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HYDROGEOLOGY OF THE PRINCIPAL AQUIFERS IN VIGO AND CLAY COUNTIES, INDIANA

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GEOLOGICAL SURVEY
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Robert F. Jackson, Chief

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ABSTRACT

The rocks which immediately underlie Vigo and Clay Counties may be placed in two general categories--consolidated and unconsolidated. The consolidated rocks contain six sandstone bodies that are extensive enough to be considered important aquifers. Yields from wells tapping these aquifers average 6.6 gpm. The total amount of water in storage in the mapped areas of these aquifers is estimated to be 523 million gallons. The estimated current withdrawal is 1.8 mgd.

Aquifers in the unconsolidated deposits of the two-county area consist of relatively clean, coarse-textured sand and gravel deposited as glacial outwash. The sand and gravel deposits of the Wabash River valley form the most productive aquifer of the entire area with yields of as much as 2,700 gpm reported. Both confined and unconfined areas are present in this aquifer. The estimated regional value of transmissibility for the confined area of this aquifer is 5,100 gpd per foot and in the unconfined area 72,000 gpd per foot. There is estimated to be 367,800 million gallons of water in storage in the Wabash River valley aquifer. The estimated current daily withdrawals by wells tapping this aquifer is 22.2 million gallons.

On the basis of the partial analysis of more than 750 water samples and the complete analysis of 35 samples in the consolidated rocks of the Vigo-Clay County area yield calcium bicarbonate, sodium bicarbonate, and sodium chloride water, while the unconsolidated rocks of the area yield calcium bicarbonate water.

INTRODUCTION

Purpose and Scope

This investigation, part of the state-wide investigation of the ground-water resources of Indiana, was planned to identify and map the principal aquifers in Vigo and Clay Counties; to determine their hydrologic characteristics and to ascertain and interpret the chemical quality of the water. This report presents an evaluation of the ground-water resources of the Vigo-Clay County area and provides information to aid in their location and development. Standard methods of investigation were used.

Previous Investigations

Detailed studies of the ground-water resources of the Vigo-Clay area have not been made previously. However, a reconnaissance of these resources was published in reports by Leverett (1897 and 1905) and Harrell (1935). Preliminary data and evaluations of the ground-water resources of both Clay and Vigo Counties were published separately (Watkins and Jordan, 1962, 1963).

Cooperation and Acknowledgments

The investigation of the ground-water resources of these counties has been conducted by the U. S. Department of the Interior, Geological Survey, in cooperation with the Department of Natural Resources, Division of Water. The authors express sincere thanks to all persons who contributed time, information, and assistance during the collection, tabulation and processing of data for this report. Among these are the following agencies of the Indiana Department of Natural Resources: the Geological Survey, the Division of Oil and Gas, and the Division of Water.

GEOGRAPHY

Physiography and Climate

The Vigo-Clay County area in west-central Indiana (fig. 1), is generally characterized by wide alluvial plains and aggraded valleys. This area is of low relief in comparison with surrounding areas. The most prominent physiographic feature of the two-county area is the Wabash River valley, which ranges from five to six miles in width and extends the entire length of western Vigo County. The area is drained by the Wabash and Eel Rivers and their tributaries.

Vigo and Clay Counties lie mostly within the Wabash Lowland physiographic province. However, the Tipton Till Plain extends into the northwest corner of Vigo County, and a small area on the eastern edge of Clay County is in the Crawford Upland. These physiographic units are those described by Malott (1922, p. 56-256).

Continous records of the air temperature and precipitation at Terre Haute, Indiana have been kept since 1894 by the U. S. Weather Bureau. Based on normals for the period 1931-1960 the average annual precipitation

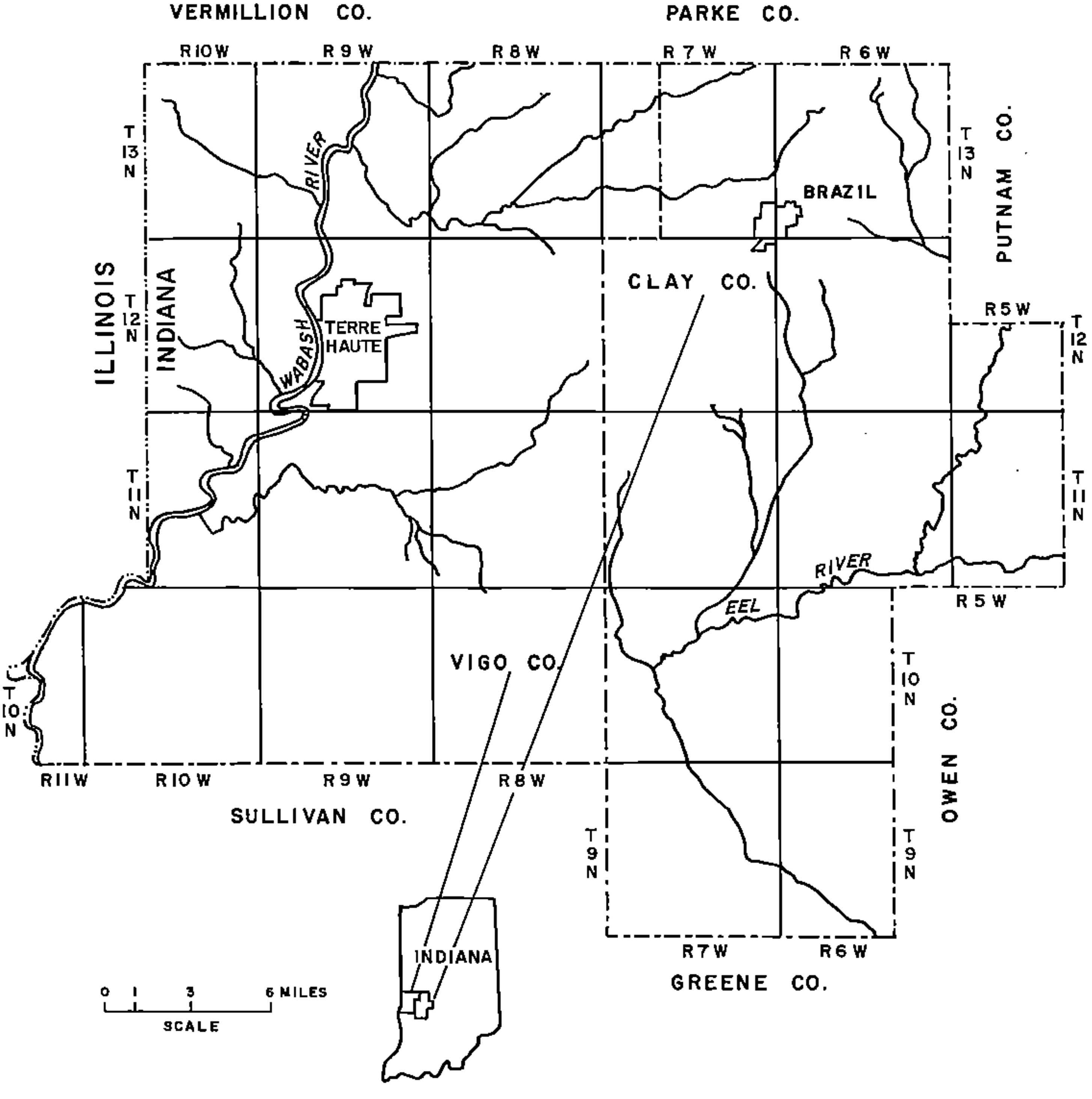

Figure 1.--Map showing the location of Vigo and Clay Counties, Indiana.

is 39.41 inches and the average annual air temperature is 54.4°. Table 1 shows the average monthly precipitation.

Table 1.--Average monthly precipitation at

Terre Haute, Indiana, (1931-1960)

Month	Precipitation (inches)
January-------	2.34
February------	2.32
March---------	3.80
April---------	3.40
May-----------	5.08
June----------	3.73
July----------	3.96
August--------	3.56
September-----	3.45
October-------	2.45
November------	3.47
December------	2.58

HYDROGEOLOGY

The rocks which immediately underlie Vigo and Clay Counties belong in two general categories: consolidated and unconsolidated. Rocks of both types contain significant water-bearing zones which occur as separate units within the hydrologic system. The stratigraphy of these rocks and the hydrologic properties of their principal aquifers are shown on table 2. The geologic names used in this report are those used by the Indiana Geological Survey and are not necessarily recognized by the U. S. Geological Survey.

Consolidated Rocks as Sources of Water

The consolidated rocks of the Vigo-Clay County area are predominantely Pennsylvanian in age and are a part of the eastern shelf of the Eastern Interior structural basin. The rocks of the basin are mostly of shale, sandy shale, and fine- to medium-grained sandstone, and their most characteristic feature is the great areal persistence of many thin, readily distinguishable beds of limestone, black shale, coal, and underclay (Wanless, 1955). These strata dip to the west or southwest at an average rate of 25 to 30 feet per mile and crop out in wide belts across the bedrock surface (pl. 1).

In the eastern shelf area, as in most of the basin, the strata of Pennsylvanian age are in repetitive sequence or cycles known as cyclothems (Weller, 1930, Wanless and Weller, 1932). Each cyclothem ideally consists of ten distinct lithologic members extending from the base of a sandstone to the base of the next higher sandstone. The basal sandstone member is the principal water-bearing zone of the sequence. In the Vigo-Clay County area there are six such zones which are extensive enough to be considered important aquifers. These aquifers show significant similarity in the geologic, hydrologic, and quality-of-water characteristics.

The sandstone bodies of the area commonly contain two phases--a sheet phase and a channel phase. The sheet phase is widespread, thin and discontinuous, while the channel phase is laterally restricted but relatively thick. Because of its greater thickness, the channel phase offers the best potential within the aquifer for an adequate water supply. For a more detailed study of Middle Pennsylvanian channel-fill sandstones in this area, see Friedman, 1960.

