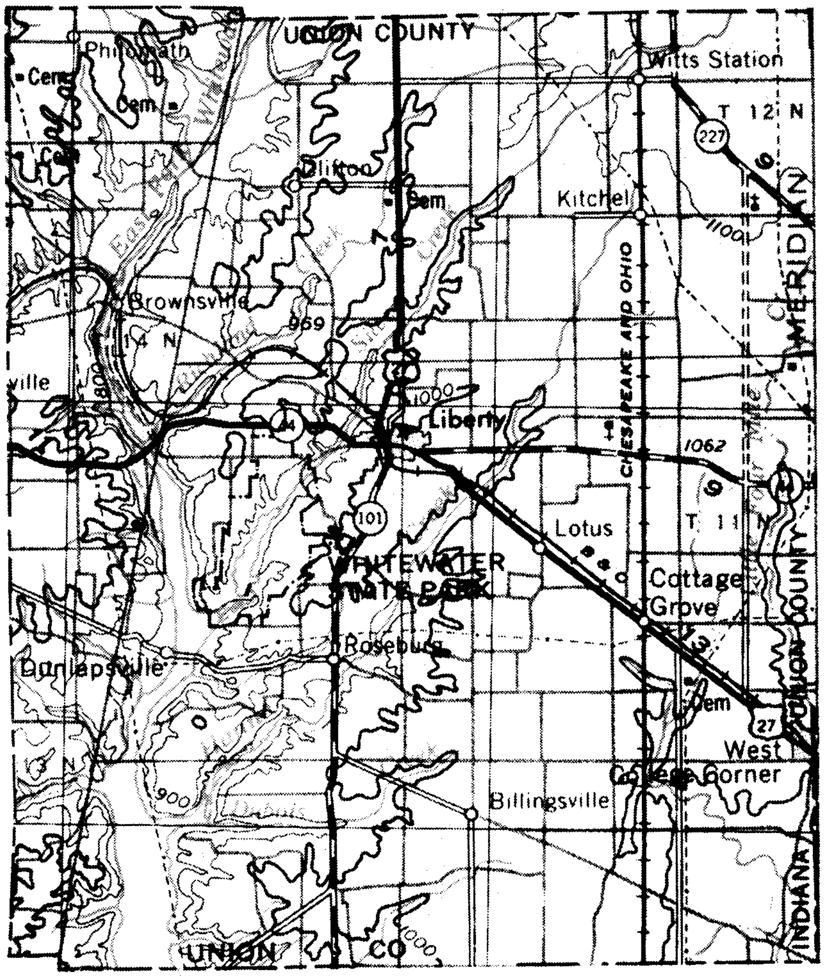
HYDROGEOLOGY OF UNION COUNTY, INDIANA

BULLETIN 42



STATE OF INDIANA
DEPARTMENT OF NATURAL RESOURCES
DIVISION OF WATER

1992

HYDROGEOLOGY OF UNION COUNTY, INDIANA

By John C. Clark

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INTRODUCTION

Union County is located in east-central Indiana (Figure 1). In Indiana it is bounded on the north by Wayne County, on the west by Fayette, and on the south by Franklin County. In terms of size and population, Union County is among the smallest counties in Indiana with an area of approximately 163 square miles and a population of nearly 10,000. The largest towns in the county are Liberty, the county seat, and West College Corner. Smaller communities include Brownsville, Cottage Grove, Dunlapsville, and Kitchel.

Ground-water resources are limited in most of Union County due to the nature of the bedrock and unconsolidated deposits. Liberty and College Corner have had problems obtaining adequate ground water supplies for municipal use. Quantities of ground water sufficient for even household use are difficult to obtain in many parts of the county.

PURPOSE AND BACKGROUND

The purpose of this report is to present existing information on the geology, ground-water availability, and ground-water quality of Union County. Information came from published reports and from unpublished well logs and water quality data on file at the Division of Water.

Since 1959, an Indiana state law has required water well drillers to submit to the Division of Water a record, or log, for each well drilled in the state. The well logs provide information on

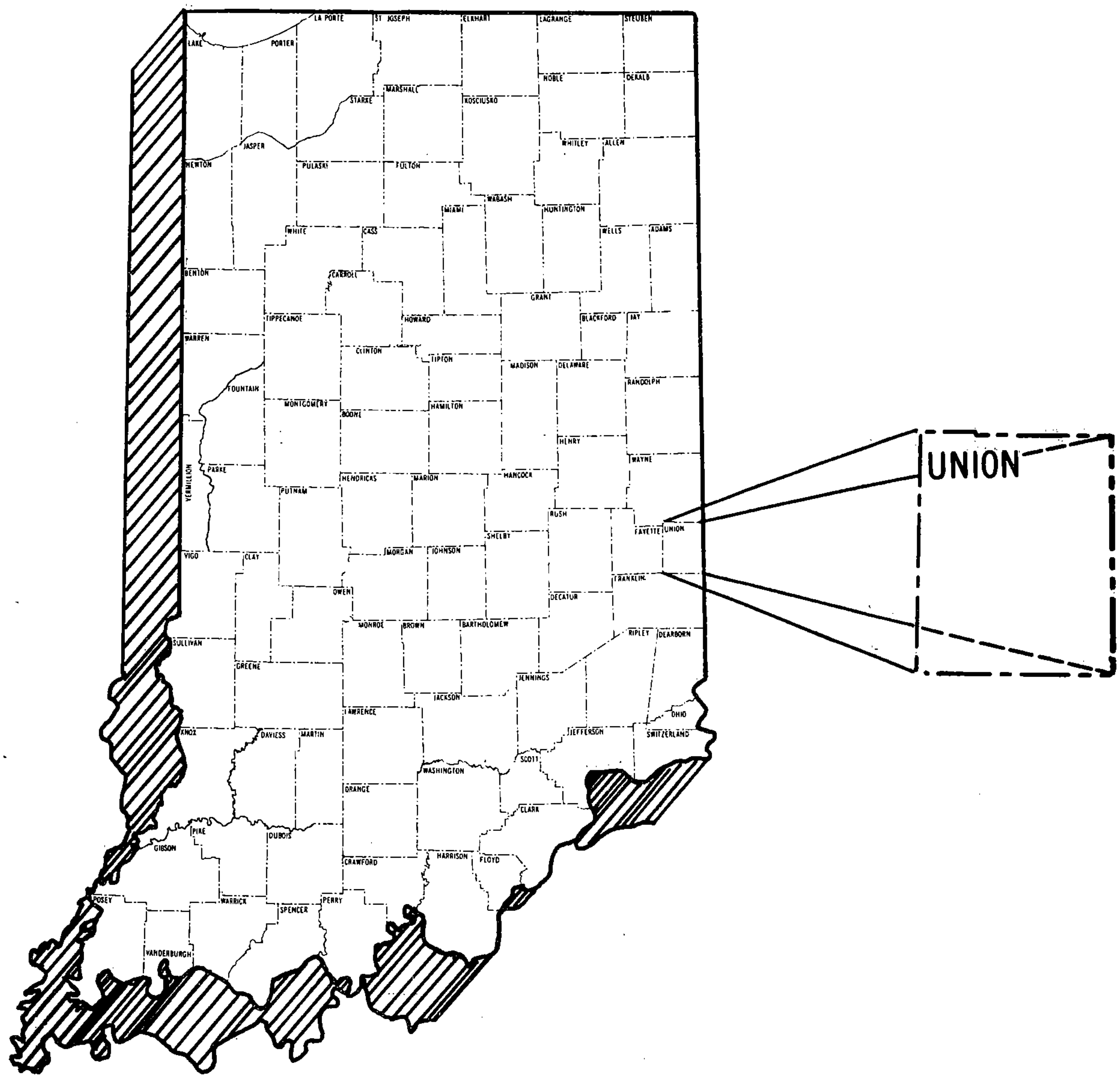


Figure 1. Location of Union County, Indiana

stratigraphy, aquifer zones and depths, ground-water levels, and ground-water availability.

Approximately 340 records of water wells drilled in Union County were reviewed for this study. The wells are fairly evenly distributed across the county (Plate 1). Approximately 21 percent of the wells were drilled into bedrock; the rest were developed in unconsolidated materials. Data from the well logs were used to evaluate ground-water availability and to determine the potentiometric surface. In addition to the well logs, seismic data from the Indiana Geological Survey were used to develop the bedrock topography map. Ground-water quality data were obtained from well sampling programs conducted by the Division of Water in conjunction with the Indiana Geological Survey in 1985 and by the Division of Water in 1988.

PHYSIOGRAPHY

Union County is located within the Dearborn Upland, an area which has been extensively eroded and dissected by downcutting streams (Malott, 1922, pg.84). Small, relatively flat upland areas remain between major valleys, and small flat areas are present in the valley bottoms, but most of the land is in hillslopes. Many slopes near major drainageways are steep, but cliffs are uncommon because of the shaley nature of the bedrock.

The western part of the county is much more dissected than the eastern part (Plate 1). To the west numerous small tributary streams are downcutting to the level of the entrenched East Fork Whitewater River. To the east lies a relatively flat, less dissected upland area which is the main surface water drainage divide in the county.

Approximately three-quarters of Union County is drained by the East Fork Whitewater River which has its headwaters in eastern Wayne County, Indiana, and western Preble County, Ohio. The river flows generally south through the western part of Union County. In Franklin County the East Fork Whitewater River converges with the Whitewater River. The river then flows southeast out of Indiana and joins the Miami River in Hamilton County, Ohio.

Major tributaries to the East Fork Whitewater River in Union County are Richland, Silver, and Hanna Creeks. Each of these tributaries developed on the east side of the river and each has a distinct northeast-southwest orientation, trending from N 40° E to N 55° E. The tributaries are roughly parallel to each other and to the northmost portion of the East Fork Whitewater River (Plate 1). The parallel nature of these stream segments suggests some geologic control over their early development. No major tributaries developed on the west side of the river in Union County.

In 1965, construction began on a dam for the East Fork Whitewater River near Brookville in Franklin County. Impoundment began in January, 1974 and the lower half of the East Fork Whitewater River valley in Union County was flooded to an elevation of 748 feet (All elevations in this report are relative to mean sea level.) by the resulting Brookville Lake (Clendenon, 1988, pg. 26 - 27).

The eastern one-quarter of Union County, approximately 40 square miles, is drained by Four Mile Creek and by the headwaters of Indian Creek. These creeks flow southeast through Preble and Butler Counties in Ohio before joining the Miami River near Hamilton, Ohio.

The drainage divide between the East Fork Whitewater River and Indian and Four Mile Creeks is a flat upland area trending roughly north-south (Plate 1). The elevation of the upland decreases from about 1130 feet in the north to about 1030 feet to the south. The highest point in the county is at an elevation slightly over 1130 feet and occurs along the divide in the northeast corner of the county. The lowest point occurs in the southwest part of the county where the East Fork Whitewater River exits the county. The land surface here has an elevation of less than 700 feet but is inundated by Brookville Lake.

BEDROCK GEOLOGY

The rocks which underlie Union County are among the oldest found in Indiana. The oldest and deepest rocks are the basement rocks which include granite, basalt, and arkose. Above the basement rocks lie about 4,000 feet of Paleozoic sedimentary rocks (Figure 2). Of these Paleozoic rocks only those of the Kope Formation or younger are exposed at the surface in Indiana, and only the Dillsboro Formation or younger rocks are exposed in Union County.

The rocks which crop out in Union County are the late Ordovician Dillsboro and Whitewater Formations and the early Silurian Brassfield Limestone and Salamonie Dolomite (Figure 3). Bedrock exposures are more common in the western and southwestern parts of the county where streams have cut through the unconsolidated materials and into bedrock. In the rest of the county, bedrock is covered by relatively thick glacial deposits.

