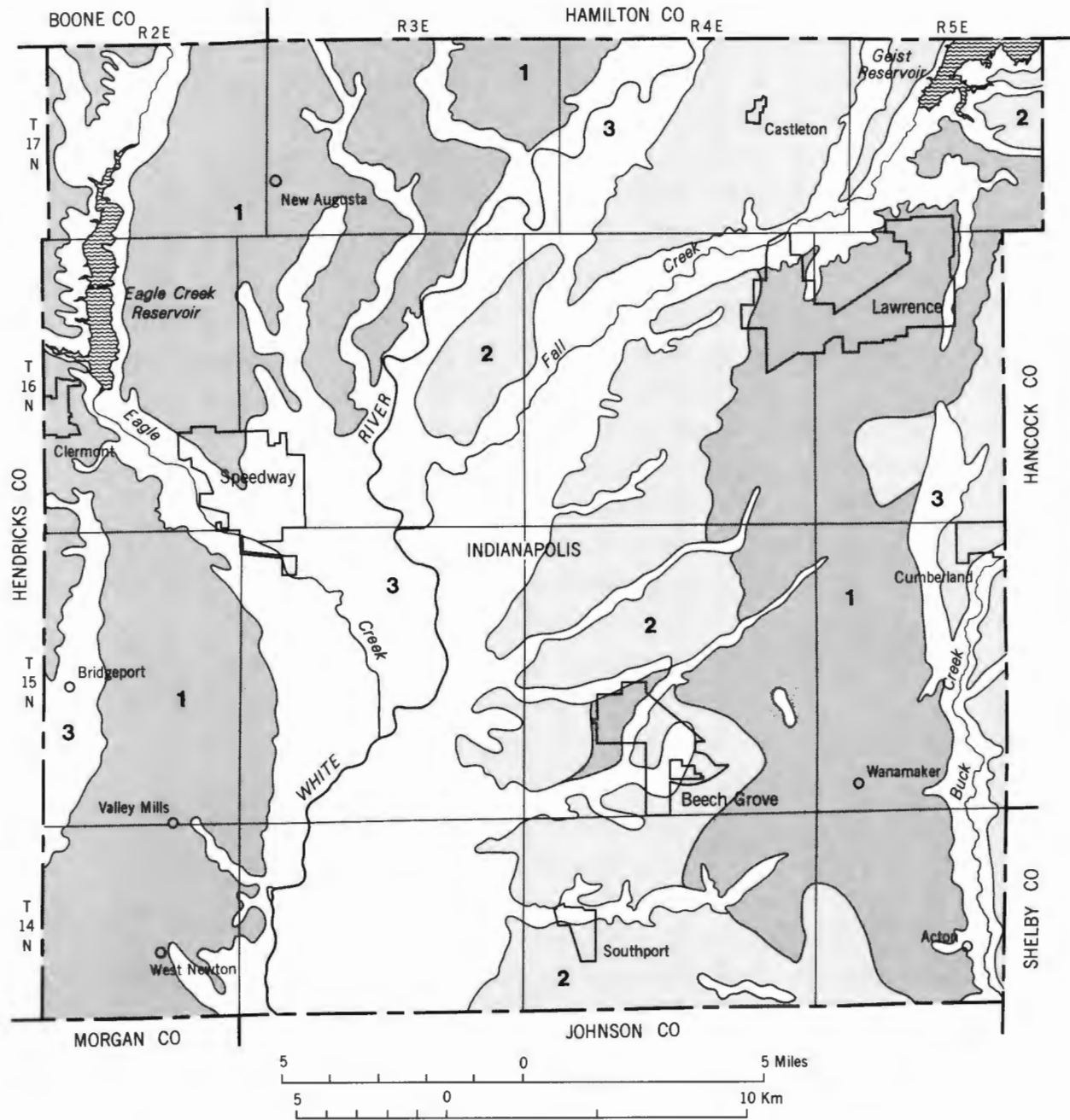


Figure 18. Map of Marion County showing geologic suitability for sanitary landfilling.

