GROUND-WATER HYDROLOGY

Ground-water supplies are obtained from *aquifers*, or subsurface formations of rock saturated with water. The hydrologic characteristics of aquifers and natural chemistry of ground water determine the availability and suitability of regional ground-water resources for specific uses.

GROUND-WATER RESOURCES

Ground water is the part of precipitation which enters the ground and continues to move downward through openings in soil and bedrock until it reaches the *water table* (figure 35). The water table is the elevation below which all openings in the rock or soil are filled with water. Water entering the saturated zone is called *recharge*.

In a general way, the configuration of the water table approximates the overlying topography (figure 35). At a depression where the land surface intersects the water table, water is discharged from the ground-water system to become part of the surface-water system.

The interaction between ground water and surface water can moderate seasonal water-level fluctuations in both of these systems. During dry periods, ground-water discharge can help maintain water levels in streams. Conversely, surface water can recharge ground water through soils saturated by flooding or through streambeds during periods when the water table falls below the elevation of the water surface in a stream.

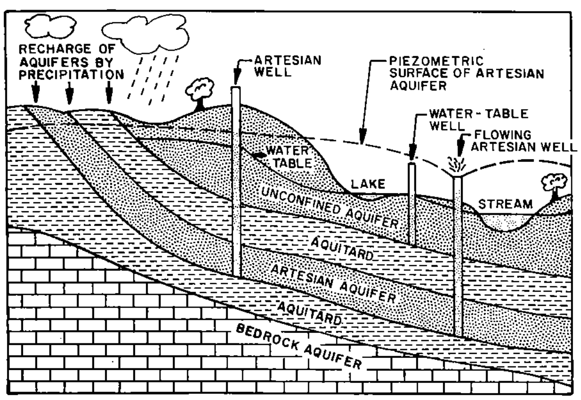


Figure 35. Aquifer types and ground-water movement

Porosity and *permeability* are the most important hydraulic properties affecting ground-water availability. Porosity is the amount of open space in rock and soil. Permeability is the degree to which pores are connected and determines how quickly water moves through the material.

In bedrock, pores occur as fractures, solution openings, and openings between grains composing the rock. In unconsolidated deposits, all of the pores are intergranular, but fine-grained deposits such as clays or silts may have secondary porosity in the form of fractures.

The size and sorting of material determines the amount and interconnection of intergranular pores. Sand and gravel deposits have a high proportion of pore space and high permeability, whereas fine-grained or clay-rich deposits have a greater proportion of pores, but a lower degree of permeability.

Aquifers have high porosity and permeability so that they may absorb, store and transmit water in usable quantities. Materials with low permeability, called *aquitards*, restrict ground-water movement. An aquitard overlying an aquifer may limit the recharge to the aquifer but may also protect an aquifer from surface contamination.

Where an aquitard overlies an aquifer, the water in the aquifer may be under hydrostatic pressure. The aquifer is said to be confined or *artesian* because the aquitard prevents or restricts upward movement of water from the aquifer. In an artesian well, the water level will rise to an elevation higher than the elevation of the top of the aquifer (figure 35). In a flowing artesian well, the water level in the well rises above the land surface. The level of water in wells in a confined aquifer is known as the potentiometric or *piezometric surface* (figure 35).

As a well discharges water from an aquifer, the water level is lowered around the well. This depression in the water level, called drawdown, causes ground water around the well to flow toward the well to compensate for water pumped from the aquifer. A greater pumping rate causes a greater depression in the water level and induces recharge to the aquifer; however, the recharge rate may be limited by the permeability of the aquifer and surrounding formations.

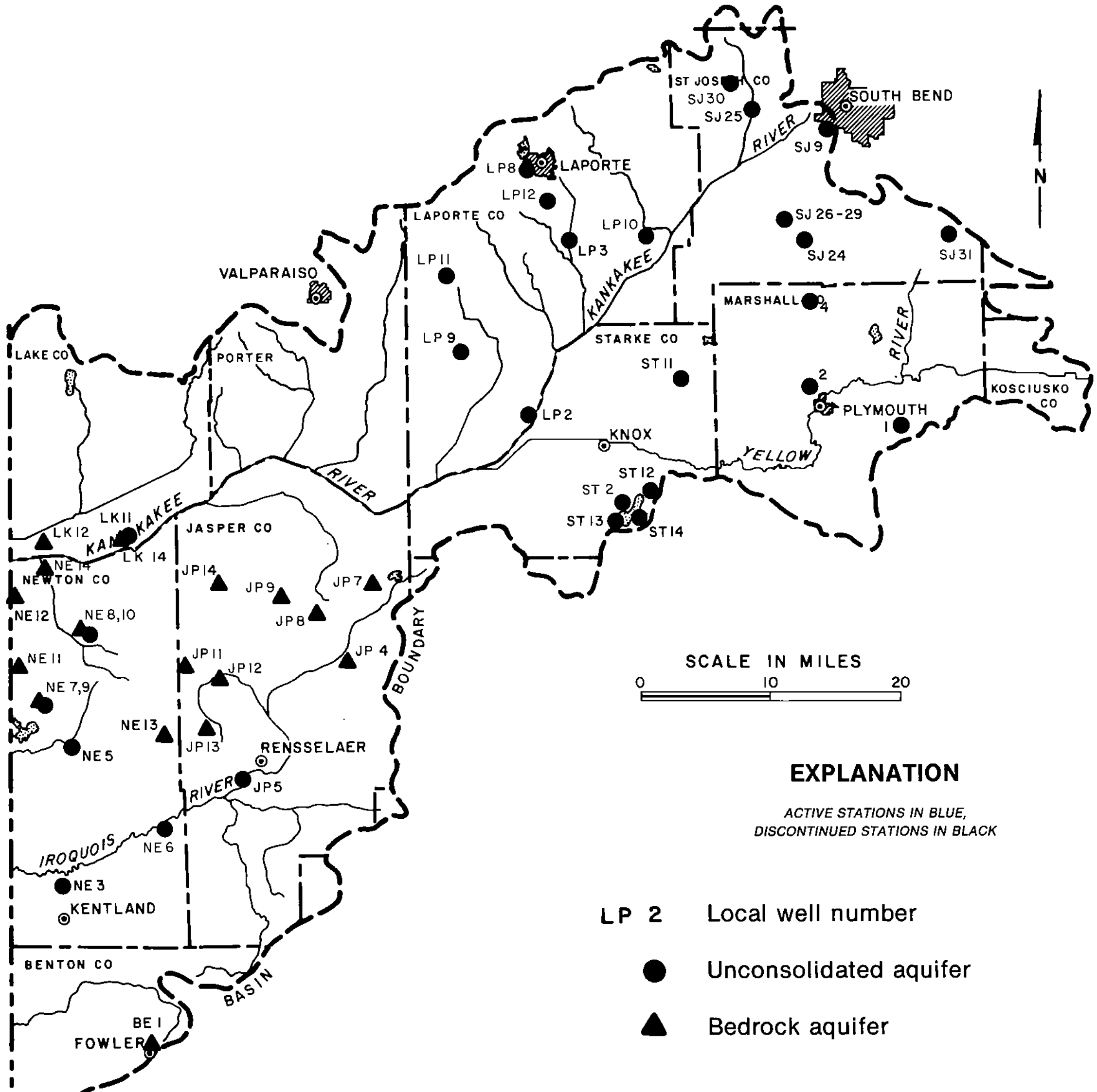


Figure 36. Location of observation wells

Ground-water levels

The ground-water level within an aquifer constantly fluctuates in response to rainfall, evapotranspiration, ground-water movement (including recharge and discharge), and ground-water pumpage. The U.S. Geological Survey, in cooperation with the Indiana Department of Natural Resources, has maintained records of ground-water levels in the Kankakee River Basin since 1935. By 1950 the observation well network within the basin included 5 wells. By late 1989 there were 25 active observation wells and 23 wells which had been discontinued from service (table 19, figure 36).

Water level is recorded automatically in each of the active observation wells. Daily records of ground-water levels are collected periodically by the U.S. Geological Survey and published annually in water-resource data reports.

Two wells in the Kankakee River Basin are equipped with special devices for transmitting encoded data via an earth-orbiting satellite. Water-level data from these wells can be obtained immediately to allow monitoring of pumpage-induced drawdown.

Table 19. Observation wells

Well number: U.S. Geological Survey county code and well number. Well locations are shown in figure 36.
Period of record: Refers to calendar year, whether or not data encompasses entire year.
Aquifer system: VM, Valparaiso Moraine; VOA, Valparaiso Outwash Apron; ES, Eolian Sands; MM, Maxinkuckee; KK, Kankakee; IQB, Iroquois Basin; NAP, Nappanee; SD, Silurian/Devonian carbonates; +SD, Silurian/Devonian carbonates overlain by Devonian shale; M1, Mississippian Borden Group.
Aquifer type: LS, limestone; DOL, dolomite; SG, sand and gravel; S, sand; G, gravel; Drift, undifferentiated glacial deposit.
Aquifer classification: A, affected by pumpage; UA, unaffected; SP, special purpose.