BEDROCK TOPOGRAPHY

In most of western Union County the bedrock surface (Plate 2) is covered by a thin layer of unconsolidated sediment; soil, clay, silt, sand or gravel. In these areas bedrock topography closely matches the

FIGURE 2

Bedrock Stratigraphic Chart For Southeast Indiana Showing Thickness of Units

Silurian System	Salamonie Dolomite		Laurel Member	27 - 55′	Laurel Member mainly dolomitic limestone. Osgood Member shale and dolomitic limestone south, limestone or dolomite north and west. North of Franklin County the Osgood cannot be distinguished from the Laurel rocks, and the units are collectively grouped in the Salamonie Dolomite.
			Osgood Member	10 - 30′	
	Brassfield Limestone			0 - 14′	Medium- to coarse-grained fossiliferous limestone with some shale and dolomite. — 435 MYBP
Ordovician System	Maquoketa Group	Whitewater Formation		60 - 100′	Whitewater Formation consists of shale and limestone. The Saluda Member at the base of the Whitewater is a distinct dolomite unit in the otherwise shaley Ordovician System.
			Saluda Member	(9 - 60′)	
		Dillsboro Formation		400′	Fossiliferous, argillaceous limestone and calcareous shale, increasingly shale-rich to the north. Oldest rocks exposed in Union County.
		Kope Formation		200 - 400′	Shale. Oldest rocks exposed in Indiana. Lower rock units are encountered only in the subsurface.
	Black River Group	Plattin Formation		200 - 230′	Limestone.
		Pecatonica Formation		50 - 65′	Limestone.
	Ancell Group	Joachim Dolomite		100 - 200′	Dolomites and limestones. Middle part relatively pure, upper and lower parts have sandy, silty, and clayey zones.
		Dutchtown Formation		10 - 65′	Argillaceous limestone with some interbedded green shale.
	Knox Supergroup	Prairie Du Chien Group	Shakopee Dolomite	400′	Fine-grained Dolomite with chert and some interbedded shale, siltstone, and sandstone.
			Oneota Dolomite	245 - 400′	Fine- to medium-grained dolomite with some chert. — 500 MYBP
Cambrian System		Potosi Dolomite		690 - 1640′	Fine- to medium-grained dolomite.
	Potsdam Supergroup	Munsing Group	Davis Formation	16 - 115′	Siltstone, shale, limestone, and dolomite.
			Eau Clair Formation	425 - 690′	Siltstone, sandstone, shale, dolomite, and limestone.
		Mount Simon Sandstone		425 - 1115′	Sandstone, fine- to very coarse-grained, poorly consolidated, with some shale beds. — 570 MYBP

Precambrian rocks include granite, basalt, and arkose. Age dates indicate the Middle Proterozoic Era, 900 to 1,600 MYBP.

MYBP - Million Years Before Present
~ ~ ~ - Indicates unconformable contact between rock units

Gray and others (1985), Shaver and others (1986).
Age estimates of geologic boundaries from U.S. Geological Survey (1988).

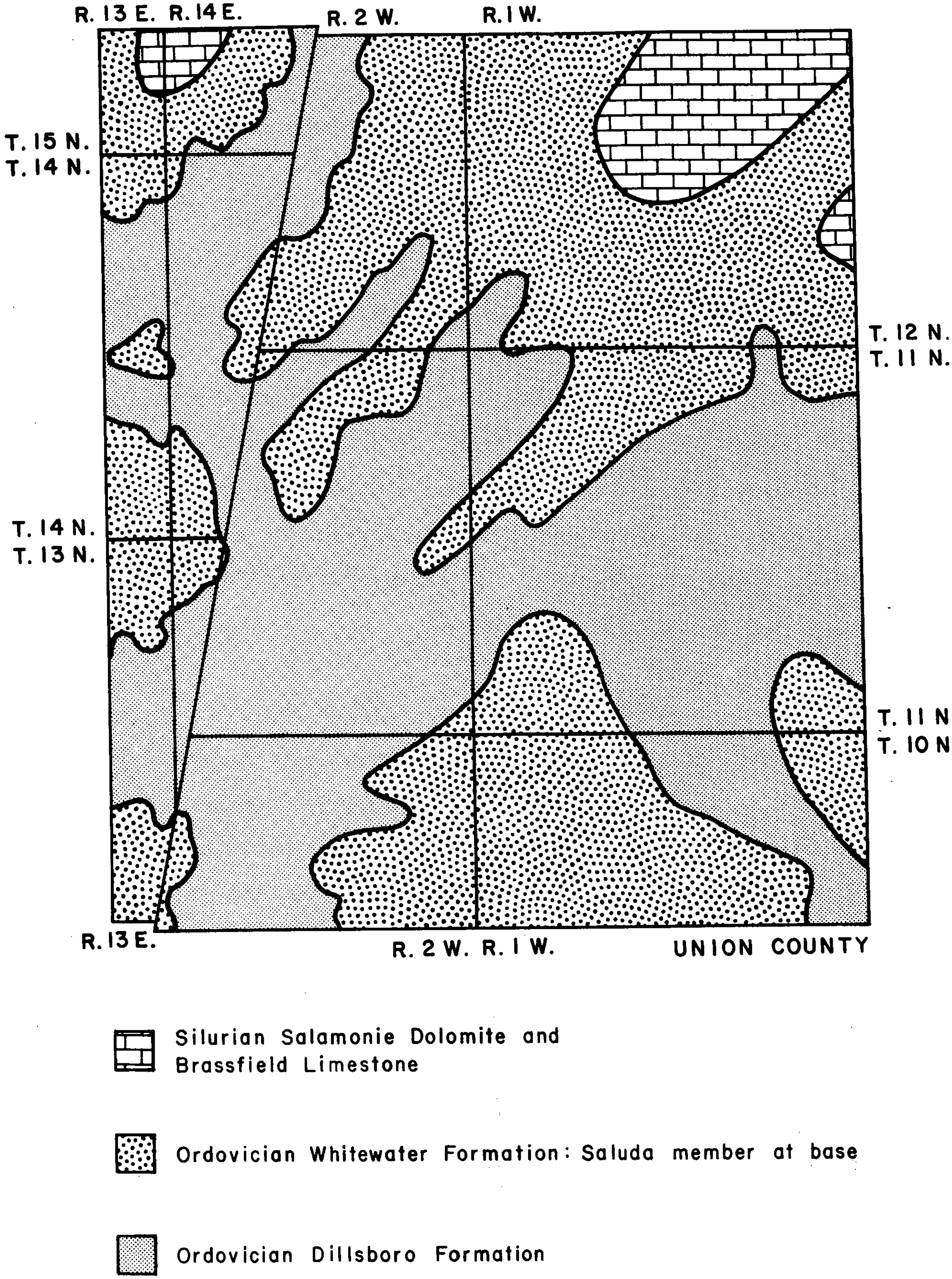


Figure 3. Bedrock Geology. Modified from Gray and others, 1987.

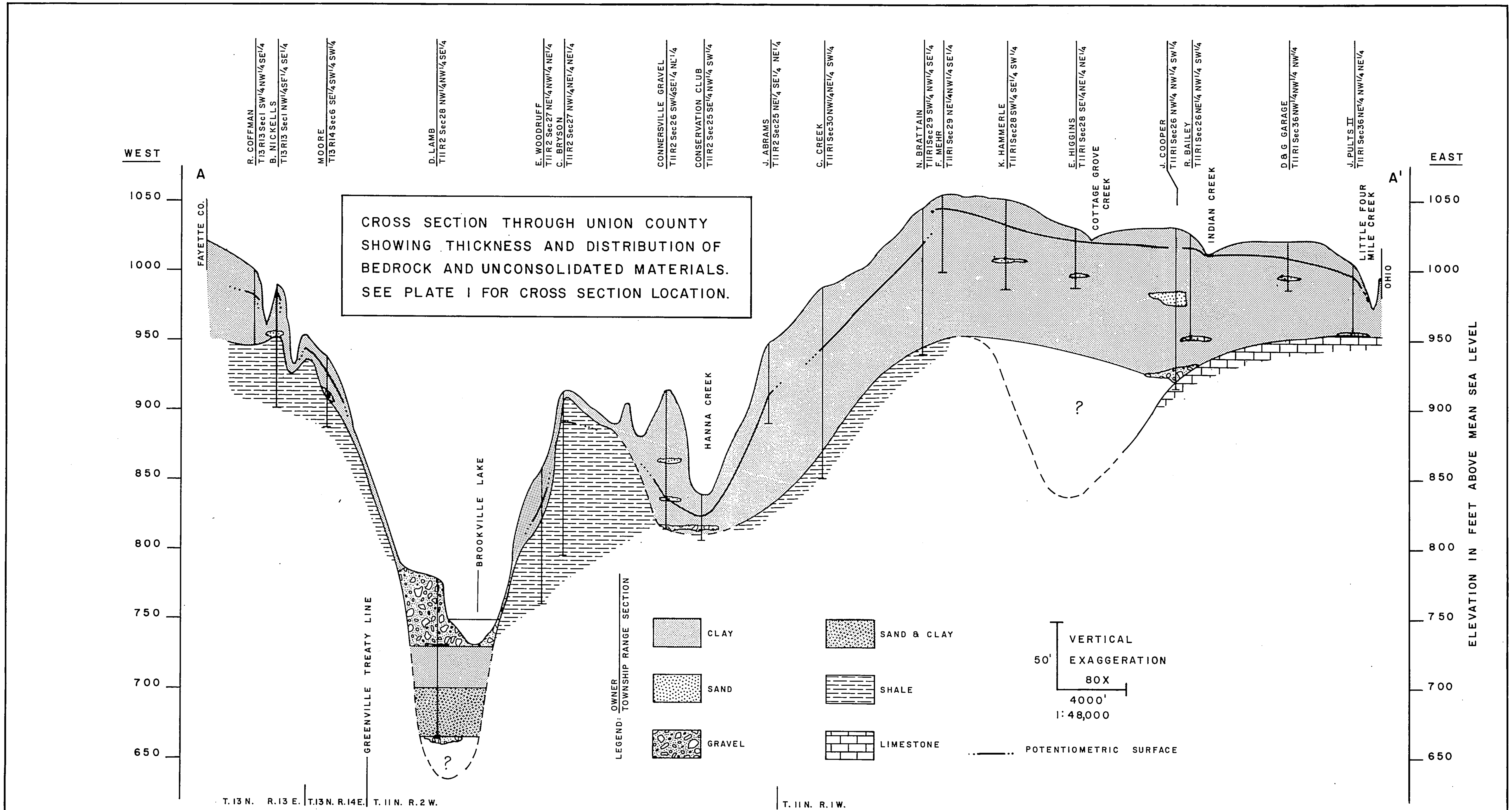
surficial topography. To the east, the bedrock surface is covered by thick layers of glacial deposits (Plate 3) and bedrock topography has less effect on the surficial topographic expression.

The highest bedrock elevation, 1050 feet, occurs in northeast Union County near Five Points. This area is covered by approximately 80 feet of unconsolidated material and also has the highest surface elevation in the county. The lowest bedrock point coincides with the lowest surface elevation and occurs where the Whitewater River leaves the county. The elevation of the bedrock here is probably less than 675 feet but is not exactly known due to the cover of valley-fill materials and the presence of Brookville Lake.

Water-well drilling and seismic testing reveal the presence of two large valleys buried beneath the upland areas of east Union County (Plate 2, Plate 3). These buried valleys appear in cross-sections through Union County (Figures 4a, 4b). See Plate 1 for cross-section locations.

In the northern valley the elevation of the floor is about 925 feet near the state line and drops to an elevation of 825 feet north of Liberty. The southern valley is the larger and deeper of the two buried valleys. This valley has two major tributaries. The elevation of this buried valley drops from around 875 feet in the upstream areas of each tributary to 775 feet at the junction of the buried valley with the East Fork Whitewater River valley.

Of the two buried valleys the southern valley was the more significant drainageway because it was cut deeper into bedrock, had well-developed tributaries, and appears to have developed a lower gradient than the northern valley. These two valleys may have been tributaries to an earlier stage of the East Fork Whitewater River or may have drained west to Fayette County before the East Fork Whitewater



CROSS SECTION THROUGH UNION COUNTY SHOWING THICKNESS AND DISTRIBUTION OF BEDROCK AND UNCONSOLIDATED MATERIALS. SEE PLATE I FOR CROSS SECTION LOCATION.
WEST
EAST
A
A'
R. COFFMAN T13 R13 Sec1 SW1/4 NW1/4 SE1/4
B. NICKELLS T13 R13 Sec1 NW1/4 SE1/4 SE1/4
MOORE T13 R14 Sec6 SE1/4 SW1/4 SW1/4
D. LAMB T11 R2 Sec28 NW1/4 NW1/4 SE1/4
E. WOODRUFF T11 R2 Sec27 NE1/4 NW1/4 NE1/4
C. BRYSON T11 R2 Sec27 NW1/4 NE1/4 NE1/4
CONNERSVILLE GRAVEL T11 R2 Sec26 SW1/4 SE1/4 NE1/4
CONSERVATION CLUB T11 R2 Sec25 SE1/4 NW1/4 SW1/4
J. ABRAMS T11 R2 Sec25 NE1/4 SE1/4 NE1/4
C. CREEK T11 R1 Sec30 NW1/4 NE1/4 SW1/4
N. BRATTAIN T11 R1 Sec29 SW1/4 NW1/4 SE1/4
F. MEHR T11 R1 Sec29 NE1/4 NW1/4 SE1/4
K. HAMMERLE T11 R1 Sec28 SW1/4 SE1/4 SW1/4
E. HIGGINS T11 R1 Sec28 SE1/4 NE1/4 NE1/4
J. COOPER T11 R1 Sec26 NW1/4 NW1/4 SW1/4
R. BAILEY T11 R1 Sec26 NE1/4 NW1/4 SW1/4
D & G GARAGE T11 R1 Sec36 NW1/4 NW1/4 NW1/4
J. PULTS II T11 R1 Sec36 NE1/4 NW1/4 NE1/4
FAYETTE CO.
GREENVILLE TREATY LINE
BROOKVILLE LAKE
HANNA CREEK
COTTAGE GROVE CREEK
INDIAN CREEK
LITTLE FOUR MILE CREEK
OHIO
1050
1000
950
900
850
800
750
700
650
ELEVATION IN FEET ABOVE MEAN SEA LEVEL
?
LEGEND: OWNER / TOWNSHIP RANGE SECTION
CLAY
SAND
GRAVEL
SAND & CLAY
SHALE
LIMESTONE
POTENTIOMETRIC SURFACE
VERTICAL EXAGGERATION 80X
50'
4000'
1:48,000
T. 13 N. R. 13 E.
T. 13 N. R. 14 E.
T. 11 N. R. 2 W.
T. 11 N. R. 1 W.

