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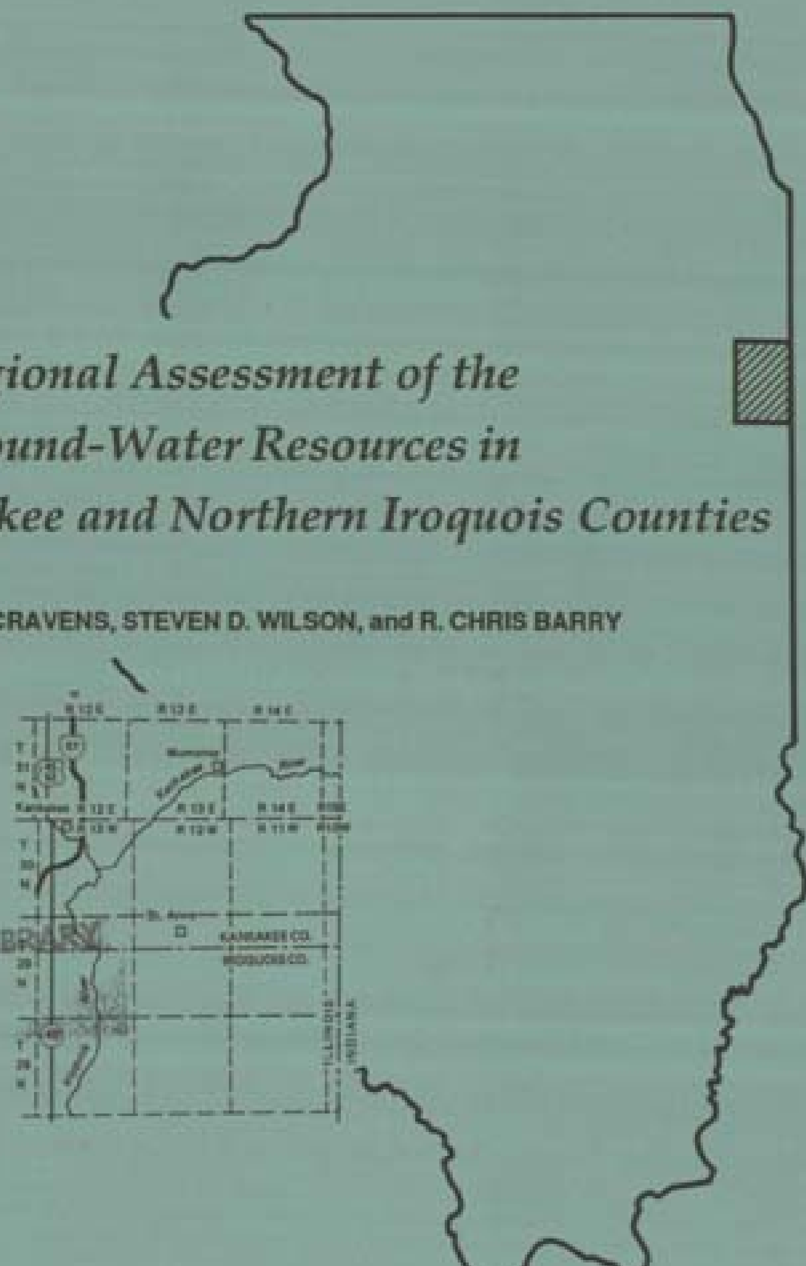

Regional Assessment of the Ground-Water Resources in Eastern Kankakee and Northern Iroquois Counties

by STUART J. CRAVENS, STEVEN D. WILSON, and R. CHRIS BARRY

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REGIONAL ASSESSMENT OF THE GROUND-WATER RESOURCES IN EASTERN KANKAKEE AND NORTHERN IROQUOIS COUNTIES

REPORT OF INVESTIGATION 111

Regional Assessment of the Ground-Water Resources in Eastern Kankakee and Northern Iroquois Counties

by STUART J. CRAVENS, STEVEN D. WILSON, and R. CHRIS BARRY

Title: Regional Assessment of the Ground-Water Resources in Eastern Kankakee and Northern Iroquois Counties.

Abstract: A regional ground-water quantity assessment was conducted in 1987 and 1988 on the ground-water resources of eastern Kankakee and northern Iroquois Counties. Ground water has been used for irrigation for more than 50 years in this region, and development is increasing. Ground-water withdrawals by irrigation wells during the drought of 1988 increased by 167 percent over withdrawals in 1987. Irrigation wells in the study area obtain their ground water from the Silurian Dolomite aquifer, the principal bedrock aquifer underlying the unconsolidated deposits of the region. The Silurian Dolomite aquifer is recharged primarily by vertical leakage of ground water from overlying unconsolidated deposits and by influent stretches of the Kankakee and Iroquois Rivers. Response of the Silurian Dolomite during several aquifer tests was isotropic. Transmissivities from pumping and aquifer tests ranged from 14,000 to 122,000 gallons per day per square foot. Coefficient of storage of the aquiferranged from 4×10^{-5} to 6×10^{-4}. Model simulations were used for initial ground-water modeling of the dolomite aquifer and to evaluate the effects of hypothetical pumping wells located in hydrologically different locations. Ground-water management options are discussed, along with current legislative mandates governing the region's ground-water resources.

Reference: Cravens, Stuart J., Steven D. Wilson, and R. Chris Barry, Regional Assessment of the Ground-Water Resources in Eastern Kankakee and Northern Iroquois Counties. Illinois State Water Survey, Champaign, Report of Investigation 111, 1990.

Indexing Terms: Dolomite, drought, ground water, Illinois, irrigation, Iroquois County, Kankakee County, management, modeling, water use.

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1. INTRODUCTION

Overview of the Study

This study was initiated in response to continued irrigation development and conflicts surrounding ground-water use in eastern Kankakee and northern Iroquois Counties. The purpose of the study was to develop a base of reliable geohydrologic data with which to form a solid conceptual understanding of the ground-water resources in the study area. Once this was achieved, initial estimates of ground-water use and yield could be made, allowing the region's resource management questions to be addressed. Additional data collection and analysis activities were appended as needed during the course of the research. The largest change in the scope of the study was brought on by the drought of 1988. To assess the impact of the drought on the ground-water resources of the study area, ground-water withdrawals and water-level elevations were monitored through September 15, 1988.

The principal bedrock aquifer underlying the unconsolidated deposits of the study area is composed of fractured dolomite of Silurian age. Dolomite of Middle Devonian age appears near the southern edge of the study area. Unconsolidated deposits overlying the dolomite comprise a complex sequence of clay, silt, and sand deposited by successive glacial advances and retreats. The dominant soil parent material, and the primary one on which irrigation has occurred, is composed of thick, sandy, Wisconsinan outwash and Aeolian deposits. Approximately 43 percent of the study area is mantled by these deposits.

Movement of ground water within the dolomite may be significantly affected by fractures. Flow occurs primarily through vertical joints and horizontal separations in the form of bedding planes in the upper 100 feet of the bedrock. Although the horizontal openings are a major factor in water flow within the dolomite, several aquifer tests show that over long time periods and large distances, the response of the aquifer to pumpage is isotropic, that is, uniform in all directions.

Recharge of the Silurian Dolomite aquifer is derived primarily from vertical leakage of ground water from overlying unconsolidated deposits. Some recharge also occurs along influent stretches of the Kankakee and Iroquois Rivers. Based on flow-net analyses, recharge to the Silurian Dolomite from vertical leakage in 1987 and 1988 ranged from 86,000 to 126,000 gallons per day per square mile (gpd/sq mi) for areas with thick confining layers of clay or till. For areas with predominantly coarser grained materials and thin to absent confining layers, recharge ranged from 245,000 to 285,000 gpd/sq mi. Average recharge rates required to balance pumpage within the irrigated region in 1987 and 1988 were 144,000 and 180,000 gpd/sq mi, respectively. Insufficient data were available to provide recharge values of the dolomite from the rivers.

Irrigation accounted for an estimated 63.2 percent (2.1 billion gallons) of the total ground-water use within the study area in 1987. Distribution of 1987 pumpage for other ground-water users was:

- Public water supply systems accounted for 15.7 percent or 527 million gallons
- Domestic pumpage was 17.4 percent or 586 million gallons.
- Industrial pumpage accounted for 1.6 percent or 55 million gallons.
- Livestock pumpage was 2.1 percent or 70 million gallons.

In 1987 a total of 96 irrigation wells irrigated 10,278 acres of diverse crops. During the 1988 drought, 133 irrigation wells applied ground water to 12,143 acres. Ground-water use for irrigation in 1988 was estimated at 5.6 billion gallons. The major irrigated crop in the region is field corn, and in 1987 and 1988, irrigated field corn acreage amounted to approximately 58 and 61 percent, respectively, of total irrigated acreage. After corn, the next major crop types irrigated were vegetables and sod, each of which accounted for 9 to 12 percent, respectively, of irrigated acreage in 1987 and 1988. Other major crops irrigated in the region are gladioli, potatoes, melons, and nursery products.

Mass water-level measurements were conducted on up to 226 dolomite wells on five occasions during the spring and summer of 1987 and 1988. The measurements assessed the effects of pumpage on the potentiometric surface of the dolomite aquifer. During both 1987 and 1988, the greatest drawdowns were observed between Leesville, Hopkins Park, and Beaverville, all within four miles of the Kankakee-Iroquois county line. Seasonal drawdowns in excess of 44 and 70 feet were observed in 1987 and 1988, respectively. Thick confining layers of semipermeable to impermeable clays and tills limit the downward movement of water and thus its ability to recharge the dolomite aquifer in this area. Conversely, decreases in ground-water levels of less than 8 feet were observed along the Kankakee and Iroquois Rivers. The drawdowns in these areas are low because recharge of the dolomite is increased by leakage through the overlying drift and interaction with the two rivers. Rates of leakage through the drift are higher in some areas because of the absence or dunning of the clay and till.

Based on observation well data, it appears that in areas with clay or till confining layers, high-capacity dolomite wells do not cause any significant drawdown in water wells installed in the shallow sand and gravel. Declining water levels in these shallow wells are caused by natural recession of the water table during the late spring to early fall, when evapotranspiration and ground-water runoff generally exceed recharge from precipitation. Where the clay and till confining layers are scattered or absent, a neighboring high-capacity dolomite well may cause additional drawdown in a sand-and-gravel well, depending on the proximity of the two wells and the degree of interconnection between the dolomite and the overlying sand and gravel

Potentiometric surface maps for the dolomite aquifer were used to delineate the position of the ground-water divide, an imaginary boundary separating directions of ground-water flow. The divide runs east-west, passing north of Hopkins Park and St. Anne and continuing west through Aroma Park. Ground water on the north side of the divide flows north and west towards the Kankakee River. To the south of the divide, the ground water flows south and west towards the Iroquois River. During periods of high irrigation discharge from the dolomite to the south, the ground-water divide migrates northward as the area of ground-water diversion into the irrigated region expands outward.

Use/yield analyses of the dolomite aquifer show that the seasonal withdrawal by wells in 1987 and 1988 did not exceed the available yield of the aquifer when assessed for the entire region of ground-water diversion. During a 90-day irrigation season in 1987, the average water use over an area of 217 square miles was 58,000 gpd/sq mi. Assuming an average dolomite aquifer yield of 180,000 gpd/sq mi, the use/yield ratio for this 90-day period was 0.32. In 1988, the ground-water use over a 90-day period during the irrigation season amounted to 139,200 gpd/sq mi over a ground-water diversion area of 271 square miles. The use/yield ratio for this period was 0.77.

When interpreting these use/yield ratios, it is important to remember that both the use and yield values are averages and do not represent the actual use or yield at any given location. They do not account for differences in ground-water withdrawals, lateral changes in unconsolidated deposits, or proximity of pumping wells to the Kankakee and Iroquois Rivers.

Ground-water modeling efforts were restricted to two-dimensional digital modeling using PLASM (the Prickett-Lonnquist Aquifer Simulation Model). The model was designed to simulate the dolomite aquifer in the study area from May through August 1987. Deviation of the model from the actual potentiometric surface map measured in mid-August of 1987 was less than 5 feet over most of the study area. Deviations of 5 to 20 feet occurred in two areas of 16 and 23 square miles, respectively, within the irrigated region. Model simulations were also developed to evaluate the effects of two pumping wells located in hydrologically different locations within the study area. As expected, the well located in an area of high recharge and high transmissivity experienced substantially less drawdown both horizontally and vertically than the well located in an area of lower recharge and transmissivity.

The ground-water resources of eastern Kankakee and northern Iroquois Counties are adequate to provide ground water to all users without causing long-term depletion of the resource. Through 1987, no long-term depletion of ground water occurred. Wells penetrating into the carbonate bedrock with appropriate pump-intake depths provided uninterrupted water supplies during seasonal declines in the potentiometric surface. Although record declines in the potentiometric surface occurred during the drought of 1988, long term-depletion of the resource will only occur if irrigation continues to be developed without regulation and if precipitation continues at below-normal levels after 1988.

Ground-water management in eastern Kankakee and northern Iroquois Counties depends on establishing both reactive and proactive strategies. The amended Water Use Act of 1983 is a reactive means of managing water use conflicts in the two counties. Under the act, withdrawals from the aquifer are not limited until water supplies are interrupted. Several proactive alternatives should be considered: 1) limit the development of ground water in areas that are highly susceptible to dewatering of the dolomite bedrock; 2) institute a ground-water use fee based on the amount pumped; 3) establish a minimum ground-water elevation, such as the top of the dolomite bedrock, as a trigger for ground-water withdrawal restrictions; and 4) establish a more stringent permit system for construction of new high-capacity wells in the management area.