The approximate depth to any bedrock aquifer can be estimated by comparing the topographic map of Vigo and Clay Counties (pl. 2) with the structure contour map of the aquifer (figs. 4-9) and subtracting the elevation of the aquifer surface from that of land surface at the desired location.

Recharge to the bedrock aquifers occurs principally at the bedrock surface where the aquifers crop out or are in direct contact with the overlying unconsolidated Quaternary deposits. Precipitation enters the aquifers directly through their outcrops at land surface or indirectly by downward percolation through the unconsolidated deposits.

Water is discharged into streams by effluent seepage through the relatively thin overburden where the aquifers are shallow. As the depth of the aquifer increases, however, the opportunity for the water to circulate decreases. The gray shale members of the cyclothems which enclose the basal sandstone body form effective confining layers with depth. Although a small amount of water may leak into the enclosing shale, the opportunity for natural discharge in the deeper areas of the aquifers is slight.

Figure 2 shows the hydrograph of observation well Vigo 5 and the monthly precipitation at Terre Haute, Indiana over an 8½ year period. This well, located in the SE¼SW¼ sec. 34, T. 11 N., R. 9 W., is open to

Table 2.--Generalized stratigraphic section and hydrologic properties of Mississippian and younger rocks in Vigo and Clay Counties

System		Series	Deposits or Formation	Important Aquifer(s)		Average yield of wells (gpm)	Estimated field coefficient of permeability	Estimated total amount of water in storage in millions of gallons	Estimated use (mgd)	Potential production considered adequate for:	Quality of Water
Quaternary		Recent	Alluvium	Sand and Gravel	Unconfined	680	1,200	367,000	21.4	Large industrial and municipal supplies	Usually very hard and deficient in fluoride. Excessive iron common
		Pleistocene	Glacial		Confined	25	550	370	.8	Moderately large industrial and municipal supplies	
Carboniferous	Pennsylvanian	Upper Pennsylvanian	Patoka (of local usage)**	None					1.8	Domestic, farm, small industrial and small municipal supplies	Shallow water usually similar to that in Quaternary rocks. At depth, water usually soft, frequently high in fluoride, and has higher concentrations of bicarbonate, total dissolved solids and chloride. Excessive iron common at all depths
		Middle Pennsylvanian	Shelburn	Sandstone Unit 6		3.2	23	34			
			Dugger	Sandstone Unit 5*		--------	-------------	42			
			Petersburg	Sandstone Unit 4		5	4	52			
			Linton	Sandstone Unit 3		8	14	44			
			Staunton	None							
			Brazil	None							
			Mansfield	Sandstone	Unit 2	7.8	11	264			
		Lower Pennsylvanian			Unit 1	8.4	12	87			
	Mississippian	Chester (?)		None							Insufficient data

*No hydrologic data available.

**See Wier and Gray, 1961

two bedrock aquifers, units 5 and 6 (table 2). Although the amount of fluctuation varies from year to year, the general configuration of the hydrograph is considered to be typical for unpumped wells in the consolidated rock aquifers.

Figure 3 shows the number of wells and yields in gallons per minute from wells in these aquifers. This illustration is based on those water-well records in which the casing depth indicated that the source of water was restricted to a single bedrock aquifer. The average yield of each of the bedrock aquifers is shown in table 2. However, because of variations in thickness and permeability within any one aquifer, it is not possible to predict with any great degree of accuracy the yield of a well before drilling.

The field coefficients of permeability (definition, p. 53) of these aquifers ranges from 4 to 23 (table 2). No values are given for the coefficients of transmissibility (definition, p. 53) because of the wide local variation of thickness of the aquifers. However, the coefficient of transmissibility of an aquifer may be estimated at any point by use of the following formula:

$$T = P\ (m)$$

where P is the field coefficient of permeability and m is the aquifer thickness at the location desired.

The total amount of water estimated to be in storage in the bedrock aquifers of the Vigo-Clay County area, along with potential recharge, greatly exceeds the present daily withdrawals. The total amount of water in storage in the mapped areas of all bedrock aquifers is estimated to be 523 million gallons, the estimated potential recharge is 7 million gallons per day, and the estimated current withdrawal is 1.8 mgd. The total amount of water in storage in the mapped area of each individual bedrock aquifer is listed in table 2. These figures are based on an estimated coefficient of storage of .0001 (definition, p. 53).

Mississippian System

Rocks of Mississippian age crop out at the bedrock surface in a small area in east-central Clay County (pl. 1). These rocks are the oldest bedrock present in the report area (table 2). Although some wells in the extreme eastern part of Clay County reach the Mississippian rocks, these wells produce very little water and no important aquifers were noted.

Pennsylvanian System

Mansfield Formation

The Mansfield Formation, the base of the Pennsylvanian System, Lower and Middle Pennsylvanian series in Indiana, rests unconformably upon rocks of Mississippian age (table 2) and crops out over extensive areas of the bedrock surface throughout central and eastern Clay County (pl. 1).

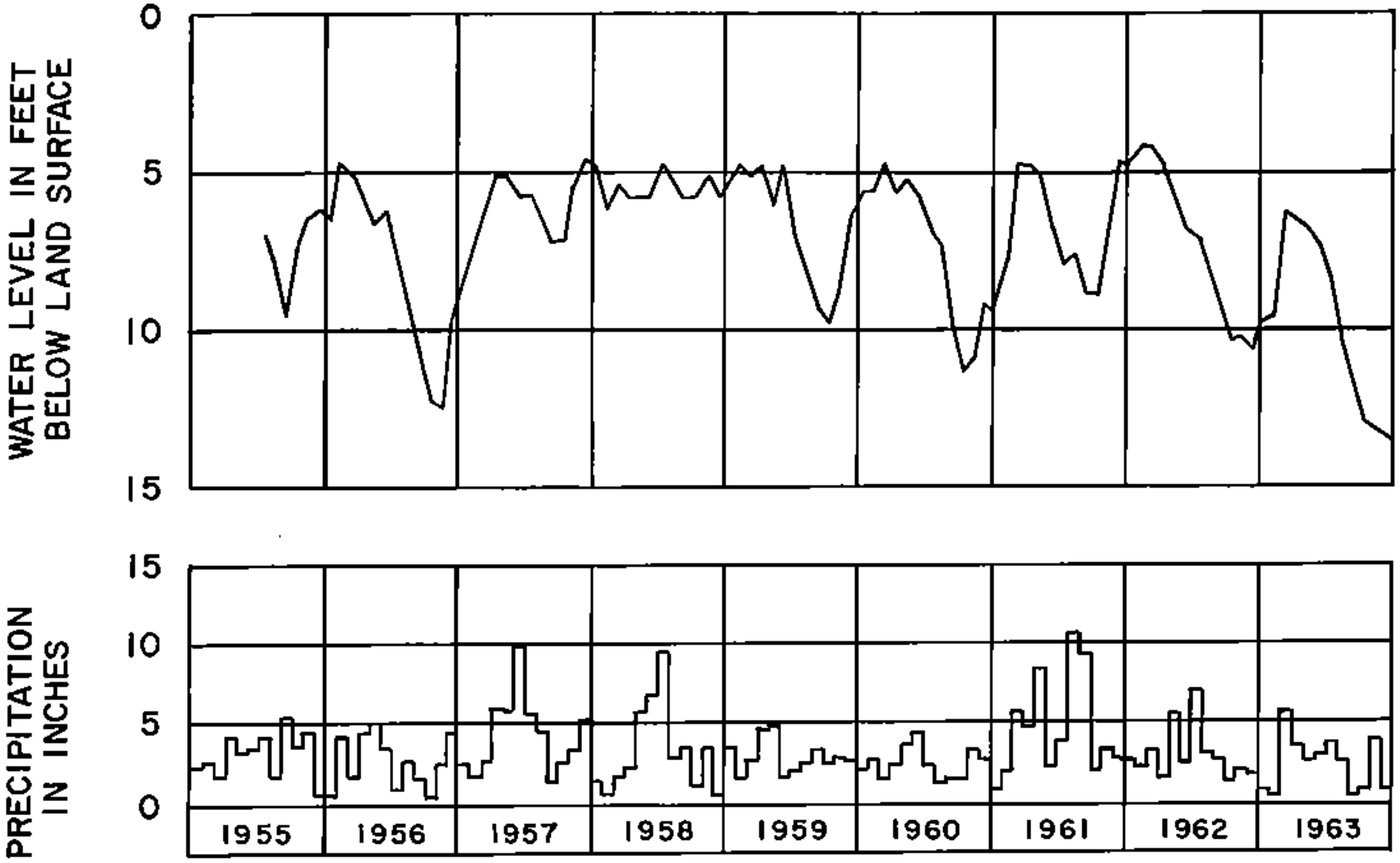

FIGURE 2 -- Hydrograph of observation well Vigo 5 and precipitation at Terre Haute, Indiana showing the amount of waterlevel fluctuation to be expected as a result of seasonal variation in recharge.