FIGURE 4a

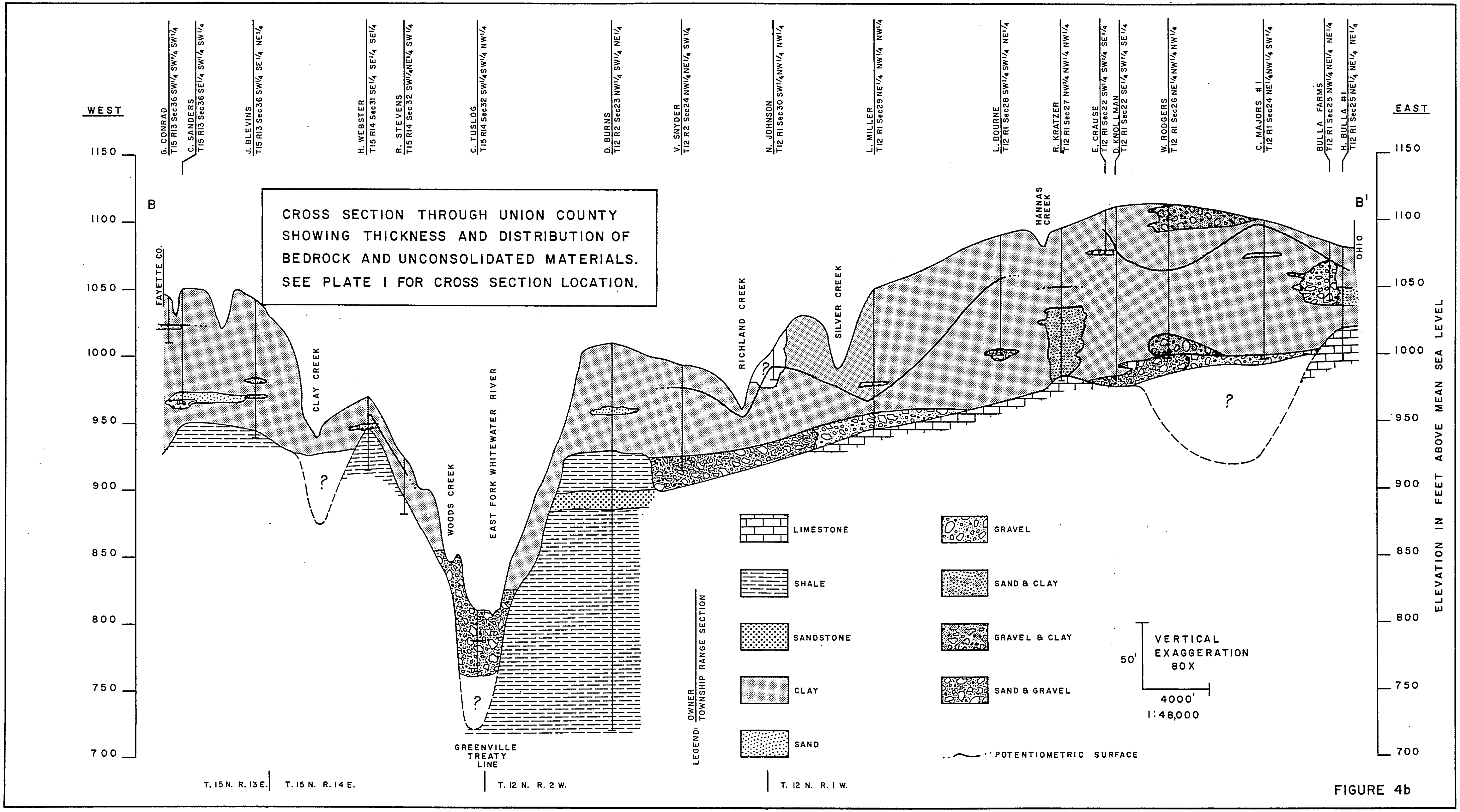

CROSS SECTION THROUGH UNION COUNTY SHOWING THICKNESS AND DISTRIBUTION OF BEDROCK AND UNCONSOLIDATED MATERIALS. SEE PLATE I FOR CROSS SECTION LOCATION.
WEST
EAST
B
B'
ELEVATION IN FEET ABOVE MEAN SEA LEVEL
LIMESTONE
SHALE
SANDSTONE
CLAY
SAND
GRAVEL
SAND & CLAY
GRAVEL & CLAY
SAND & GRAVEL
POTENTIOMETRIC SURFACE
VERTICAL EXAGGERATION 80X
4000'
1:48,000
GREENVILLE TREATY LINE
T. 15 N. R. 13 E.
T. 15 N. R. 14 E.
T. 12 N. R. 2 W.
T. 12 N. R. 1 W.
EAST FORK WHITEWATER RIVER
CLAY CREEK
WOODS CREEK
RICHLAND CREEK
SILVER CREEK
HANNAS CREEK
FAYETTE CO.
OHIO

FIGURE 4b

River developed. The valleys were abandoned and filled with glacial drift and subsequently the East Fork Whitewater River cut down below the level of the valleys to an elevation of 675 feet or lower.

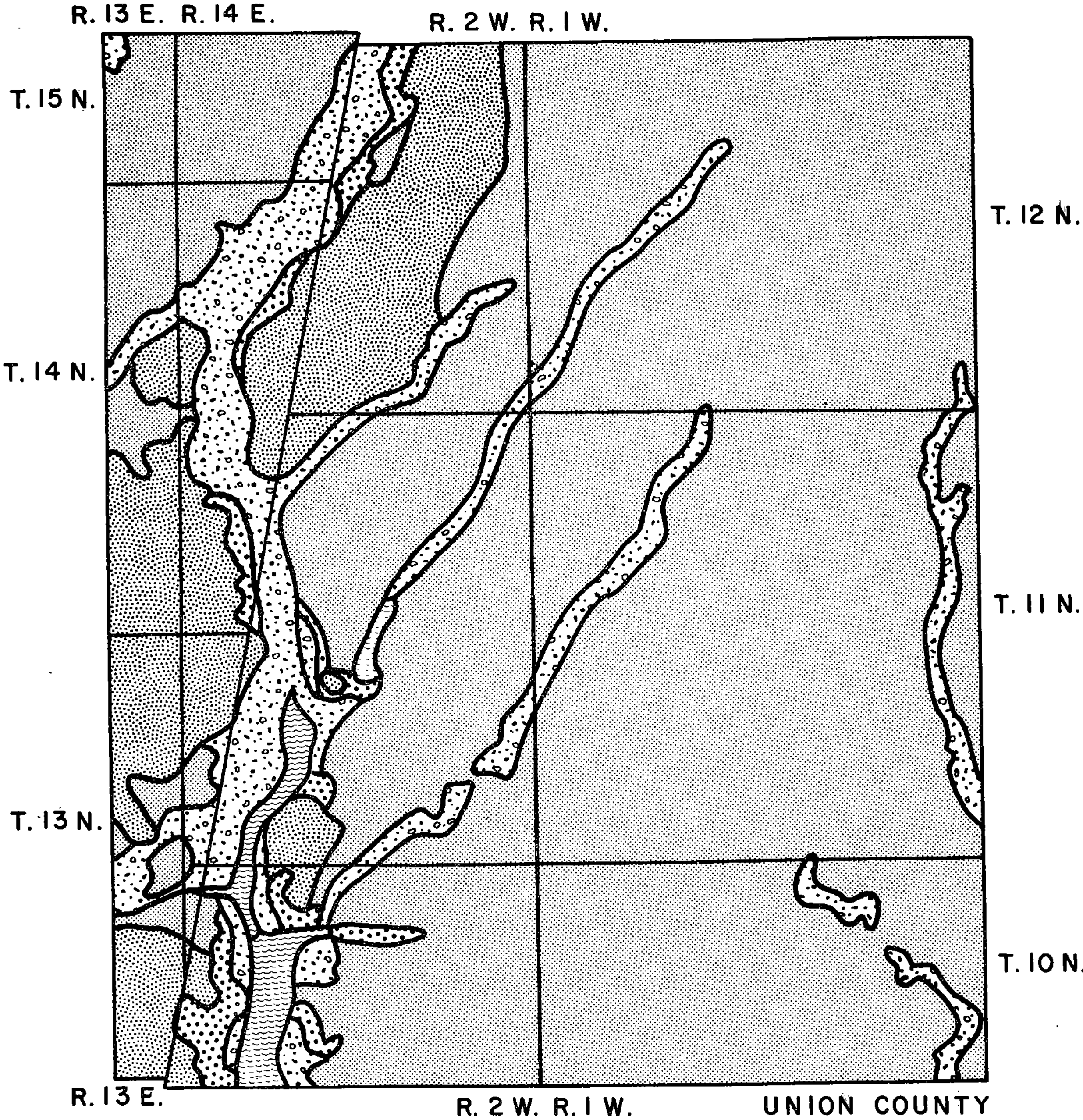
GLACIAL GEOLOGY

Union County was covered by ice sheets many times during the Quaternary Period, the most recent period of geologic time. Various types of unconsolidated deposits, including moraines, outwash, and valley trains, were left behind by the glaciers that covered the area.

Moraine is an accumulation of glacially transported material which is deposited directly from the glacier. The main component of moraine is till, an unsorted and unstratified deposit of clay, silt, sand, and rock debris. Because of the large amount of fine-grained sediment contained in most tills, they generally do not transmit large quantities of ground water to wells.

There are two main types of moraine, ground moraine and end moraine. Ground moraine is moraine having little topographic variation. It is usually thought of as being deposited beneath the glacier as lodgement till, although ablation till from the glacier surface may be included (Flint, 1971, pgs. 198-205). Most of the eastern two-thirds of Union County is covered with ground moraine (Figure 5).

End moraines are formed at the edges of active glaciers and are composed primarily of till, although they may have some stratified drift. End moraines may have a distinct ridge-like topographic form and may mark the farthest extent of an ice advance. End moraine deposits are found in western Union County (Figure 5).



Sand, Gravel and Silt Alluvium and Outwash Deposits

Bedrock, Veneer of Unconsolidated Materials thin or absent

Till, mostly as Ground moraine

Water (Brookville and Whitewater Lakes)

Till, mostly as End moraine

Figure 5. Surficial Deposits. Modified from Gray and others, 1972.

Outwash is a deposit of sorted, stratified material washed from the glacial margin by meltwaters. Fine materials, silts and clays, are usually washed away leaving the coarser grained sands and gravels. Outwash deposits confined to a valley are referred to as valley train deposits and may substantially fill the valley. The coarse-grained sediments of outwash deposits often make excellent aquifers.

Valley train deposits may be partially eroded by glacial meltwaters leaving outwash terraces along a valley wall. Terraces are former floodplain levels perched above present river levels. In Union County deposits of outwash, valley trains, outwash terraces, and recent alluvium are confined to the East Fork Whitewater River and its major tributaries (Figure 5).

GROUND-WATER AVAILABILITY

Ground-water availability is largely related to the glacial deposits, and quantities are limited in much of Union County. The principle aquifer systems are ice-contact glacial deposits, valley-train outwash deposits, and bedrock. Approximately 21 percent of the wells in the county produce from bedrock; the remainder produce from unconsolidated glacial deposits.