EXPLANATION FOR FIGURE 18

- 1 Generally well suited for solid-waste disposal; upland area of low-permeability till 50 feet or more thick with the highest annual ground-water level more than 20 feet below the surface.
Potential hazards: (1) poor surface drainage in flat areas and in closed depressional areas and (2) possible small lenses of sand and gravel in the till that serve as aquifers locally.
- 2 Generally suited for solid-waste disposal with reservations; upland and hillside areas of low-permeability till 50 feet or more thick with the highest annual water table greater than 20 feet below the surface.
Potential hazards: (1) shallow sand and gravel lenses within the till provide local water supplies and (2) steep slopes require special construction procedures to prevent seepage of leachate onto the surface.
- 3 Generally poorly suited for solid-waste disposal; low-lying area of thick highly permeable outwash with highest annual water table less than 10 feet below the surface.
Potential hazards: (1) leachate will contaminate ground water in the most productive aquifer in the county and (2) much of the area is also floodway, and therefore there is a high risk of surface-water contamination.

The criteria used to delineate and categorize various areas are: (1) nature of unconsolidated material, (2) nature of bedrock, (3) drift thickness, (4) depth to water table, (5) depth to highest aquifer, (6) topography, and (7) surface drainage. The areas most suitable for solid-waste disposal are the uplands, which have low-permeability tills, reasonably good drainage, and the water table at sufficient depth to prevent migration and to allow detoxification of the leachate. Nearly all till areas meet the permeability requirement except those areas containing significant lenses and stringers of sand and gravel. In other places, surface drainage of the till is poor because of low relief and closed depressions. It is possible to control and improve drainage through proper site engineering and thereby overcome this problem. The effect of the water-table depth on landfill suitability depends on such factors as the type of landfill, the permeability of the material, its ion-exchange capacity, and its proximity to an aquifer. Therefore, the water-table depth should be determined and related to the landfill type and the geology of individual sites.

Most of the county is till upland and therefore is potentially suited for sanitary landfills (fig. 18). Further definition of the areas shown as suitable can be achieved by coordinating the landfill-suitability map with topographic maps to locate topographically high areas that are reasonably well drained. Flood-plain maps that depict the flood-prone areas should also be consulted (U.S. Army Corps of Engineers, Louisville, Ky., District, 1970a and b and 1971a and b). Site selection should also include a preliminary engineering evaluation, which entails a test-drilling program and laboratory analyses of soil and rock samples. Some of the geologic, physical, and chemical properties of the soil and underlying material that should be determined are water-table level, aquifer depth, flow direction and velocity of ground water, and the permeability, porosity, chemical composition, and ion-exchange capacity of the surface and subsurface materials. All requirements for an acceptable landfill site are stated in Indiana Stream Pollution Board Regulation SPC-18.

Management of surface drainage is perhaps the most important factor in the proper operation of a landfill in a thick section of till or other low-permeability material. Unless surface drainage is diverted from the fill area, the highly permeable refuse will quickly become saturated, a ground-water mound will form, and leachates will flow into adjacent areas. To minimize the drainage problem, it is advisable to stabilize the final fill surface as a mound and to establish vegetation that will reduce infiltration. The surface of a landfill may subside for a period of 5 years or longer, depending on the initial compaction of the refuse and the rate and degree of its decomposition. Depressions created by subsidence hold surface water and promote infiltration, thereby adding to the leachate problem. Therefore, some provision should be made to monitor the movement of leachate from the landfill after it is abandoned. The final landfill cover, which is generally more permeable than the base of the fill because it has been disturbed, permits surface water to enter the refuse more rapidly than it passes through the base. Therefore, more leachate will be produced and will seep out at the surface or escape through permeable subsurface materials surrounding the fill.

If geologically suitable sites cannot be found, poor sites may be made environmentally acceptable by proper engineering design. Cover material, if unavailable, can be hauled in. Leachate production and migration can be controlled in various ways. Such artificially designed sanitary landfills are generally far more expensive to operate and usually require continued maintenance after the site is abandoned.