	County	Well no.	Period of record	Aquifer system	Aquifer type	Well diameter (in.)	Well depth (ft.)	Aquifer class
Active	Jasper	JP4	1956-	SD	LS	16	300	A
		7	1967-	+SD	LS	6	130	A
		8	1978-	SD	LS	12	310	A
		9	1978-	SD	LS	18	260	A
		11	1981-	+SD	LS	16	630	A
		12	1982-	+SD	LS	5	150	A
		13	1982-	+SD	DOL	5	150	A
		14	1989-	SD	LS	6	97	A
	Lake	LK12	1967-	SD	DOL	6	82	A
		14	1989-	SD	LS	6	107	A
	LaPorte	LP8	1976-	VM	SG	3	22	SP
		9	1976-	KK	S	6	32	A
		10	1980-	VOA	SG	6	104	A
		11	1981-	VOA	SG	6	100	A
		12	1981-	VM	SG	6	77	A
	Newton	NE6	1967-	IQB	SG	6	80	A
		7	1976-	SD	LS	6	150	A
		8	1976-	SD	LS	6	150	A
		9	1978-	KK	S	2	45	UA
		10	1978-	KK	S	2	45	UA
		11	1981-	SD	LS	5	150	A
		14	1985-	SD	DOL	6	150	A
	St. Joseph	SJ30	1980-	KK	S	5	87	A
		31	1986-	NAP	SG	6	109	UA
	Starke	ST2	1935-	ES	G	6	85	SP
Discontinued	*Benton*	*BE1*	*1944-58*	*M1*	*LS*	*10*	*114*	*A*
	Jasper	*JP5*	*1955-56*	*IQB*	*SG*	*16*	*47*	*A*
	Lake	*LK11*	*1956-81*	*KK*	*SG*	*4*	*18*	*UA*
	LaPorte	*LP2*	*1942-66*	*VOA*	*SG*	*6*	*116*	*SP*
		3	*1955-69*	*VOA*	*SG*	*7.5*	*89*	*A*
	Marshall	*1*	*1948-66*	*NAP*	*Drift*	*12*	*18*	*UA*
		2	*1956-71*	*MM*	*SG*	*16*	*127*	*A*
		4	*1957-71*	*MM*	*SG*	*6*	*141*	*A*
	Newton	*NE3*	*1954-71*	*IQB*	*SG*	*10*	*103*	*A*
		5	*1956-74*	*KK*	*SG*	*16*	*49*	*A*
		12	*1981-85*	*SD*	*LS*	*5*	*150*	*A*
		13	*1982-85*	*SD*	*DOL*	*5*	*130*	*A*
	St. Joseph	*SJ9*	*1945-71*	*KK*	*SG*	*8*	*82*	*UA*
		24	*1957-70*	*MM*	*SG*	*12*	*92*	*UA*
		25	*1959-80*	*KK*	*SG*	*6*	*41*	*UA*
		26	*1975-82*	*MM*	*SG*	*1.5*	*25*	*SP*
		27	*1975-82*	*MM*	*SG*	*1.5*	*16*	*SP*
		28	*1975-82*	*MM*	*SG*	*1.5*	*25*	*SP*
		29	*1975-82*	*MM*	*SG*	*1.5*	*14*	*SP*
	Starke	*ST11*	*1948-70*	*ES*	*G*	*1*	*67*	*UA*
		12	*1976-86*	*ES*	*S*	*2*	*17*	*SP*
		13	*1976-86*	*ES*	*S*	*3*	*13*	*SP*
		14	*1976-86*	*ES*	*S*	*2*	*24*	*SP*

Three active observation wells in the basin record natural water-level fluctuations in unconsolidated deposits. Twenty wells record ground-water levels in areas affected by high-capacity pumpage, mostly for irrigation. There are no unaffected observation wells completed in bedrock in the Kankakee River Basin.

Figure 37a shows the hydrograph of observation well Newton 9, which is completed in a shallow *unconfined* aquifer. Although there is extensive irrigation in the area, the water level in Newton 9 is classified by the Division of Water as unaffected by nearby pumpage. The annual fluctuation shown in figure 37a ranges from 2 to 6 feet. The difference between the maximum high and low for the period 1978-1988 is 14.2 feet.

Figure 37b shows the hydrograph of Cass 3. This observation well is located outside of the Kankakee River Basin, but is completed in the same Silurian and Devonian dolomitic limestone that is used extensively for irrigation in Jasper and Newton Counties. The water level in Cass 3 is unaffected by high-capacity withdrawal. The range of the seasonal fluctuation shown in the hydrograph of Cass 3 is 1 to 3 feet, and the maximum fluctuation over the period 1967-1988 is 5.1 feet.

Figure 37c shows the hydrograph for Jasper 13, which records the piezometric water-level change in a bedrock aquifer affected by nearby pumpage. The Jasper 13 hydrograph shows that irrigation pumpage induces a decline of 15 to 25 feet in the piezometric level during the irrigation season, May through September. The difference between the minimum and maximum water levels in Jasper 13 is 39.3 feet for the period 1982-1988.

When irrigation ceases, typically in September, the ground-water level in Jasper 13 begins to rise as recharge replaces water removed from the aquifer. Water levels reach their seasonal peaks during March through May of the following year.

In general, the effect of irrigation on unconfined aquifers is not as great as the effect on the Silurian and Devonian carbonate aquifer. Observation wells LaPorte 9 and St. Joseph 30 monitor the water table level near irrigation wells. These wells have recorded an annual water-table fluctuation of 2 to 7 feet during the period 1983-87 (appendix 8). The difference between the recorded maximum and minimum water-table levels in both wells is approximately 7 feet.

The remaining observation wells in the Kankakee River Basin have a special-purpose classification. The active and discontinued special-purpose observation

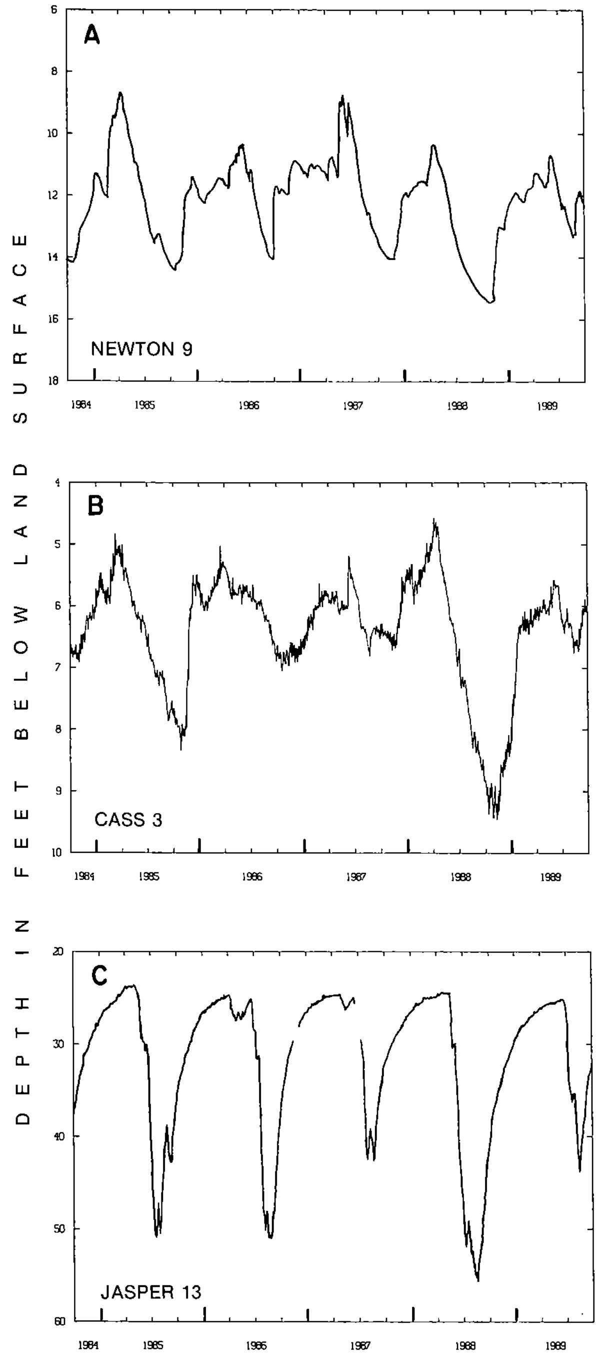


Figure 37. Water-level fluctuations in observation wells affected or unaffected by nearby pumpage

wells in the Kankakee River floodplain and near Pine and Bass Lakes were intended to monitor hydrologic interactions between surface-water and ground-water systems. Discontinued special-purpose observation wells in St. Joseph County were intended to monitor the effect of Worster Lake (Potato Creek Reservoir) on the surrounding water table.

Detailed analysis of the data from special-purpose wells is not available and was not attempted for this study. However, hydrographs for observation wells near Bass Lake were plotted in figure 38 to provide general information on local ground-water conditions.

Although the discontinuity of interbedded sand and clay deposits underlying Bass Lake make it difficult to determine the nature of the lake and ground-water interaction, ground-water levels near the lake indicate that the water table slopes to the northwest. As figure 38 shows, water-table levels in observation wells Starke 12 and 14 located east of the lake are consistently higher than lake level, whereas water levels west of the lake in Starke 13 are consistently lower than lake level. Because water flows from higher to lower elevations, the water levels in shallow observation wells near Bass Lake show a potential movement of water following the regional trend from the basin divide northwestward toward the Yellow River.

Piezometric surface

The piezometric surface map for the Kankakee River Basin (plate 1) depicts the elevation to which water levels will rise in wells. The map is created by plotting elevations of the *static water level* and contouring lines of equal elevation. Static water levels used to develop the piezometric surface map are from wells completed at various depths and under confined and unconfined conditions.

The piezometric level is a measure of the pressure of water in an aquifer. Water in a water-table aquifer is at atmospheric pressure, whereas water in a confined aquifer is under hydrostatic pressure and will rise in a well above the top of the water-bearing formation.