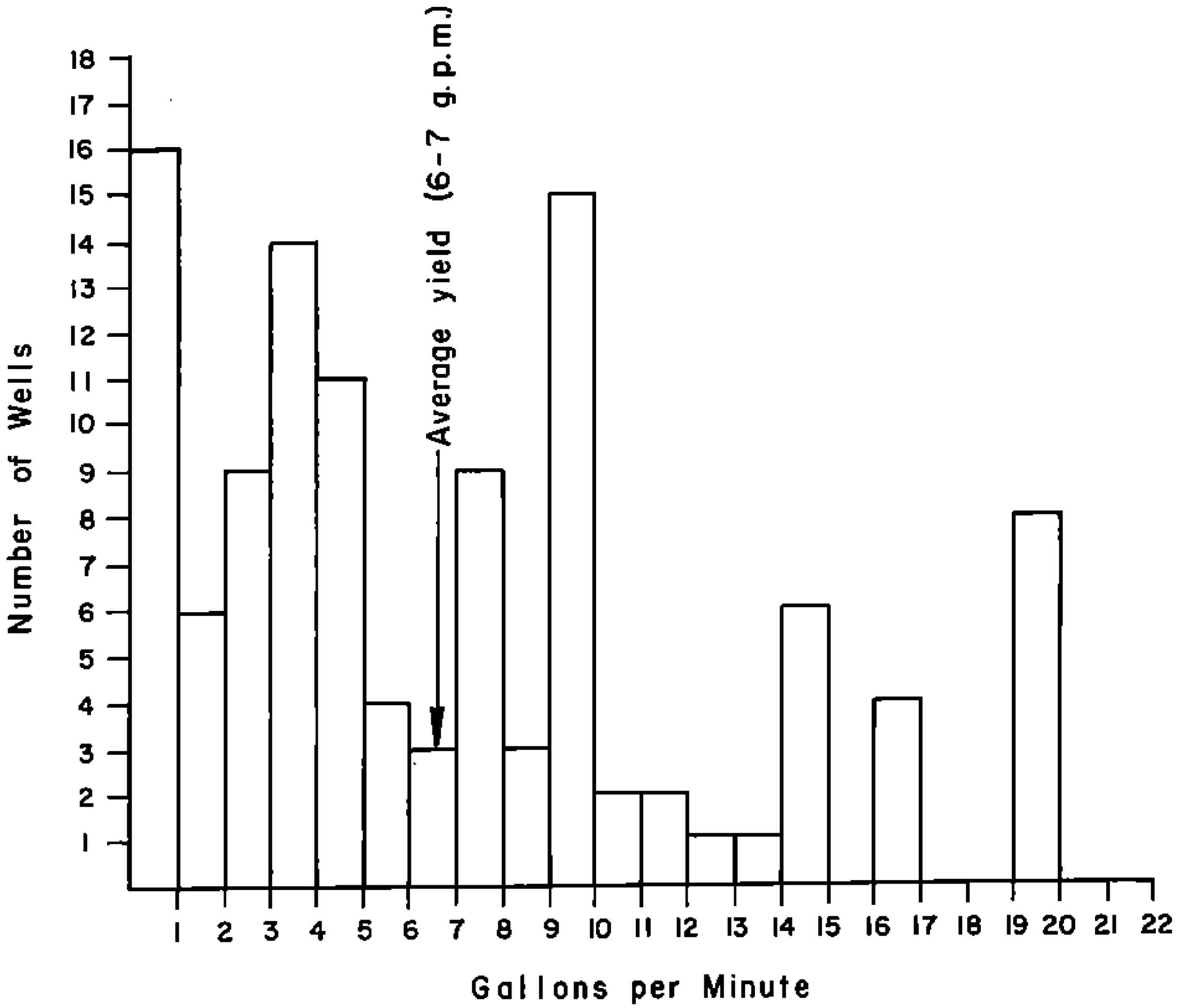

Figure 3. Yields from wells in which the casing record indicated that the source of water was restricted to a single bedrock aquifer.

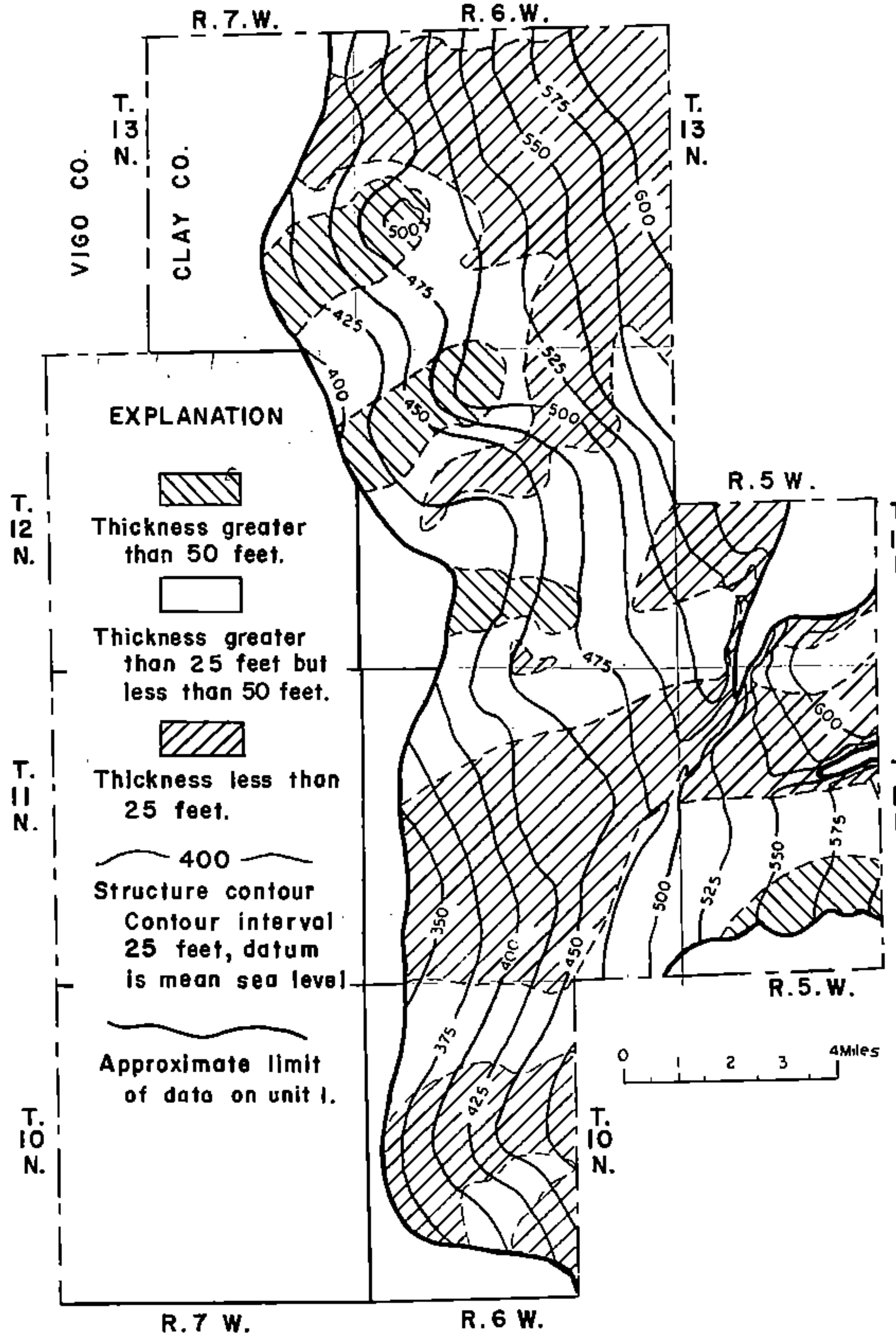

FIGURE 4. -- map showing the thickness and surface configuration of unit I of Mansfield Formation.

Lower or basal Mansfield

This formation yields water from two principal zones, herein designated unit 1 and unit 2. Unit 1 is located at or near the base of the formation (table 2). Figure 4 shows the surface configuration, altitude, and range in thickness of this aquifer.

Unit 2 is at or near the top of the formation (table 2), and in places forms a split aquifer in which the upper and lower parts may be separated locally by as much as 50 feet of dense shale and sandy shale. Unit 2 is the most extensive bedrock aquifer of the area. Figure 5 shows the configuration and altitude of the aquifer surface and also the range in thickness. Together units 1 and 2 constitute the principal source of ground water in Clay County. These aquifers supply water for domestic, farm, small industrial, and small municipal systems.

Brazil and Staunton Formations

The Brazil and Stauton Formations constitute the lowest and next to lowest formations in the Middle Pennsylvanian Series in Indiana respectively (table 2). These formations crop out over a wide area of the bedrock surface in western Clay County and eastern Vigo County (pl. 1). There are no extensive water-bearing zones present in either of these two formations; however, water of sufficient quantity and quality for domestic supplies is produced locally from small sandstone lenses and coalbeds.

Linton Formation

The Linton Formation overlies the Stauton Formation and is a part of the Middle Pennsylvanian Series of Indiana. This formation crops out at the bedrock surface in eastern Vigo County and western Clay County (pl. 1). At the base of this formation is a fine- to medium-grained massive sandstone. This sandstone is an aquifer and is herein designated unit 3 (table 2).

Unit 3 supplies water for farm, domestic, small industrial, and small municipal systems in east-central and southeastern Vigo County. Figure 6 shows the configuration and altitude of the aquifer surface plus the range in thickness. That part of unit 3 which is in northwestern Vigo County was mapped almost exclusively on the basis of information from coal tests and oil well logs; therefore, no hydrologic data were available.

Petersburg Formation

The Petersburg Formation overlies the Linton Formation and is also a part of the Middle Pennsylvanian Series of Indiana. This formation crops out at the bedrock surface in central and southeastern Vigo County (pl. 1). Just as in the underlying Linton Formation, the base of the Petersburg Formation is formed by a fine- to medium-grained massive sandstone which is an aquifer. This aquifer is herein designated unit 4 (table 2).