To aid in managing the ground-water resources of Kankakee and Iroquois Counties, the existing network of three dolomite observation wells was expanded to nine wells, all of which are equipped with water-level recording devices. An additional seven dolomite and eight sand-and-gravel observation wells are available for periodic measurement of water levels by hand. Ground-water hydrographs from the observation wells are used to monitor changes in water levels that reflect not only seasonal variation, but factors such as changing climatic conditions and pumpage.

Future efforts in Kankakee and Iroquois Counties should focus on the design of an aquifer model that could properly manage the region's ground-water resources. Under proper management, the yield of the dolomite aquifer can be maximized without causing long-term depletion of the resource or loss of water supply to well owners. Ground water is a renewable resource that can be managed to benefit all users.

Implications and Objectives

Ground water in eastern Kankakee and northern Iroquois Counties, Illinois, has been used extensively for irrigation. In this part of Illinois, irrigation has along history: the first development was reported as early as 1926, and 100 irrigation systems were in place by 1950. Irrigation continues to be developed, and nine new irrigation wells were drilled in this area in 1988.

As irrigation activity increases, conflicts with other ground-water users—especially those with domestic and livestock wells—will inevitably occur. Reports of ground-water supply interruptions began surfacing in the early 1980s. These temporary interruptions lasted for periods of hours to months, and they have made it necessary for well owners to replace their wells, lower pump intakes, or find alternate sources of supply.

In addition to domestic supply interruptions in the Illinois counties of Kankakee and Iroquois, the adjacent Indiana counties of Jasper and Newton have also been affected. Basch and Funkhauser (1985) reported that an intensive irrigation project in the dolomite aquifer in these two Indiana counties affected nearly 130 domestic wells on nearby properties. These problems resulted in litigation and legislation that now protects owners of small wells in Indiana.

Responding to continued irrigation development in Illinois and recognizing the interstate implications of problems in the Kankakee-Iroquois area, the Illinois State Water Survey (ISWS) and the Illinois State Geological Survey (ISGS) began a two-year study of the ground-water resources in this area in 1986.

The objectives of the study were to develop a base of reliable geohydrologic data and to develop a solid conceptual understanding of the ground-water system. Domestic supply interruptions and other resource management questions were addressed as by-products of this study. With these goals in mind, seven major tasks were accomplished as part of the study: 1) the design and implementation of a database system; 2) geologic mapping by the ISGS; 3) an inventory of irrigation wells and pumpage; 4) periodic mass water-level measurements; 5) aquifer testing; 6) data analysis and digital flow modeling; and 7) the design and initiation of a long-term observation well network.

Acknowledgments

This study was supported under contract through the University of Illinois at Urbana-Champaign by the Division of Water Resources (DWR) of the Illinois Department of Transportation (IDOT) and the Illinois Department of Energy and Natural Resources (ENR). Funding for the ISWS was provided by ENR and the DWR. Funding for the Illinois State Geological Survey was provided by ENR.

This report was prepared under the administrative guidance of Richard G. Semonin, Chief, and Ellis W Sanderson, Head of the Ground-Water Section, both at the Illinois State Water Survey. Technical review of the final report was completed by Richard J. Schicht and Adrian P. Visocky at the State Water Survey. The project was begun and developed in its early stages by Mark A. Collins.

The following Water Survey personnel participated in the extensive field work and data entry required for *this* project: Mickey Peyton, Mary Stover, Ken Hlinka, Paul Jahn, Steve Burch, Doug Kelly, Marcia Schulmeister, Scott Ludwigs, Jeff Stollhans, Bob Kohlhase, and Rachael Hammen.

Invaluable assistance was also provided by individuals and agencies too numerous to name. Of special note are the aerial photographs and surveys provided by the Illinois Department of Transportation. Special thanks go to all the well owners and irrigators of Kankakee and Iroquois Counties who permitted us access to their wells and fields.

This report was typed by Patti Hill and Pamela Lovett. Artwork was prepared by John Brother. Laurie McCarthy edited the report.

2. GEOGRAPHY AND CLIMATE

Geography

The study area (figure 1) comprises 414 square miles of eastern Kankakee and northern Iroquois Counties, located in the south part of northeastern Illinois and adjacent to the Illinois-Indiana state line. Greatest emphasis in this study was given to the area south of the Kankakee River and east of the Iroquois River.

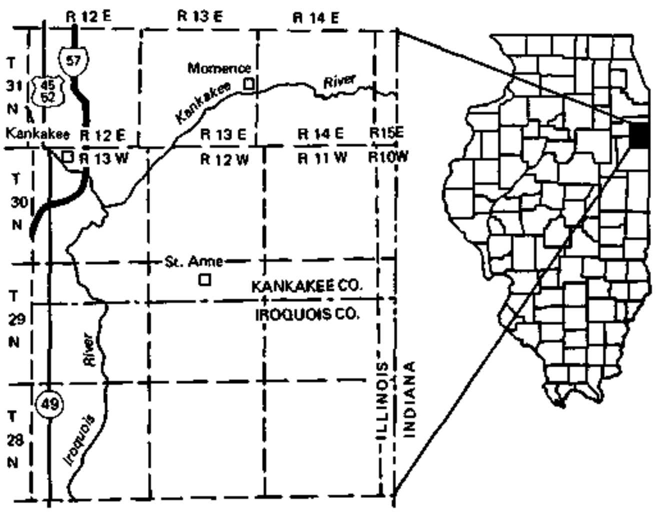


Figure 1. The ground-water study area

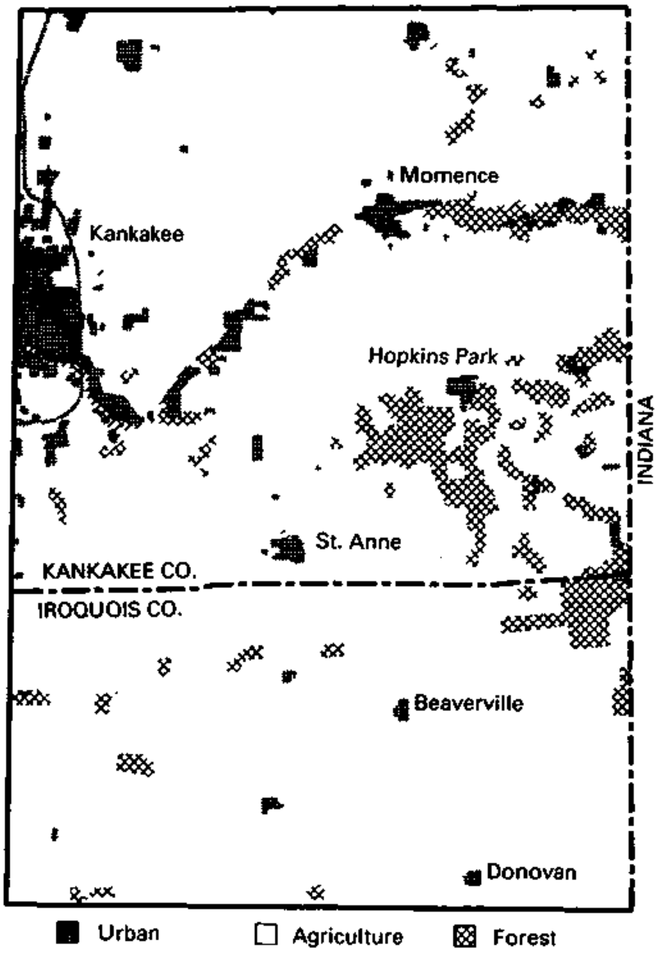


Figure 2. Land use in the study area
(U.S. Geological Survey)

Land in the study area is used predominantly for agriculture (figure 2). Those lands not under cultivation are primarily urban or forested. Forest covers much of the east-central part of the area, adjacent to the state line. This forested tract is characterized by extensive windblown dune deposits with local relief of up to 50 feet.

The population of the 414 square miles of the study area is approximately 28,460 as estimated from 1987 projections using 1980 population census data (U.S. Department of Commerce, 1982). An estimated 21,480 people, or 75 percent of the total population, live in rural areas outside the incorporated municipalities. Populations of the incorporated municipalities are: Aroma Park, 643; Beaverville, 367; Donovan, 293; Martinton, 353; Momence, 3,149; Papineau, 174; Hopkins Park, 643; and St. Anne, 1,357. Population density for the 414 square miles averages about 69 persons per square mile.

Climate

The study area is classified within the humid climate zone of the United States. The mean annual precipitation in eastern Kankakee and northern Iroquois Counties is 37.75 inches, as measured for the period 1967 through 1987 by the National Weather Service (NWS) at the Kankakee, Illinois, station. This is the same period for which ground-water observation well data are available. Table 1 shows the mean monthly precipitation at the Kankakee station and the monthly precipitation for 1987 and 1988. Mean summer precipitation for the months of June through August is 12.00 inches, or about 32 percent of the mean yearly precipitation. In 1987, summer rainfall accounted for 11.21

Table 1. Mean Monthly Precipitation at Kankakee, 1967-87, and Monthly Precipitation, 1987 and 1988 (inches)

Month	*1987*	*1988*	*Mean monthly, 1967-87*
January	1.88	1.48	1.49
February	0	1.32	1.37
March	1.05	2.96	2.57
April	3.08	2.25	3.89
May	5.21	1.12	4.42
June	3.18	1.65	4.15
July	3.08	1.97	4.38
August	4.95	1.62	3.47
September	3.12	3.54	3.51
October	1.69	3.11	2.63
November	2.98	4.40	3.08
December	4.93	2.64	2.79

Note: Data were taken at Kankakee 3SW Recording Station (1967-73) and at Kankakee Water Poll. Ctrl. Recording Station (1974-87).

inches of the 35.15 inches received during the entire year. Summer rainfall during the record drought year of 1988 amounted to only 5.24 inches. It is important to remember that precipitation varies dramatically over the study area. Precipitation measurements at the Kankakee station may be significantly higher or lower than precipitation received in other parts of the region.

Figure 3 shows the mean monthly temperatures, as measured for the period 1951 through 1980 at the Watseka, Illinois, NWS station. Mean temperatures for this same period were not available for the Kankakee station. Highest average temperatures are recorded in June, July, and August. Mean annual temperature for this area is 50.6° F. Mean annual minimum and maximum temperatures are 40.2 and 60.9° F, respectively.

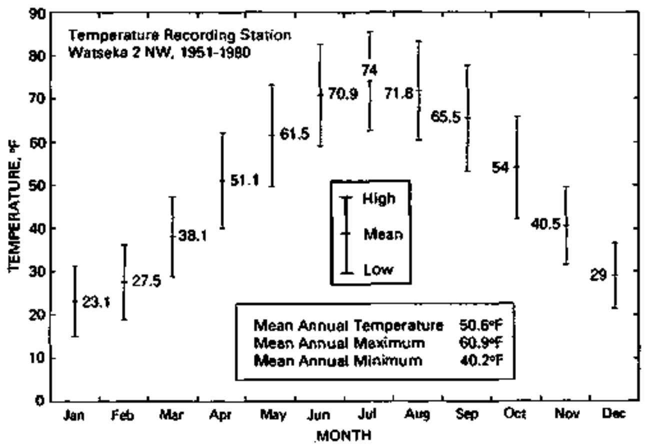


Figure 3. Mean monthly temperatures and departures from the mean, Watseka reporting station

3. GEOLOGY

Geologic mapping in eastern Kankakee and northern Iroquois Counties was undertaken by the Illinois State Geological Survey as a part of the investigation of the ground-water resources in the region. Geologic maps of eastern Kankakee and Iroquois Counties were prepared by Edward Smith and William Dey of the ISGS in 1987, using existing well records and previously prepared geologic maps by John Kempton. In the area of heavy irrigation water use and complex geology, denoted by the shaded area in figure 4, the ISGS executed more detailed mapping using surficial and borehole geophysical methods. The geology mapped by the ISGS was limited to the glacial drift and underlying shallow bedrock, which contains the fresh-water aquifers of the study area. Results of the detailed hydrogeologic mapping are found in the ISGS report *Geophysical Study of Shallow Groundwater Geology in Kankakee and Northern Iroquois Counties, Illinois* (McFadden et al., 1988). Other than the following section on soils, geology data are derived largely from that report.

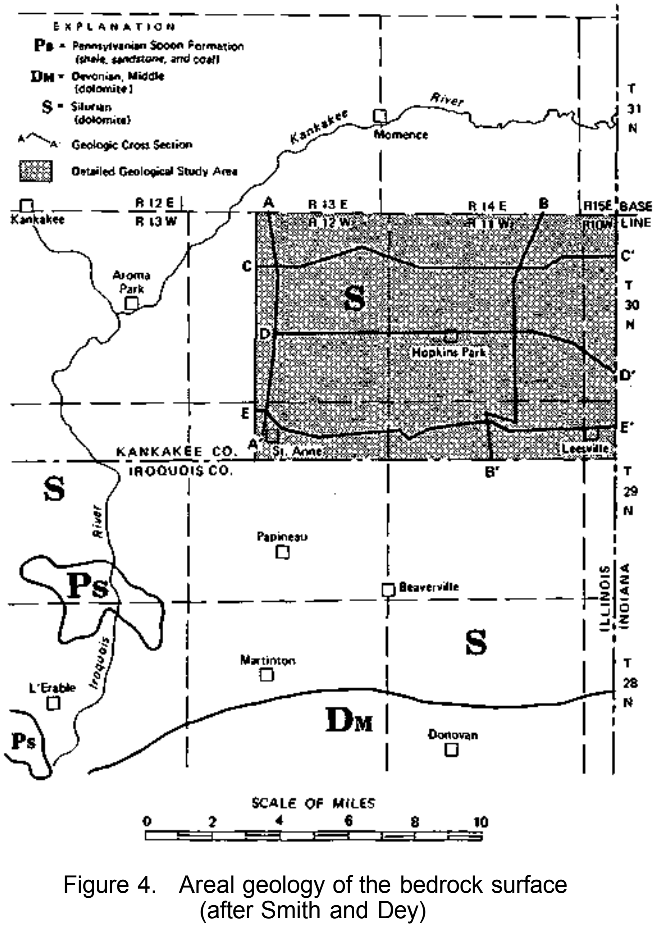


Figure 4. Areal geology of the bedrock surface (after Smith and Dey)

Soils

The soil types found in the study area have developed from a variety of parent materials (figure 5). The dominant soil parent material is composed of thick, sandy outwash of Wisconsinan age and Aeolian deposits. This is the primary material on which irrigation development has occurred. The sandy outwash and Aeolian deposits cover approximately 43 percent of the study area. Soils formed in these materials generally exhibit moderately high to high permeability. Irrigation also occurs on soils developed from the thin silty or loamy materials on sandy and loamy outwash of Wisconsinan age. These thin silty or loamy materials are outwash-plain and stream-terrace deposits with moderate to moderately high permeability (Fehrenbacher et al., 1984).