SEPTIC SYSTEMS

Septic systems, when used in the proper geologic environment, are suitable devices for processing and purifying limited volumes of domestic waste liquids. The proper environment is one in which subsoil permeability, surface and subsurface drainage, depth to the water table, and lot size permit adequate dispersal and purification of effluent. Permeability must be high enough to allow infiltration but not so high as to permit direct

and rapid movement of waste liquid to the water table. Good surface and subsurface drainage is important to prevent water mounding, leakage to the surface, and subsequent surface contamination. Depth to the water table is particularly important if there are wells nearby. There must be adequate travel distance for purification of the effluent by ion exchange and bacterial action before the effluent reaches the water table. Lot and tile-field size must therefore be large enough to permit effective interaction of the above-mentioned factors and dispersal of effluent without producing surface or subsurface contamination.

Three categories were established for mapping the hydrogeologic suitability of the various areas within the county for septic systems (fig. 19): (1) generally well suited, (2) poorly to moderately well suited, and (3) generally unsuited. The map is for use as a general guide only. More detailed study must be completed before specific site suitability can be determined. For example, although the area in category 1 is generally suitable, specific sites may be unsuitable because permeability is too low and surface drainage is too poor. Furthermore, specific locations in the area of category 3 may prove adequate for individual or isolated systems. Boundaries between the categories are gradational because geologic conditions are gradational.

The areas classified as category 1 are almost entirely glacial-till uplands; those classified as category 2 are a combination of glacial till (primarily sloping stream-valley sides), kames, and some alluvial materials; and those classified as category 3 are primarily valley bottom, highly permeable glacial-outwash materials, and some alluvial materials.

For planning and permit requirements for septic-system installations in Indiana, refer to Indiana State Board of Health Bulletin S. E. 8, "Septic Tank Sewage Disposal Systems." A more detailed description of the suitability of Marion County soils for septic systems can be obtained from the soil survey for Marion County (U.S. Department of Agriculture Soil Conservation Service, 1978).

STORAGE LAGOONS FOR LIQUID WASTES

Storage lagoons provide an inexpensive and

efficient physical and biologic means for storing and treating liquid wastes. They can, through use of the proper geologic setting and engineering design, be designed to be nearly compatible with the environment.

Storage lagoons are used to hold wastes, which may be highly toxic, for further treatment, or the lagoons may be one phase of a complex treatment process. Therefore, the primary function of the lagoon is the absolute retention of waste. To achieve this goal, the lagoon must be constructed in an impermeable material, well above the highest annual water table, and above the highest expected flood level. In Marion County these conditions are met only on the upland tills.

The geologic and hydrologic conditions required for a satisfactory lagoon site are similar to those required for a sanitary landfill. Figure 18, which depicts the geologic suitability for sanitary-landfill sites, can also be used as a guide for locating potential lagoon sites.

Geologic conditions that will best protect against surface-water and ground-water contamination are: a low-permeability preferably clay-loam soil that extends to at least 20 feet below the base and far beyond the sides of the lagoon, an even land surface with low gradient and relief, little or no organic matter in the soil, a minimum annual water-table depth of 5 feet below the base of the lagoon, a depth to bedrock of at least 60 inches below the base of the lagoon, and a site that is not subject to flooding (Olson, 1974).

Conditions suitable for the use of liquid-waste storage lagoons exist only in the flat areas of the till uplands, where the loam to sandy loam till is only slightly permeable, is generally considerably more than 20 feet thick, is more than 20 feet above the water table, and is well above flood level. Precautions must be taken to avoid placing a lagoon over a shallow sand lens that could serve as an aquifer locally. Test borings are required to establish the actual suitability of every proposed site. The information provided in this report is general and designed to be used as a guide only.

The low-lying flood plains are poor sites for lagoons because the glacial outwash in the flood plains is highly permeable the water