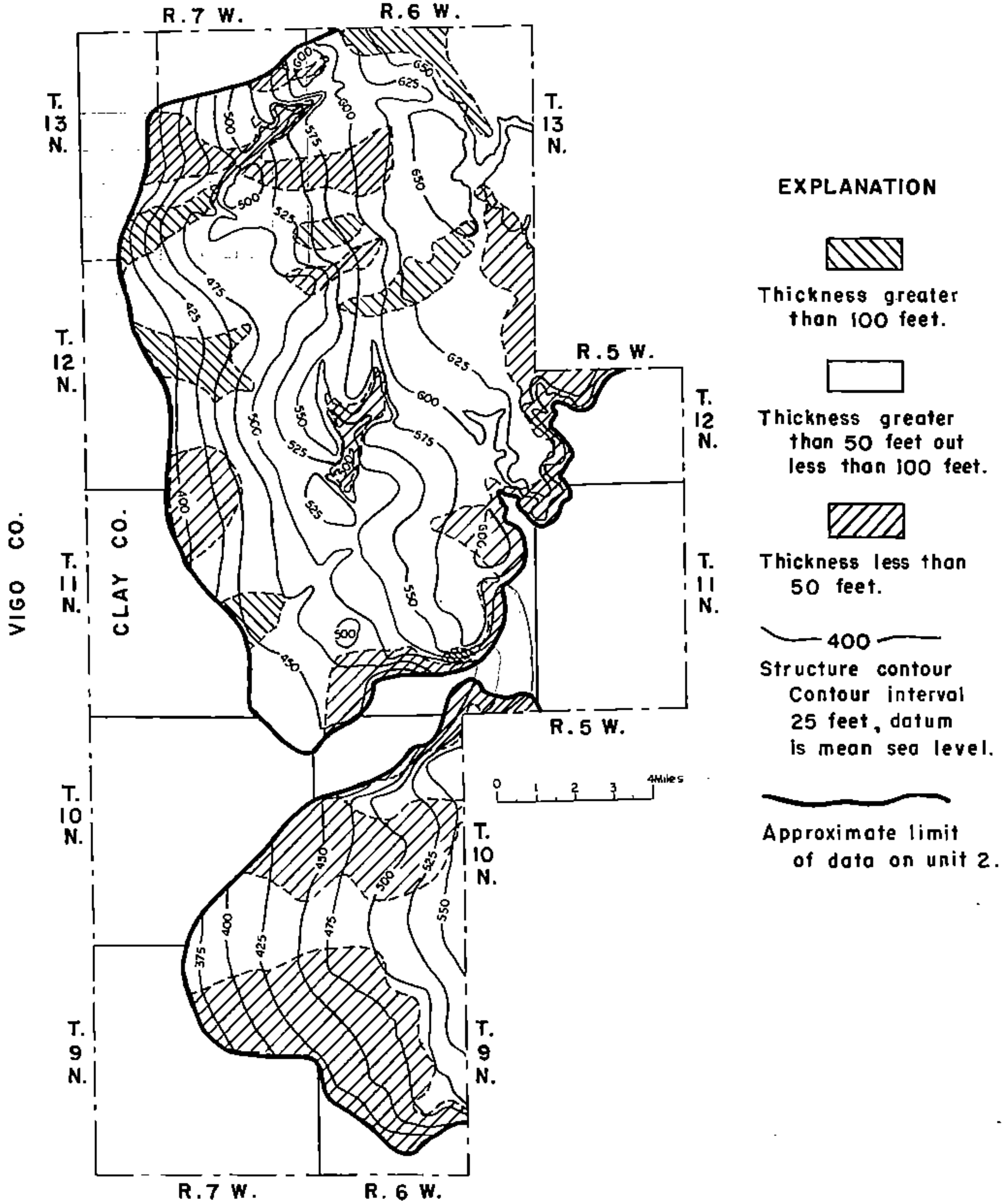

FIGURE 5.--Map showing the thickness and surface configuration of unit 2. of Mansfield Formation.

Upper Mansfield

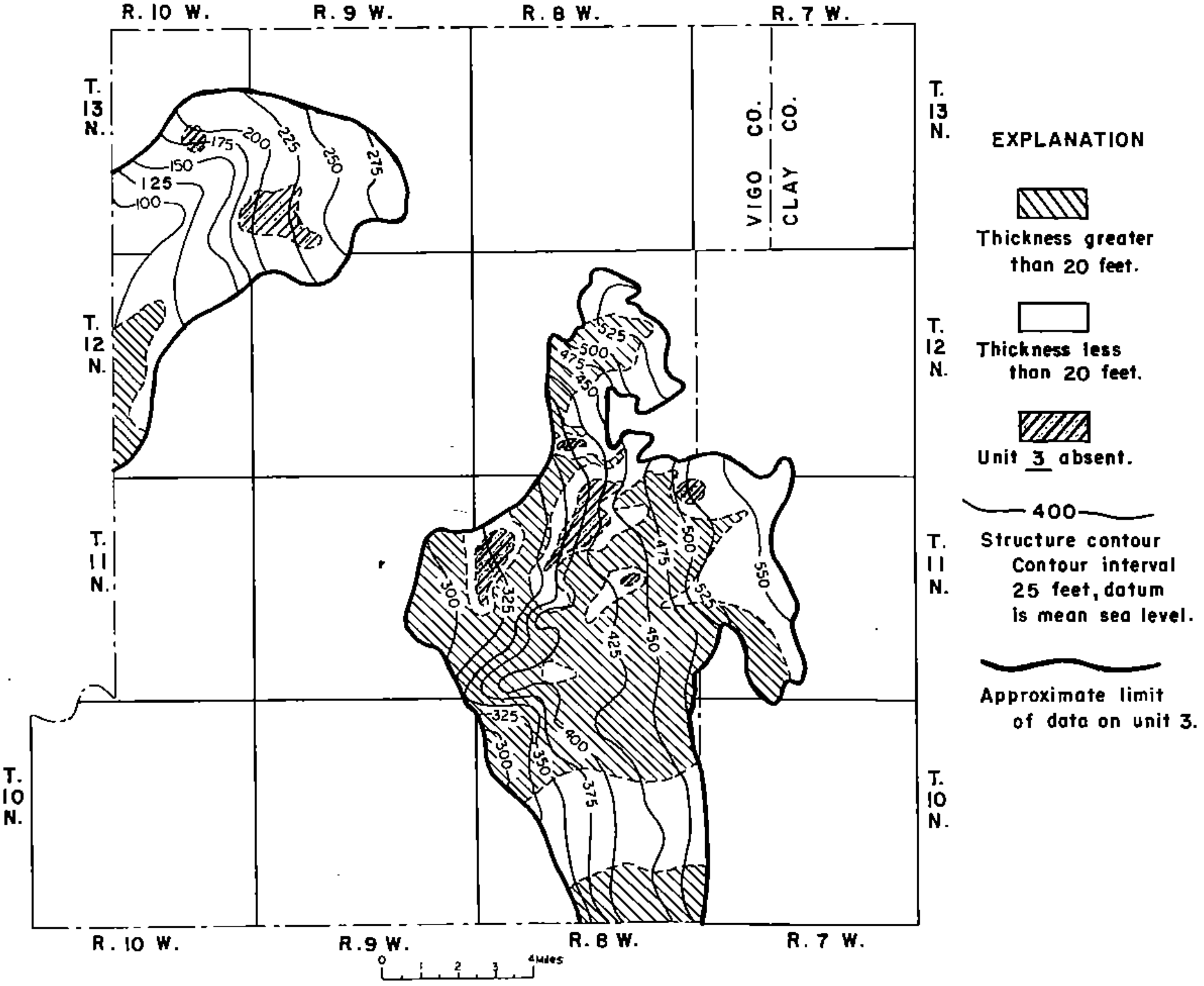

FIGURE 6.-- Map showing the thickness and surface configuration of unit 3.

Linton Fm.

basal sandstone

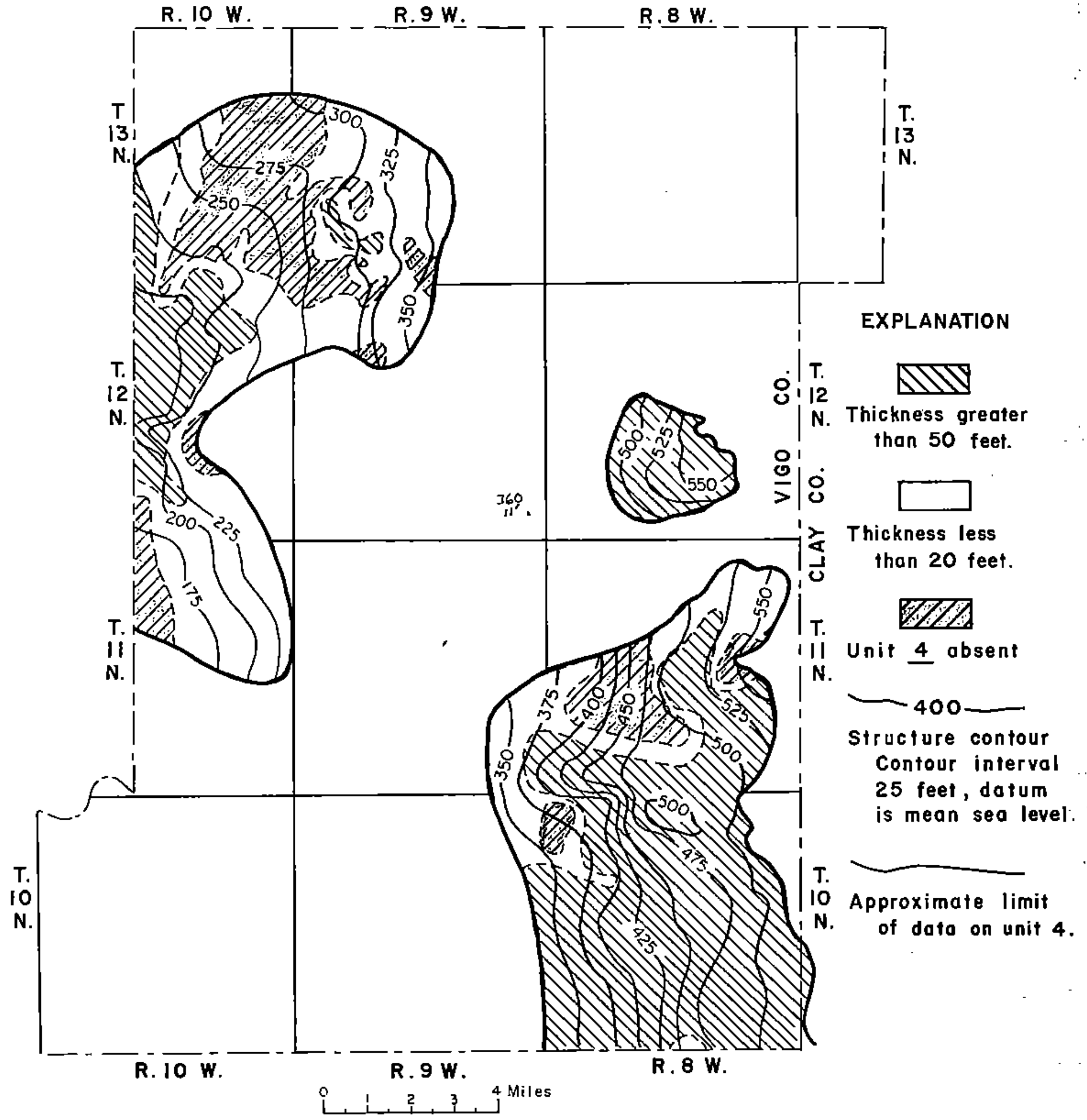

FIGURE 7. -- Map showing the thickness and surface configuration of unit 4.