Bedrock Geology

The principal bedrock aquifer underlying the unconsolidated deposits of the study area is fractured dolomite of Silurian age (figure 4). The Niagaran and Alexandrian Series, both of Silurian age, are composed of dolomites and dolomitic limestones. Henceforth, these Silurian-age rocks will be referred to as the Silurian Dolomite. Dolomite of the Middle Devonian Series appears near the southern edge of the study area. The Spoon Formation of the Pennsylvanian System is composed of shale, limestone, sandstone, and clay and can be found in the southwest, in the area of the Iroquois River.

The thicknesses of the bedrock aquifers and the generalized column of rock stratigraphic units in the study area are shown in figure 6. Where present, the Pennsylvanian Spoon Formation and Devonian Dolomite are less than 20 and 50 feet thick, respectively. The Niagaran Series of the Silurian Dolomite is 350 to 400 feet thick, and the underlying Alexandrian Series is 20 to 40 feet thick. Beneath the Silurian Dolomite is the Maquoketa Group of Ordovician age. The upper and lower units of the Maquoketa are shale. The middle unit consists of dolomite and limestone interbedded with shale. The Maquoketa acts as a confining layer between the deeper bedrock aquifers and the Devonian and Silurian Dolomite aquifers. Beneath the Maquoketa are deeper bedrock aquifers that are not within the scope of the study.

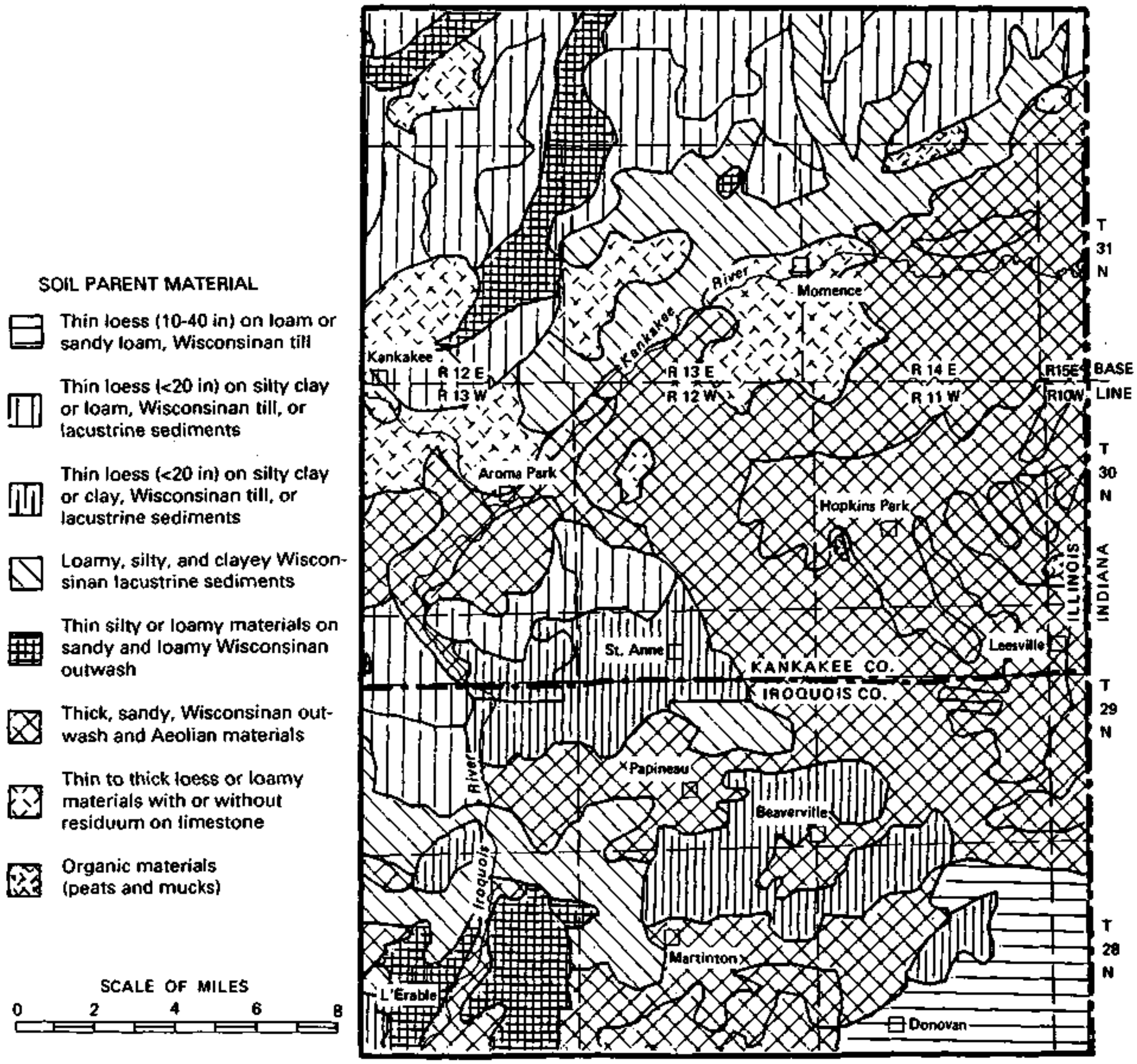


Figure 5. Soil parent materials of eastern Kankakee and northern Iroquois Counties

Bedrock Surface Topography

The bedrock surface is characterized by bedrock uplands dissected by east-west and north-south trending valleys. These valleys are typically narrow, in some places less than one-quarter mile wide, and steep-sided. Locations of cross-sections through the central part of the study area are shown in figure 4. North-south cross sections (figure 7) and east-west cross sections (figure 8) show the irregularity of the bedrock surface, with bedrock highs and intervening bedrock valleys. The valleys that developed into the bedrock surface were likely formed preglacially and during the early stages of glaciation of the area.

Glacial Drift Geology

The unconsolidated deposits overlying the shallow bedrock consist of a complex sequence of clay, silt, and sand deposited by successive glacial advances and retreats. After glaciation, these glacial deposits were modified by erosion. The drift thickness varies from 0 to more than 175 feet throughout the area. The drift is generally less than 50 feet duck within a few miles of the Kankakee and Iroquois Rivers, but it is more than 100 feet thick in the many bedrock valleys traversing the study area.

The geology of the glacial drift in the central part of the study area, which encompasses most of the irrigated

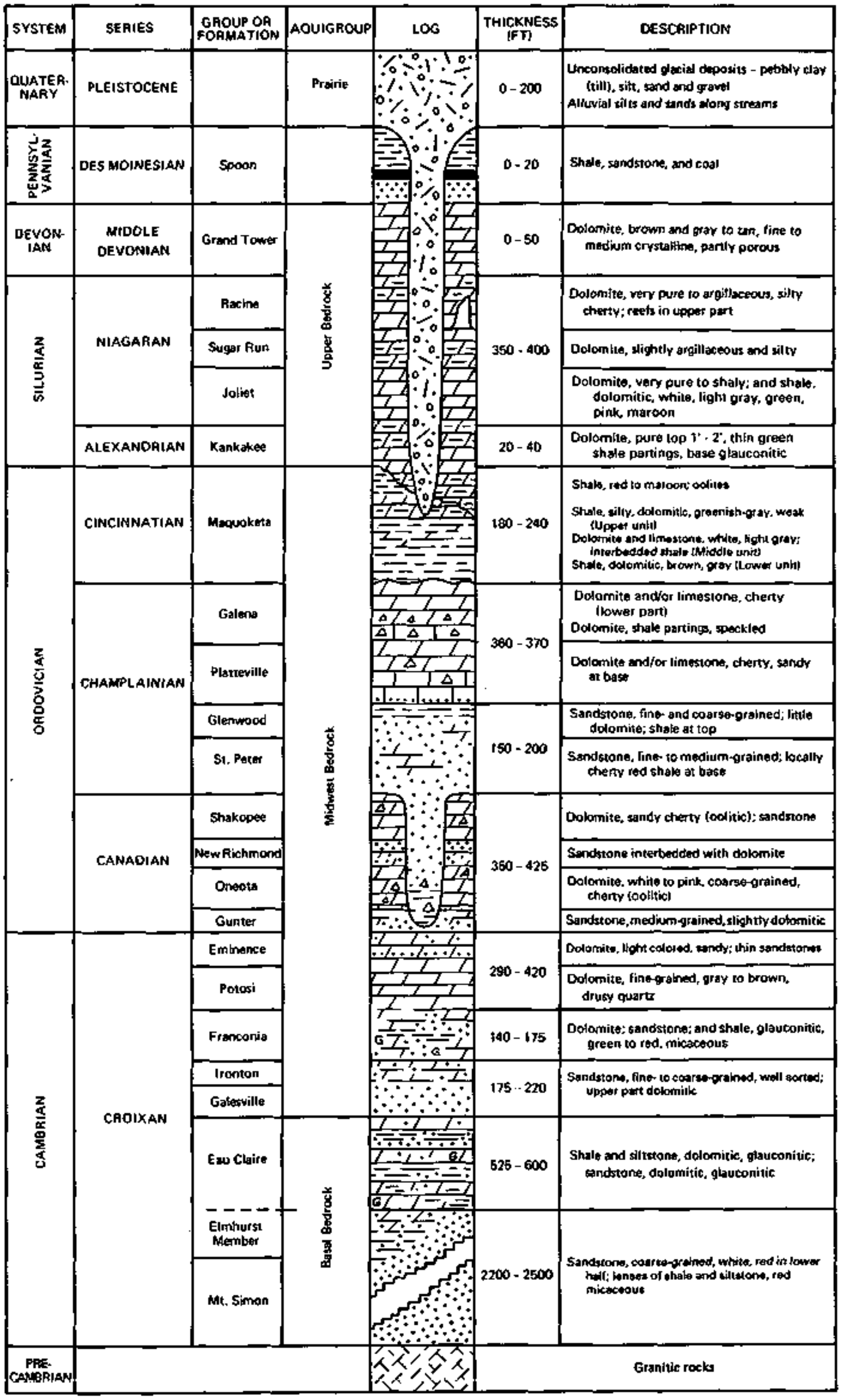


Figure 6. Generalized rock stratigraphy and aquigroups in southeastern Kankakee and northeastern Iroquois counties (after Woller and Sanderson, 1983)

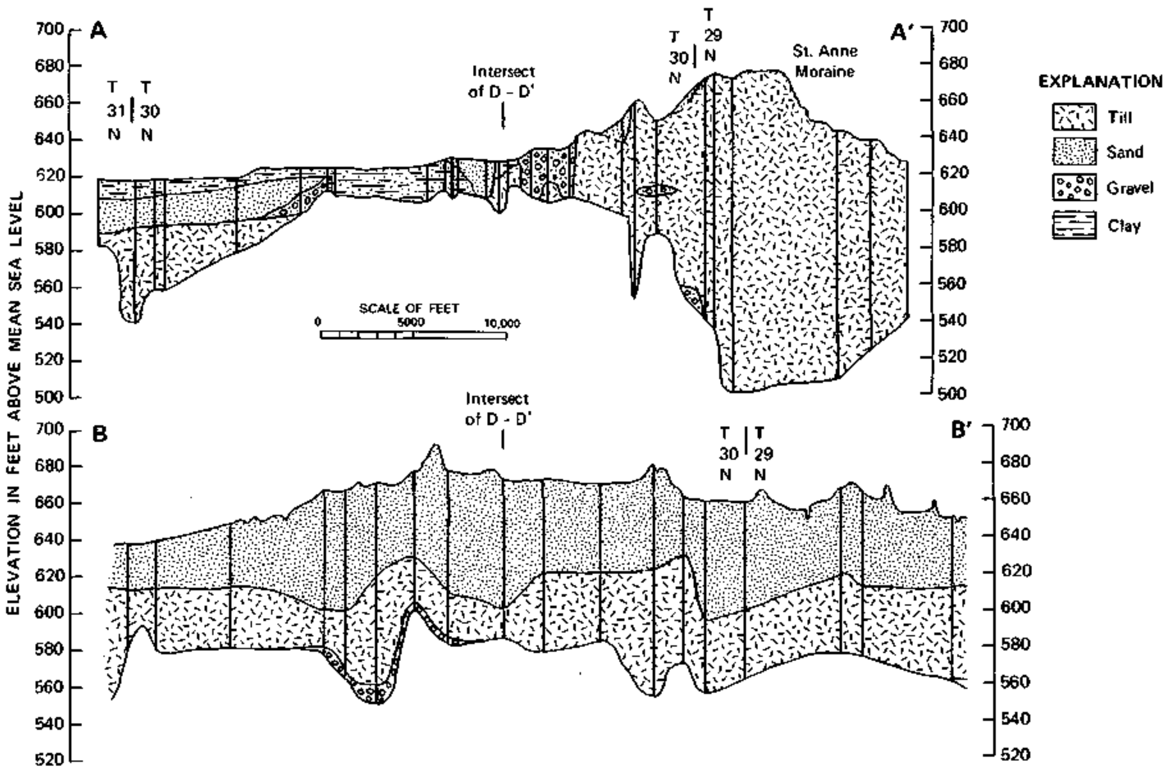


Figure 7. North-south cross-sectional views through the central study area (after McFadden et al., 1989)

region, is shown in the cross sections in figures 7 and 8. This glacial drift can be characterized as a two- or three-layer system. The upper layer of coarse-grained material attains a thickness of 60 or more feet as indicated by tie cross sections. Underlying the coarse material is a fine-grained confining layer of lacustrine clay or till. This fine-grained unit directly overlies the dolomite bedrock of the region. Where present, the clay or till is generally 10 to 50 feet thick, although till that is more than 150 feet thick occurs under areas of the St. Anne moraine. The lowest unit, occurring between the clays and the bedrock, is a second coarse-grained layer of sand and gravel. This unit is often absent and typically occurs within the bedrock valleys.