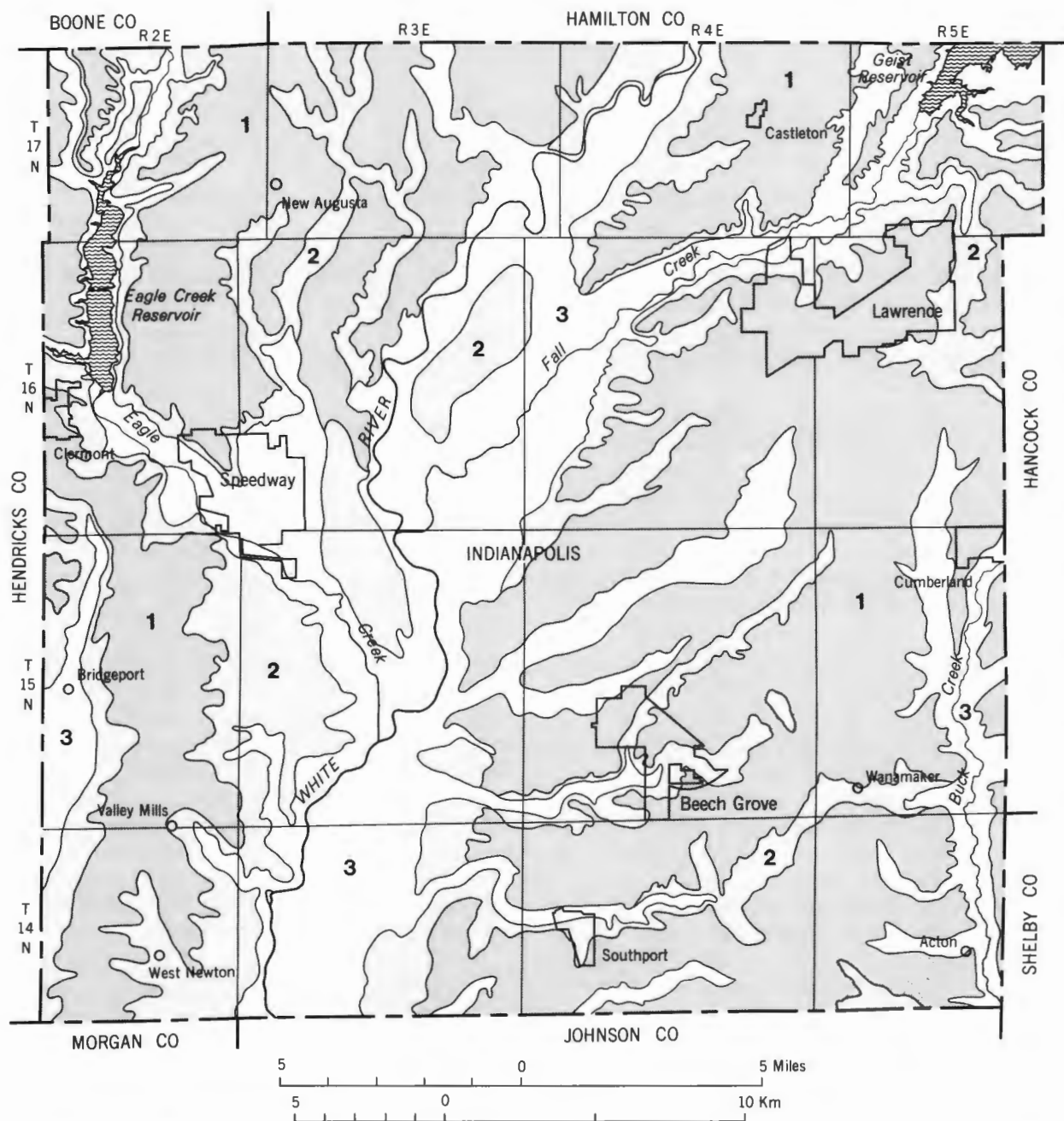


Figure 19. Map of Marion County showing geologic suitability for environmentally acceptable septic systems.

EXPLANATION FOR FIGURE 19

- 1 Generally suitable for septic systems. Areas include flat to gently sloping upland till in which low permeability and poor drainage may require particular attention to tile-field size and design.
- 2 Generally moderately well to poorly suited for septic-system installations. Areas include moderately to steeply sloping till in stream-valley walls and some relatively thick alluvium (greater than 5 feet) over outwash; steep slopes, high water table, and locally high permeability may allow effluent to reach ground-water or surface-water systems.
- 3 Generally unsuitable for septic-system installations. Areas include excessively steep valley walls in till and highly permeable outwash in the stream valleys; extreme slopes and flood potential almost assure surface seepage of effluent, and high water table in combination with highly permeable outwash leads to ground-water contamination.

table is high, and the flood plains are subject to periodic flooding. Lagoons constructed in flood plains must be specially designed to prevent leakage and flooding by sealing the bottom with some material that does not react with the waste liquid and by constructing a suitable levy. Such measures are expensive and prone to failure.