Petersburg Fm.
basal sandstone

Unit 4 supplies water for farm, domestic, and small industrial and municipal systems. Figure 7 shows the surface configuration, altitude, and the range in thickness of this aquifer. That part of unit 4 which is in the northern and central portion of western Vigo County was mapped almost exclusively on the basis of information from coal tests and oil well logs, therefore, no hydrologic data were available. Together with unit 3 this aquifer constitutes the principal source of ground water in east-central and southeastern Vigo County.

Dugger Formation

The Dugger Formation is the youngest formation in the Middle Pennsylvanian Series of Indiana. This formation crops out at the bedrock surface throughout central Vigo County (pl. 1). Located in the upper-middle part of this formation and directly below the Universal Limestone Member is a water-bearing body of sandstone. This sandstone serves as an aquifer in western Vigo County and is herein designated unit 5 (table 2). In Vigo County wells in unit 5 yield water mostly for domestic use. Figure 8 shows the configuration and altitude of the aquifer surface as well as the range in thickness.

Shelburn Formation

The Shelburn Formation is the base of the Upper Pennsylvanian Series in Indiana. This formation crops out at the bedrock surface throughout central and western Vigo County (pl. 1). At the base of this formation is the Busseron Sandstone Member, which is a fine- to medium-grained massive sandstone. This sandstone is an aquifer and is herein designated unit 6 (table 2).

Although this aquifer is somewhat restricted in the report area, some domestic wells are made in it in the southwestern part of Vigo County. Figure 9 shows the configuration and altitude of the aquifer surface and also the range in its thickness.

Patoka Formation[1] (of local usage)

The Patoka Formation (of local usage) is directly above the Shelburn Formation and constitutes the youngest consolidated rocks in the report area (table 2). This formation crops out at the bedrock surface discontinuously along the western edge of Vigo County (pl. 1). No important aquifers are present in this formation in the report area.

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[1] This formation name follows the usage proposed by Wier. (See Wier and Gray, 1961).

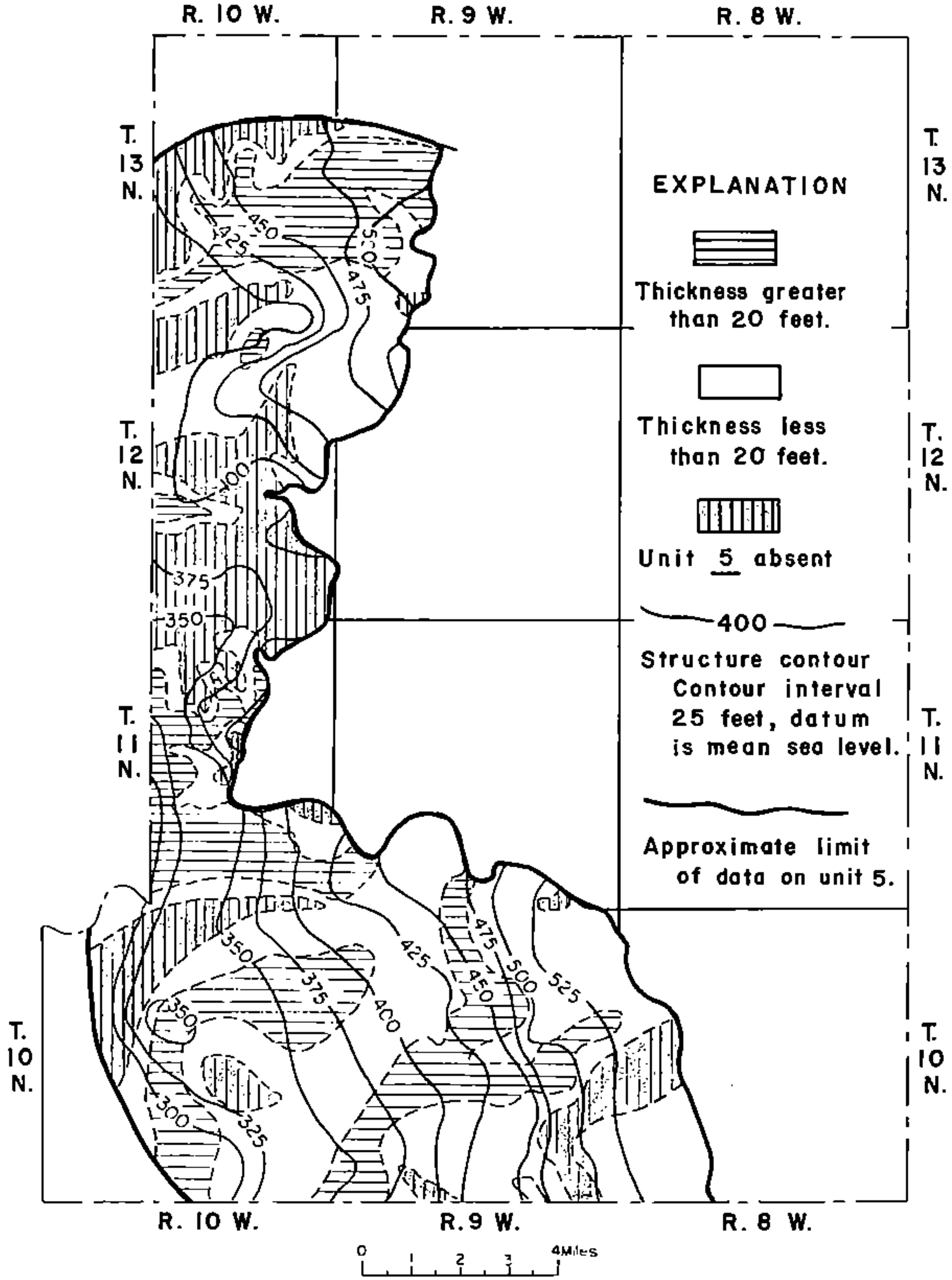

FIGURE 8.--Map showing the thickness and surface configuration of unit 5.

Dugger Fm.
upper ss.

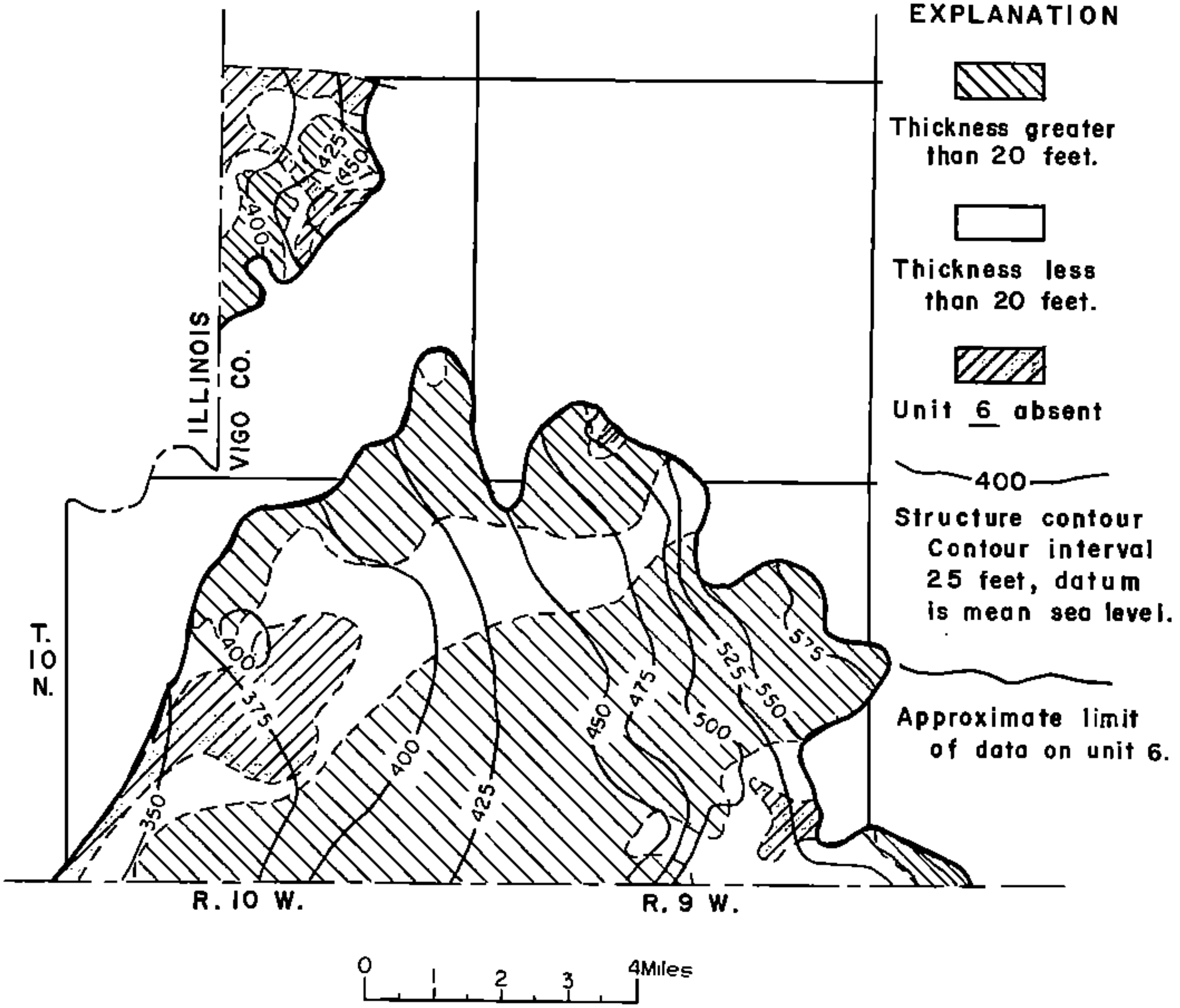

FIGURE 9.-- Map showing the thickness and surface configuration of unit 6.