Union County is divided into four areas according to ground-water availability (Plate 4). The areas are ranked according to increasing ground-water availability; Area 1 has limited ground-water resources and Area 4 the greatest. The areas are also in order according to how much of the county they cover. Area 1 is the largest and Area 4 the smallest. Therefore, the least ground-water availability is found over the largest part of the county, whereas the greatest ground-water resources are found in only a small part of the county.

Area 1

Area 1 covers most of the southwestern half of the county and has the poorest ground-water resources (Plate 4, pink part). Aquifer systems in this area are the shaley Ordovician bedrock and the thin overlying glacial deposits. Approximately two-thirds of the wells in this area produce water from the unconsolidated deposits, and one-third produce from bedrock.

The bedrock units in this area are the Dillsboro and Whitewater Formations of the Maquoketa Group (Figure 2). The shaley nature of these rocks inhibits infiltration of water, because shale generally has very low permeability. The presence of till overlying the bedrock may further inhibit percolation and recharge of water to the bedrock aquifers. Bedrock wells in this area do not produce much water. Well yields range from 0 to 16 gallons per minute (gpm) with most bedrock wells producing less than 5 gpm. Although deep, large-diameter bedrock wells may have significant storage volume, they often have excessive drawdown when pumped, due to the limited permeability of the rocks.

The glacial deposits overlying bedrock in this area are commonly thin, 15 to 50 feet, and are predominantly tills (Figure 5). Scattered thin layers of sand may occur within the till. Because these glacial deposits are thin and mainly composed of relatively impermeable fine-grained sediments, wells developed in them usually yield little water.

Wells completed in the unconsolidated glacial materials in this area are usually of bucket-rig construction. These wells are large-diameter, 30- to 36-inch, shallow wells designed to capture and store the small amounts of water available from thin sand zones or fractures in the till. Because these wells cannot penetrate rock, they are limited in depth to the thickness of the unconsolidated materials overlying bedrock.

Wells in Area 1 which produce from the unconsolidated deposits commonly yield 5 gpm or less. A few wells produce 5 to 15 gpm. Dry holes are common, and often several wells must be drilled before an adequate ground-water supply is obtained.

Wells capable of producing less than 5 gpm are marginal for even domestic supply purposes. Some method of water storage is necessary for peak-use periods. Since the water availability is limited and many wells are shallow, wells may fail to yield adequate water during the dry summer months or during drought periods. Some well owners have water hauled in by truck to supplement marginal wells during dry periods.

Area 2

Area 2 occurs mainly in the northeast portion of Union County with a small portion in the northwest corner (Plate 4, brown part). This area has somewhat better ground-water resources than Area 1. Wells in this area are usually adequate for domestic purposes. Aquifers utilized in Area 2 are typically sand and gravel zones within the glacial deposits, although about 16 percent of the wells produce from bedrock.

Bedrock is mainly shale and limestone of the Ordovician Whitewater and Dillsboro Formations, but small areas of Silurian limestone and dolomite occur to the northeast and northwest (Figure 3). Bedrock wells in this area produce from 1 to 20 gpm, with usual yields of 5 to 10 gpm.

The unconsolidated materials in Area 2 are thicker than in Area 1. Wells in Area 2, therefore, are more likely to encounter a productive aquifer in the unconsolidated deposits, and bedrock wells are less common. In general the chances of obtaining a good ground-water supply are greater where the unconsolidated materials are thicker (Plate 3). Although the two buried valleys are not well tested they may have deep sand and gravel zones capable of good water yields.

Yields from wells which produce from the unconsolidated deposits range from 5 to 75 gpm but are usually from 5 to 15 gpm. High-capacity volumes of ground water, 70 gpm or greater, are unusual and cannot be expected in most cases. Dry holes are rare in Area 2, although bucket-rig wells are common in the less productive southern parts of the area.

Area 3

Area 3 lies in the northeast portion of the county (Plate 4, yellow part) and has better ground-water resources than Areas 1 and 2. Ground-water yields are more than adequate for most domestic purposes in this area. The bedrock is covered by 100 feet or more of glacially deposited sediment. These sediments are predominantly tills but have erratically distributed thin lenses of sand and gravel. Most wells in this area produce from these intertill sand and gravel lenses, although about 8 percent of the wells produce from bedrock.

The bedrock underlying this area is Silurian carbonate of the Brassfield Limestone and Salamonie Dolomite in the north, Ordovician Whitewater Formation in the middle part, and Ordovician Dillsboro Formation in the south. The few bedrock wells in this area produce from 6 to 10 gpm.

Most wells in this area which produce from the unconsolidated deposits are domestic wells yielding from 10 to 25 gpm. Two wells, each capable of producing 50 gpm, are registered with the Division of Water. Dry holes are not known in this area, and low-yield wells are rare. Because the sand and gravel aquifer zones are thin, development of high capacity quantities of ground water is unlikely. However, compared to most of the county, the ground-water conditions are good, at least for domestic water supplies. The unconsolidated deposits thicken to the north and east from Area 1 to Area 3 and the sand and gravel zones also become thicker and more numerous (Figures 4a and 4b).

Area 4

The most productive part of the county is Area 4, the valley-train outwash along the valley of the East Fork Whitewater River (Plate 4, blue part). In this area, thick deposits of sand and gravel were deposited by advancing glaciers and were washed, sorted, and redeposited along the East Fork Whitewater River valley by meltwaters from the subsequent glacial retreat. In some parts of this area, interbedded clays or sandy clays are present which split the outwash into two zones, an upper and a lower aquifer (Figure 4a). In these areas well yields may be reduced. In the southern part of the county, the outwash deposits are covered by Brookville Lake. To the north, these deposits are present as terraces and valley fill in the East Fork Whitewater River valley. The small communities of Dunlapsville and Brownsville are located on outwash terraces along the East Fork Whitewater River.

The bedrock underlying Area 4 is the Ordovician Dillsboro Formation. Because the unconsolidated deposits in this area are so productive, no water wells have been drilled into bedrock. Bedrock wells in the area are not expected to yield significant quantities of water.

Area 4 is the only part of Union County with potential for significant ground-water development. All high-capacity wells in Union

County are found in this area. Records of wells for Whitewater State Park, the Liberty well field, and Corps of Engineers test wells show that properly constructed, large-diameter wells are capable of yielding 200 to 300 gpm. All of these high-capacity wells are located in the southern part of the area. The northern parts of Area 4 have not been tested for high-capacity wells, but conditions are expected to be similar. Smaller diameter domestic wells throughout Area 4 produce 10 to 30 gpm. Dry holes or low-yield wells are unknown in this area.

High Capacity Wells

Indiana law requires any facility which has the capacity to withdraw 100,000 gallons of water per day, about 70 gpm, to be registered with the Indiana Department of Natural Resources, Division of Water. Registration is required whether the source is surface water, ground water, or a combination of the two. Such significant water withdrawal facilities are required to submit a tally of actual water use on an annual basis. The law applies to any facility capable of pumping 100,000 gallons per day (gpd), whether or not they actually withdraw that much water. The law also applies whether there is only one well or intake capable of producing the 100,000 gpd or several with a combined capacity of 100,000 gpd.

Three high-capacity ground-water facilities are registered in Union County. Whitewater State Park has two wells with a rated capacity of 200 gpm each, a combined capacity of 576,000 gpd. The town of Liberty has two registered wells capable of producing 250 and 320 gpm, or 820,800 gpd. Both of these facilities are in the southern part of Area 4 (Plate 4, blue part). The other registered facility is a fertilizer plant located in Area 3 (Plate 4, yellow part). This facility has two wells rated at 50 gpm each, a combined capacity of

144,000 gpd. Few, if any, facilities run their wells at full capacity 24 hours a day. The amount of water produced by a significant withdrawal facility is almost always much less than the rated capacity. Often the water use is seasonal, with demand significantly less during the winter months. In Union County, the Whitewater Park and fertilizer plant wells show seasonal use. Municipal well production is somewhat more consistent throughout the year.

POTENTIOMETRIC SURFACE

In confined aquifers, aquifers bounded by impermeable strata, the level of water standing in a well will be above the level of the aquifer, because confined aquifers are under hydrostatic pressure. When the elevation of water levels for many wells in an aquifer is plotted and contoured the surface defined is called the potentiometric surface and represents the confining pressure or hydrostatic head of each point in the aquifer. This surface does not indicate the level of the aquifer or the level at which water will be encountered, but rather the static level of water in a well which taps the aquifer.

Ground-water flows downgradient in a direction perpendicular to the contours of the potentiometric surface at a rate proportional to the hydraulic gradient, or change in water surface elevation over distance. Ground water usually flows from upland recharge areas to low-lying discharge areas along major surface water drainageways. The configuration of the potentiometric surface generally follows the topography of the land surface (Plate 5). A ground-water divide trends roughly north - south through eastern Union County following the trend of the surface water divide (Plate 1). East of the divide, ground water flows to Little Four Mile and Indian Creeks. West of the divide ground water flows to the East Fork Whitewater River and its tributaries. Potentiometric elevations range from about 1100 feet in the northeast to about 750 feet in southwest Union County. The potentiometric level rises and falls several feet seasonally and in response to precipitation events.

A potentiometric surface map is strictly valid only for a single, horizontal aquifer with horizontal flow (Freeze and Cherry, 1979, pg. 49). Since Plate 5 is countywide in scale and covers numerous aquifers it should be regarded as an approximation. In areas where there are shallow and deep aquifers, the potentiometric levels between the aquifers may be significantly different and vertical flow gradients between the aquifers will exist. Plate 5 can be used, however, to give a general idea of ground-water flow directions and the static water levels in wells.

From September, 1966 to July, 1974 the Division of Water in conjunction with the U.S. Geological Survey maintained an observation well in Union County as part of a statewide observation well network. The well, Union 6, was located east of Whitewater State Park, about 2 miles southwest of Liberty (Plate 1). This well was equipped with a recorder to continuously monitor ground-water levels. The well was drilled to a depth of 65 feet and measured the water levels in the bedrock of the Dillsboro Formation. Detailed records of water levels were kept from October, 1966 to September, 1971. From September, 1971 until July, 1974 water levels were measured twice a year, in the spring and fall. The well was removed from the observation well network in July, 1974.

The hydrograph (Figure 6), or water level record, of Union 6 shows the normal seasonal fluctuation of ground-water levels in the bedrock. Wells developed in the unconsolidated deposits will show a similar

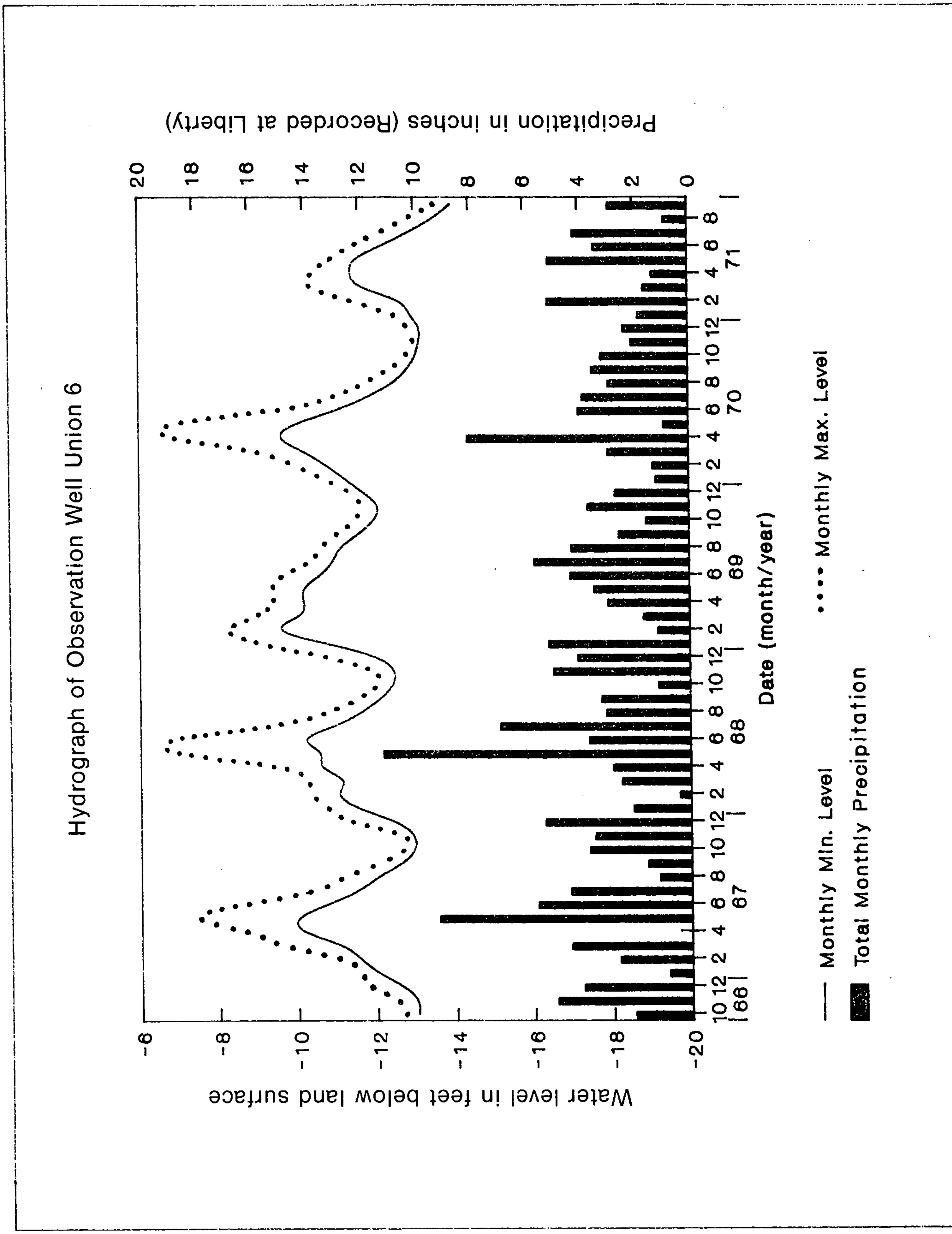

Hydrograph of Observation Well Union 6
Water level in feet below land surface
-6
-8
-10
-12
-14
-16
-18
-20
Precipitation in inches (Recorded at Liberty)
20
18
16
14
12
10
8
6
4
2
0
Date (month/year)
66
67
68
69
70
71
Monthly Min. Level
Monthly Max. Level
Total Monthly Precipitation