As seen in the cross sections, exceptions to the two- and three-layer characterization of the glacial drift are common, particularly in the western part of cross sections C-C' and D-D'. In large areas, a single fine- or coarse-grained layer lies directly over the bedrock. The areal distribution of the fine-grained layer is important because it confines the dolomite aquifer. The fine-grained unit is generally present throughout the detailed study area, the shaded region of figure 4, except in the northwest corner.

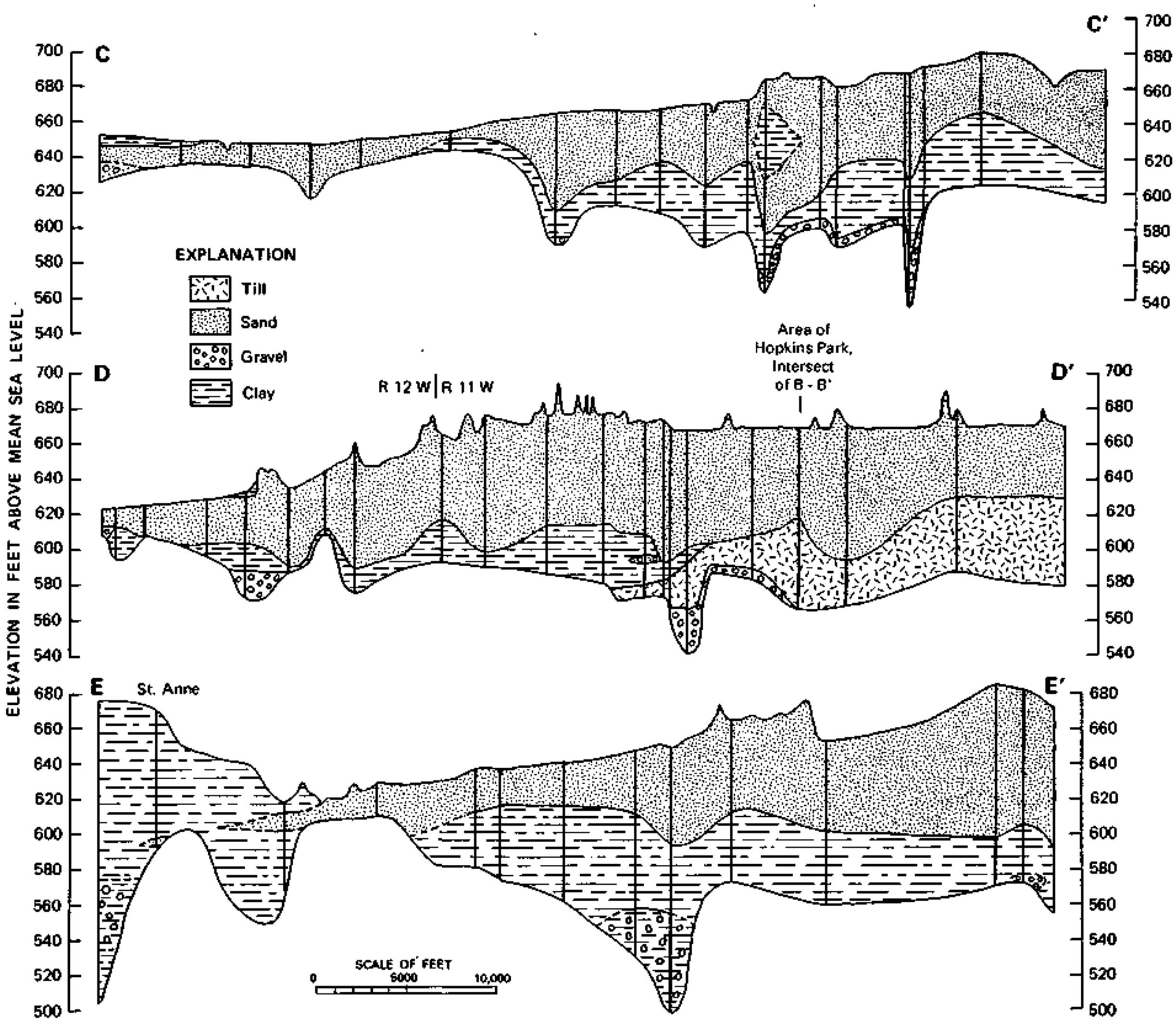


Figure 8. East-west cross-sectional views through the central study area (after McFadden et al., 1989)

4. HYDROLOGY

Aquifers

An aquifer is a saturated bed, formation, or group of formations that yields enough water to be economically useful (Driscoll, 1986). The principal hydraulic properties of an aquifer are storage and transmissivity. The rate at which water is transmitted through an aquifer is the transmissivity (T). Transmissivity is defined as the rate of flow of water through a unit width of the aquifer under unit hydraulic gradient. Storage of water in an aquifer is termed the storage coefficient (S), which is the amount of water taken into or released from storage per unit of surface area of the aquifer per unit change in head.

Storage coefficients of 10" to 10^{-3} usually signify that an aquifer is confined between two units of material that are of lower permeability, such as shale, till, or thick clay. In confined aquifers, water released from storage depends on the elastic properties of both the water and the aquifer. Confined aquifers may be classified as artesian or leaky artesian. Leaky artesian conditions exist when fine-grained deposits, which retard the vertical movement of water, overlie the aquifer. Under leaky conditions, water in the aquifer is subject to artesian pressure and rises in wells above the top of the aquifer into the overlying fine-grained deposits (Prickett et al., 1964). Ground water in the Silurian and Devonian Dolomite is generally under leaky artesian conditions.

When an aquifer is not confined by overlying impermeable materials, it is under water-table conditions and yields water almost entirely through gravity drainage. The highest storage values, generally ranging from 0.01 to 0.30, are found in unconfined, water-table aquifers. In a water-table aquifer the storage coefficient is almost equal to the specific yield. Specific yield is the ratio of 1) the volume of water that the saturated aquifer material (rock or soil) will yield to gravity to 2) the volume of the aquifer material

An aquifer test is a controlled scientific experiment that monitors the effect of a discharging well on water levels in both the pumped well and nearby observation wells. The test data are then analyzed to determine the hydraulic properties that govern the movement of water within the aquifer. Introductory aquifer test methodology is covered in most beginning ground-water hydrology texts. More detailed information on aquifer testing is included in Walton (1962 and 1970). If no observation wells are available for monitoring, then a production test is conducted on the pumping well. Production tests provide less information than aquifer tests, but they are still valuable for use in specific-capacity analyses, as discussed later in this chapter.

Bedrock Hydrology

The carbonate bedrock of the study area, consisting of theSilurian and Devonian Dolomite, is the primary aquifer or water-yielding unit. Although the unconsolidated deposits in the southern part of the study area lie over Devonian Dolomite that is hydrologically similar to the Silurian Dolomite, future discussions concerning the carbonate bedrock will focus chiefly on the Silurian Dolomite.

Movement of ground water within the Silurian Dolomite is due chiefly to secondary permeability caused by solution. Ground water in the Silurian Dolomite occurs in joints, fissures, solution cavities, and bedding plane openings that appear mainly in the upper 100 feet of the bedrock. Most water-yielding openings are irregularly distributed, both vertically and horizontally (Csallany and Walton, 1963). However, a regional set of vertically oriented fractures within the dolomite have been observed on aerial photographs and investigated in local quarries (Foote, 1982). These vertically oriented fractures form a patterned network of secondary flow channels. Figure 9 shows lineaments in two areas of Kankakee County that were identified from aerial photographs provided by the Illinois Department of Transportation. The bedrock at both these locations is generally mantled by less than 25 feet of sand over thin or patchy layers of finer grained materials. These lineaments may be surface expressions of fractures in the underlying bedrock.

In addition to these features, the upper part of the Silurian bedrock is usually weathered, and the upper few feet often feature a gravelly or broken surface. Openings within the carbonate bedrock are more abundant near the surface, generally decreasing in size and frequency with depth.

Ground-Water Flow in Fractured Bedrock

Movement of ground water within the Silurian Dolomite may be affected significantly by fractures. Caliper logs and driller reports suggest that flow occurs primarily through horizontal separations in the form of bedding planes and through vertical joints. High-capacity water wells in the Silurian Dolomite are generally associated with the intersection of large openings that range from several inches to several feet. When the drill bit encounters these openings, a large volume of water immediately enters the well bore.

The most effective method of modeling ground-water flow through fractured bedrock depends on the degree of anisotropy at the spatial and time scale within which the problem is being defined. Anisotropy is the condition

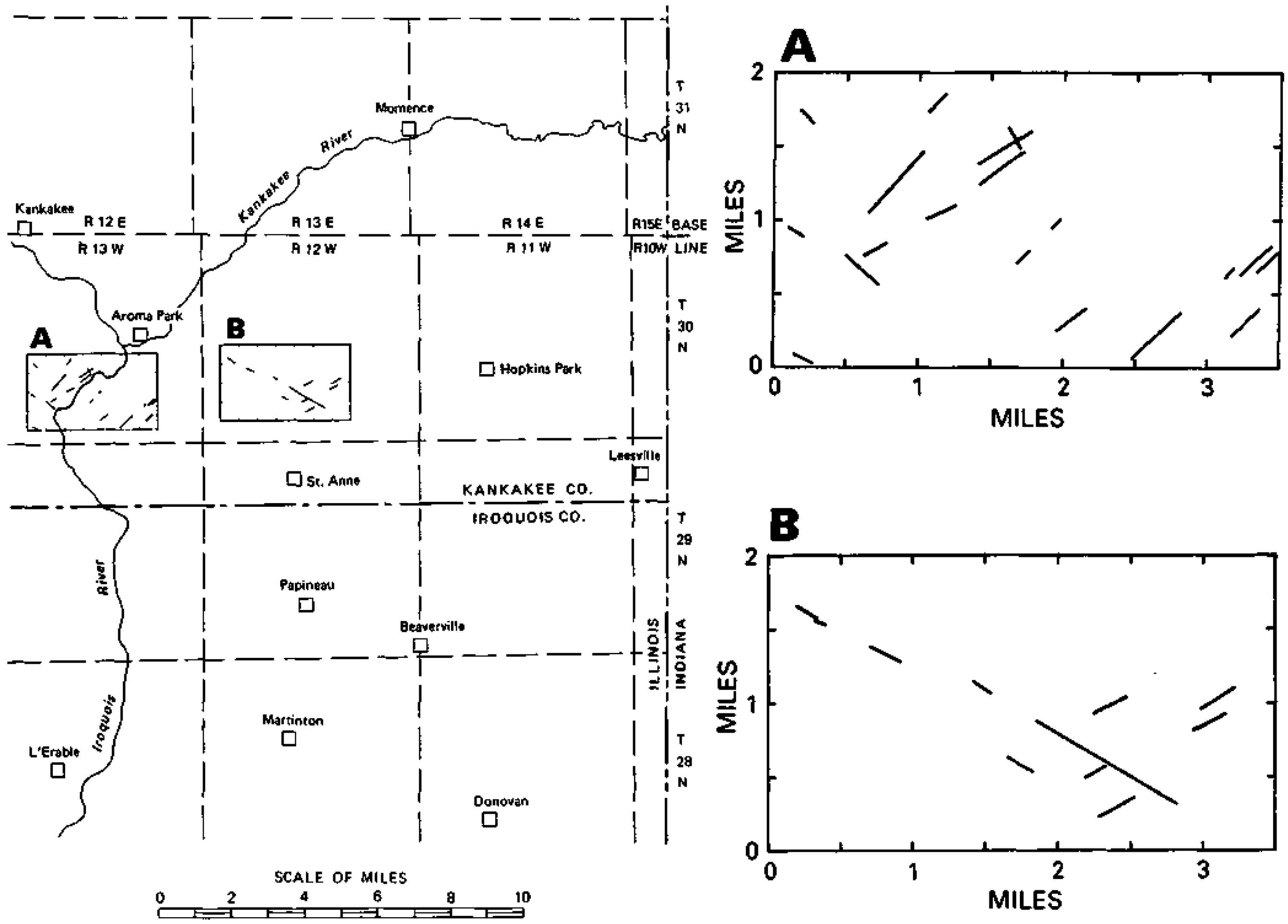


Figure 9. Lineaments located by interpretation of aerial photographs at two locations in Kankakee County

under which the hydraulic properties of an aquifer may vary according to the direction of flow. In an anisotropic aquifer, drawdown varies with direction at a unit distance. If the area being studied is very small, or the time period over which the aquifer is being pumped is small, the aquifer may respond anisotropically. Over a very long period or over a large region, however, an aquifer may respond to pumpage isotropically as a porous medium. In an isotropic aquifer, the hydraulic properties do not vary according to the direction of flow, but are equal in all directions. Drawdown at a unit distance from a pumped well in an isotropic medium is the same in all directions.