Busseron Ss. Mbr.

Shelburn Fm.

Bedrock Topography

The topography of the bedrock surface underlying the unconsolidated glacial deposits of Vigo and Clay Counties is the result of a long interval of weathering and erosion which lasted from late Paleozoic to Pleistocene time. Except in the immediate vicinity of the Wabash and Eel River valleys, this buried surface is a gently rolling plain with moderate relief.

An extensive system of buried bedrock valleys is located in the north-central part of the area. These valleys generally trend southwestward and are part of the buried Montclair Valley system which represents the pre-Pleistocene course of the Upper Wabash River (Wayne, 1956, p. 43-44). Portions of this system were also mapped by Hutchison (1960, fig. 2). This system joins the present day valley of the Wabash River in the vicinity of north Terre Haute.

A detailed knowledge of the features of the bedrock surface is important in ground-water investigations in this area. This surface is the interface between the consolidated and unconsolidated rocks, thus separating them lithologically but at the same time connecting them hydrologically. Aquifers in the overlying unconsolidated material may be in direct contact with the outcrop of one or more bedrock aquifers, thereby forming one continuous hydrologic system. Because of the contrasting lithologic characteristics of the rocks on either side of this interface, yields from wells in this system generally will be substantially less in the consolidated rock aquifers than those in the unconsolidated rock aquifers.

Unconsolidated Rocks as Sources of Water

The unconsolidated deposits of the Vigo-Clay County area are mostly of Pleistocene age, with some recent alluvium present (table 2). These deposits form a cover over most of the area (pl. 4) and generally mask the underlying bedrock. Aquifers in this material consist of relatively clean, coarse-textured, sand and gravel which occur as alluvium and glacial outwash deposited primarily in the Wabash and Eel River valleys (pl. 5). No attempt has been made herein to differentiate these deposits stratigraphically. The tills of the area are commonly too poorly sorted and fine grained to be considered aquifers.

The water-bearing sand and gravel deposits associated with the present and pre-Pleistocene valleys of the Wabash River constitute the thickest and most extensive aquifer of the entire area. This huge deposit of glacial-outwash sand and gravel forms one continuous hydrologic system in

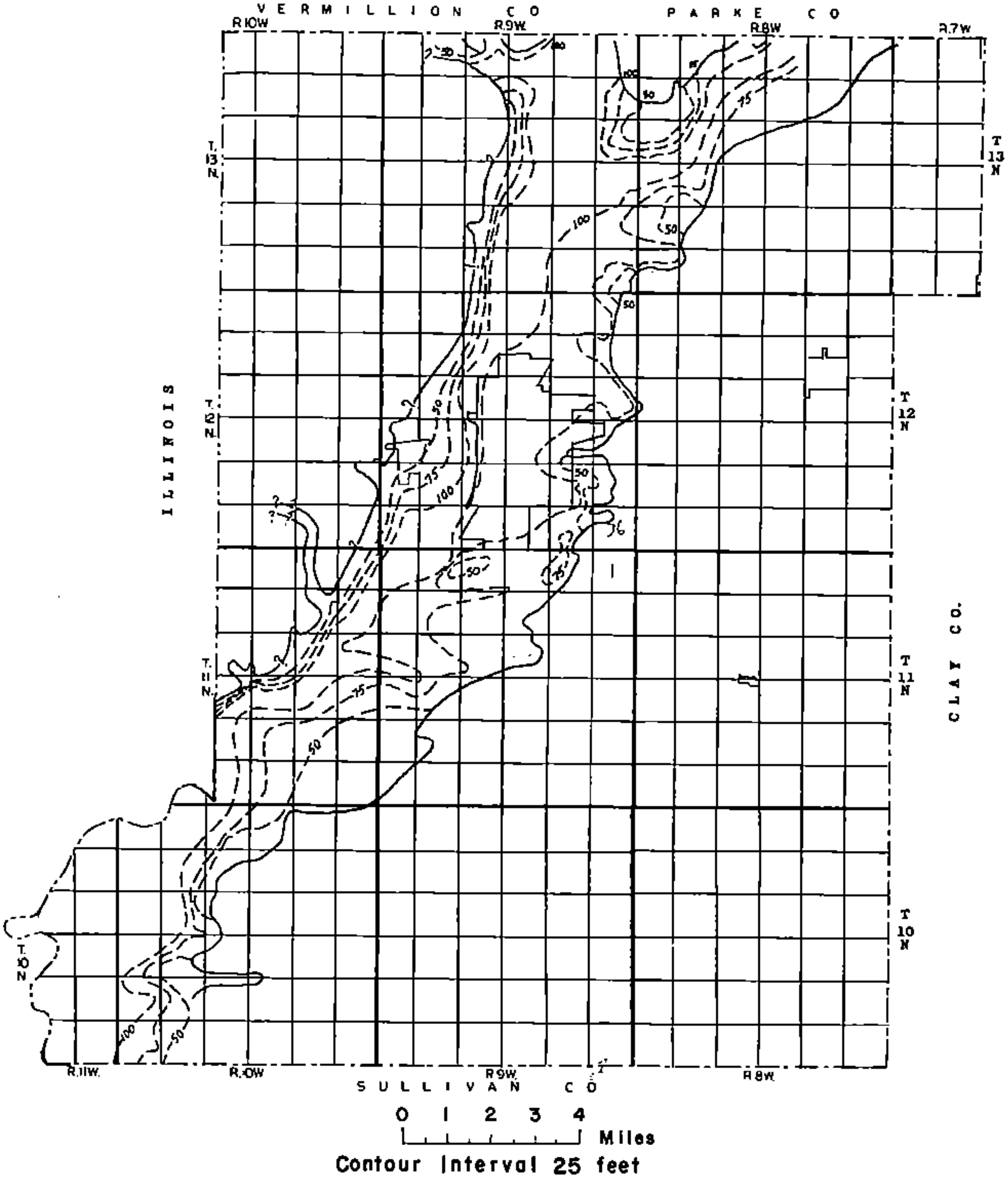

FIGURE 10 -- Map of Vigo County showing saturated thickness, of the unconfined aquifer in the Wabash River valley.

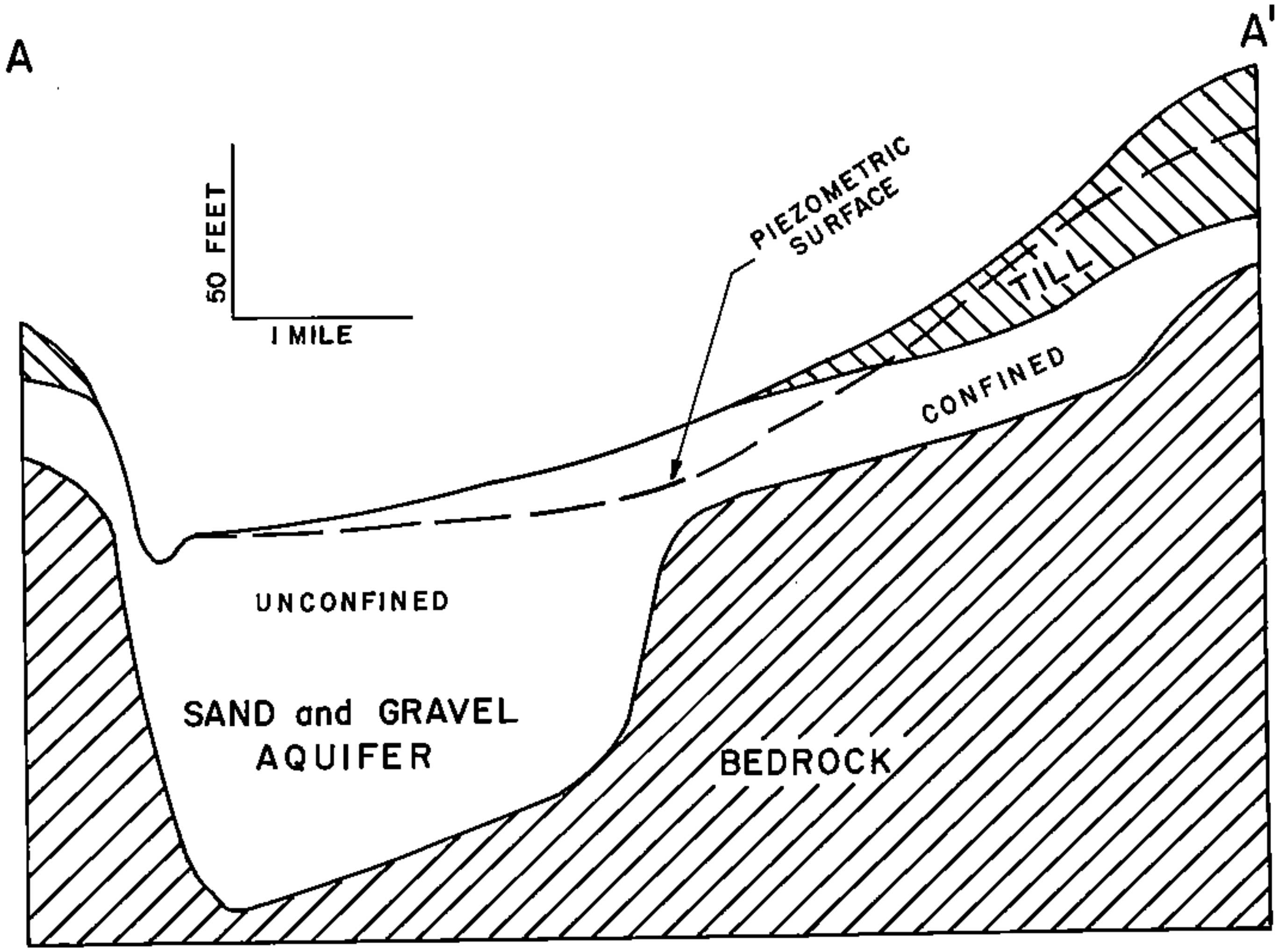

FIGURE 11. --Cross section of the Wabash River valley (See pl. 4) showing the relationship of the confined and unconfined areas of the aquifer.