Figure 6

seasonal pattern. Water levels are highest in the spring and early summer months, April to June, and gradually decline to the lowest levels in late fall, from October to November. This pattern is due to increased evaporation and transpiration in the spring and summer. Evaporation of precipitation and transpiration by plants consume water and decrease the amount of water available to recharge aquifers. In the autumn when plants become dormant and evaporation decreases, a higher proportion of precipitation infiltrates and recharges aquifers. Ground-water levels begin to gradually increase until the next growing season. Minimum water levels in Union 6 fluctuated 3 to 5 feet between spring highs and autumn lows during the period of record (Figure 6).

The highest peaks on the hydrograph correspond to unusually wet months. Average annual precipitation for Union County is about 40 inches. The years 1966 and 1967 had nearly normal annual precipitation of about 39 and 42 inches, respectively. 1968 was a wetter than average year with almost 47 inches of precipitation. The year 1969 was nearly normal with almost 40 inches, whereas 1970 and 1971 were drier than normal, with less than 37 and about 35 inches of precipitation, respectively. The effect of the wet year, 1968, is shown on the hydrograph as a slightly elevated peak water level. The hydrograph clearly shows the decline in water levels during the dry period, late 1970 to 1971.

GROUND-WATER QUALITY

The Division of Water has on file the results of 34 analyses of well water from Union County (Table 1). Water samples from 18 wells (labelled "UC" on Table 1) were collected in the summer of 1988

Table 1

Ground Water Chemistry Data

Domestic Wells
Unconsolidated

Wells labeled WW sampled fall 1985, analyses by Indiana Department of Natural Resources, Geological Survey. Data previously published in Clendenon (1988, pgs. 120-125).
Wells labeled UC sampled summer 1988, analyses by Indiana State Board of Health.

Well Number	UC-1	UC-2	UC-3	UC-4	UC-5	UC-6	UC-7	UC-8	UC-12	UC-13	UC-14
Location											
Township	11N	11N	11N	11N	11N	11N	11N	10N	12N	12N	12N
Range	1W	1W	1W	1W	1W	2W	2W	1W	1W	1W	1W
Section	1	33	25	24	8	26	11	6	32	8	12
Well Depth	107	80	35	42	45	101	44	42	50	33	95
Chemical Constituents											
pH (field)	7.04	6.90	--	7.09	7.25	7.63	7.33	--	7.00	6.88	7.46
pH (lab)	6.90	7.00	7.10	7.10	7.10	7.30	7.10	7.20	7.00	7.10	7.40
Hardness	568.00	454.00	378.00	444.00	386.00	348.00	356.00	434.00	376.00	296.00	306.00
Alkalinity	306.00	328.00	278.00	300.00	338.00	356.00	322.00	274.00	382.00	276.00	350.00
Iron	<0.02	0.04	<0.02	1.50	0.31	1.60	<0.02	0.04	0.22	1.10	1.10
Manganese	<0.01	0.10	<0.01	0.17	0.18	0.01	0.08	<0.01	0.12	0.14	0.01
Calcium	143.00	134.00	96.00	114.00	97.00	80.00	96.00	112.00	106.00	82.00	78.00
Magnesium	51.00	28.00	34.00	38.00	34.00	36.00	28.00	37.00	27.00	22.00	27.00
Sodium	13.00	21.00	5.60	9.30	8.30	15.00	15.00	15.00	10.00	4.80	36.00
Potassium	16.00	2.00	0.80	1.00	1.10	1.30	1.60	3.00	1.40	0.70	1.00
Chloride	43.00	41.00	26.00	34.00	10.00	<5.00	18.00	21.00	<5.0	<5.0	<5.0
Sulfate	70.00	98.00	47.00	12.00	42.00	10.00	34.00	140.00	11.00	17.00	28.00
Phosphate	<0.09	<0.09	<0.09	<0.09	<0.09	<0.09	<0.09	<0.09	<0.09	<0.09	0.09
Fluoride	0.70	0.20	0.50	0.80	0.70	1.40	0.50	0.30	0.70	0.30	0.80
Nitrate	<0.1	0.60	3.40	0.10	<0.1	<0.1	1.20	0.30	<0.1	<0.1	<0.1
Temperature											
Degrees F.	61.20	65.10	--	60.40	65.10	68.20	56.50	--	57.70	62.10	57.20
Degrees C.	16.20	18.40	--	15.80	18.40	20.10	13.60	--	14.30	16.70	14.00

Values for all constituents have units of milligrams per liter (mg/l) except pH and temperature.
Milligrams per liter is approximately equal to parts per million (ppm) for fresh water.

Table 1

Ground Water Chemistry Data, Continued

Domestic Wells
Unconsolidated

Well Number	UC-15	UC-16	UC-18	WW-41	WW-44	WW-77	WW-86	WW-87	WW-102	WW-103	WW-104
Location											
Township	12N	12N	14N	12N	15N	11N	11N	14N	12N	11N	11N
Range	1W	2W	13E	1W	13E	2W	1W	13E	2W	1W	1W
Section	23	27	25	28	36	27	15	1	24	15	31
Well Depth	75	22	57	91	84	50	40	32	79	96	30
Chemical Constituents											
pH (field)	7.35	7.14	7.16	7.50	7.20	7.00	6.90	7.00	6.30	7.30	7.20
pH (lab)	7.40	7.10	7.00	--	--	--	--	--	--	--	--
Hardness	266.00	293.00	366.00	249.00	358.00	350.00	327.00	347.00	290.00	304.00	404.00
Alkalinity	320.00	246.00	226.00	355.00	351.20	321.80	288.10	305.10	325.30	406.10	325.90
Iron	1.40	<0.02	<0.02	1.60	1.30	<0.1	<0.1	<0.1	1.70	0.90	<0.1
Manganese	0.07	<0.01	<0.01	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Calcium	70.00	89.00	109.00	58.00	91.90	91.30	87.20	94.00	69.40	68.00	101.00
Magnesium	22.00	17.00	23.00	25.40	31.30	29.70	26.50	27.40	28.50	32.80	36.80
Sodium	41.00	3.90	5.20	46.00	5.00	5.50	11.30	6.50	6.80	38.40	6.20
Potassium	1.00	1.00	0.60	0.70	0.40	0.50	3.30	0.70	0.50	1.00	0.70
Chloride	<5.0	13.00	35.00	2.50	2.60	8.00	15.10	17.10	1.40	1.90	16.40
Sulfate	10.00	37.00	62.00	<0.1	20.40	37.00	37.10	38.20	3.70	<0.1	61.40
Phosphate	<0.09	<0.09	<0.09	--	--	--	--	--	--	--	--
Fluoride	1.10	0.30	0.20	0.30	0.30	0.10	0.40	0.20	0.50	0.70	0.50
Nitrate	0.10	2.10	7.80	<0.02	<0.02	2.80	3.20	3.20	<0.02	<0.02	<0.02
Temperature											
Degrees F.	59.00	54.30	58.80	56.50	55.00	56.00	58.20	58.20	56.70	55.80	56.20
Degrees C.	15.00	12.40	14.90	13.60	12.80	13.35	14.55	14.55	13.70	13.20	13.45

Table 1

Ground Water Chemistry Data, Continued

Domestic Wells
Unconsolidated

Well Number

Location

	Minimum Value	Maximum Value	Average Value	Standard Deviation
Well Depth	22	107	60.45	26.86
Chemical Constituents				
pH (field)	6.30	7.63	7.13	0.29
pH (lab)	6.90	7.40	7.13	0.15
Hardness	249.00	568.00	359.09	72.39
Alkalinity	226.00	406.10	317.30	42.49
Iron	<0.02	1.70	--	--
Manganese	<0.01	0.18	--	--
Calcium	58.00	143.00	93.95	20.69
Magnesium	17.00	51.00	30.11	7.21
Sodium	3.90	46.00	14.95	13.09
Potassium	0.40	16.00	1.83	3.25
Chloride	1.40	43.00	18.00	13.66
Sulfate	3.70	140.00	40.79	33.33
Phosphate	<0.09	0.09	--	--
Fluoride	0.10	1.40	0.52	0.32
Nitrate	<0.01	7.80	--	--
Temperature				
Degrees F.	54.30	68.20	58.91	3.73
Degrees C.	12.40	20.10	14.95	2.07

Table 1

Ground Water Chemistry Data, Continued

Domestic Wells
Bedrock

Well Number	UC-9	UC-10	UC-11	UC-17	WW-85				
Location									
Township	10N	10N	10N	12N	11N				
Range	1W	1W	2W	2W	1W	Minimum	Maximum	Average	Standard
Section	12	15	2	12	21	Value	Value	Value	Deviation
Well Depth	40	80	45	122	208	40	208	99.00	69.22
Chemical Constituents									
pH (field)	7.14	7.30	7.11	7.06	7.30	7.06	7.30	7.18	0.11
pH (lab)	7.00	7.00	7.10	7.30	--	7.00	7.30	7.10	0.14
Hardness	412.00	454.00	314.00	363.00	259.00	259.00	454.00	360.40	77.24
Alkalinity	316.00	312.00	246.00	308.00	211.80	211.80	316.00	278.76	47.18
Iron	<0.02	0.15	<0.02	<0.02	1.90	<0.02	1.90	--	--
Manganese	<0.01	0.02	<0.01	0.01	<0.1	<0.01	0.02	--	--
Calcium	112.00	126.00	83.00	90.00	58.60	58.60	126.00	93.92	26.16
Magnesium	32.00	34.00	26.00	33.00	27.50	26.00	34.00	30.50	3.54
Sodium	9.40	26.00	3.10	4.40	365.40	3.10	365.40	81.66	158.88
Potassium	4.10	21.00	0.70	1.70	5.10	0.70	21.00	6.52	8.29
Chloride	26.00	58.00	7.00	15.00	640.00	7.00	640.00	149.20	275.05
Sulfate	48.00	100.00	37.00	40.00	<0.1	<0.1	100.00	--	--
Phosphate	<0.09	<0.09	<0.09	<0.09	--	<0.09	<0.09	--	--
Fluoride	0.20	0.60	0.20	0.20	0.40	0.20	0.60	0.32	0.18
Nitrate	11.00	8.60	5.90	0.10	<0.2	<0.2	11.00	--	--
Temperature									
Degrees F.	63.50	60.30	58.50	59.00	56.80	56.80	63.50	59.62	2.51
Degrees C.	17.50	15.70	14.70	15.00	13.80	13.80	17.50	15.34	1.39