Horizontal and vertical fractures are present in the Silurian Dolomite and are undoubtedly a factor in water flow within the dolomite. Nevertheless, the response of the aquifer to pumpage may be isotropic if the area being tested is large relative to the fracture density (Yager and Kappel, 1987). A fractured aquifer modeled on a scale of miles may be represented as a porous medium in which the fractures act as the interstices between the dolomite blocks or grains. In such a simplification, flow through the dolomite blocks can be assumed to be negligible compared to the flow through the fractures. The use of a porous-medium model for the Silurian Dolomite depends on whether the aquifer responds isotropically at the appropriate scale and time period during an aquifer test. An aquifer responding anisotropically on a scale of inches or feet may respond isotropically on a much larger scale. For an aquifer model to be valid, the scale at which the aquifer is tested should be similar to the scale of the model.

In a homogenous, anisotropic, confined aquifer of infinite lateral extent, the Papadopulos method (1965) can be used to analyze aquifer test data. The method employs one constant-rate pumping well and three observation wells. Modifications of the Papadopulos method have been presented by Hantush and Thomas (1966), Way and McKee (1982), and Maslia and Randolph (1987). Fracture orientations in an anisotropic medium can be determined by plotting the directional diffusivities [$(T/S)^{1/2}$ where T = transmissivity and S = storage coefficient] calculated for each observation well on polar paper versus the observation well azimuth from the pumped well. Directions of maximum and minimum diffusivity should be parallel to the directions of the largest and smallest drawdowns, respectively. In the case of an aquifer that behaves anisotropically at the scale of the aquifer test, an ellipse should be plotted. In this case, the principal diffusivities will be represented by the minor and major axes of the ellipse. An isotropic aquifer, in which the principal diffusivities are equal, is represented as a circle on the polar plot.

Aquifer Test Results

Six aquifer tests and one well production test have been conducted within the study area, and their locations are shown in figure 10. The pumping period for these tests ranged from as little as 3 hours for production tests to 24 hours for the aquifer tests. Transmissivity values calculated from these tests ranged from 14,242 to 122,503 gallons per day per foot (gpd/ft). Storage coefficients ranged from 0.00004 to 0.0006. Results of the tests conducted on wells penetrating into the Silurian Dolomite aquifer are shown in table 2.

Transmissivity values determined for the Silurian Dolomite were considerably higher in the northern part of the study area than in the south. The lowest transmissivities, averaging about 16,000 gpd/ft, were produced by the village of Papineau aquifer test. Transmissivities determined from all of the aquifer and production tests, except that from Papineau, were conducted on high-yielding irrigation or municipal water wells. Transmissivity values from these tests are therefore biased towards larger values than might be present in adjacent areas. Poorly producing wells were not tested. Many irrigation wells drilled into the bedrock failed to produce adequate amounts of water and were abandoned or sealed. Transmissivities from these wells might be substantially lower than those of high-yielding wells.

Storage coefficients determined from all the aquifer tests were much more consistent than transmissivities. A storage coefficient value of 0.0001 is representative of the Silurian Dolomite aquifer over most of the study region. The tests conducted for the study all showed storage coefficients within the range of a confined (artesian) aquifer. Two 24-hour aquifer tests and one 3-hour test, conducted on wells penetrating the Silurian Dolomite under confined conditions, are discussed in detail below.

Prudential Aquifer Test

A 1,300-minute aquifer test was conducted on six observation wells on December 21 and 22, 1981, at well 30NllW11.4d on the Prudential Tallmadge Ranch. The

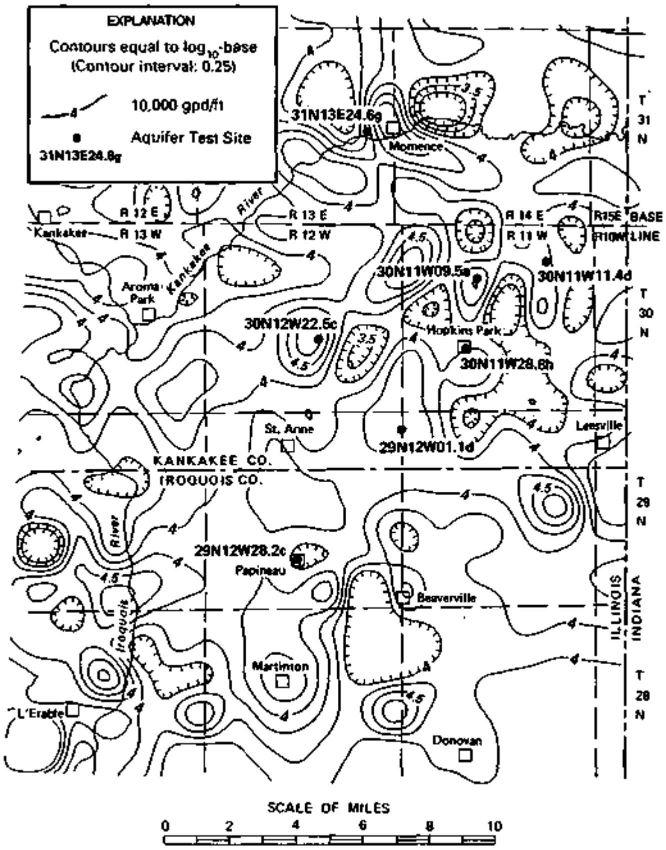


Figure 10. Transmissivity distribution of the Silurian and Devonian Dolomite aquifer

test well was discharged for 1,300 minutes at 1,612 gallons per minute (gpm), and the drawdown in the observation wells ranged from 0 to 12.55 feet. Observation wells O W11, OW10, and IW1, located 3,600, 5,600, and 6,300 feet from the pumping well, respectively, showed drawdowns of 12.55,3.59, and 12.17 feet after 1,300 minutes of pumping. Observation well OW31, located 10,500 feet from the pumping well, showed a drawdown of 0.66 feet at the end of the test. At 11,500 feet from the pumping well and at the same azimuth as OW31 from the pumped well, observation well OW9 demonstrated no drawdown response for the duration of the aquifer test. The average transmissivity for the Silurian Dolomite aquifer at this site was 32,000 gpd/ft, and transmissivities ranged from 22,500 gpd/ft for OW11 and IW1 to 48,600 gpd/ft for OW31 and OW10. Average storage coefficient was 0.00008, ranging from 0.0001 to 0.00004.

For each well responding to pumpage, the observed directional diffusivities were plotted on polar paper (figure 11). The diffusivities of three of the four wells, OW10, OW11, and OW31, formed a circle instead of an ellipse. This suggests that the aquifer behaves isotropically at a horizontal scale of several miles. A fourth well, IW1, had a

Table 2. Aquifer and Well Production Test Results

Date	*Well*	*Test length (min)*	*Trans-missivity (gpd/ft)*	*Coefficient of storage*	*Distance from pumped well (feet)*	*Direction from pumped well (0°=north)*	*Average discharge (gpm)*	*Specific capacity (gpm/ft)*
9/29/81	30N11W09.5a	180	26,000	–	–	–	350	31.82
	OW 1		32,750	.0001	240	0°		
	OW 2		32,757	.0001	720	0°		
12/21-22/81	30N11W11.4d	1,300	53,200	–	–	–	1,612	38.90
	OW 31		48,600	.00025	10,500	52°		
	OW 9		------No response-----		11,500	52°		
	IW1		22,500	.00004	6,300	59°		
	OW 11		22,500	.00012	3,600	140°		
	OW 10		48,600	.00025	5,600	240°		
	OW 2		------No response-----		6,100	347°		
9/29-30/87	29N12W01.1d	1,460	67,240	–	–	–	930	20.86
	OW 1		------No response-----		7,750	287°		
	OW 3		101,877	.0006	3,750	315°		
	OW 4		122,503	.0004	3,400	39°		
	OW 5		--Indefinite results--		2,450	125°		
	OW 7		--Indefinite results--		6,300	34°		
11/4-5/87	30N12W22.5c	1,418	54,380	–	–	–	826	52.04
	OW 1		86,054	.0001	1,000	–		
11/6/87	31N13E24.6g	180	101,431	–	–	–	140	82.00
4/19-20/88	30N11W28.8h-2	1,300	37,571	–	–	–	750	31.70
	30N11W28.8h-1		37,714	.00006	320	343°		
	OW 4		37,571	.00007	390	293°		
	OW 3		--Indefinite results--		307	269°		
4/25/88	30N11W28.8h-1	180	37,781	–	–	–	405	3.72
	30N11W28.8h-2		39,896	.00005	320	164°		
	OW 4		35,521	.00018	313	240°		
	OW 3		--Indefinite results--		388	216°		
9/21/88	29N12W28.2c	180	17,692	–	–	–	128	10.53
	OW1		17,057	.00019	400	70°		
	OW2		14,242	.00004	600	330°		
	OW3		16,482	.00004	1,000	334°		

very high directional diffusivity. Yager and Kappel (1987) noted that if an aquifer is heterogenous, a discrete fracture penetrated by a well will result in "a much larger value of transmissivity along the azimuth of the well that intersects the fracture than in the direction of other wells which do not intersect the fracture."

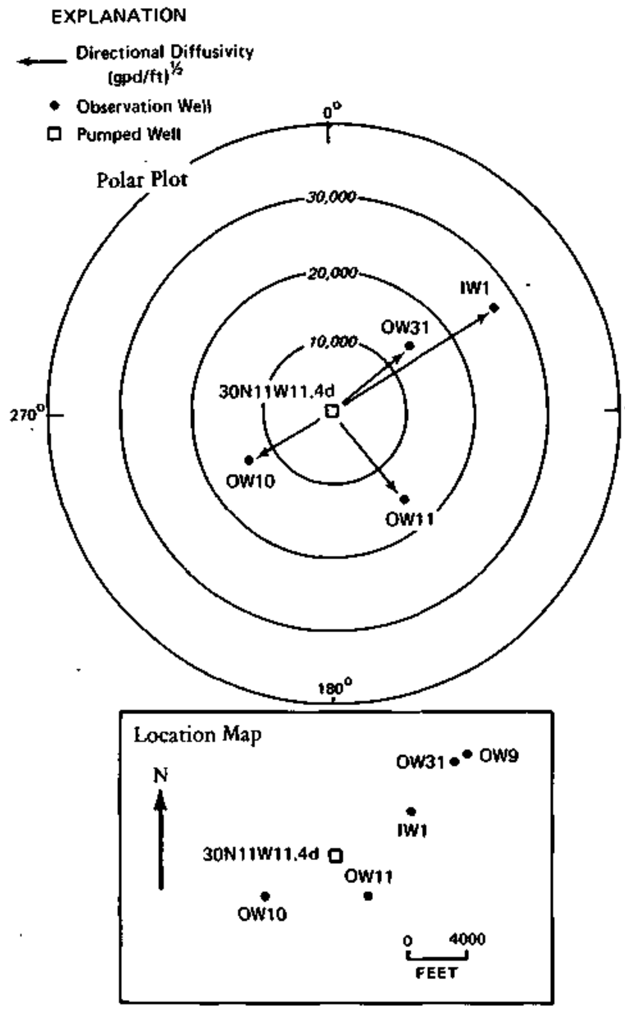


Figure 11. Polar plot of directional diffusivity from an aquifer test at Prudential's Tallmadge Ranch

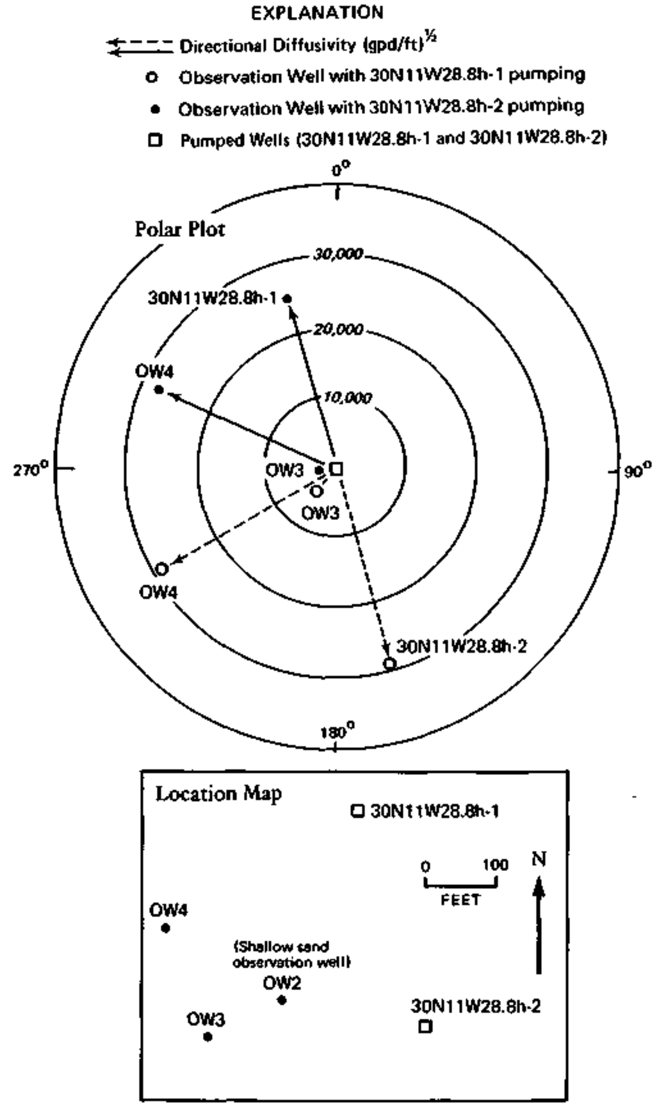


Figure 12. Polar plot of directional diffusivity from an aquifer test at the village of Hopkins Park, Pembroke Township

Hopkins Park-Pembroke Township Aquifer Test

Another test in the Silurian Dolomite was conducted in April 1988 using the two new supply wells of the village of Hopkins Park, Pembroke Township. The aquifer test was conducted on four dolomite wells, two of which were pumped in sequence, and one sand and gravel observation well (figure 12). Here the dolomite aquifer lies under 20 to 30 feet of clay, which in turn lies under 65 feet of sand and gravel. The two tests used wells 30NllW28.8h-l and 30NllW28.8h-2 as pumped wells, and tests lasted 180 and 1,300 minutes, respectively. Well 30NllW28.8h-l was pumped at an average rate of 405 gpm, and 30NllW28.8h-2 was pumped at a rate of 750 gpm. No response was recorded in tie sand-and-gravel observation well (OW2), located about 213 feet west of 30NllW28.8h-2. Based on directional diffusivities, average transmissivity of 41,000 gpd/ft was determined from the aquifer tests at this site. The average storage coefficient was 0.00006.