SUBSURFACE WASTE INJECTION

Subsurface waste injection, the injection of economically unrecoverable liquid wastes through wells deep into the subsurface, is not now practiced in Marion County. It is difficult to predict potential success of deep waste injection, because little is known of the deep subsurface rocks under the county. The deepest test wells reach only to the top of the Knox Dolomite, or about 1,800 feet below the land surface. Many gas and oil wells penetrate the Trenton Limestone, but these are not more than 1,300 feet deep. Data from deep wells in other parts of the state, however, make possible some interpretations regarding the deeper rocks (fig. 6).

The Mount Simon Sandstone, a fine- to coarse-grained moderately well-cemented sandstone, provides the best conditions for receiving and storing liquid wastes. The rock units above the Mount Simon do not appear to have the physical characteristics required to accept or safely store large amounts of liquid wastes. The Mount Simon has an average thickness of about 1,200 feet under Marion County, but it is not certain that this formation has the required porosity, permeability, and storage capacity to handle liquid-waste storage. There are operating waste-injection wells in northern Indiana, where the porosity exceeds 15 percent, that use the Mount Simon, but in some southern areas tests indicate that it may lack the required porosity and permeability. A study sponsored by the Ohio River Valley Water Sanitation Commission (1976) indicates that the overall porosity of the Mount Simon beneath Marion County is less than 5 percent. Therefore, the suitability of the Mount Simon

for waste injection in Marion County cannot be predicted with certainty without one or more physical tests of the formation. The Eau Claire Formation, a 600-foot-thick section of nearly impermeable shale, siltstone, and carbonate directly overlying the Mount Simon, should serve as a suitable confining unit. Other factors that must be considered are the quality of the resident water in the Mount Simon, the compatibility of the liquid waste and the resident water and formation material, and the potential presence of such leakage conduits as faults.

Ground water is a dynamic substance that is constantly migrating through the earth materials in which it resides. Its rate of migration depends on the head differential and viscosity of the water and the permeability of the material through which it moves. The injection of waste liquid can alter all three of these natural properties and cause an imbalance in the system. Increased pressure may open escape routes for either resident fluid or the liquid waste to move into aquifer systems or to the surface. Such zones of weakness as the Fortville Fault (fig. 3) or other fractures or joints provide ideal escape routes for liquid under pressure. Pretesting of the injection horizon can detect possible failures, and installing an adequate number of properly placed observation wells will facilitate the detection of a failure in its early stages. An improperly prepared and operated waste-injection well can be a serious environmental hazard, because subsurface contamination resulting from a faulty well is very difficult to control or neutralize. On the other hand, if geologic conditions are satisfactory, the deep subsurface may provide an acceptable, inexpensive storage space for liquid waste until it can be economically recycled or treated.

Questions related to the regulations for liquid-waste injection in Indiana should be directed to the Industrial Waste Disposal Section, Division of Water Pollution Control, Indiana State Board of Health.

Selected Bibliography

Ault, C. H.

- 1974 - Indiana's abandoned quarries — Environmental problems or community assets?: *Outdoor Indiana*, v. 39, no. 2, p. 4-9.

Ault, C. H., and Carr, D. D.

- 1975 - Directory of crushed stone, ground limestone, cement, and lime producers in Indiana: *Indiana Geol. Survey* [unnumbered directory].

Bleuer, N. K.

- 1970 - Geologic considerations in planning solid-waste disposal sites in Indiana: *Indiana Geol. Survey Spec. Rept. 5*.

Bleuer, N. K., and Hartke, E. J.

- 1971 - Diagrammatic cross-sections of Indiana geology in relation to solid waste disposal sites: *Indiana Geol. Survey Spec. Rept. 5* (Supp.).

Carr, D. D.

- 1966 - Sand and gravel resources in eastern Johnson County and western Shelby County, Indiana: *Indiana Geol. Survey Spec. Rept. 4*.