The piezometric map may be used to calculate expected depths to water in a well completed in a specific aquifer, but cannot be used to determine recommended depths of wells. The appropriate well depth is determined by the local geologic conditions.

The piezometric surface map also may be used to define the probable regional flow path of contaminants or to identify areas of ground-water recharge and discharge. In general, the composite piezometric surface follows overlying land-surface topography and intersects the land surface at major streams. The expected

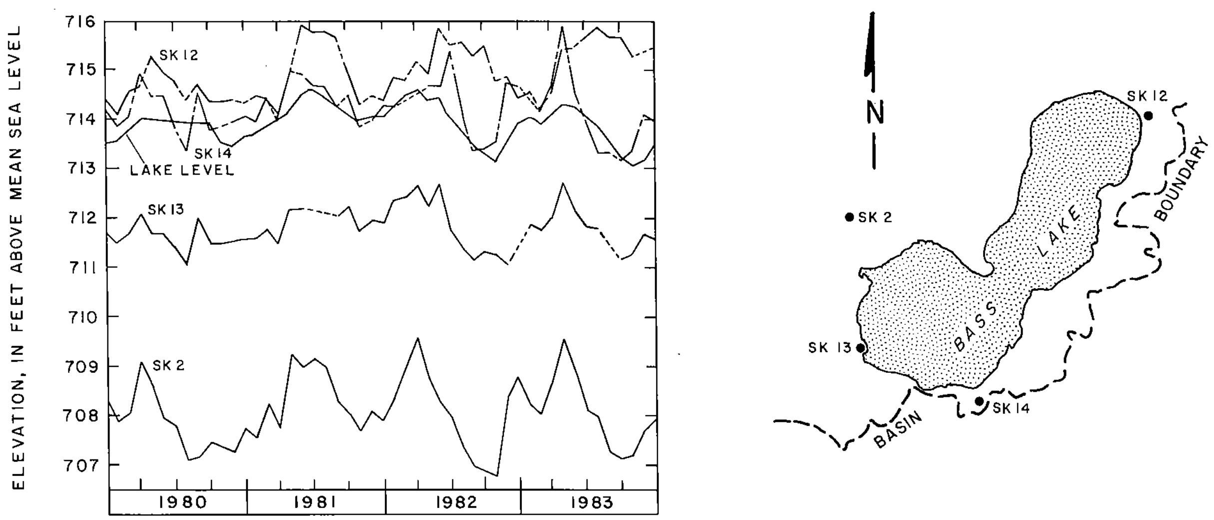


Figure 38. Water-level fluctuations in observation wells near Bass Lake

flow path is downslope or perpendicular to lines of equal elevation of the piezometric surface. In general, ground water flows from areas of recharge toward areas of discharge.

In the Kankakee River Basin, ground-water levels range from an elevation of 825 feet m.s.l. at the basin divide in St. Joseph County to a low of about 625 feet m.s.l. where the Kankakee River enters Illinois. This range is a function of the basin topography and the ground-water flow from areas of recharge to areas of ground-water discharge. Regional ground-water flow is toward the Kankakee River and its major tributaries.

The surficial aquifers in the low-lying center of the basin have a very high water table. The ground-water level in the Kankakee floodplain is often less than 10 feet below land surface.

Until the late 1800s, the Kankakee River floodplain was a large marsh with water above the ground surface most of the year. Extensive ditching of the floodplain provided an outlet for water in the marsh and resulted in some dewatering of the surficial sand deposits and more rapid runoff (Rosenshein and Hunn, 1968a).

AQUIFER SYSTEMS

The ground-water resources of the Kankakee River Basin are mapped and described as regional aquifer systems (plate 2). Lack of data and complexity of the glacial geology preclude detailed aquifer mapping.

Ground-water supplies in the Kankakee River Basin are obtained from unconsolidated and bedrock aquifer systems. Ten unconsolidated aquifer systems and one subsystem are defined according to hydrologic characteristics of the deposits and their environments of deposition. Seven bedrock aquifer systems are defined on the basis of hydrologic and lithologic characteristics; however, not all of the bedrock formations are productive aquifers.

Unconsolidated aquifer systems

Unconsolidated aquifer systems in the Kankakee River Basin are glacial and eolian deposits formed in various environments and at different times. Unconsolidated aquifer systems have gradational boundaries and individual aquifers may extend across the boundaries of aquifer systems.

The most productive unconsolidated formations are outwash deposits of the Kankakee, St. Joseph and Tributary Valley, and Valparaiso Outwash Apron Aquifer Systems. As figure 39 shows, thick sands and gravels predominate in these systems.

The least productive unconsolidated systems are the clayey tills of the Iroquois Moraine Aquifer System. Water-bearing sand and gravel deposits in this system generally are thin and discontinuous.

The following discussion of unconsolidated aquifer systems begins in the northeast portion of the Kankakee River Basin and progresses westward and southward to the Iroquois River Basin. The locations of aquifer systems are shown in plate 2.

Nappanee Aquifer System

Wisconsinan glacial lobes deposited materials that form an elevated till plain in the eastern part of the Kankakee River Basin. This till plain with its *intratill* sand and gravel aquifers forms the Nappanee Aquifer System.

This aquifer system covers much of Marshall County (plate 2) and extends into the St. Joseph River Basin. The aquifer system grades into deposits of the Maxinkuckee Moraine Aquifer System to the west.

The Nappanee Aquifer System is characterized by surficial till, in places as much as 90 feet thick, which overlies variably thin, coarse sand and fine gravel lenses interbedded with thin layers of clay. Individual aquifers, which typically range from 3 to 10 feet thick, seldom cover more than 1 or 2 square miles. Locally, sand and gravel units may thicken to 30 feet, and in general are thickest to the west where they grade into deposits of the Maxinkuckee Moraine.

Aquifers in the Kankakee River Basin portion of the Nappanee Aquifer System commonly occur at an elevation of 720 to 740 feet m.s.l.

The Nappanee Aquifer System yields from 5 to 50 gpm to domestic wells, and may yield 50 to 600 gpm to properly constructed, large-diameter wells (table 20).

Maxinkuckee Moraine Aquifer System

The Maxinkuckee Moraine was deposited at the eastward terminus of the Lake Michigan Lobe and the western edge of Saginaw Lobe (see figure 12). The