which both water-table and artesian conditions are present (pl. 5). The aquifer is unconfined in the vicinity of the Wabash River and water-table conditions prevail. Saturated thicknesses in excess of 100 feet are noted (fig. 10). Where the aquifer is covered by tills of Illinoian age, artisian conditions prevail. Figure 11 is a cross section of the Wabash River valley in western Vigo County (pl. 5) and shows the relationship of the confined and unconfined areas.

Recharge to the unconfined part of this aquifer is by the downward percolation of precipitation. Where the aquifer is confined recharge takes place by slow percolation of the water through the till layer. The configuration of the piezometric surface (pl. 5) indicates that the water in the aquifer flows toward the Wabash River where natural discharge takes place by effluent seepage.

Fluctuations of the water level in this aquifer as a result of seasonal variations in recharge are shown on figure 12. Figure 12A shows the hydrograph of observation well Vigo 3 which is in the confined area, and figure 12B shows the hydrograph of observation well Vigo 2 which is in the unconfined area. These wells are in the NW¼SW¼ sec. 29, T. 12 N., R. 8 W., and the NE¼SW¼ sec. 28, T. 12 N., R. 9 W. respectively.

Yields as high as 2,700 gpm from wells in the unconsolidated deposits have been reported by water well drillers. The average yields for the confined and unconfined areas are shown in table 2. These figures are based on the records of 106 water wells of which 42 were in the confined and 64 in the unconfined area of the aquifer.

The field coefficient of permeability for the confined and unconfined areas of this aquifer are given in table 2. The estimated coefficients of transmissibility range from 91 gpd per foot in the confined area to 280,000 gpd per foot in the unconfined area. The estimated regional value of transmissibility for the confined area of the aquifer is 5,100 gpd per foot; that of the unconfined area is 72,000 gpd per foot.

In the Wabash River valley aquifer, as in the bedrock aquifers, the total amount of water estimated to be in storage and the potential recharge both greatly exceed current daily withdrawals. The total amount of water in storage in both the confined and unconfined areas of this aquifer in the Vigo-Clay County area is approximately 367,370 million gallons, the estimated potential recharge is 68 mgd, and the estimated current withdrawal is 22.2 mgd. The total amounts of water in storage in the confined and unconfined areas of this aquifer are listed separately in table 2. These figures are based on and estimated coefficient of storage of .002 for the confined area and .20 for the unconfined area.

The Eel River valley is mostly in Clay County. (See pl. 5). In this valley as in the Wabash River valley, the water-bearing sand and gravel deposits form one continuous hydrologic system. This aquifer is entirely confined by clay and till and is somewhat more restricted in size than that of the Wabash River valley. The piezometric map (pl. 5) indicates that recharge and discharge take place in much the same manner as they do in the Wabash River valley aquifer. A detailed analysis of the hydrologic properties of this aquifer is not possible due to insufficient data.

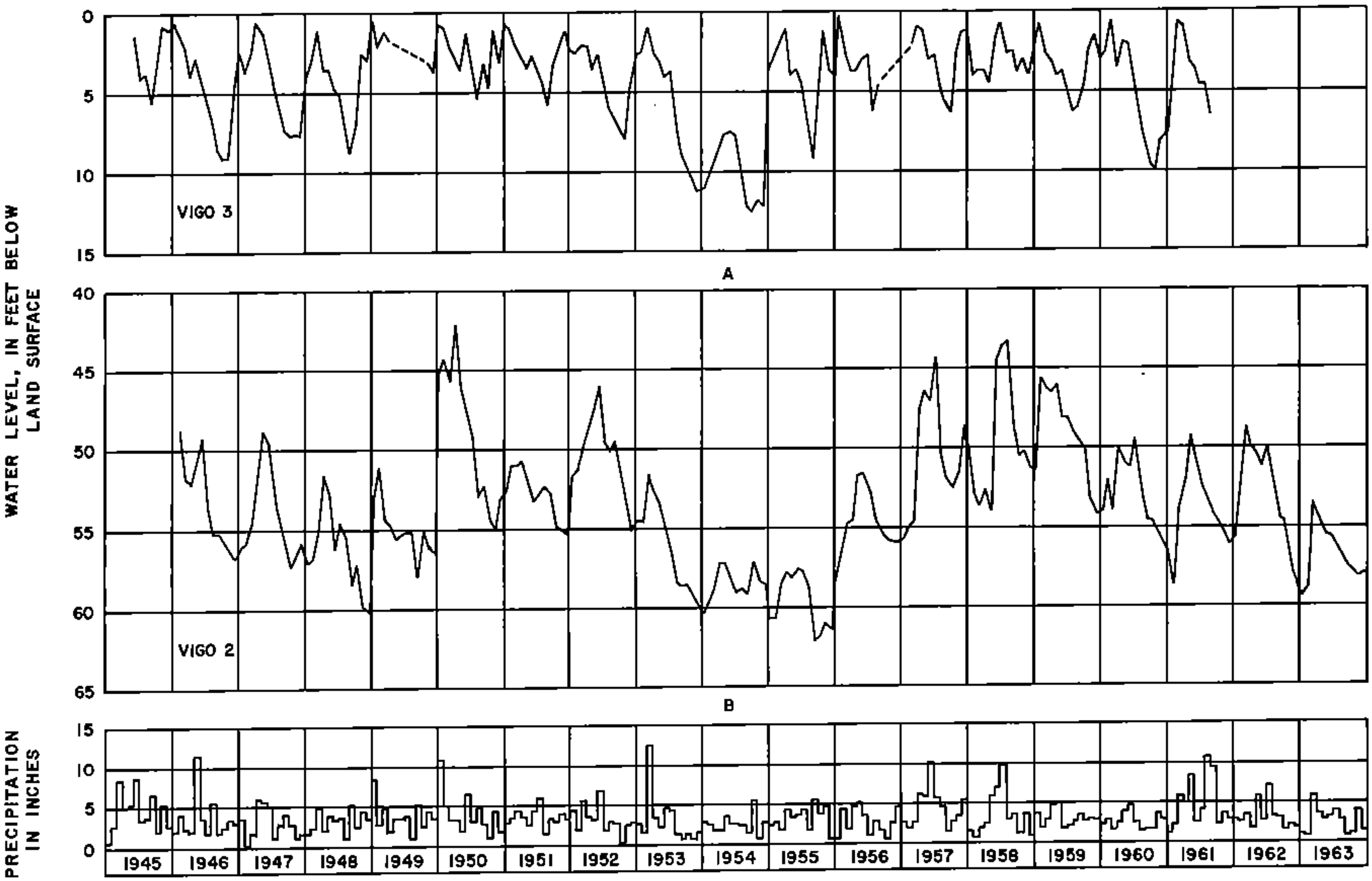

FIGURE 12.--Hydrographs of observation wells in the Wabash River valley and precipitation at Terre Haute, Indiana showing the amount of water-level fluctuation to be expected as a result of seasonal variation in recharge.

QUALITY OF WATER

The chemical quality of the ground water of Vigo and Clay Counties was determined from the partial analysis of over 750 water samples and the complete analysis of 35 water samples. A tabulation of the complete analyses of 25 water samples is given in table 3. The significance of, and recommended limits for, the various constituents are given in table 4.

The waters from the consolidated and unconsolidated rocks are discussed together in this section because they are interrelated, one modifying the other, and therefore, not readily discussed separately. Tje term "consolidated rocks" as used in this section refers only to rocks of Mississippian age to derive meaningful interpretations.

Hardness

The water from the unconsolidated rocks and from the shallower wells in the consolidated rocks is generally very hard. This is due to the presence of fragmented calcareous material such as limestone or dolomite in the unconsolidated rocks. As water form precipitation passes through these rocks, calcium and magnesium ions are taken into solution, primarily as bicarbonates. The water in the underlying consolidated rocks is mostly derived from the unconsolidated rock and would, therefore, be expected to be of similar quality. (See fig. 13). This is true, however, only for the upper part of the consolidated rocks. The water from the deeper wells, having had contact with a thicker section of the rock for a longer period of time, has apparently been softened by contact with ion exchange minerals. It is also possible that the ion exchange minerals have been progressively depleted of sodium toward the surface.

The decrease in hardness with depth is especially apparent in the Middle and Upper Pensylvanian rocks of Vigo County where the median hardness concentrations of deep-well water is only 10 ppm. The lower hardness values for water from deep wells in this area can be attributed principally to progressive sodium-depletion of ion-exchange minerals eastward and to the progressively higher percentages of clay in the younger Pennsylvanian beds westward (Potter and Glass, 1958, p. 12). Many clay minerals have ion-exchange properties.