- 1971 - Specialty sand resources of Indiana: *Indiana Geol. Survey Bull. 42-F*.

Carr, D. D., French, R. R., and Ault, C. H.

- 1971 - Crushed stone aggregate resources of Indiana: *Indiana Geol. Survey Bull. 42-H*.

Carr, D. D., and Webb, W. M.

- 1970 - Sand and gravel resources of Indiana: *Indiana Geol. Survey Bull. 42-D*.

Corps of Engineers, U.S. Army

- 1970a - Flood plain information, Crooked Creek and Williams Creek, Marion County, Indiana: *Marion County Metropolitan Plan Dept. and Flood Control Dist.*

- 1970b - Flood plain information, Pogues Run, Pleasant Run, and Bean Creek, Marion County, Indiana: *Marion County Metropolitan Plan Dept. and Flood Control Dist.*

- 1971a - Flood plain information, Lick Creek and Little Buck Creek, Marion County, Indiana: *Marion County Metropolitan Plan Dept. and Flood Control Dist.*

Corps of Engineers, U.S. Army

- 1971b - Flood plain information, Little Eagle Creek and tributaries, Marion County, Indiana: *Marion County Metropolitan Plan Dept. and Flood Control Dist.*

Fraser, G. S.

- 1978 - Directory of sand and gravel producers in Indiana: *Indiana Geol. Survey* [un-numbered directory].

French, R. R.

- 1969 - Transportation of mineral aggregates in Indiana: *Indiana Acad. Sci. Proc.*, v. 78, p. 348-354.

French, R. R., and Carr, D. D.

- 1967 - Geologic factors affecting the exploration for mineral aggregates in the Indianapolis area, in *Proceedings of the 18th Annual Highway Geology Symposium: Purdue Univ. Eng. Bull.*, v. 51, no. 4, p. 86-103.

Harrison, W.

- 1959 - Petrographic similarity of Wisconsin tills in Marion County, Indiana: *Indiana Geol. Survey Rept. Prog. 15*.

- 1963a - Geology of Marion County, Indiana: *Indiana Geol. Survey Bull. 28*.

- 1963b - Pages from the geologic past of Marion County: *Indiana Geol. Survey Circ. 9*.

Herring, W. C.

- 1974 - Water resources of Marion County with emphasis on ground-water availability: *Indiana Div. Water*.

- 1976 - Technical atlas of ground water resources of Marion County, Indiana: *Indiana Div. Water*.

Indiana Department of Commerce,
Economic Research Division

- 1969 - Indiana population projections 1960-1985: *Indiana Dept. Commerce Econ. Research Div. Population Projection*.

Indiana State Board of Health

- 1974 - Septic tank sewage disposal systems: *Indiana State Board Health Bull. S. E. 8*.