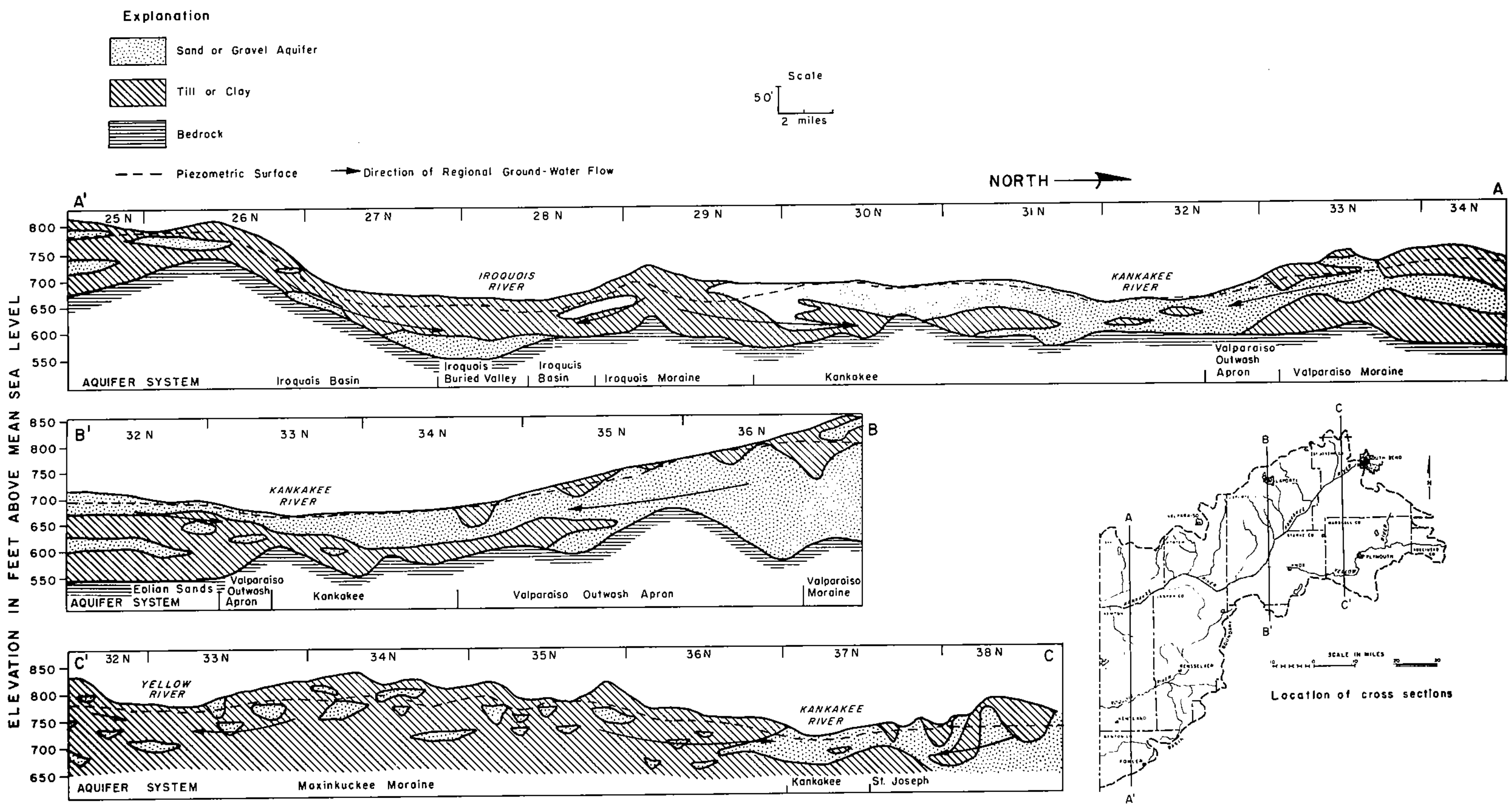


Figure 39. Generalized cross section of unconsolidated aquifer systems

Table 20. Hydrologic characteristics of unconsolidated aquifer systems

Aquifer system	Range of aquifer thickness (ft)	Common aquifer thickness (ft)	Range of pumping rates (gpm)		Expected high-capacity yield (gpm)	Hydrologic condition
			Domestic	High-capacity		
Nappanee	3 - 30	3 - 10	5 - 50	50 - 1000	50 - 600	Confined
Maxinkuckee Moraine	3 - 35	5 - 20	4 - 80	100 - 1400	100 - 600	Confined, Unconfined
Hilltop	10 - 100+	60	10 - 15	25 - 250	25 - 150	Confined, Unconfined
St. Joseph and Tributary Valleys	10 - 100+	10 - 60	8 - 60	500 - 1500	500 - 1000	Unconfined, Confined
Valparaiso Moraine	18 - 100+	40	10 - 60	100 - 800	100 - 600	Confined, Unconfined
Valparaiso Outwash Apron	10 - 100+	50	15 - 60	100 - 1100	150 - 600	Unconfined
Kankakee	20 - 150	30	15 - 50	100 - 1500	100 - 1200	Unconfined
Eolian Sands	4 - 72	10 - 30	10 - 50	100 - 1200	100 - 600	Confined, Unconfined
Iroquois Moraine	3 - 25	3	4 - 10	NA	0 - 50	Confined
Iroquois Basin	2 - 3	3	4 - 25	10 - 400	10 - 100	Confined, Unconfined
Iroquois Buried Valley Subsystem	3 - 40	5 - 20	10 - 40	50 - 500	100 - 400	Confined

combined influence of these glaciers left a complex interbedded deposit of till and outwash.

The extent of the Maxinkuckee Moraine Aquifer System follows the trend of the Maxinkuckee Moraine from southwest of South Bend to Lake Maxinkuckee and into the Tippecanoe River Basin. The eastern border of the moraine grades into the Nappanee Aquifer System. To the west, the deposits grade into the Kankakee Aquifer System and the Eolian Sands Aquifer System (plate 2).

The Maxinkuckee Moraine Aquifer System, the most complicated aquifer system in the Kankakee River Basin, consists of a complex mixture of outwash sand and gravel, eolian sand, and till. Permeable materials consist of locally thick, coarse-grained, surficial sand and gravel deposits and intratill lenses of sand or sandy gravel.

The coarse-grained deposits are commonly outwash which occur as *alluvial fans* on the surface and buried intratill aquifers within the moraine. The surficial aquifers were probably deposited in an ice-contact or ice-marginal environment where coarse sediments accumulated in *kames* and alluvial fans. Where they occur at relatively low elevations, the surficial aquifers may be saturated and produce significant volumes of water.

Although relatively thick surficial deposits of sand and gravel may be productive aquifers, most wells in the Maxinkuckee Moraine Aquifer System are completed in thin intratill sand and gravel lenses. Intratill aquifer thickness ranges from 3 to 35 feet, and deep wells may penetrate several intratill lenses.

Well depths in the Maxinkuckee Moraine Aquifer System range from 26 to 273 feet; however, most wells are 50 to 150 feet deep. Wells less than 40 feet deep typically are completed in surficial sand and gravel deposits.

Aquifer elevations generally range from 660 to 790 feet m.s.l. Static water levels range from 0 to 90 feet deep, but in most areas are 10 to 50 feet deep.

Domestic wells may produce 4 to 80 gpm, although yields of 10 to 25 gpm are most common. High-capacity wells may produce up to 1400 gpm, but maximum expected yields are 100 to 600 gpm (table 20).

Hilltop Aquifer System

The Hilltop Aquifer System is located in a small area of St. Joseph County southeast of South Bend (plate 2). The system is a thick outwash fan of sand and gravel containing a few interbedded clay lenses and locally thin to moderately thick surficial till deposits. Surficial sand and gravel deposits in excess of 100 feet thick are commonly encountered. In contrast to the adjoining till-dominated Nappanee Aquifer System, the Hilltop Aquifer is comprised primarily of sand and gravel.

Static water levels are relatively deep in the Hilltop Aquifer System, and range from 40 to 60 feet below ground surface.

Domestic wells usually yield 10 to 15 gpm. In most areas of the Hilltop system, large-diameter wells can yield 25 to 150 gpm (table 20).

St. Joseph and Tributary Valley Aquifer System

The St. Joseph Tributary Valley Aquifer System consists of thick deposits of outwash sand and gravel in the major tributary valleys of the St. Joseph River. Large meltwater rivers sorted and deposited thick beds of coarse-grained sand and gravel.

In the Kankakee River Basin, the aquifer system is located in St Joseph and Kosciusko Counties (plate 2). In St. Joseph County, the aquifer system is interbedded with the outwash deposits of the Kankakee Aquifer System. In Kosciusko County, it is bordered by the Nappanee Aquifer System, which is primarily an intratill system.

Sand and gravel thickness of the St. Joseph Tributary Valley Aquifer System increases toward the southeast. Sand and gravel deposits in this system are as much as 129 feet thick, but are commonly from 10 to 60 feet thick. The aquifer texture ranges from very fine-grained or muddy sand to gravel.

Clay layers within the outwash are thin or absent in St. Joseph County, but are as much as 50 feet thick in Kosciusko County. Most wells in Kosciusko County pass through two sand and gravel deposits which are separated by thick clays.

Shallow well depths of 40 to 90 feet are common in this system due to the presence of thick, near-surface sands and gravels. Well depths range from 30 to 145 feet.

Shallow aquifers range in elevation from 775 to 855 feet m.s.l. Static water levels range from 4 to 70 feet deep, but primarily are between 10 and 30 feet deep.

Although large-diameter well yields as high as 1500 gpm have been reported, yields of 500 to 1000 gpm are expected in the Kankakee River Basin portion of this system. Domestic wells produce from 8 to 60 gpm (table 20).

Valparaiso Moraine Aquifer System

The Valparaiso Moraine Aquifer System lies beneath the crest of the moraine and extends from the Illinois state line to Hudson Lake (plate 2). Although the glacial environment was similar, there are differences in the glacial deposits which comprise the Valparaiso Moraine east and west of Valparaiso.

East of Valparaiso the moraine is composed of a thick outwash apron formed by coalesced stream deposits capped by till. The thick outwash core of the moraine forms a continuous aquifer.

West of Valparaiso, the meltwater stream deposits within the moraine are discrete and separated by till. The intratill channel-shaped sands form many discrete aquifers.

Although isolated sand lenses occur at various elevations within the moraine east of Valparaiso, the primary aquifer consists of widespread fine- to medium-grained sand and fine-grained gravel deposited in an outwash fan. Within the Valparaiso Moraine Aquifer System, the outwash is buried beneath the till cap and grades into the unconfined Valparaiso Outwash Apron Aquifer System to the south (figure 39). In portions of Lake and Porter Counties, outwash channels filled with sand and gravel occur at elevations between 670 and 775 feet m.s.l.

The outwash thickness ranges from 18 feet in the outwash apron near Lomax to as much as 136 feet within the moraine near LaPorte. Average thickness of the aquifer is 40 feet.

In general, deep static water levels of 25 to 80 feet are expected in this system. Because of the deep static water levels, the saturated thickness ranges from 20 to 60 feet. Thickness of the till cap ranges from 15 to as much as 72 feet.

Production from domestic wells typically is between 10 to 20 gpm, although yields up to 60 gpm have been reported. High-capacity wells yield 100 gpm to more than 600 gpm (table 20).

Valparaiso Outwash Apron Aquifer System

This aquifer system is the wedge of outwash sediments forming the southern slope of the Valparaiso Moraine. The deposits are continuous with the outwash within the Valparaiso Moraine and overlap the till in the Eolian Sands Aquifer System. The outwash apron consists of interbedded sand and fine-grained gravel, and has clay lenses and zones of shale-rich gravel.

The Valparaiso Outwash Apron Aquifer System is distinguished from other aquifer systems by its position as the southern slope of the Valparaiso Moraine. The apron is dissected in part by the Kankakee Aquifer System which underlies the floodplain of the Kankakee River and some of its major tributaries. A distinct *scarp* separates the Kankakee Aquifer System from the outwash apron in Lake and Porter Counties.

The outwash apron was deposited over lacustrine clays and channel sands. The clays are of unknown lateral extent and vary in thickness up to 20 feet. Although in places the clay separates the outwash apron deposits and the deeper channel sands, the two permeable units are considered to be one aquifer system.

South of the Kankakee River in Starke County, the Valparaiso Outwash Apron Aquifer System consists of sand and gravel overlying either the bedrock surface or a thick till. Some intratill sand and gravel lenses are present, but the overlying outwash apron is the dominant aquifer.