As seen in the polar plot of directional diffusivity (figure 12), the outer range of data from the two tests describe a circle, which indicates that the aquifer is behaving isotropically at the scale of the aquifer test. The inner two points, both of which are from well OW3, appear to be erroneously low because the well partially penetrates the aquifer. Well OW3 penetrates to a depth of 187 feet, which maybe above the major water-transmitting fractures penetrated by wells 30NllW28.8h-l, 30NllW28.8h-2, and OW4, whose depths are 445,450, and 201 feet, respectively.

Papineau Aquifer Test

A final test was conducted on September 21,1988, on an old railroad well identified as 29N12W28.2c. The well is 140 feet deep and located in the village of Papineau. The unconsolidated deposits in this area are approximately 45 feet thick and consist of about 2 feet of soil over 40 to 45 feet of clay-rich, pebbly, fine-grained material. Approximately one foot of sand and gravel usually occurs between the base of the fine-grained deposits and the top of the Silurian Dolomite. The elevation of the Silurian Dolomite decreases with distance in all directions from Papineau, whereas drift thickness increases.

The September 1988 aquifer test lasted three hours and used three observation wells at distances of 400,600, and 1,000 feet from the pumped well. All three observation wells penetrate into the Silurian Dolomite. Before the test, the static water level ranged from 22 to 24 feet below the land surface.

Transmissivities determined from the aquifer test ranged from 14,242 to 17,692 gpd/ft (table 2). The average transmissivity for the Papineau area, based on the results of the test, is approximately 16,000 gpd/ft. The storage coefficient determined for the Silurian Dolomite ranged from 0.00004 to 0.00019. The average storage coefficient was 0.00009.

Specific-Capacity Analyses

Specific capacity is the rate of discharge from a well divided by the drawdown of the water level within the well. Specific-capacity data were drawn from 885 drillers' reports for bedrock wells within the study area. Data were used to estimate the range and distribution of transmissivity within the carbonate bedrock (Silurian and Devonian Dolomite). Although subject to many sources of error, specific-capacity data are frequendy used to estimate aquifer properties. Detailed descriptions of specific-capacity analyses used for determining transmissivity are found in Csallany and Walton (1963), Peters (1987), Brown (1963), and Theis (1963).

Transmissivity is estimated from specific capacity according to the Theis equation, in which the specific capacity is treated as a short nonequilibrium pumping test. The Theis equation requires making assumptions about factors such as storage coefficient, minimal well loss, and full aquifer penetration. It is most applicable to nonleaky, homogenous, and isotropic artesian aquifers of infinite areal extent.

Transmissivity calculations for the 885 specific-capacity values were facilitated by a computer program written by Bradbury and Rothschild (1985). The program corrects for partial penetration, well diameter, and well loss, if known. Partial penetration of wells was adjusted to a standard aquifer thickness of 100 feet (Bergeron, 1981). Although the carbonate aquifer may be as thick as 500 feet in places, the predominant water-yielding openings occur in the upper 100 feet. The storage coefficient of the bedrock was assumed to be 0.0001, based on studies in Indiana and on the aquifer test results reported earlier. Actual storage coefficients of the aquifer may vary from the assumed value, but because specific capacity varies with the logarithm of the inverse of the storage coefficient, the transmissivity solution has a low sensitivity to variations in the storage coefficient.

Specific-capacity values were uncorrected from field data for the 885 bedrock wells analyzed; they ranged from 0.02 to 90.91 gallons per minute per foot (gpm/ft) of drawdown. The median specific capacity was 2.14 gpm/ft. The median values are commonly used for specific capacity and transmissivity because they usually have a log-normal distribution. Figure 13 shows that both the specific-capacity and transmissivity data are log-normally distributed. The

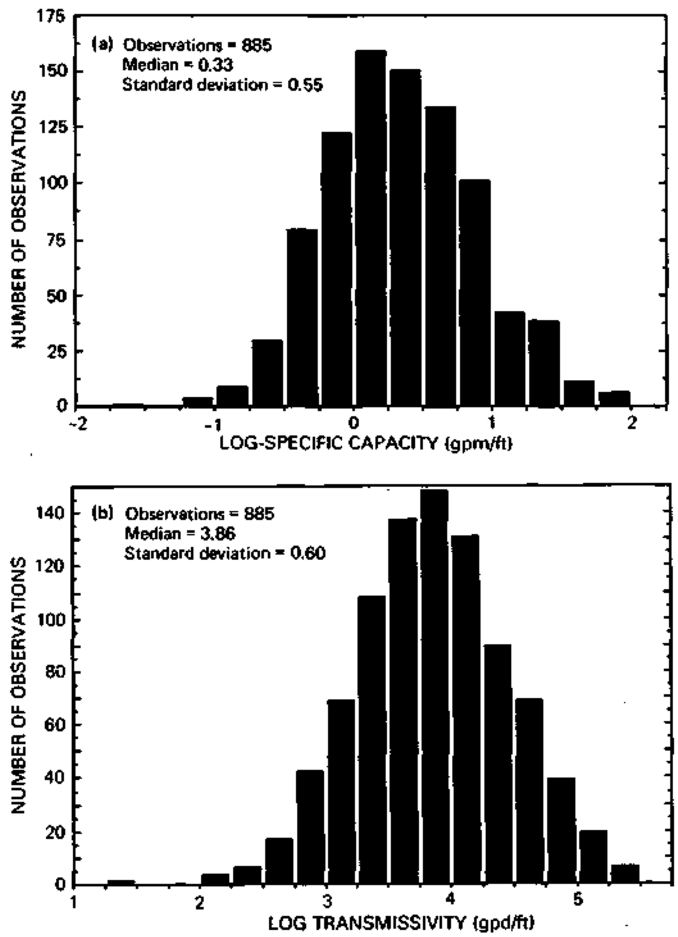


Figure 13. Histograms of log_{10}-base specific capacity (a) and transmissivity (b)

median transmissivity value is 7,244 gpd/ft. Minimum and maximum values calculated for transmissivity are 18 and 244,881 gpd/ft, respectively.

The distribution of transmissivities calculated from specific- capacity values within the bedrock aquifer can be represented on a contour map (figure 10). Since transmissivity within the bedrock is log-normally distributed, the base-10 logs of the transmissivity are plotted. No distinct trend in the distribution of transmissivity values appears, although areas of particularly low and high transmissivity exist within localized areas. The lack of a clear trend in the data conforms to the nonhomogenous nature of the flow system, which is defined by the secondary permeability of the dolomite.

There is little correlation between the transmissivities calculated from specific-capacity data and those determined from aquifer and production tests. However, as discussed earlier, aquifer and production test data are biased towards high-yielding irrigation and municipal wells, whereas the specific-capacity data incorporate all water wells that penetrate into the dolomite.

In addition to determining transmissivity, specific-capacity data can also be used to estimate depth intervals within the bedrock that provide the highest yields of ground water. Table 3 presents the statistical results of specific-capacity data from irrigation, public, and industrial water wells that penetrate 100 to 400 feet and 400 to 600 feet of Silurian Dolomite. Wells penetrating 100 to 400 feet of dolomite have a mean specific capacity of 19.9 gpm/ft. Wells with more than 400 feet of bedrock penetration have a mean specific capacity of 5.1 gpm/ft. As previously discussed, openings within the carbonate bedrock are most frequent in the upper 100 feet and decrease with depth. Although drillers will penetrate deeper into the bedrock to gain higher yields, additional drilling beyond a few hundred feet will probably add only negligible quantities of water to a well. Studies by Walton and Neill (1963) and Zeizel et al. (1962) also show that ground water derived from Silurian Dolomite wells diminishes as well depth increases.

Surficial Hydrology

Sand-and-Gravel Aquifer Properties

Beneath most of the study area in Kankakee County and the northeastern corner of Iroquois County, the surficial sand-and-gravel aquifer provides water for domestic, livestock, and agricultural purposes. Most wells installed in the sand and gravel are sandpoints, and suction-type pumps are used to withdraw water. No high-capacity irrigation wells use the surficial deposits for ground water, although the potential yield of the sand is sufficient in some areas to serve as a viable source of irrigation water.

The transmissivity and hydraulic conductivity of the shallow sand and gravel were estimated using aquifer test data from a site near Hopkins Park. Aquifer test data from a pumping well and four observation wells yielded an average transmissivity of 11,600 gpd/ft using the Theis log-log method of graphical analysis (Walton, 1962). Average hydraulic conductivity for the site was 232 gpd/sq ft. The test was too short to determine the specific yield of the aquifer.

Specific-capacity data for two high-capacity sand-and-gravel test wells constructed near Hopkins Park were taken from the drillers' reports. Evaluation of the data yielded hydraulic conductivities of 490 and 690 gpd/sq ft, respectively, for pumping rates of 386 and 450 gpm. The transmissivities determined from these tests were approximately 20,000 and 31,000 gpd/ft for an assumed specific yield of 0.10. No data were available for determining the actual specific yield of the shallow sand- and-gravel aquifer. The saturated aquifer thickness at the time of the tests was approximately 40 feet.

Sand-and-Gravel Observation Wells

Eight observation wells were installed in the shallow sand-and-gravel aquifer (figure 14 and table 4) between November 1987 and April 1988. The observation wells were designed to monitor the water table in response to

Table 3. Statistical Results of Specific-Capacity Data for High-Capacity Wells Penetrating more than 100 Feet of Dolomite

Bedrock penetrated (feet)	*Total observations*	*Specific capacity (gpm/ft)*			
		Mean	*Median*	*Standard deviation*	*Range*
100-400	47	19.9	10.0	21.8	.3-90.9
400-600	14	5.1	2.6	6.5	.4-24.5

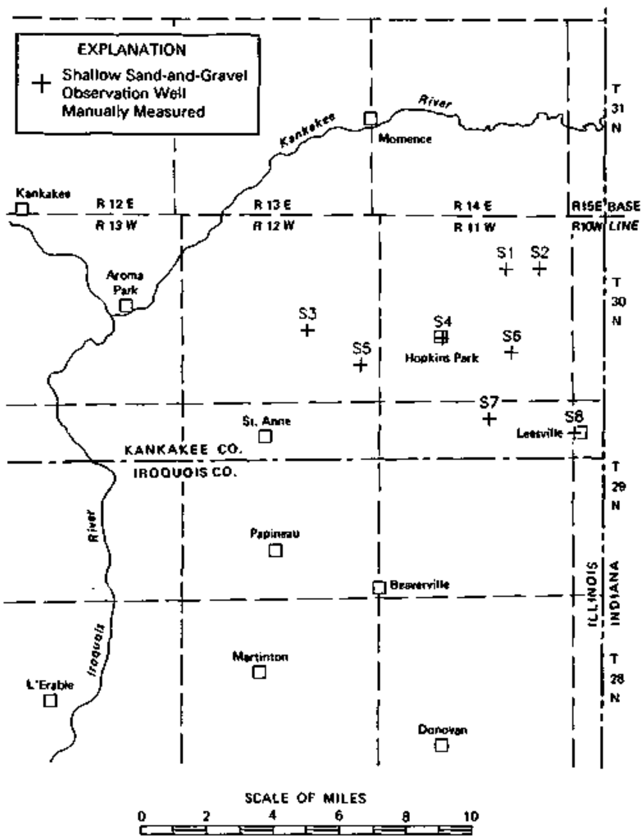


Figure 14. Shallow sand-and-gravel observation wells

local concerns that water levels in shallow wells were dropping because of irrigation pumpage. The eight wells were constructed at depths of 19 to 71 feet below the land surface using a hollow-stem auger drill rig. At seven of the eight drill sites, the augered holes penetrated the top of the underlying clay confining layer, ensuring that the full thickness of the surficial sand was penetrated during drilling. This was not the case at the western drill site, observation well S3, where the clay confining layer was absent. The drill hole at this site was augered to the top of the dolomite bedrock 19 feet below the land surface. At all observation well sites, the wells were constructed using standard 2-inch diameter PVC well casing with a 5-foot length of screen at the bottom.

Ground-water hydrographs from the eight observation wells installed in the shallow sand-and-gravel aquifer generally show a seasonal fluctuation: water levels in most wells decline in the late spring, summer, and early fall (figure 15 and appendix 2). Water levels drop during this period as evaporation, transpiration, and ground-water discharge to streams exceeds precipitation. The record drought year of 1988 accelerated this natural decline of the water table: in six of the eight observation wells, water levels declined from 2.5 to 4 feet from April through September 1988. Water-level recession during June and July ranged from 0.17 to 0.24 foot per week. The hydrograph of observation well S4 (figure 15), located in Hopkins Park, is representative of water levels observed in the shallow sand and gravel over most of the study area.