Table 1

Ground Water Chemistry Data, Continued

Municipal, Public Supply, and Observation Wells

Well	Liberty No.1	Liberty Old	Dunlapsville N	Dunlapsville S	Union 6 Br - Obs	Brookville Reservoir	Whitewater State Park
Location							
Township	14N	11N	11N	11N	11N	14N	11N
Range	14E	1W	2W	2W	2W	14E	2W
Section	21	6	21	28	14	29	15
Well Depth	42	56	39	60	65	55	38
Chemical Constituents							
pH (field)	7.5	7.8	7.1	7.7	7.6	--	--
pH (lab)	--	--	--	--	--	7.20	6.90
Hardness	306.00	408.00	314.00	282.00	294.00	402.00	334.00
Alkalinity	241.00	356.00	266.00	236.00	357.00	344.00	302.00
Iron	0.20	1.20	<0.1	<0.1	0.66	0.20	<0.1
Manganese	0.03	0.20	<0.02	<0.02	26.00	0.02	<0.02
Calcium	77.00	104.00	80.00	72.00	75.00	115.00	86.00
Magnesium	28.00	36.00	28.00	25.00	26.00	28.00	28.00
Sodium	10.00	9.00	4.00	4.00	88.00	3.00	6.00
Potassium	2.00	1.00	2.00	5.00	6.00	2.00	2.00
Chloride	13.00	10.00	5.00	8.00	74.00	16.00	13.00
Sulfate	46.00	54.00	38.00	32.00	12.00	28.00	27.00
Phosphate	--	--	--	--	--	<0.1	<0.1
Fluoride	4.70	0.20	0.20	0.20	0.50	0.20	0.20
Nitrate	3.00	0.10	0.50	4.10	0.10	5.80	0.50
Temperature							
Degrees F.	--	--	--	--	--	--	--
Degrees C.	--	--	--	--	--	--	--

All wells except Union 6 are developed in unconsolidated deposits.
Data for wells except Whitewater State Park previously published in Clendenon (1988, pg. 125).
Wells sampled 1958-1978, analyses from different sources.

by the Division and were analyzed by the State Board of Health. Nine samples (labelled "WW" on Table 1) were collected in the fall of 1985 by the Division and were analyzed by the Indiana Geological Survey. The results of samples marked "WW" were previously published in Clendenon (1988, pgs. 121-125) as part of a study of the Whitewater River Basin. The seven remaining samples were collected and analyzed by various agencies between 1958 and 1978.

The water samples collected by the Division of Water were analyzed to determine the natural inorganic quality of the ground water of Union County. The samples were not tested for contaminants or pollutants such as bacteria, organic compounds, or pesticides.

The samples were obtained from household wells and were collected from a water tap as close as possible to the well. Special care was taken to avoid sampling water which had been softened. Since the samples were collected from the household plumbing system and not directly from the well, the results of the analyses may not exactly represent the true nature of the ground water. Chemical changes may occur in the plumbing system which alter the concentrations of ground water constituents. Prior to sampling, the wells were purged for 15 to 30 minutes. Temperature and pH were measured in the field prior to sample collection. An attempt was made to evenly distribute the samples across the county. The location of sample sites is shown on Plate 1.

The U.S. Environmental Protection Agency has established limits for common chemical constituents in public drinking-water supplies. These limits do not apply to private water supplies but may be useful as guidelines in interpreting the analyses presented in Table 1. Primary standards (Table 2), or maximum concentration levels (MCL), are legally enforceable limits for a particular constituent in a

Table 2

Maximum levels for selected inorganic chemical constituents in drinking water.

MCL are primary, enforceable limits for public drinking water supplies. RMCL are secondary, recommended limits.

All values except pH are in milligrams per liter (mg/l): Milligrams per liter are approximately equal to parts per million (ppm) for fresh water.

Constituent	Value	MCL/RMCL	Reference
Arsenic	0.05	MCL	EPA, 1986a
Barium	1.0	MCL	EPA, 1986a
Cadmium	0.01	MCL	EPA, 1986a
Chloride	250.0	RMCL	EPA, 1979
Chromium	0.05	MCL	EPA, 1986a
Copper	1.0	RMCL	EPA, 1979
Fluoride	4.0	MCL	EPA, 1986b
Fluoride	2.0	RMCL	EPA, 1986b
Iron	0.3	RMCL	EPA, 1979
Lead	0.05	MCL	EPA, 1986a
Manganese	0.05	RMCL	EPA, 1979
Mercury	0.002	MCL	EPA, 1986a
Nitrate (as Nitrogen)	10.0	MCL	EPA, 1986a
Selenium	0.01	MCL	EPA, 1986a
Silver	0.05	MCL	EPA, 1986a
Sulfate	250.0	RMCL	EPA, 1979
Zinc	5.0	RMCL	EPA, 1979
pH	6.5-8.5	RMCL	EPA, 1979

U. S. Environmental Protection Agency, 1979, 1986a, 1986b.

public water supply. Constituents covered by primary standards usually involve a health hazard if consumed in excessive amounts. Secondary standards (Table 2), or recommended maximum contaminant levels (RMCL), are recommended limits but are not enforceable. Constituents covered by secondary standards are usually nuisance parameters which may affect the potability of the water but which are not detrimental to health. The significance of some common ground-water constituents is presented in Table 3.

Results of the ground-water sampling performed by the Division of Water are discussed below. Other data are not discussed because the wells are of different types and sampling and analysis techniques are unknown. The data are subdivided according to well type; wells producing from bedrock aquifers and wells producing from unconsolidated deposits. The two types of wells may be expected to have significant differences in chemical constituents. The results of the analyses on file at the Division of Water for Union County are presented in Table 1 along with the range of values and the average value for each constituent.

Values of pH for all wells sampled were within or close to the RMCL of 6.5 to 8.5. Most of the water samples were slightly alkaline with average pH values of 7.1 for the unconsolidated wells and about 7.2 for the bedrock wells. All bedrock wells had a pH greater than 7.0. Three of the 22 unconsolidated wells were slightly acidic, with pH about 6.9, and one well had a pH of 6.3, slightly less than the RMCL of 6.5.

All wells sampled had hardness values of about 250 parts per million (ppm) or greater, considerably above the 180 ppm value for very hard water (Clark, 1980, pg. 80). Bedrock and unconsolidated wells had nearly equal average hardness. Most of the homes where

Table 3

Significance of Selected Chemical Constituents of Ground Water

Constituent	Significance
pH	The pH of water is a measure of the degree of the acidity or alkalinity and is expressed in values ranging from 0 to 14. A pH of 7 is neutral. Values less than 7 are acidic and over 7 are alkaline. The normal range of pH values in Indiana is close to neutral, 6.5 to 8.0. Values in this range have no adverse significance for most users. The U.S. Environmental Protection Agency (EPA) has a recommended (secondary) range of pH values in drinking water from 6.5 to 8.5.
Hardness ($CaCO_3$)	Hardness is due to the presence of calcium and magnesium compounds such as bicarbonates, sulfates, and chlorides and is expressed as the calcium carbonate ($CaCO_3$) equivalent of these compounds. Water with values of 120 to 180 parts per million (ppm) is considered hard, and values greater than 180 ppm are considered very hard. The normal range of hardness in Indiana ground water is 200 to 400 ppm. At hardness values of 200 ppm or greater water is commonly softened for household use. Hardness is a nuisance property in water and is not a health hazard. Consequences of hard water include reduced cleaning ability of soaps and detergents and the formation of soap scum. High hardness levels may cause lime and scale deposits to form in water heaters and pipes reducing efficiency and increasing repair costs.
Iron (Fe)	Iron is found in solution naturally in ground water. It is commonly found in amounts greater than 0.5 ppm in Indiana. The U.S. EPA has a recommended limit of 0.3 ppm iron in drinking water. When exposed to oxygen the iron oxidizes to an insoluble form and precipitates out of solution. The oxidized iron is brown to yellow and may stain laundry and plumbing fixtures. Iron may encrust and clog well screens and pipes. Ground water with excessive iron favors the growth of iron bacteria which may further clog and degrade wells. Iron also imparts a taste to water but is not a health hazard.

Table 3 Continued

Constituent	Significance
Manganese (Mn)	Manganese is similar to iron in its behavior and characteristics but is usually found in lower concentrations in ground water. Manganese values in Indiana normally range from 0.01 to 1.0 ppm. The EPA has recommended a limit of 0.05 ppm in drinking water. Like iron, manganese is not a health hazard. The recommended limit is due to aesthetic considerations. Encrusting and clogging of well screens and staining may occur with elevated values of manganese.
Chloride (Cl)	Chlorides are usually found in Indiana ground water in concentrations between 10 and 50 ppm. The EPA recommended limit is 250 ppm. Water with less than 150 ppm chloride is usually satisfactory for most purposes. At 500 ppm the water frequently will have a disagreeable taste. Sand and gravel aquifers will usually have a low chloride concentration, whereas bedrock aquifers will often have higher amounts. In bedrock aquifers chloride concentrations usually increase with depth. In shallow aquifers elevated chloride may be associated with contamination from road salting. In conjunction with elevated nitrates high chlorides may indicate sewage contamination.
Sulfate (SO_4)	Sulfates normally range from 0 to 1,000 ppm in Indiana ground water. The recommended limit for sulfates is 250 ppm. Concentrations in Indiana vary widely according to rock type, well depth, and location. High concentrations of sulfates may form slimes, encrust wells, or cause odor problems in water. Sulfates in concentrations of 250 ppm or greater may act as a laxative for people unaccustomed to drinking the water.
Fluoride (Fl)	Fluoride normally occurs in Indiana ground water at concentrations between 0.1 and 1.5 ppm. The EPA has set a primary fluoride limit at 4 ppm and a secondary limit at 2 ppm for public drinking water supplies. Small amounts of fluoride are considered to be beneficial in preventing tooth decay. Many public water utilities add fluoride to their water supplies. Depending on local average temperature concentrations from 1.4 to 2.4 ppm may be added. Higher amounts of fluoride may cause mottling of tooth enamel, and teeth may become brittle.

Table 3 Continued

Constituent	Significance
Nitrate (NO_3)	Naturally occurring nitrate normally occurs in concentrations from 0.1 to 3.0 ppm in Indiana. The EPA has set a primary limit of 45 ppm nitrate or 10 ppm nitrogen as nitrate. Nitrates in concentrations from 20 to 50 ppm produce a bitter taste in water. At levels as low as 5 ppm nitrates can cause a blood oxygen deficiency in infants called methemoglobinemia. Older children and adults are not susceptible to this condition. Elevated levels of nitrate in ground water often is an indicator of contamination. Sources of nitrate include human or animal waste and agricultural chemicals. If the source of the nitrate is sewage elevated chloride levels would also be expected. A well with high nitrates should be tested for bacterial contamination.

Clark, 1980, pgs. 80-81
Driscoll, 1986, pgs. 97-104

samples were collected had water softeners and used softened water for cleaning and cooking.

Ten of 22 unconsolidated wells had iron above the 0.3 ppm RMCL whereas only one bedrock well had elevated iron. Iron ranged as high as 1.70 ppm in the unconsolidated wells and 1.90 ppm in the bedrock wells. All bedrock wells were below the 0.05 ppm RMCL for manganese. Fifteen of the unconsolidated wells were below the RMCL or below the analytical detection limit. Manganese values ranged up to 1.80 ppm for the unconsolidated wells.

Only one well had chloride levels above the RMCL of 250 ppm. This well produces from bedrock and had a chloride value of 640 ppm. The well is 208 feet deep, the deepest well sampled. Water in bedrock usually becomes increasingly mineralized with depth; however, elevated chlorides may also indicate a contamination problem. Because the well is deep, had elevated sodium in addition to chloride, and had no detectable nitrate, the elevated chlorides were probably naturally occurring and not indicative of contamination. The rest of the wells had chloride levels well below the RMCL.

Fluoride values for both bedrock and unconsolidated wells were all less than the RMCL of 2.0 ppm. Average values were 0.32 ppm for bedrock and 0.52 ppm for unconsolidated wells. Maximum values were 0.6 ppm for bedrock and 1.4 ppm for unconsolidated wells.

Values of nitrate as nitrogen ranged up to 7.8 ppm for the unconsolidated wells and up to 11.0 ppm for the bedrock wells. The MCL for nitrate as nitrogen is 10.0 ppm. Madison and Brunett (1984, pg. 95) suggest nitrate values in excess of 3.0 ppm may indicate elevated concentrations due to human activities. They found elevated nitrates usually occur in wells less than 100 feet deep.

Of the five bedrock wells sampled three had nitrate in excess of 3.0 ppm. The two bedrock wells with low nitrate were the deepest wells, each more than 120 feet deep. Four of the 22 unconsolidated wells had nitrate in excess of 3.0 ppm. All four of these wells were shallower than the average well depth of approximately 60 feet. All unconsolidated wells of average or greater depth had low nitrate levels, 1.0 ppm or less.