The thickness of the outwash apron ranges from 10 feet near the Kankakee River to 50 feet on the river terraces in southern LaPorte County, and can exceed 100 feet near the crest of the moraine.

The thickness of the lower aquifer unit is primarily determined by bedrock topography. The thickness ranges from zero at bedrock ridges where clay rests on bedrock to more than 100 feet in deep bedrock valleys.

Most wells are completed in the upper aquifer unit and have depths ranging from 30 feet to more than 100 feet. The wells completed in the lower aquifer unit typically exceed 50 feet deep and may be more than 150 feet deep.

The depth to the static water level typically is less than 20 feet deep, but at higher surface elevations, depths may exceed 40 feet.

Yields in the upper and lower aquifer units are similar, ranging from 15 to 60 gpm for domestic wells and 100 to 600 gpm for large-diameter wells. Yields up to 1100 gpm are reported for some areas. Special well-construction techniques may be necessary because of the dominance of fine-grained sand.

Kankakee Aquifer System

The Kankakee Aquifer System is an unconfined deposit of sand in the floodplain of the Kankakee River and some of its tributaries. Meltwater streams sorted and deposited glacial sediments into this slightly entrenched valley that dissects the Valparaiso outwash apron.

Most of the sediments of the Kankakee Aquifer System are well-sorted, fine- to medium-grained sand, which is interbedded with gravel in the tributary valleys. Some of the sand, particularly south of the river, has been reworked by wind into dunes. In the valley of the Little Kankakee River in LaPorte County and in St. Joseph County where the Kankakee Aquifer System grades into the St. Joseph Aquifer System, the glacial deposits generally are coarser grained than in the main river valley.

The thickness of the aquifer ranges from 20 feet or less in the lower basin to as much as 150 feet in the Little Kankakee River valley. The aquifer is about 30 feet thick in most areas, and overlies bedrock or clay. The clay is as much as 145 feet thick in the lower basin.

The Kankakee Aquifer System has a gradational boundary with the Valparaiso Outwash Apron Aquifer System to the north (figure 39, plate 2). The deposits of these systems are interbedded and hydrologically connected. The distinction between these two aquifer systems is mostly topographic, but clay lenses are more common in the outwash apron system. Recharge to the Kankakee Aquifer System comes in part from the Valparaiso Outwash Apron Aquifer System.

In the lower basin, the Kankakee Aquifer System deposits lap onto the Iroquois Moraine Aquifer System to the south. The distinction between these systems is based on topography and the absence of interbedded clays in the Kankakee Aquifer System.

Static water levels are shallow in the Kankakee River floodplain, and are usually less than 20 feet deep. Wells typically are shallow, and few exceed depths of 50 feet. In the tributary valleys, however, the depth to the water table may exceed 50 feet and well depths may exceed 150 feet.

Domestic wells usually produce from 15 to 50 gpm, and high-capacity wells may produce 100 to 1200 gpm depending on the saturated thickness and coarseness of aquifer material. Yields up to 1500 gpm for high-capacity wells may be possible in some locations in the upper basin, whereas high-capacity wells in the lower basin may yield 100 to 500 gpm. Areas which have thick coarse-grained deposits have high potential yield. High-yield areas include the Little Kankakee River Valley in LaPorte County and the Kankakee River Valley in St. Joseph County.

Eolian Sands Aquifer System

Sand dunes are the most visible geologic feature in the intermoraine lowlands of Starke County. The dunes were formed from the blanket of sand that overlies till in this relatively flat area of the basin.

The Eolian Sands Aquifer System is characterized by a thick blanket of windblown sand overlying a variable but generally thick till deposit. Additional sand and gravel zones usually are found beneath the till. Some of these deeper aquifers are thick and have multiple sand and gravel lenses separated by till. The proportion of gravel in a sand deposit may increase with depth. In a few locations, surficial sand is absent and till is present at the surface. The thickness of the till ranges from less than 5 feet to as much as 100 feet.

Aquifer materials range from fine-grained sand to gravel. The thickness of the aquifers ranges from 4 to 72 feet. Most wells produce from aquifers 10 to 30 feet thick.

The Eolian Sands Aquifer System borders the Valparaiso Outwash Apron Aquifer System to the west (plate 2). The outwash apron system contains very little till compared to the eolian sand. Furthermore, the Eolian Sands Aquifer System occupies higher ground than the outwash apron.

The Eolian Sands Aquifer System is bounded to the east by the Maxinkuckee Moraine Aquifer System. The boundary between these aquifer systems is marked by the eastward thinning of the eolian sand deposit as the distance from the source of the sand increases.

Although some shallow wells are completed in surficial sand less than 40 feet deep, most wells pass through till to produce from deep sand and gravel beds. Well depths in this system range from 24 to 211 feet, but most wells are between 50 and 120 feet deep.

Static water levels throughout the Eolian Sands Aquifer System range from land surface to 48 feet deep. Most static water levels are between 5 and 20 feet deep.

Most large-diameter wells produce at least 150 to 200 gpm and some large-diameter wells reportedly produce up to 1200 gpm (table 20). Domestic-well yields range from 10 to 50 gpm. Despite the erratic distribution of sand lenses, only one dry hole has been reported in the aquifer system.

Iroquois Moraine Aquifer System

The Iroquois Moraine Aquifer System consists of isolated sand and gravel deposits encompassed within thick sections of clay (figure 39). Dunes overlie portions of the moraine in western Newton and Jasper Counties, but these sand deposits contain very little water.

There are severe limitations to water resources in this aquifer system. Thickness of the discontinuous aquifers range from 3 to about 37 feet, but most aquifers are less than 10 feet thick. Fine-grained sand deposits which occur near the land surface have limited saturated thickness and therefore have a limited potential for water-supply development. Deeper and generally thicker sand and gravel lenses may yield higher quantities of water.

The Iroquois Moraine Aquifer System is distinguished from the Kankakee Aquifer System to the north by the increase in elevation at the moraine's northern slope and the lack of till in the Kankakee Aquifer System. The Iroquois Basin Aquifer System, which forms the southern border of Iroquois Moraine Aquifer System (plate 2), has a lower surface elevation and thinner unconsolidated deposits with more variation in aquifer elevations.

Two potential zones for water production exist within the Iroquois Moraine. The first zone is a deposit of fine- to medium-grained sand at elevations between 640 and 685 feet m.s.l. Thickness of these discontinuous sand deposits ranges from 3 to 25 feet, and averages about 9 feet. Although some shallow domestic wells produce from the upper sands, the deposits commonly are not saturated and thus have limited potential as aquifers.

A second aquifer zone may occur at elevations between 545 and 590 feet m.s.l. These sand and gravel deposits range from 5 to 37 feet thick, and have an average of 13 feet. Where present, the deposits occur at depths between 60 and 125 feet. Static water levels are most often between 15 and 30 feet, although reported values range from 5 to 80 feet. Well depths for the Iroquois Moraine Aquifer System range from less than 50 to more than 170 feet.

Domestic wells completed in deeper aquifers yield from 4 to 10 gpm (table 20). However, because these aquifers are present only in small areas of the moraine, many wells pass through the unconsolidated deposits to obtain water from the underlying bedrock.

Iroquois Basin Aquifer System

The Iroquois Basin Aquifer System consists predominantly of glacial till having thin intratill aquifers and some deeply buried aquifers in bedrock valleys. Two- to three-foot-thick lenses of intratill sand and gravel are present in a wide range of elevations, but most occur between 630 to 650 feet m.s.l. These deposits consist of fine- to medium-grained sand with local gravel deposits.

This system adjoins the Iroquois Moraine Aquifer System to the north (plate 2). Several of the sand and gravel units in this system occur at elevations similar to those in the Iroquois Moraine Aquifer System, and the two aquifer systems may be hydrologically connected in places.

Static water levels in this aquifer system generally range from 7 to 20 feet deep, but records include flowing wells and static water levels as much as 75 feet deep.

The elevation of the bedrock surface increases toward the southern boundary of the Iroquois Basin (figure 39), and in this area many of the wells are drilled through the unconsolidated deposits of the Iroquois Basin Aquifer System to obtain water from the underlying bedrock. The northern part of the aquifer system overlies the New Albany Shale, Antrim Shale and Silurian and Devonian carbonates. The Borden Group forms the bedrock high to the south.

Well yields generally are adequate for domestic use (4-25 gpm), but dry holes can occur because of the erratic distribution of the intratill aquifers. Large-diameter wells completed in locally thick, deeper sand and gravel deposits may be capable of producing from 100 to 400 gpm (table 20), but lower yields commonly are expected.

Iroquois Buried Valley Subsystem

This subsystem of the Iroquois Basin Aquifer System parallels the Iroquois River from southwest of Rensselaer into Illinois (plate 2). The deposit is composed of sand and gravel in a buried bedrock valley beneath tills of the Iroquois Basin Aquifer System. The thickness of the sand and gravel deposits ranges from about 3 to 40 feet and the aquifers occur at elevations between 540 and 590 feet m.s.l. Well depths to these aquifers range from about 60 to 125 feet, with an average of about 80 feet.

In contrast to the overlying deposits, sand and gravel zones in the Iroquois Buried Valley subsystem are more consistent, and wells may encounter more lenses of water-bearing sand and gravel. Domestic wells produce from 10 to 40 gpm, and high-capacity wells yielding up to 400 gpm can be expected (table 20).