Bicarbonate

As shown on figure 14, the bicarbonate content of water from deep wells in the consolidated rock is significantly greater than that fron shallower wells. This effect is much less significant in wells in the unconsolidated rocks. No single reason for the increase of the bicarbonate concentration with depth in the consolidated rocks is apparent. However, this may be due to a combination of the following conditions: presence of carbon dioxide supply; abundant sodium and potassium ions; lack of acid-forming conditions.

Table 3.--Chemical analyses of Ground Water in Vigo and Clay Counties, Indiana

(Constituents given in parts per million, except hydrogen ion concentration (pH))

	Well Location	County	Well Depth (feet)	Date of Collection	Temp. (°F.)	Silica (SiO_2)	Iron (Fe)	Manganese	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved Solids (Calculated)	Hardness as $CaCO_3$	Noncarbonate Hardness	Specific Conductance (Micromhos at 25° C.)	Hydrogen ion Concentration (pH)
Pennsylvanian - Mansfield Formation - Unit 1																							
SE¼	SE¼, Sec. 18 T. 11 N., R. 5 W.	Clay	168	6-26-63	60	12	6.1	0.02	58	21	32	1.6	280	0	82	11	0.2	0.7	353	231	18	589	7.1
NE¼	NE¼, Sec. 3 T. 12 N., R. 7 W.	Clay	220	3-11-57	58	9.0	.26	.03	21	9.2	202	2.8	628	0	3.2	7.9	2.6	.2	568	90	0	914	8.1
SE¼	SW¼, Sec. 28 T. 13 N., R. 6 W.	Clay	220	6-2-60	58	9.3	.09	.00	4.8	1.6	217	1.6	580	0	7.6	7.0	2.2	.0	537	18	0	889	7.2
Pennsylvanian - Mansfield Formation - Unit 2																							
NE¼	NE¼, Sec. 26 T. 13 N., R. 6 W.	Clay	40	6-26-63	61	28	3.6	.15	5.6	4.1	11	.4	21	0	19	0.0	.1	18	108	31	14	132	6.3
NW¼	NE¼, Sec. 30 T. 11 N., R. 5 W.	Clay	100	4-29-58	55	19	31	.18	63	27	31	1.4	383	0	10	20	.2	.1	363	273	0	623	7.2
SW¼	SW¼, Sec. 2 T. 13 N., R. 7 W.	Clay	150	6-2-60	58	16	.42	.00	51	19	71	4.3	415	0	20	2.5	.4	.0	391	208	0	647	6.6
NE¼	SW¼, Sec. 36 T. 9 N., R. 7 W.	Clay	241	6-7-57	59	8.4	.14	.00	4.0	2.3	1,470	3.2	1,430	0	9.2	1,400	1.7	.1	3,360	20	0	5,900	8.0
Pennsylvanian - Linton Formation - Unit 3																							
SW¼	SE¼, Sec. 17 T. 11 N., R. 7 W.	Clay	112	6-1-60	60	34	.13	.06	69	24	26	2.1	400	0	2.2	2.0	.3	1.2	358	271	0	683	7.3
NE¼	NE¼, Sec. 21 T. 11 N., R. 8 W.	Vigo	212	12-19-57	56.5	9.3	.28	.02	6.2	2.8	255	2.4	584	35	.8	20	2.7	.1	622	24	0	1,000	8.8
NE¼	NW¼, Sec. 36 T. 10 N., R. 9 W.	Vigo	355	6-27-63	57	7.9	.24	.01	.3	1.2	693	4.0	1,240	49	3.6	280	15	1.4	1,640	6	0	2,760	8.7
Pennsylvanian - Petersburg Formation - Unit 4																							
SE¼	SE¼, Sec. 36 T. 10 N., R. 8 W.	Vigo	75	6-26-63	61	17	3.0	.56	98	43	40	1.1	500	0	69	22	.2	1.2	541	422	12	885	7.4
SW¼	SW¼, Sec. 4 T. 10 N., R. 8 W.	Vigo	185	6-27-63	62	8.2	.12	.04	.2	.7	365	2.1	800	54	1.6	40	8.9	.1	872	4	0	1,430	8.9
SE¼	SW¼, Sec. 5 T. 10 N., R. 8 W.	Vigo	285	6-27-63	59	7.6	.29	.02	.8	1.4	612	4.1	1,540	69	4.6	280	13	.6	1,960	8	0	3,280	8.7
Pennsylvanian - Shelburn Formation - Unit 6																							
NW¼	SW¼, Sec. 14 T. 10 N., 9 W.	Vigo	81	6-2-60	58	24	.02	.27	71	30	47	1.2	438	0	18	13	.2	.6	431	301	0	702	7.1
Quaternary - Wabash River Valley Aquifer - confined portion																							
SE¼	NE¼, Sec. 1 T. 12 N., R. 10 W.	Vigo	67	6-2-60	56	21	2.4	.15	93	39	18	1.8	545	0	12	3.5	.6	.1	462	395	0	811	6.5
NE¼	NE¼, Sec. 14 T. 13 N., R. 8 W.	Vigo	76	6-2-60	58	19	2.9	.11	102	37	12	.9	380	0	109	4.5	.3	.9	476	407	95	743	7.0
NW¼	NE¼, Sec. 30 T. 12 N., R. 8 W.	Vigo	79	4-16-58	--	16	1.3	.08	64	25	3.3	.2	304	0	23	2.5	.2	.1	285	263	14	487	7.6

Quaternary - Wabash River Valley Aquifer - unconfined portion																							
SW¼	NW¼, Sec. 3 T.11 N., R. 9 W.	Vigo	72	12-19-57	59	13	.18	.08	90	25	7.6	1.2	276	0	110	4.5	.1	.9	389	328	102	622	7.6
NE¼	SE¼, Sec. 27 T. 13 N., R. 9 W.	Vigo	93	4-18-52	--	11	1.7	.03	70	24	6.2	1.6	226	0	67	6.0	.1	.2	320	272		512	7.7
NE¼	SE¼, Sec. 34 T. 13 N., R. 9 W.	Vigo	100	4-11-56	56	16	.18	.00	112	35	12	2.2	278	0	175	10	.1	12	511	423	196	779	7.4
NW¼	NE¼, Sec. 25 T. 13 N., R. 9 W.	Vigo	112.5	7-29-55	59	10	.18	.16	62	16	3.2	.7	214	0	52	2.6	.2	1.6	254	222	47	421	7.8
NE¼	SW¼, Sec. 26 T. 12 N., R. 9 W.	Vigo	131	7-28-53	61	13	.19	.04	106	33	33	4.4	302	0	157	32	.00	19	568	402		875	7.7
Quaternary - Eel River Valley Aquifer																							
SW¼	SE¼, Sec. 14 T. 9 N., R. 7 W.	Clay	82	5-7-57	57	22	6.4	.11	79	19	8.9	.4	334	0	9.6	3.0	.1	3.0	316	275	2	501	7.2
SW¼	SW¼, Sec. 28 T. 13 N., R. 6 W.	Clay	90	6-2-60	60	16	1.9	.00	109	38	39	1.2	470	0	119	5.5	.4	4.0	589	436	50	694	6.8
NW¼	NE¼, Sec. 34	Clay	162	4-29-56	63	17	1.9	.00	55	21	5.1	.8	266	0	5.4	1.5	.1	.3	249	224	0	419	8.0

TABLE 4.-- SIGNIFICANCE OF DISSOLVED MINERAL CONSTITUENTS AND PROPERTIES OF GROUND WATER.

Constituents or property	Significance
Iron (Fe)	Excessive amounts cause: "red water"; yellowish- or reddish-brown laundry fixture stains; slimy iron bacteria growths in wells, pipes and tanks; bitter taste. The U. S. Public Health Service recommends that iron should not exceed 0.3 ppm on the basis of taste and laundry use.*
Manganese (Mn)	Similar to iron. Causes dark stains. U. S. Public Health Service recommends that the manganese concentration should not exceed 0.05 ppm.*
Calcium (Ca) and Magnesium (Mg)	Principal cause of hardness. (See Hardness.)
Sodium (Na)	High concentrations may cause water to be unsuitable for agriculture.
Potassium (K)	Chemically similar to sodium.
Bicarbonate (HCO$_3$) and Carbonate (CO$_3$)	Principal alkaline factors in water. (See Hardness.)
Sulfate (SO$_4$)	In combination with calcium forms hard scale in boilers. In high concentrations imparts bitter taste to water. U. S. Public Health Service recommends that the sulfate concentrations should not exceed 250 ppm, based largely on taste.*
Chloride (Cl)	In high concentrations chloride increases the corrosiveness of water and imparts a salty taste. The U. S. Public Health Service recommended maximum is 250 ppm, based upon taste.*
Fluoride (F)	In low concentrations fluoride reduces tooth decay. In higher concentrations tooth mottling or bone damage may occur. The U. S. Public Health Service recommendations are based on the annual average of maximum daily air temperatures.* For the Vigo-Clay area the recommended limits are: minimum - 0.8 ppm, optimum - 1.0 ppm, maximum - 1.3 ppm.
Nitrate (NO$_3$)	A high nitrate concentration may cause methemoglobinemia (blue-baby disease) in infants. The U. S. Public Health Service recommends a limit of 45 ppm.*
Dissolved Solids	U. S. Public Health Service recommends a limit of 500 ppm.*
Hardness as CaCO$_3$	Consumes soap by formation of scum. Primarily due to calcium and magnesium. When these constituents are combined with bicarbonate they cause temporary or carbonate hardness. A widely used hardness scale is: 60 ppm, soft; 61 to 120 ppm, moderately hard; 121 to 200 ppm, hard; more than 200 ppm, very hard.
Hydrogen-ion concentration (pH)	Measure of alkalinity-acidity. 0 to 7 denotes decreasing acidity; 7 neutrality; 7 to 14 increasing alkalinity.

* Public Health Service Publication No. 956, 1962.