Indiana State Highway Commission

- 1975 - Standard specifications: Indianapolis, *Indiana State Highway Comm.*

- Lamar, J. E.
1961 - Uses of limestone and dolomite: Illinois Geol. Survey Bull. 37.
- Leonards, G. A., and Altschaeffl, A. G.
1960 - Subsurface materials of Marion County, Indiana: Purdue Univ. Eng. Bull. 103 (Eng. Ext. Ser.).
- McGuinness, C. L.
1943 - Ground-water resources of the Indianapolis area, Marion County, Indiana: Indiana Div. Geology [unnumbered pub.].
- Malott, C. A.
1922 - The physiography of Indiana, in Handbook of Indiana geology: Indiana Dept. Conserv. Pub. 21, pt. 2, p. 59-256.
- Meyer, W., Reussow, J. P., and Gillies, D. C.
1975 - Availability of ground water in Marion County, Indiana: U.S. Geol. Survey open-file rept. 75-312.
- Ohio River Valley Water Sanitation Commission
1976 - Underground wastewater injection, Ohio Valley region — Evaluation of the basal sandstone as an injection interval: Ohio River Valley Sanitation Comm. and U.S. Geol. Survey Water Resource Div.
- Olson, G. W.
1974 - Using soils of Kansas for waste disposal: Kansas Geol. Survey Bull. 208.
- Roberts, C. M., Widman, L. E., and Brown, P. N.
1955 - Water resources of the Indianapolis area, Indiana: U.S. Geol. Survey Circ. 366.
- Rooney, L. F.
1970 - High-calcium limestone and high-magnesium dolomite resources of Indiana: Indiana Geol. Survey Bull. 42-B.
- Rooney, L. F., and Carr, D. D.
1971 - Applied geology of industrial limestone and dolomite: Indiana Geol. Survey Bull. 46.
- Shaffer, N. R.
1976 - Directory of clay and shale producers and ceramic plants in Indiana: Indiana Geol. Survey [unnumbered directory].
- Shampine, W. J.
1975 - A river-quality assessment of the upper White River, Indiana: U.S. Geol. Survey Water Resources Inv. 10-75.
- Terzaghi, K., and Peck, R. B.
1948 - Soil mechanics in engineering practice: New York, John Wiley and Sons, Inc.
U.S. Department of Agriculture,
Soil Conservation Service
1978 - Soil survey information and interpretation for Marion County, Indiana: U.S. Dept. Agriculture Soil Conserv. Service.
- Wayne, W. J.
1963 - Pleistocene formations in Indiana: Indiana Geol. Survey Bull. 25.
- Weist, W. G., Jr.
1975 - Index to maps of flood-prone areas in Indiana: U.S. Geol. Survey Water Resources Inv. 48-74.

Glossary

Aggregate. A hard, inert construction material used for mixing in various-sized fragments with a cement or bituminous material to form concrete, mortar, plaster, etc., or used alone, as in railroad ballast.

Alluvium. Unconsolidated material deposited during comparatively recent geologic time by running water as a sorted or semisorted sediment.

Aquifer. A permeable, saturated body of rock able to conduct ground water and to yield economically significant quantities to wells and springs.

Carbonate rock. A consolidated rock made up of compounds which consist of a single carbon ion with three oxygen ions packed around it (CO_3)²⁻; for example, the common sedimentary rock, limestone, which is formed largely by the accumulation of organic skeletal fragments.

Chert. A hard, extremely dense or compact sedimentary substance composed of silica. Also called flint.

Consistency. The relative ease with which a soil can be deformed. The term expresses the degree of firmness or cohesion of soil particles and their resistance to rupture or deformation.

Dendritic drainage. A drainage pattern in which streams branch irregularly in many directions and at almost any angle, although generally less than a right angle. It is indicative of uniform resistance to erosion.

Evapotranspiration. Loss of water from a land area through transpiration of plants and evaporation from the soil.

Flood plain. The relatively flat area or lowlands adjoining the channel of a stream or lake which has been or may be covered periodically by floodwater.

Glacial drift. All rock material transported by a glacier and deposited directly by or from the ice or by running water emanating from a glacier.

Hydraulic conductivity. The rate of flow of water in gallons per day through a cross section of 1 square foot under a unit hydraulic gradient, at the prevailing temperature.

Ion-exchange capacity. The capacity of a soil to complete the reversible replacement of certain ions by others without complete loss of crystal structure.

Kame. A long, low mound or knob or short irregular ridge composed chiefly of poorly sorted and stratified sand and gravel deposited by a subglacial stream.

Lithofacies. A laterally disposed and mappable subdivision of a designated stratigraphic unit distinguished from other adjacent subdivisions on the basis of physical, chemical, and biologic characteristics.

Loam till. A sandy silt or silty sand of low plasticity; ratios range from a trace to 20 percent clay, 30 to 50 percent silt, and 30 to 50 percent sand.

Outwash. Stratified sand and gravel washed out from a glacier by meltwater streams and deposited beyond the margin of the glacier.

Overconsolidated. Consolidation (of sedimentary material) greater than that normal for the existing overburden.