Bedrock aquifer systems

The occurrence of bedrock aquifers depends on the original composition of the rocks and subsequent changes which influenced the hydraulic properties. Erosion has removed layers of bedrock from the crest of the Kankakee Arch and has increased permeability in the exposed bedrock by weathering and solution activity.

Because permeability is greatest near the bedrock surface, the upper bedrock units are in many cases the most productive aquifers. Rock types exposed at the bedrock surface range from unproductive shales to highly productive limestones and dolomites.

The yield of bedrock aquifers depends on hydraulic characteristics and the nature of the overlying deposits. In part, the overlying glacial deposits determine the recharge rate to the bedrock aquifers. In many locations, the bedrock aquifer has a high potential yield, but has little use because the overlying strata have good hydraulic characteristics.

In general, bedrock aquifers are not used in the upper Kankakee River Basin because of the predominance of unproductive shales and the availability of water from the unconsolidated materials overlying bedrock. In the lower basin, a thin mantle of unconsolidated materials and the presence of thick, highly productive carbonate aquifers favor the development of bedrock aquifers.

In the southwest part of the lower basin in and near Benton County, shale, sandstone, siltstone, and thin limestone are covered by a variable but often thin covering of unproductive drift. There are a large number of bedrock wells in this shale-dominated area but they generally yield water in amounts sufficient only for domestic use.

Silurian and Devonian Carbonate

In the Kankakee River Basin, the Silurian and Devonian carbonate rocks are the most productive bedrock aquifers. Because individual units of the Silurian and Devonian Systems are composed of similar carbonate rock types and cannot be distinguished on the basis of water-well records, they are considered as a single water-bearing system. The small areas of Silurian and Devonian carbonate occurring in the upper basin are not used because adequate water supplies generally can be obtained from the overlying unconsolidated materials (Plate 2).

In carbonate aquifers water is stored and transmitted in joints, fractures, bedding planes and solution openings within the rock. The reef facies of the Silurian carbonates have high porosities (from 5 to 25 percent) and high permeabilities. The bank and inter-reef facies contain significantly lower porosities and permeabilities. Devonian carbonates have porosity values which are highly variable and range from 0 to 14 percent (Rupp, Indiana Geological Survey, written communication, 1988).

The carbonate bedrock strata in and near the Kankakee River Basin may be extremely thick. Deep, high-capacity wells commonly penetrate 200 to 450 feet of carbonate rock, and some wells have been reported to penetrate up to 550 feet of uninterrupted rock. Domestic wells commonly only penetrate the upper 15 to 100 feet of the carbonate bedrock.

In some areas near the contact between the Antrim Shale and the Devonian carbonates, wells are drilled through the shale and into the more productive underlying carbonate rocks. Because the overlying shale inhibits recharge and fracturing may not be well developed in the carbonates, these wells are less productive than wells completed in carbonates not overlain by shale. In many places, limestones and dolomites are interbedded with shale units of variable thickness.

Static water levels are quite variable in the wells completed in the carbonate aquifer. Water levels ranging from 1 foot to 117 feet have been reported; however, levels usually are between 10 and 40 feet. Flowing wells in this bedrock unit are rare. Only three flowing wells have been reported at scattered locations in the basin.

Well yields depend on the diameter of the well and aquifer characteristics. Most of the wells in this bedrock system are 4- to 6-inch-diameter domestic wells. Most domestic wells can be expected to produce between 10 and 30 gpm, but well yields range from 8 to 200 gpm.

The Silurian and Devonian carbonate system is the only bedrock system in the Kankakee River Basin capable of sustaining high-capacity well yields. Most deep, large-diameter wells produce 300 to 1000 gpm, but some wells yield up to 1850 gpm. Large wells, having 8- to 16-inch diameters, are usually industrial, municipal, or irrigation supply wells. Only a few dry holes have been reported in this aquifer system.

Devonian Antrim Shale

The Devonian Antrim Shale forms the bedrock surface in a broad east-to-west band across the basin and in a few scattered areas in Jasper County (plate 2). Although the Antrim Shale is not considered to be a significant aquifer, it may yield sufficient quantities of water for domestic uses.

In areas where the Antrim Shale is at the bedrock surface, wells are usually attempted in the unconsolidated glacial material overlying bedrock.

Less than two dozen wells producing from the Antrim Shale have been reported, and most are located in the lower basin. The wells are from 66 to 140 feet deep and penetrate as much as 62 feet into the shale.

Static water levels in the wells range from 10 to 50 feet deep. Wells in the Antrim Shale have varying yields, but most produce 15 gpm or less. No high-capacity wells have been reported. No dry holes have been reported, but it is likely that many dry holes exist.

Devonian and Mississippian New Albany Shale

The Devonian and Mississippian New Albany Shale forms the bedrock surface in southern Newton and Jasper Counties. Like the Antrim Shale, the New Albany is a black shale, often mistakenly reported as slate, and overlies the Devonian carbonate bedrock. Although several dozen wells are reported producing water from the New Albany Shale, the formation is not considered as a significant aquifer. Wells often are drilled through the New Albany Shale into the underlying carbonates in an attempt to get higher well yields.

Most wells developed in the New Albany Shale penetrate at least 30 feet of shale, but wells are reported to penetrate from 11 to 102 feet. Well depths range from 45 to 120 feet and static water levels are usually between 4 and 15 feet.

Most wells in the Devonian and Mississippian New Albany Shale yield 5 gpm or less, but some yields of up to 20 gpm have been repoted. A number of dry holes have been reported in the New Albany Shale.

Devonian and Mississippian Ellsworth Shale

The Devonian and Mississipian Ellsworth Shale is at the bedrock surface over a large area in the northern portion of the basin (plate 2). Because thick glacial deposits overlying the shale usually provide adequate water supplies, the Ellsworth Shale is an unlikely supply source. There are no known wells in the Kankakee River Basin that produce from the Ellsworth Shale.

Mississippian Borden Group

Mississippian Borden Group rocks are at the bedrock surface in the southwestern portion of the Kankakee River Basin in Benton County. Most of the productive wells in this area have penetrated limestone, although some wells produce from shale or sandstone units.

Although most bedrock wells in this area produce sufficient quantities of water for domestic purposes, there is little chance for development of high-capacity wells. A number of dry holes have been reported.

Many deep wells are completed in this aquifer system. Deep wells may pass through the shales to reach more productive limestones or to increase the storage capacity of a well completed in a low-yield aquifer.

Most wells penetrate less than 70 feet of bedrock, but wells penetrate from 8 to 270 feet. Bedrock well depths range from 40 to 325 feet. Most wells are more than 100 feet deep.

Static water levels range from 3 to 150 feet but are usually between 20 and 50 feet.

Generally, domestic wells completed in the Borden Group yield from 5 to 15 gpm, although reported yields range from 4 to 55 gpm. One high-capacity well reportedly produces 80 gpm.

Pennsylvanian Raccoon Creek Group

Several small areas of Pennsylvanian-age rock occur in the lower basin. Wells drilled in these areas reportedly encounter sandstone, but these areas are too small to be well defined on the basis of water-well data. The water-bearing capabilities of this aquifer system should be similar to the adjacent bedrock aquifers.

Kentland Anomaly

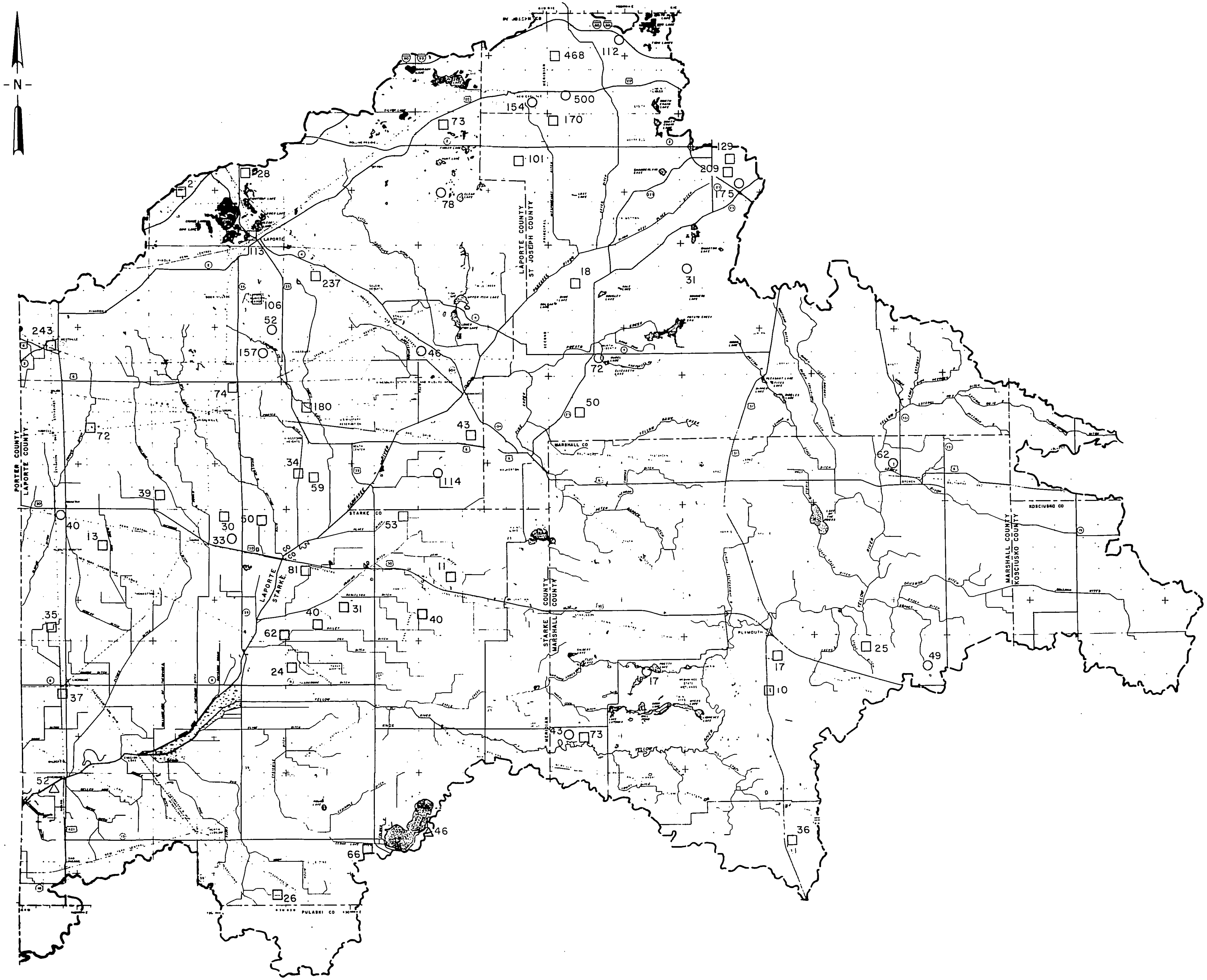
Beneath a small area in Newton County, the bedrock has been faulted and folded by undetermined forces that brought deeply buried Ordovician rocks to the bedrock surface where they contact Pennsylvanian formations. The faulting has probably increased the permeability of the dolomite and limestone in this feature, but the aquifer characteristics are unknown.