Water levels in two of the sand-and-gravel observation wells did not follow the natural recession of the water table observed in other wells. Water levels in wells S3 and S5 were heavily influenced by irrigation (appendix 2). The water level in observation well S3 declined by 5.1 feet between April and late August, with recession of up to 0.65 foot per week in June and July. This water-table decline amounts to more than twice the natural rate recorded in other observation wells and may be attributed to two factors. First, no clay or till confining layer separates the sand and gravel from the dolomite bedrock. Second, the observation well is located within several feet of an irrigation well that pumped water from the dolomite during the months of May through August. Pumping the irrigation well caused a large hydraulic gradient that increased leakage from the sand and gravel into the dolomite. This resulted in an increased rate of water-table decline. When irrigation ended in late August, water levels in observation well S3 recovered promptly.

Table 4. Sand-and-Gravel Observation Wells

Observation well	*Location*	*Depth of well (feet below land surface)*	*Measuring point elevation (feet)*	*Land surface elevation (feet)*
S1	KNK 30N11W-10.4A	48	663.79	661.8
S2	KNK 30N11W-13.8F	56	675.64	673.2
S3	KNK 30N12W-22.5C	19	632.41	630.9
S4	KNK 30N11W-28.8H	71	686.36	684.2
S5	KNK 30N12W-25.8A	31	648.01	646.0
S6	KNK 30N11W-26.8D	47	667.92	665.9
S7	KNK 29N11W-03.7A	48	654.80	653.3
S8	KNK 29N11W-01.1A	63	688.87	686.9

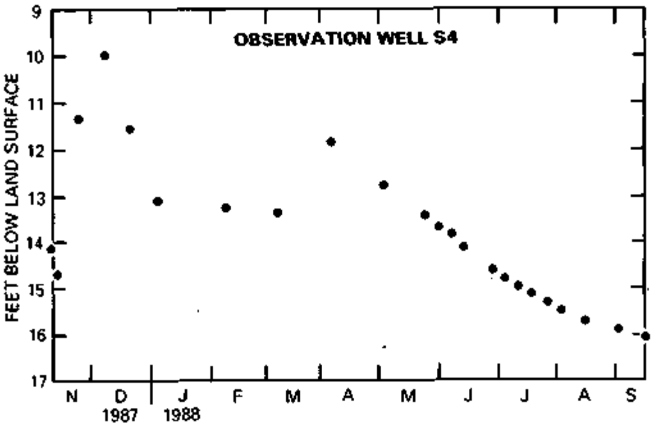


Figure 15. Hydrograph for shallow sand-and-gravel observation well S4

While irrigation caused major water-level declines in observation well S3 in 1988, it was responsible for maintaining water levels in observation well S5 at a higher than natural level through June and July. The water table around well S5 remained higher than expected because of local irrigation and because a large irrigation ditch, used for holding and transporting irrigation water, was located within one-quarter mile of the observation well. The shallow sand and gravel penetrated by well S5 is separated from the dolomite aquifer by a clay confining layer.

The observation well data indicate that in areas with a clay or till confining layer, high-capacity wells do not cause any significant drawdown in nearby water wells installed in shallow sand and gravel. Declining water levels in these shallow wells can be attributed to natural recession of the water table from late spring to early fall, when evapotranspiration and ground-water runoff generally exceed recharge from precipitation.

Clay - Till Aquitard

The fine-grained lacustrine clay or till that underlies the shallow sand and gravel throughout much of the study area acts as an aquitard or confining layer. The low permeability of this layer restricts downward and lateral movement of ground water, inhibiting recharge of the underlying aquifer. Vertical hydraulic conductivity values for the clay and till layers over the dolomite aquifer were computed using the following formula, which was modified from Walton (1965):

$$K' = m'[(Q_c/A_l)/(2.8 \times 10^7)\Delta h]$$

where:

K' = vertical hydraulic conductivity of deposits in gallons per day per square foot
m' = saturated thickness of deposits, in feet
Q_c/A_l = recharge rate, in gallons per day per square mile
Q_c = leakage (recharge) through deposits, in gallons per day
A_l = area of flow channel between flow lines and flow cross sections, in square miles
Δh = difference between the head in the aquifer and in the source bed above deposits through which leakage occurs, in feet

Recharge rates were determined for selected areas using flow-net analyses of the spring 1987 potentiometric surface map of the dolomite aquifer. A detailed description of the methods used to calculate recharge rates is presented in Walton (1965). The flow channels chosen for computing recharge rates and vertical hydraulic conductivity are shown in figure 16. Recharge rates, vertical head losses, and clay and till thicknesses for the selected flow

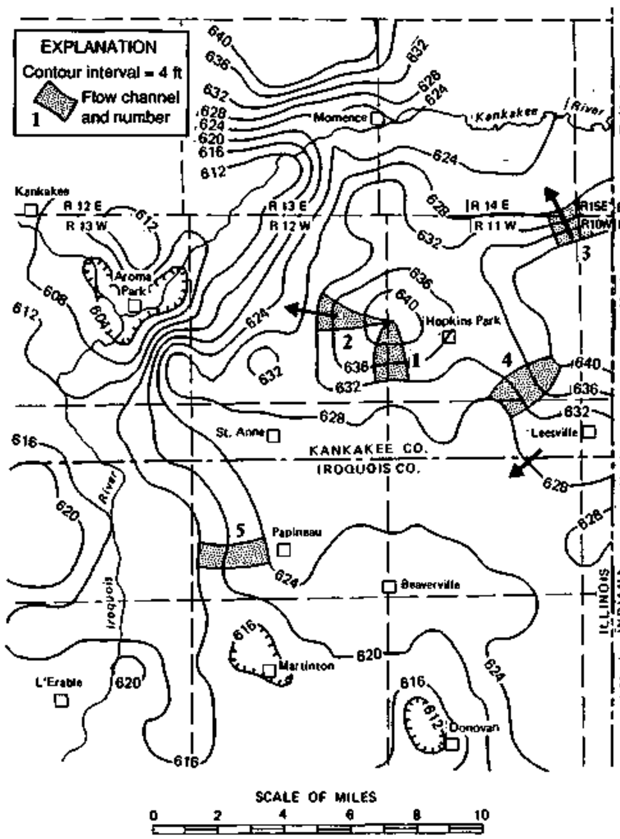


Figure 16. Potentiometric surface of the dolomite aquifer, May 25-28, 1987, and locations of flow channels

Table 5. Silurian Dolomite Recharge Rates and Vertical Hydraulic Conductivity of Confining Layers **for** Selected Flow Channels

Flow channel	*Q_c/A_t (gpd/sq mi)*	*Δh (feet)*	*m' (feet)*	*K' (gpd/sq ft)*
1	245,562	13	11	.007
2	285,681	Confining unit thin to absent.		
3	126,663	19	28	.007
4	97,342	24	50	.007
5	86,625	4	40	.031

channels were substituted into the above equation to compute vertical hydraulic conductivities (table 5).

Vertical hydraulic conductivity values computed for clay and till deposits within the study area range from 0.007 to 0.031 gpd/sq ft. This range is comparable to hydraulic conductivities of clays in Jasper and Newton Counties, Indiana. Vertical hydraulic conductivity of the clay and till was estimated at 0.003 to 0.03 gpd/sq ft based on Indiana data compiled by Bergeron (1981) and Basch and Funkhouser (1985).

Vertical hydraulic conductivity values derived for lithologically diverse drift deposits in Illinois, including some tills, were presented by Walton (1965). Using aquifer test, flow-net, and geohydrologic system analyses, Walton determined that the vertical hydraulic conductivity for drift composed of clay and silt with some sand and gravel ranged from 0.01 to 0.08 gpd/sq ft. Walton's values of vertical hydraulic conductivity correspond to the higher hydraulic conductivity values determined both in this study and in Indiana.

5. GROUND-WATER RECHARGE AND RUNOFF

Recharge from Precipitation

Ground water within the unconsolidated deposits and the underlying dolomite bedrock of the study area is recharged through deep percolation from precipitation, seepage from streams and ditches, and artificial recharge from irrigation wells. Most of the precipitation falling on the land surface is not available to recharge the ground-water system because it is lost to the atmosphere by evaporation and plant transpiration, known as evapotranspiration. During an average year, evapotranspiration exceeds precipitation only during the months of June, July, and August. Precipitation exceeds evapotranspiration throughout the remaining nine months, during which time the excess water recharges the moisture- deficient soiL Once the soil moisture reaches field capacity, continuing precipitation (soil-moisture surplus), becomes surface runoff and recharges the unconsolidated and bedrock aquifers. Ground water recharging the unconsolidated, or surficial, aquifer may discharge to local ditches and streams, or it may recharge the underlying bedrock aquifer. Ground water within the bedrock flows laterally to discharge into streams or outside the bounds of the study area.

Evapotranspiration and soil-moisture surplus calculations were determined with a method outlined by Bowman and Collins (1987), in which actual evapotranspiration is equivalent to the sum of precipitation and the change in soil moisture. This method does not account for surface and ground-water runoff and changes in ground-water storage. Table 6 presents the actual evapotranspiration (AET) determined for the principal types of vegetation and soil-texture groups found in the study area. In 1987 the evapotranspiration for deep-rooted crops, such as field corn, ranged from about 22 inches in fine sand to 24.8 inches in a silt or clay loam. Evapotranspiration for shallow-rooted crops, such as small vegetables, ranged from 17.6 inches in fine sand to 18.5 inches in fine sandy loam. Evapotranspiration for 1987 was approximately 1 to 2 inches less than the mean evapotranspiration for 1967 through 1987. The ratio of evapotranspiration and precipitation for deep-rooted crops in 1987 ranged from 63 to 71 percent for the different soil types. For shallow-rooted crops, the ratio was 50 to 52 percent.

Soil-moisture surplus, the water remaining after evapotranspiration and soil-moisture replenishment, is shown for this period in table 7. Average soil-moisture surplus for the period 1967 through 1987 was 13 inches for corn and 18 inches for vegetables and other shallow-rooted crops. Under irrigation, and assuming no soil-moisture deficit, the average soil-moisture surplus was estimated at about 16 inches for corn and 20 inches for vegetables. Soil-moisture surplus was also calculated for the recharge season (September through May) preceding the summers of 1987 and 1988. The 1987 soil-moisture surplus ranged from 13.9 to 16.5 inches for fields with corn and from 18.7 to 19.3 inches for vegetable fields. In 1988 the soil-moisture surplus ranged from 9.7 to 12.4 inches for corn and 15.1 to 15.8 inches for vegetables.

Table 6. Actual Evapotranspiration, 1987, and Mean Evapotranspiration, 1967-87 (inches)

	1987[1]			1967-87[2]		
	Fine sand	*Fine sandy loam*	*Silt/clay loam*	*Fine sand*	*Fine sandy loam*	*Silt/clay loam*
Deep-rooted crops (corn)	22.0	24.0	24.8	23.0	24.6	25.1
Shallow-rooted crops (vegetables)	17.6	18.5	-	19.8	20.5	-

[1] Annual precipitation = 35.15 inches.

[2] Annual precipitation = 37.75 inches.

Table 7. Soil-Moisture **Surplus, 1987, 1988, and 1967-87** (inches)

	1987			*1988*			*1967-87*		
	Fine sand	*Fine sandy loam*	*Silt/clay loam*	*Fine sand*	*Fine sandy loam*	*Silt/clay loam*	*Fine sand*	*Fine sandy loam*	*Silt/clay loam*
Deep-rooted crops (corn)	16.5	14.6	13.9	12.4	9.7	9.7	13.3	13.1	12.6
Shallow-rooted crops (vegetables)	19.3	18.7	-	15.8	15.1	-	18.3	17.6	-

Recharge of the Silurian Dolomite

The Silurian Dolomite is recharged predominantly by the vertical leakage of ground water from the overlying glacial drift deposits. Additional recharge occurs along influent, or losing, stretches of the Kankakee and Iroquois Rivers. Recharge rates for the Silurian Dolomite were estimated by flow-net analysis of the potentiometric surface maps presented in figure 16 and by examining the relationship between ground-water withdrawals and ground-water levels.

The rate at which the dolomite is recharged by vertical leakage of ground water depends on 1) the permeability and thickness of overlying unconsolidated materials, and 2) the head differential between the water table in those materials and the head in the dolomite. Over most of the study area, ground water moves downward towards the dolomite aquifer because water levels in the dolomite are lower than those in the overlying unconsolidated deposits. This situation establishes a downward gradient.

The distribution and thickness of fine-grained materials (lacustrine clay and till) are important to understanding the recharge of the dolomite aquifer within the study area. Figure 17 shows a generalized thickness map of fine-grained materials. The map was created by overlaying stack-unit maps produced by Edward Smith and William Dey of the Illinois State Geological Survey. A stack-unit map shows the distribution of earth materials moving from the surface downward to a specified depth.

As seen in figure 17, the north-central and northwestern parts of the study region are generally mantled by less than 20 feet of fine-grained materials, whereas eastern and southern areas show fine-grained deposits in excess of 20 feet. Fine-grained materials in the area a few miles north of St. Anne are generally absent to patchy, allowing large rates of recharge through the coarser grained deposits to the dolomite aquifer. Southeast of this area, around Leesville and Beaverville, fine-grained materials range from 30 to more than 100 feet in thickness, reducing ground-water recharge to the dolomite.