CONTAMINATION POTENTIAL

The susceptibility of an aquifer to contamination depends on the permeability of the aquifer and overlying units, depth to the aquifer or water table, and proximity to sources of contamination. The portion of Union County in Area 4 (Plate 4, blue part), is the most susceptible to ground water contamination. This area has thick, highly permeable deposits of outwash sand and gravel and a shallow water level allowing surface contaminants to infiltrate and migrate quickly with little mitigation. In some parts of this area clay layers may provide some protection to the underlying confined aquifers. Wells in this area are commonly shallow increasing the potential risk to ground-water users.

Area 1 (Plate 4, pink part) is probably the next most susceptible area to ground-water contamination, although much less susceptible than Area 4. The surficial materials in Area 1 are mostly tills which are relatively impermeable, but thin, and many wells in this area are shallow. Contaminants will not migrate quickly through these sediments, but shallow or improperly constructed wells near a contamination site may be vulnerable.

Areas 2 and 3 (Plate 4, brown and yellow parts) are the least susceptible areas to ground-water contamination. These areas have thick deposits of fine-grained materials which will inhibit contaminant infiltration and migration. Wells in these areas are generally deeper than those in Area 1. The deeper confined aquifers in these areas are well protected, but shallow wells may be at risk if near a potential source of contamination.

SUMMARY

The geologic conditions and ground-water availability and quality for Union County were evaluated using well-log data, previously published geologic reports, and the results from analyses of ground water samples collected by the Division of Water.

The bedrock of Union County consists of the Ordovician Age Dillsboro and Whitewater Formations and the Brassfield Limestone and Salamonie Dolomite of Silurian Age. Most of the county is underlain by Ordovician-Age rocks, but Silurian rocks occur in small areas to the northeast and northwest. The Dillsboro and Whitewater Formations consist primarily of shale with interbedded limestone. The Brassfield Limestone and the Salamonie Dolomite are relatively pure carbonates unlike the shaley Ordovician rocks.

The unconsolidated deposits of Union County are the product of multiple episodes of glacial deposition. Most of the county is covered with till. Meltwaters from retreating glaciers deposited outwash sand and gravel in the East Fork Whitewater River valley. The unconsolidated deposits are thickest in northeast Union County, along the East Fork Whitewater River, and over the two large, buried valleys in eastern Union County.

Four areas of ground-water availability are defined for the county. Area 1 (Plate 4, pink part) covers about half the county and has expected well yields of 0 to 5 gpm. Wells in Areas 2 and 3 (Plate 4, brown and yellow parts) usually will yield quantities of ground water sufficient for domestic purposes, 5 to 25 gpm, but generally will not yield high-capacity ground water volumes. Area 4 (Plate 4, blue part) is the only area capable of yielding high-capacity volumes. Yields up to several hundred gpm may be expected in this area for properly designed, large-diameter wells. Because of the shaley nature of the bedrock over most of the county, wells in bedrock are only capable of producing 0 to 20 gpm.

Inorganic ground-water quality is generally good. Of 27 wells sampled, 22 in unconsolidated materials and five bedrock wells, all showed excessive hardness. Ten unconsolidated and one bedrock well had iron above the RMCL, and seven unconsolidated wells had manganese above the RMCL. One bedrock well had elevated chlorides, and one bedrock well showed nitrate above the MCL.

Aquifers of Areas 1, 2, and 3 are relatively resistant to contamination from surficial sources due to the impermeable nature of the unconsolidated deposits. Area 4 is highly susceptible to contamination because of the permeable deposits and shallow water levels.

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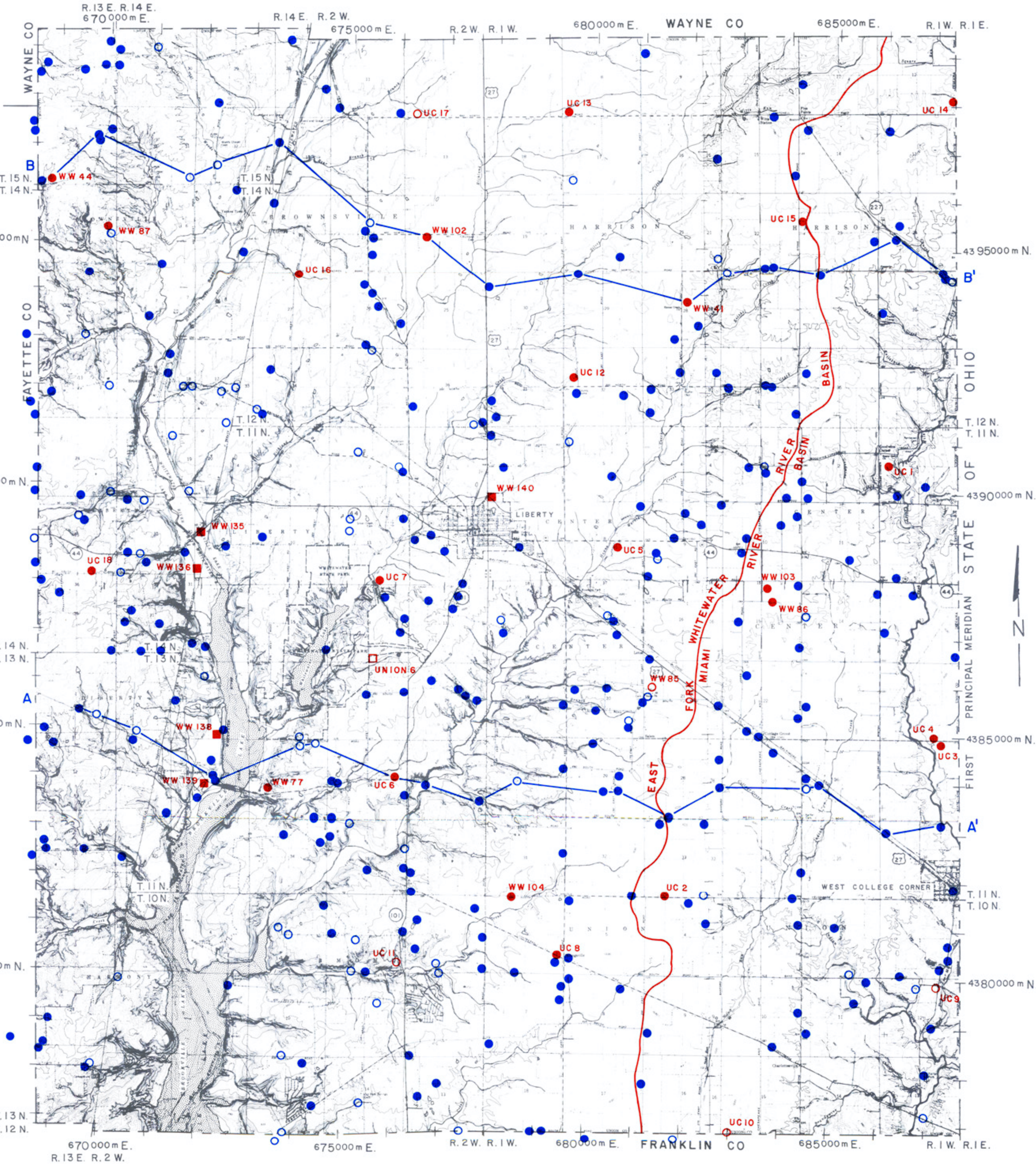
DEPARTMENT OF NATURAL RESOURCES

DIVISION OF WATER



Compiled from USGS 1:24000 scale topographic maps.

SCALE 1:48000

1 0 1 2 3 4 MILES

5000 0 5000 10000 15000 20000 FEET

1 0 1 2 3 4 5 6 KILOMETERS

UNION COUNTY

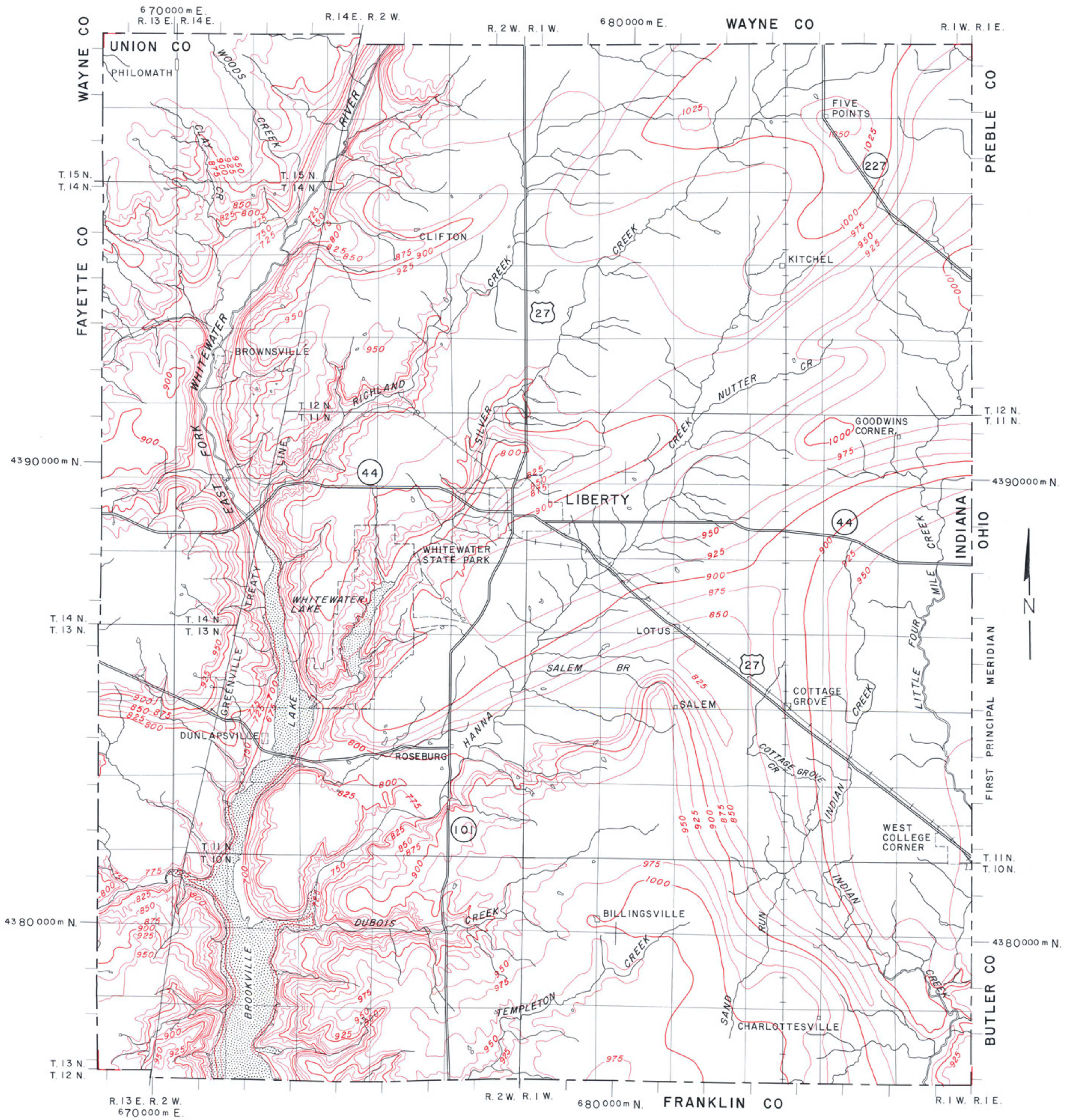
LEGEND

- Domestic Water Well Finished In Unconsolidated Deposits.
- Domestic Water Well Finished In Bedrock.
- A — A' Cross Section Profile
- Municipal, Industrial, or Test Well.
- WW 140 Wells Sampled Fall of 1985 Whitewater River Basin Study.
- UC5 Wells Sampled in 1988 Union County Study.
- UNION 6 Observation Well

Map Showing Surficial Topography, Basin Drainage Divide, Well Locations, and Cross Section Locations.