GROUND-WATER DEVELOPMENT POTENTIAL

The development or potential yield of an aquifer depends on aquifer characteristics (*transmissivity*, *hydraulic conductivity*, and storage), aquifer thickness, areal extent, ground-water levels and recharge. The outwash aquifers cover a large part of the basin and are very thick in places. In particular, the tributaries and northeastern areas of the Kankakee Aquifer System have exceptional ground-water development potential. Of the basin's bedrock aquifers, the Silurian and Devonian Carbonate has the greatest potential for ground-water development, but in places *recharge* to it is limited by overlying till or shale.

STATE OF INDIANA
DEPARTMENT OF NATURAL RESOURCES
DIVISION OF WATER

UPPER KANKAKEE RIVER BASIN



EXPLANATION

BEDROCK WELLS IN RED, UNCONSOLIDATED WELLS IN BLUE.

TRANSMISSIVITY VALUES IN 1000 GALLONS PER DAY PER FOOT

METHODS

△ Aquifer test

○ Specific capacity, adjusted drawdown

□ Specific capacity, unadjusted drawdown

Figure 40a. Transmissivity values

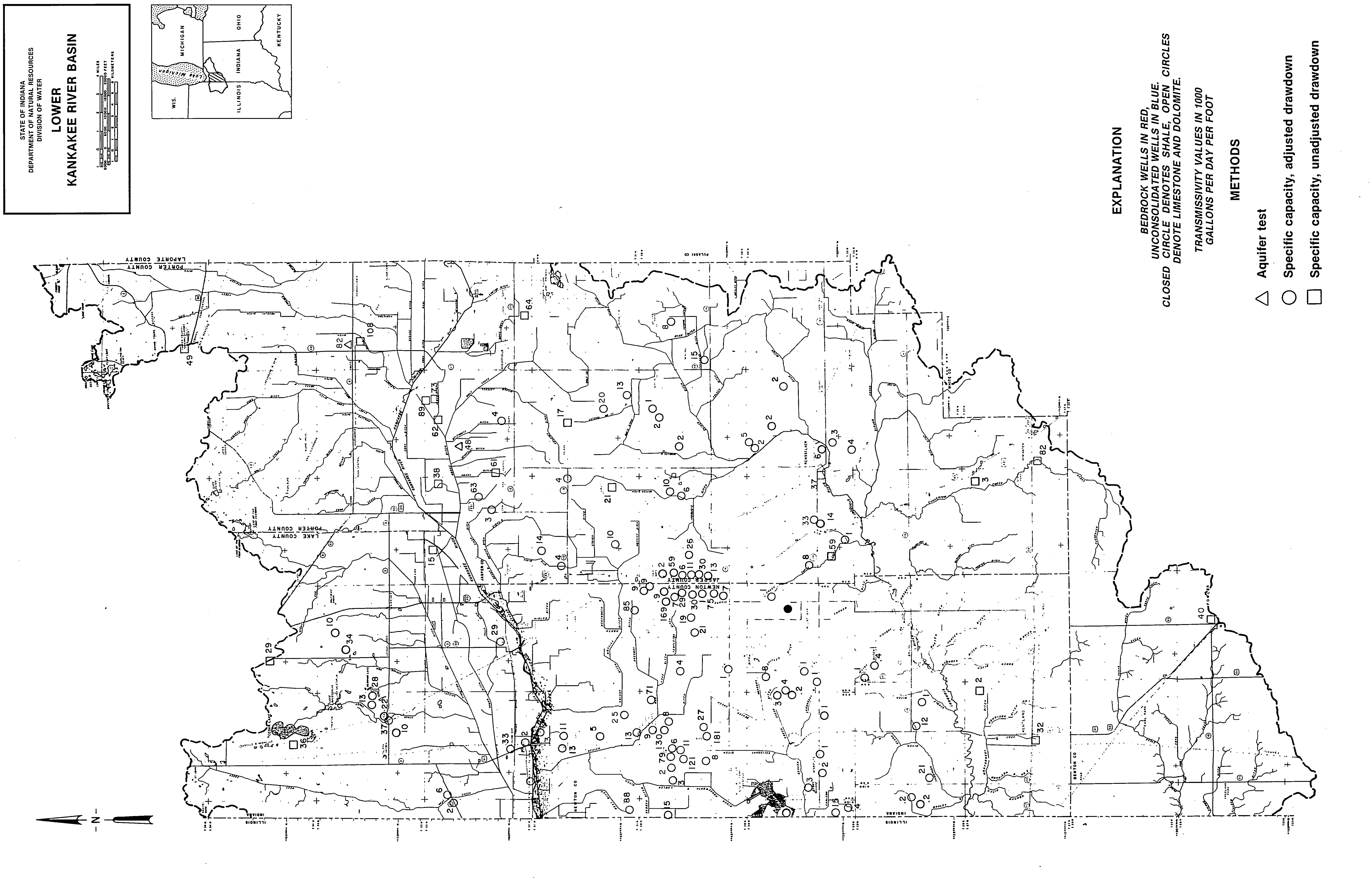


Figure 40b. Transmissivity values

Transmissivity

Transmissivity, a measure of the water-transmitting capability of an aquifer, is defined as the product of the hydraulic conductivity and the saturated thickness of an aquifer. Methods used to compute transmissivity establish a mathematical relationship between the pumping rate and the resultant drawdown in the aquifer for a given set of well and aquifer conditions. The three methods used to estimate the transmissivities of aquifers within the Kankakee River Basin include the use of 1) graphical plots based on aquifer-test data, 2) specific capacity data based on adjusted drawdown, and 3) specific capacity data based on unadjusted drawdown (figure 40).

The graphical approach can be used only when extensive data have been collected from aquifer tests. In most aquifer tests, water levels are recorded simultaneously at observation wells while the test well is being pumped. The response of the aquifer is monitored over an areal extent that is determined by the spatial distribution of the observation wells. Graphical plots of time versus drawdown and distance versus drawdown can yield reliable estimates of the hydraulic parameters of the aquifer. However, unless an extensive well field is being developed, an aquifer test is not warranted because the cost of installing observation wells is too high.

Piezometer tests are much less expensive than aquifer tests because drawdown is measured only at the test well while it is being pumped. After the completion of a water well, the driller conducts a piezometer test to determine the specific capacity of the aquifer. Specific capacity, defined as the rate at which water can be pumped from a well under unit decline in head, can be used to estimate hydraulic properties of aquifers if other information is not available (Peters, 1987). Specific capacity data can be easily attained by inspection of the driller's log. Prior to estimation of aquifer tranmissivity, drawdown must be adjusted for the effects of well loss, partial penetration, and dewatering of the aquifer unless it is confined. In most cases, these factors tend to cause lower estimates of specific capacity (Walton, 1970).

Transmissivity estimates based on specific capacity data may not be very accurate in cases where an aquifer of unknown thickness is partially penetrated by a test well. These values represent minimum estimates of transmissivities and are described as aquifer transmissivity based on unadjusted drawdown. As a result, these values are the least reliable estimates of aquifer transmissivity.

For this report, estimates of aquifer transmissivity from specific capacity data were generated using a computer program called 'Tguess' (Bradbury and Rothschild, 1985). The computer program adjusts specific capacity data for well loss, partial penetration and dewatering of the aquifer if appropriate, and generates estimates of transmissivity by using an iterative technique.

The transmissivities of the aquifers within the Kankakee River Basin are highly variable (figure 40). The wide range in values is probably the result of the heterogeneity of the geologic formations and the use of different methods in estimating aquifer transmissivity.

For comparative purposes, it may be best to examine transmissivity values that were computed by the same method. The differences from such comparison may reflect local variations in the geologic conditions, especially aquifer thickness and permeability. However, interpretation of a given transmissivity is complex because it is a product of hydraulic conductivity and saturated thickness. A thick, moderately permeable aquifer can have a similar transmissivity as a thin, highly permeable aquifer.