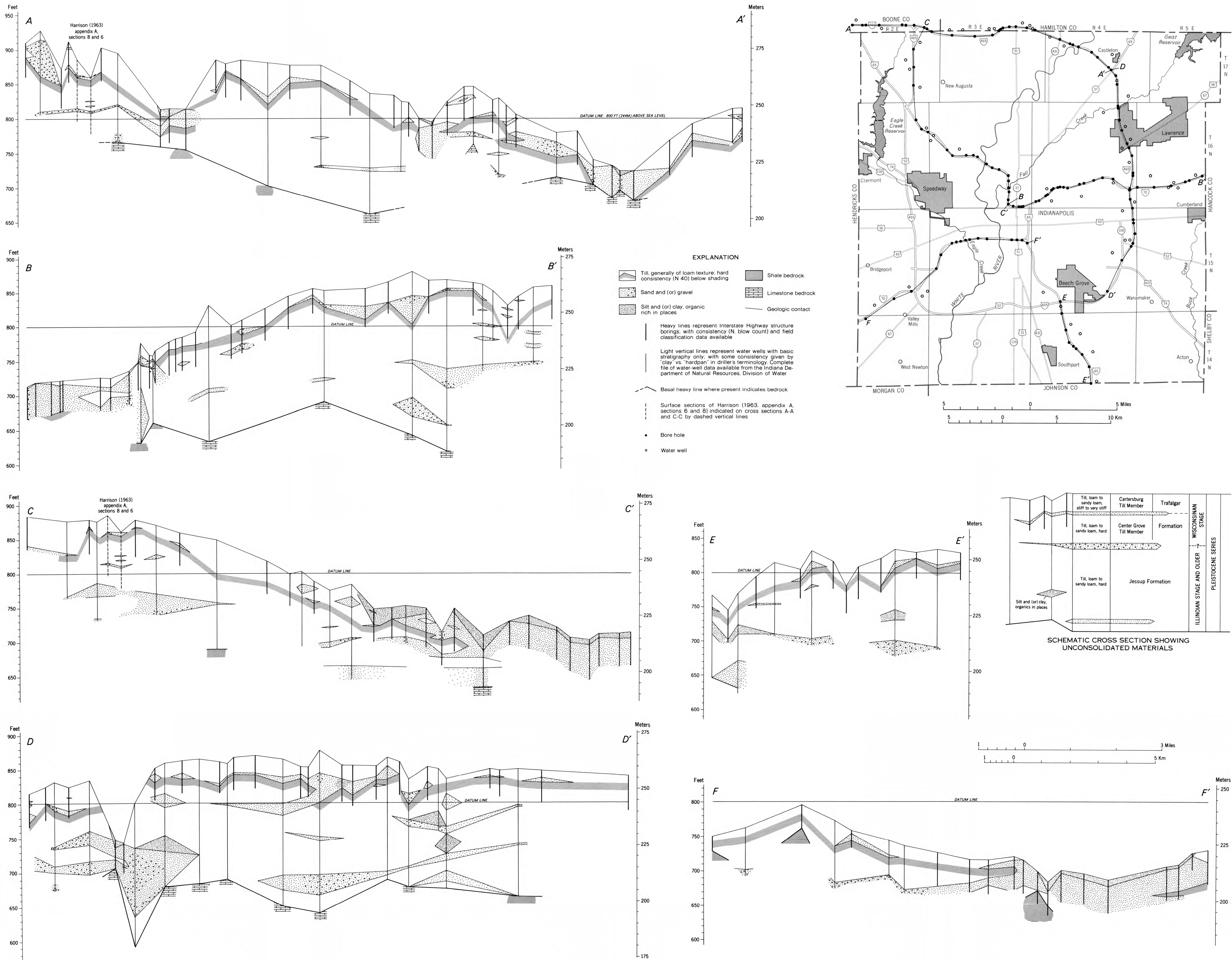
Relative density. The ratio of the difference between the void ratio of a cohesionless soil in the loosest state and any given void ratio to the difference between its void ratios in the loosest and densest states.

Transmissivity. The rate at which water is transmitted through a unit width under a unit hydraulic gradient.

Water table. The surface of an unconfined body of ground water at which the pressure is equal to that of the atmosphere.

OVERSIZED DOCUMENT

**The following pages are oversized and
need to be printed in correct format.**



GEOLOGIC CROSS SECTIONS THROUGH THE UNCONSOLIDATED DEPOSITS OF MARION COUNTY, INDIANA