DEPARTMENT OF NATURAL RESOURCES

DIVISION OF WATER



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SCALE 1:48000

1 0 1 2 3 4 MILES

5000 0 5000 10000 15000 20000 FEET

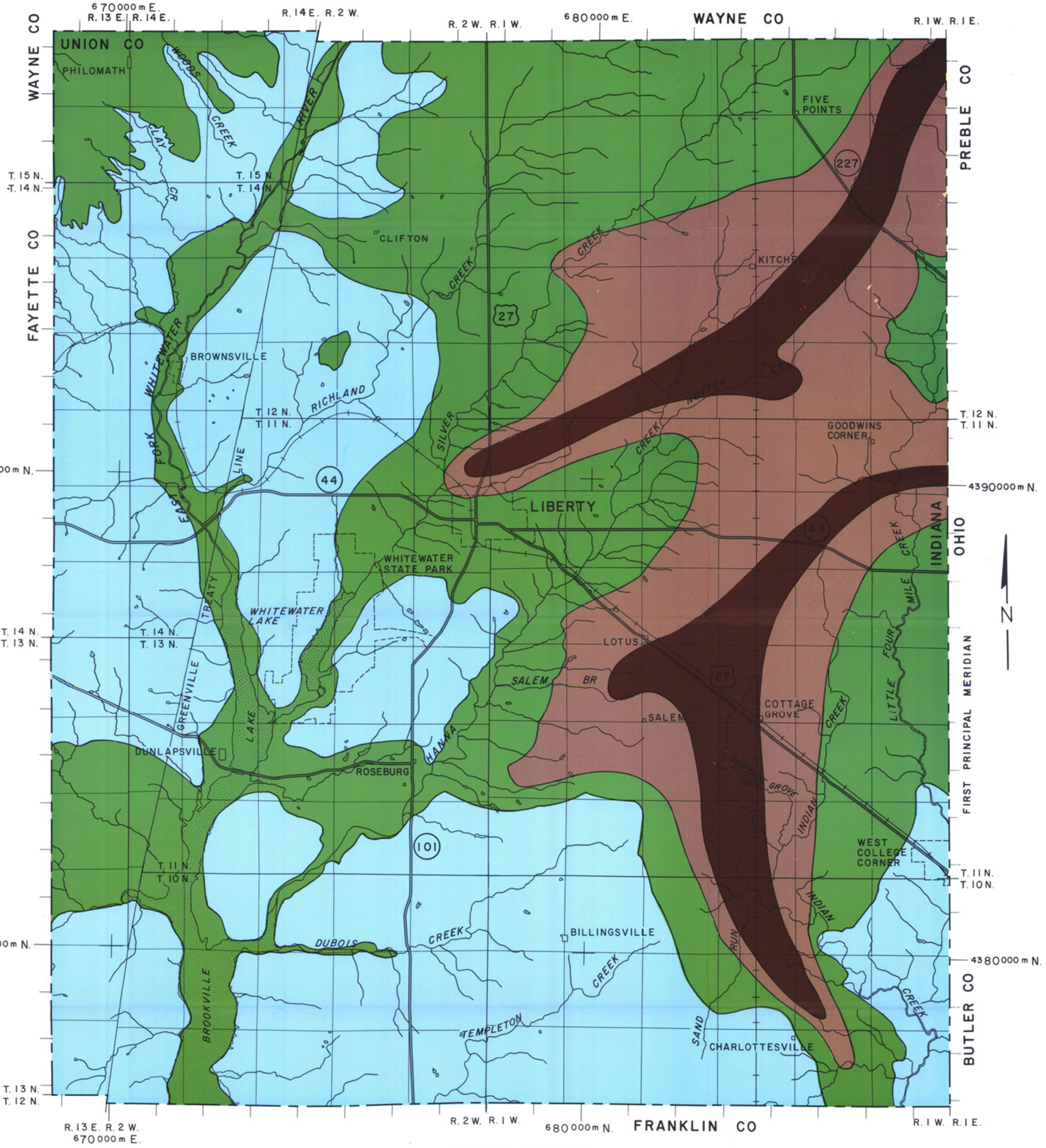
1 0 1 2 3 4 5 6 KILOMETERS

CONTOUR INTERVAL 25 FEET

UNION COUNTY

BEDROCK TOPOGRAPHY MAP

DEPARTMENT OF NATURAL RESOURCES DIVISION OF WATER



SCALE 1: 48 000

Compiled from USGS 1:24000 scale topographic maps.

UNION COUNTY

1 0 1 2 3 4 MILES

5000 0 5000 10000 15000 20000 FEET

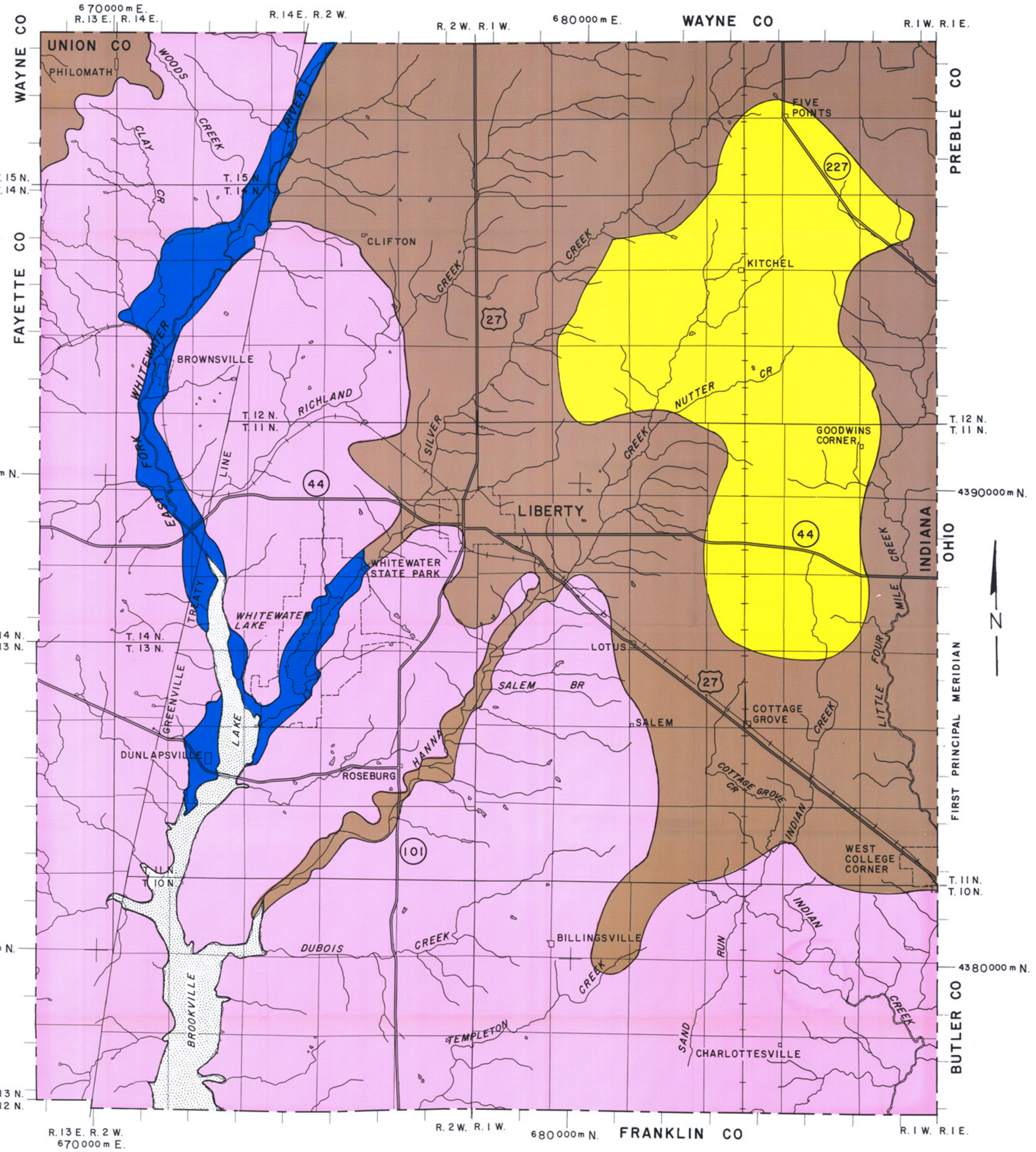
1 0 1 2 3 4 5 6 KILOMETERS

0-50' 50-100' 100-150' > 150'

UNCONSOLIDATED DEPOSITS THICKNESS MAP

DEPARTMENT OF NATURAL RESOURCES

DIVISION OF WATER



Compiled from USGS 1:24000 scale topographic maps.

SCALE 1:48 000

1 0 1 2 3 4 MILES

5000 0 5000 10000 15000 20000 FEET

1 0 1 2 3 4 5 6 KILOMETERS

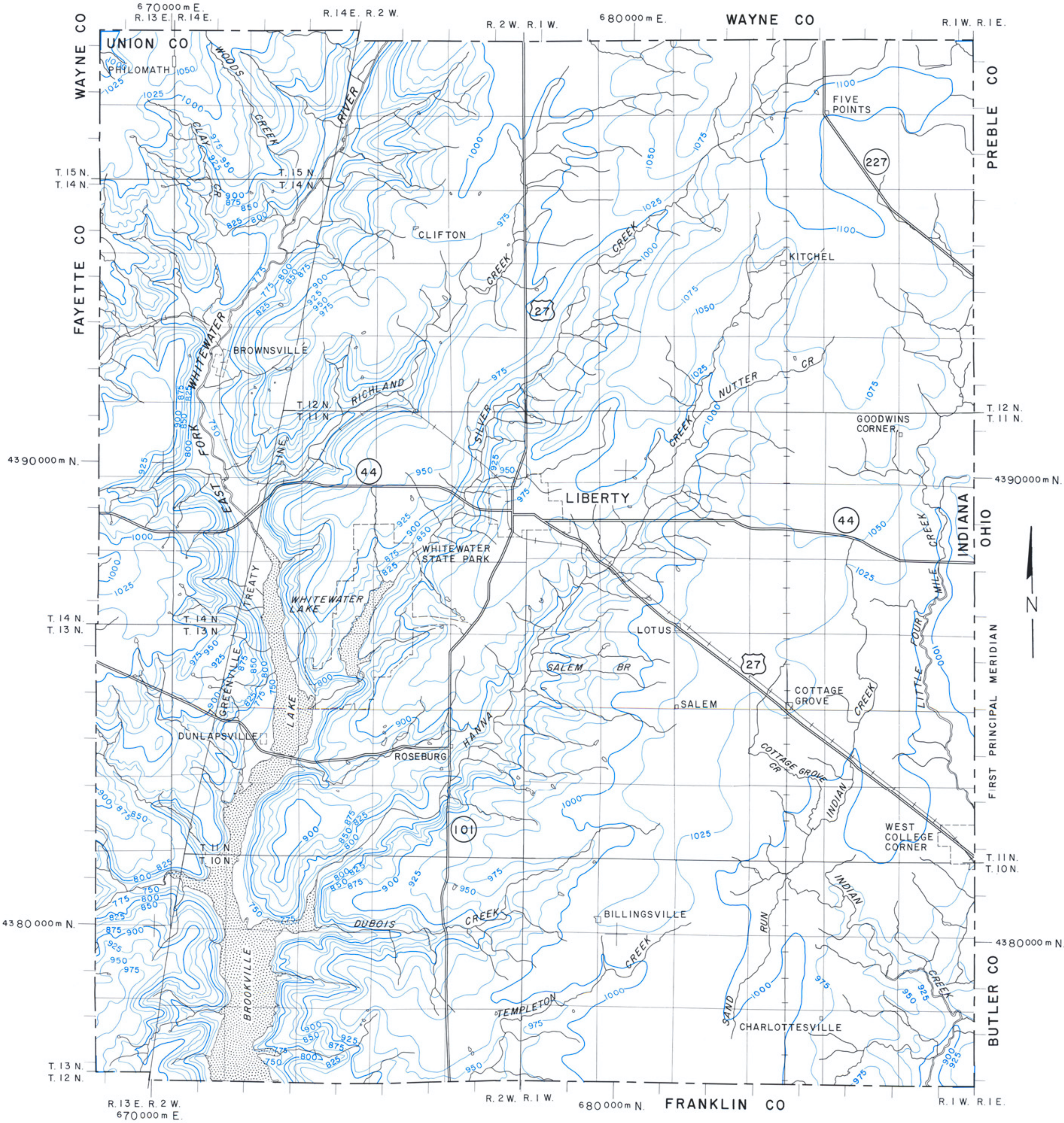
UNION COUNTY

0–5 GPM | 5–15 GPM | 15–25 GPM | OVER 25 GPM

GROUND WATER AVAILIBILITY MAP

DEPARTMENT OF NATURAL RESOURCES

DIVISION OF WATER



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SCALE 1:48000

1 0 1 2 3 4 MILES

5000 0 5000 10000 15000 20000 FEET

1 0 1 2 3 4 5 6 KILOMETERS

CONTOUR INTERVAL 25 FEET

UNION COUNTY

POTENTIOMETRIC SURFACE MAP