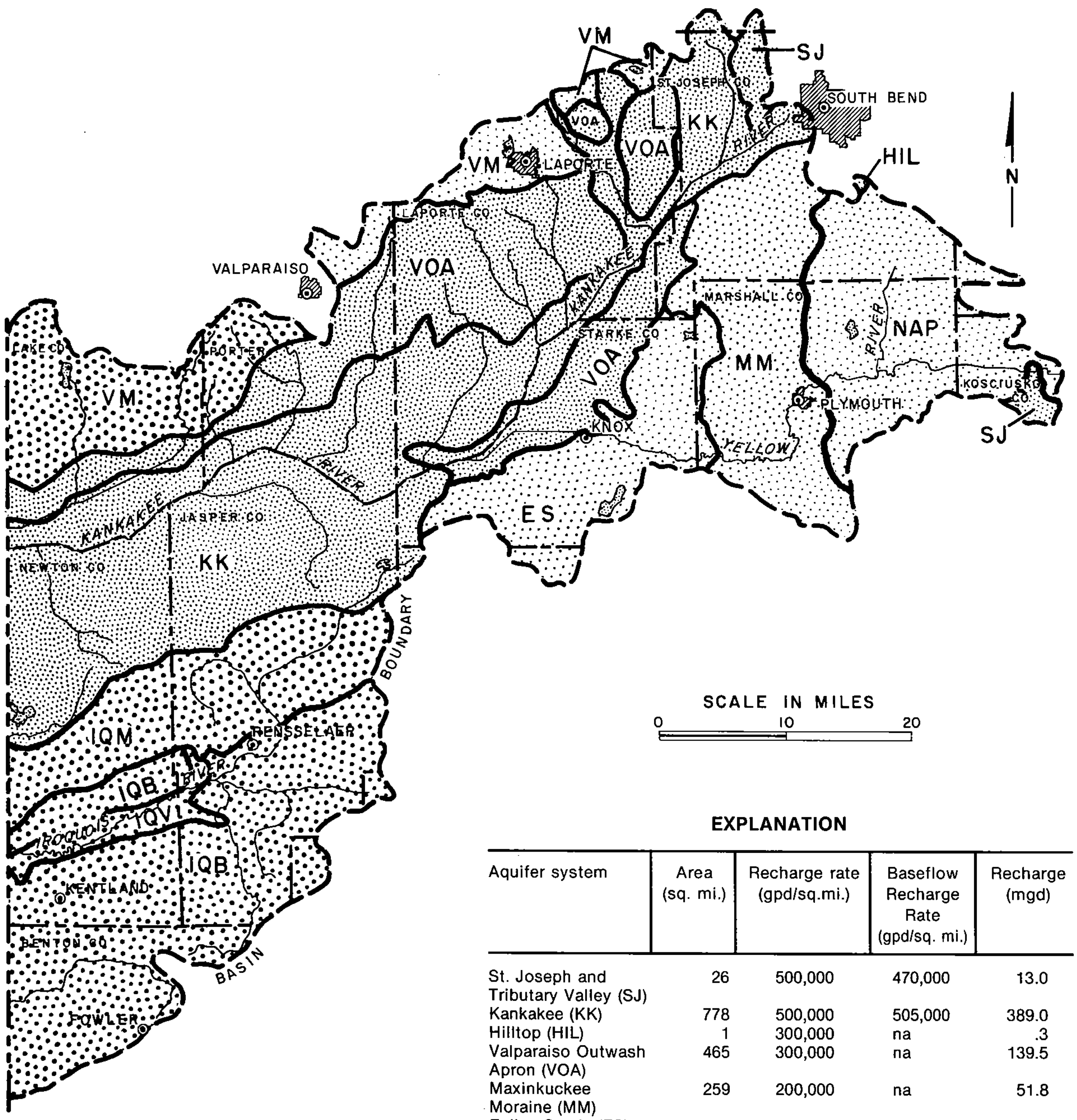
Recharge

The yield of an aquifer depends primarily on its porosity, permeability and saturated thickness. These factors determine the amount of water available for use and the rate at which it can be removed. However, the long-term productivity of an aquifer depends on recharge, which determines how quickly ground water is replenished.

The potential amount of ground water available for development in the Kankakee River Basin is a combination of natural recharge (derived chiefly from precipitation), recharge which can be induced to infiltrate from existing streams, and water in storage.

Natural recharge rates for aquifer systems in the Kankakee Basin have been estimated on the basis of aquifer geometry and hydrogeologic conditions. The sum of the recharge to the aquifer systems (806 mgd) is an estimate of the recharge to the entire basin.

Recharge rates are highest in the unconfined outwash aquifer systems, including the St. Joseph and Tributary Valley, Kankakee, Hilltop, and Valparaiso Outwash



EXPLANATION

Aquifer system	Area (sq. mi.)	Recharge rate (gpd/sq.mi.)	Baseflow Recharge Rate (gpd/sq. mi.)	Recharge (mgd)
St. Joseph and Tributary Valley (SJ)	26	500,000	470,000	13.0
Kankakee (KK)	778	500,000	505,000	389.0
Hilltop (HIL)	1	300,000	na	.3
Valparaiso Outwash Apron (VOA)	465	300,000	na	139.5
Maxinkuckee Moraine (MM)	259	200,000	na	51.8
Eolian Sands (ES)	188	175,000	na	32.9
Nappanee (NAP)	249	175,000	240,000	43.6
Valparaiso Moraine (VM)	286	125,000-200,000	343,000	46.5
Iroquois Basin (IQB)	487	150,000	210,000	73.1
Iroquois Buried Valley (IQB)	38	150,000	na	5.7
Iroquois Moraine (IQM)	215	50,000	250,000	10.8

Figure 41. Estimated recharge rates of unconsolidated aquifer systems

Apron Aquifer Systems (figure 41). Two of these aquifer systems, the Kankakee and Valparaiso Outwash Apron, account for approximately 70 percent of the total recharge to the basin even though they only occupy about 50 percent of the basin area.

The aquifer systems underlying the Iroquois Moraine and the western portion of the Valparaiso Moraine have fairly low recharge rates of 50,000 gpd/sq mi (gallons per day per square mile) and 125,000 gpd/sq mi, respectively. The thick tills in the moraines and the sloping land surface limit the infiltration and percolation of precipitation. Because the overlying till cover in the eastern portion of the Valparaiso Moraine Aquifer System is thinner than in the western portion, the eastern portion has a somewhat higher recharge rate of 200,000 gpd/sq mi.

The aquifer systems with lowest recharge rates occur in the Iroquois River Basin. The recharge to intratill aquifers in this area is limited by the surrounding material of low permeability.

Recharge rates to the bedrock aquifers are largely influenced by the overlying strata. Where shale or till overlies a bedrock aquifer, recharge to the underlying aquifer is generally limited by the overlying material of low permeability.

Rosenshein (1963) estimated an average recharge rate of 20,000 gpd/sq mi for the till-covered Silurian carbonate in Lake County. Areas of Silurian and Devonian carbonate which are overlain by outwash sand and gravel are expected to have higher recharge rates than the till-covered bedrock.

GROUND-WATER QUALITY

Water quality is an important factor in determining the utility of a ground-water source. Naturally-occurring concentrations of various constituents define ground-water quality and determine whether the resource is potable or otherwise suitable for municipal and domestic supplies, industrial processing, irrigation, or livestock watering. Human-induced levels of naturally-occurring or man-made chemicals may diminish the use of the resource or render it unacceptable as a water supply.

Sources of ground-water quality data

Inorganic chemical analyses of water samples from 374 wells were used to characterize the ground-water quality of the unconsolidated and bedrock aquifer systems defined in the Kankakee River Basin (appendices 9, 10, 11; plate 2). Major data sources include the following: 1) 200 domestic, livestock, industrial, public-supply, irrigation, and observation wells sampled during the summer and fall of 1986 in a cooperative effort between the Division of Water and the Indiana Geological Survey (DOW-IGS); 2) municipal and other public-supply wells sampled periodically by the Indiana State Board of Health (ISBH); 3) domestic, commercial, and public-supply wells sampled by the ISBH in 1981 for a ground-water strategy study in Lake and Porter Counties; 4) wells in northern Jasper and Newton Counties sampled by a private consulting firm during the summer of 1985; and 5) public supply, irrigation, industrial, commercial, and domestic wells sampled by the U.S. Geological Survey (USGS). Appendices 12 and 13 list data for individual wells.

A subset of the 200 wells included in the DOW-IGS sampling program were selected for organic chemical analyses (appendices 9, 10, 11). Samples from 23 of these wells were analyzed for 10 pesticides and 24 organic chemicals in a cooperative effort with the Indiana Department of Environmental Management (IDEM). In addition, during 1987 and 1988 Purdue University studied agricultural impacts on ground-water quality in Newton and Jasper Counties from point and nonpoint sources of nitrate-nitrogen and pesticides (Turco and Konopka, 1988).

Additional inorganic chemistry data provided information on the water quality of aquifer systems but were not used in the statistical analyses (Rosenshein, 1961, 1962; Rosenshein and Hunn, 1962a, 1962b, 1964a, 1964b, 1964c, 1964d). The reports were used for summarizing occurrence of hydrogen sulfide and interpreting generalized concentration maps for sulfate, hardness, iron, and alkalinity. A ground-water quality study conducted by Indiana University (1985) and funded by the U.S. Environmental Protection Agency (USEPA) provided 367 nitrate-nitrogen analyses.