Flow-net analyses of the potentiometric surface map for spring 1987 were used to determine the amount of recharge occurring in different parts of the study area under steady-state conditions. Flow nets were constructed only in areas whose local hydrogeologic controls were well-known. Ground-water levels in the dolomite are closest to their natural levels during the late spring, and changes in storage within the aquifer are usually minimal. Using a method outlined by Walton (1965) and presented in section 4,

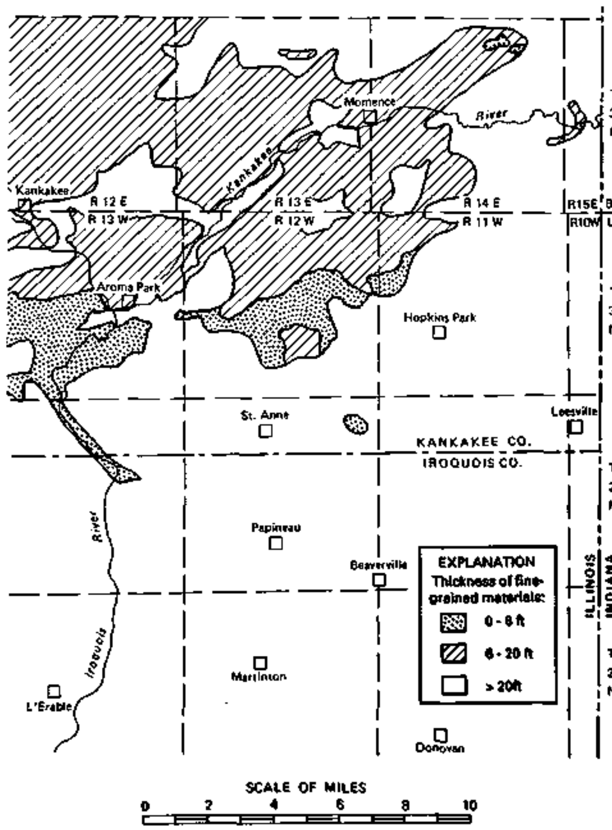


Figure 17. Thickness map showing fine-grained materials confining the dolomite (after Smith and Dey)

recharge rates were estimated as the quotients of flow through cross sections and surface areas of five flow channels (figure 16). Recharge to the Silurian Dolomite for flow channels 1 and 2, which are located near areas mantled by predominantly coarser grained materials, were more than 245,000 and 285,000 gpd/sq mi, respectively, as shown in table 5. Recharge in areas with thicker confining layers of clay and till, calculated for flow channels 3,4, and 5, ranged from 86,000 to 126,000 gpd/sq mi.

Assuming that leakage occurs through fine-grained deposits of a given thickness and a given vertical hydraulic conductivity, the recharge rate per unit area increases with the differential between the head in the source bed (sand and gravel) above the fine-grained deposits and the head in the dolomite aquifer. The recharge rate to the dolomite aquifer is highest when the potentiometric surface of the dolomite is at the base of the fine-grained deposits through which the leakage occurs, if the water table in the source bed above those deposits does not decline significantly (Walton, 1965). Thus, for a given well or field of wells, recharge increases as drawdown increases.

When the head in the dolomite aquifer drops below the bottom of the deposits through which leakage occurs, gravity drainage begins. This results in lowered transmissivity and a change from confined conditions (artesian or leaky artesian) to unconfined conditions (water table). In a study of the Silurian Dolomite in the Chicago Heights area of northeastern Illinois, Prickett et al. (1964) found a specific (gravity) yield of 0.03 for the upper portion of the dolomite aquifer. At this rate, one foot of decline in head within the dolomite would release approximately 6.3 million gallons of ground water per square mile dewatered over a period of several years. However, the specific yield of the dewatered dolomite over a period of weeks would be much smaller than the specific yield computed for a period of several months or years.

Dewatering of the dolomite aquifer was negligible in 1987, and only a few isolated bedrock highs were affected by lowered water levels. During the latter part of the 1988 irrigation season, however, as much as 20 square miles of dolomite may have been dewatered by several feet in southeastern Kankakee and northeastern Iroquois Counties (see section 7).

Recharge of the dolomite aquifer was also determined for a diversion area created by withdrawing ground water from the dolomite during the summers of 1987 and 1988. The rate of recharge to the aquifer was estimated using the summer potentiometric surface maps and ground-water use records for 1987 and 1988. A full discussion of this method is presented by Prickett et al. (1964). Since water levels in most dolomite observation wells stabilized by the end of the 1987 and 1988 irrigation seasons, recharge within the irrigated region appeared to have been balanced by discharge. Based on that assumption, the average rate of recharge to the dolomite was calculated by dividing the total ground-water use within the diversion area during the irrigation season by both the area of diversion and the number of days in the irrigation season. In order to account for water-level declines within the dolomite before steady-state conditions were reached, changes in ground-water storage within the dolomite aquifer were subtracted from the total amount of ground water discharged.

Using this analysis, the average recharge required to balance pumpage over a 60-day irrigation season in 1987 was 144,000 gpd/sq mi. In 1988 the average recharge was computed for a 105-day season on an area of 20 square miles of the dolomite aquifer that was dewatered by 3 feet: recharge was found to be 180,000 gpd/sq mi, which was 25 percent greater than in 1987. Because the gradient of the potentiometric surface increased by as much as 100 percent during summer 1988 over summer 1987 (see figures 32 and 37), recharge had to increase to balance pumpage during summer 1988 within the irrigated region.

Based on the recharge rates determined from the two methods discussed above, the diversion area analyses fall between the recharge rates determined from the flow-net analyses. When comparing recharge rates, it is important to remember that the flow-net analyses were conducted on a spring 1987 potentiometric surface map, while diversion area analyses were conducted on potentiometric surface maps for the summers of 1987 and 1988. Rates of recharge to the dolomite aquifer increase during the summer, when ground-water withdrawals from the aquifer and potentiometric gradient are greatest.

Silurian Dolomite recharge rates have also been determined for other areas in northeastern Illinois, and studies have been summarized by Walton (1965). Recharge rates of the dolomite for five areas in DuPage and Cook Counties range from 136,000 to 225,000 gpd/sq mi. The dolomite is manded by glacial drift composed predominantly of till. A sixth area, located in DuPage County, shows Silurian Dolomite mantled by drift — largely till — and shaly dolomite. The recharge rate at mis location is 64,000 gpd/sq mi. Recharge rates from flow-net and diversion area analyses in Kankakee and Iroquois Counties are similar to the recharge rates determined in these studies. An exception is the area northwest of Hopkins Park in Kankakee County with recharge rates of 245,000 and 285,000 gpd/sq mi. Here the dolomite is overlain by predominandy coarse-grained materials, resulting in higher rates of recharge than in areas with thick layers of clay or till directly over the dolomite aquifer.

Interaction Between Ground Water and Major Streams

Streams and other bodies of surface water also interact with aquifers. They receive discharge from the aquifer (gaining or effluent stream) and recharge the aquifer (losing or influent stream) at various places. On the other hand, the aquifer may be isolated from the river when impermeable materials such as clays occur beneath the riverbed. To delineate zones of potential recharge and discharge between the Kankakee and Iroquois Rivers and the bedrock aquifer, water elevations were measured in 22 bedrock wells adjacent to the two rivers. Water elevations in the wells were then compared to river elevations. Measurements were conducted over a three-day period during the first week of May 1988.

The Illinois State Geological Survey conducted extensive mapping of materials below the Kankakee River and the lower portion of the Iroquois River near its confluence with the Kankakee River (Gross and Berg, 1981). The geologic mapping showed that the Kankakee River channel is underlain by sand and bedrock. At those stretches of river not directly underlain by bedrock, varying thicknesses of sand deposits lie over the bedrock. No significant fine-grained deposits, which would separate the surface water from the ground water in the bedrock, were mapped. Figure 18 shows how the four-mile stretch of the Kankakee River channel at Momence, the two-mile stretch downstream of Aroma Park, and a small stretch of the Iroquois River upstream from Aroma Park flow directly over Silurian Dolomite bedrock.

Although geologic mapping of the Iroquois River channel terminated about one mile south of Aroma Park, geologic maps from drillers' logs show that surficial deposits along the northern stretch of the river are predominantly coarser grained. Beginning about two miles north of the Kankakee-Iroquois county line, the deposits adjacent to the river change to finer grained materials. Surficial deposits over most of northern Iroquois County, through which the Iroquois River flows, are primarily finer grained, although coarser grained material is often found near the surface.

Comparing ground-water elevations to river elevations, the ground-water level is above the Kankakee River elevation all the way downstream from the beginning of the bedrock high near Momence. Figure 19 illustrates ground-water elevations relative to river elevations along the Kankakee River. Assuming a hydraulic connection between the Silurian Dolomite and the river channel, the entire Kankakee River downstream from Momence is recharged by ground water from the bedrock. This is also true of the Iroquois River, where ground-water elevations in the surrounding bedrock are 4 to 18 feet above the elevation of the river channel However, finer grained deposits along much of the Iroquois River isolate the river channel from the bedrock, limiting the upward flow of ground water from the bedrock to the stream.

Conversely, the entire stretch of the Kankakee River channel upstream from the bedrock high near Momence is higher than the ground-water levels measured in adjacent bedrock wells. This indicates that when measurements were taken in May 1988, the river was influent; that is, some of the river water was migrating into the Silurian Dolomite. As shown in figure 19, the magnitude of the head difference of the river over ground-water levels increases upstream from the bedrock high. Proceeding upstream from the

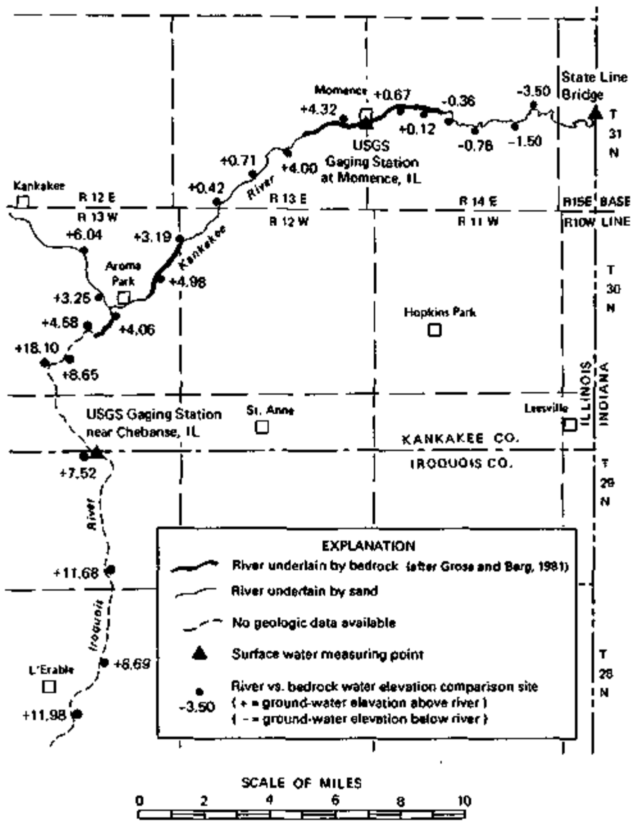


Figure 18. Comparison of surface water levels with ground-water levels in dolomite wells along the Kankakee and Iroquois Rivers, May 3-5, 1988

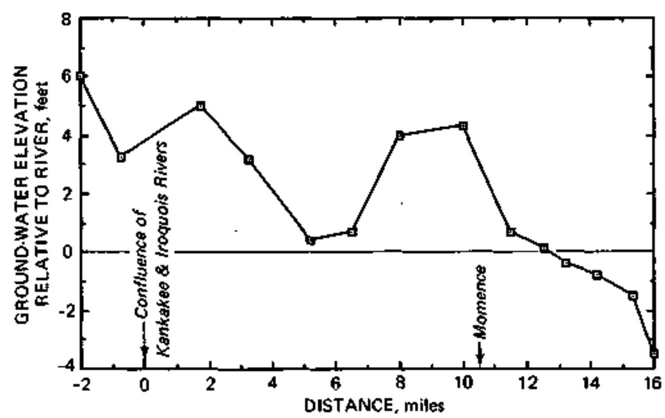


Figure 19. Ground-water levels in the Silurian Dolomite relative to surface water levels along the Kankakee River

bedrock high, where the elevation of the Silurian Dolomite ranges from about 600 to 620 feet above mean sea level (msl), the bedrock suddenly drops off to an elevation of 575 feet above msl. This depression in the bedrock corresponds to the area of ground-water recharge along the river.

It is important to note that the above measurements were taken in one three-day period in May 1988. Based on these data, a stretch of the Kankakee River upstream from Momence is influent; that is, it is losing water to the dolomite. Potentiometric surface maps presented in section 7 show that during other periods of the year, this same stretch of the Kankakee River gains water from the dolomite.

Ground-Water Runoff

While precipitation accounts for much of the water that recharges most surficial aquifers, discharges can be accounted for by ground-water withdrawals from pumping wells, leakage to other aquifers, or water that seeps into streams to become ground-water runoff or baseflow. Baseflow is that part of a stream discharge derived from ground water seeping into the stream. Surface runoff, the other component of a stream's flow, is the water that runs over the ground or penetrates only the upper reaches of the soil during a storm, eventually finding its way into a surface stream without ever entering the aquifer. Surface runoff usually contributes to a stream until several days after a storm, while baseflow accounts for the flow at all other times, even when there has been little rain.

Baseflow contributions to the Kankakee and Iroquois Rivers are derived from both the surficial unconsolidated deposits and in places, from the carbonate bedrock (Silurian Dolomite in the north and Devonian Dolomite in the south). Baseflow estimates made for this study did not attempt to distinguish between contributions from surficial materials and underlying bedrock. The estimates of baseflow presented here were derived from analyses of both published and provisional surface water discharge data from U.S. Geological Survey (USGS) gaging stations at Momence, Illinois, and Shelby, Indiana, on the Kankakee River; and near Chebanse, Illinois, on the Iroquois River (figure 20).

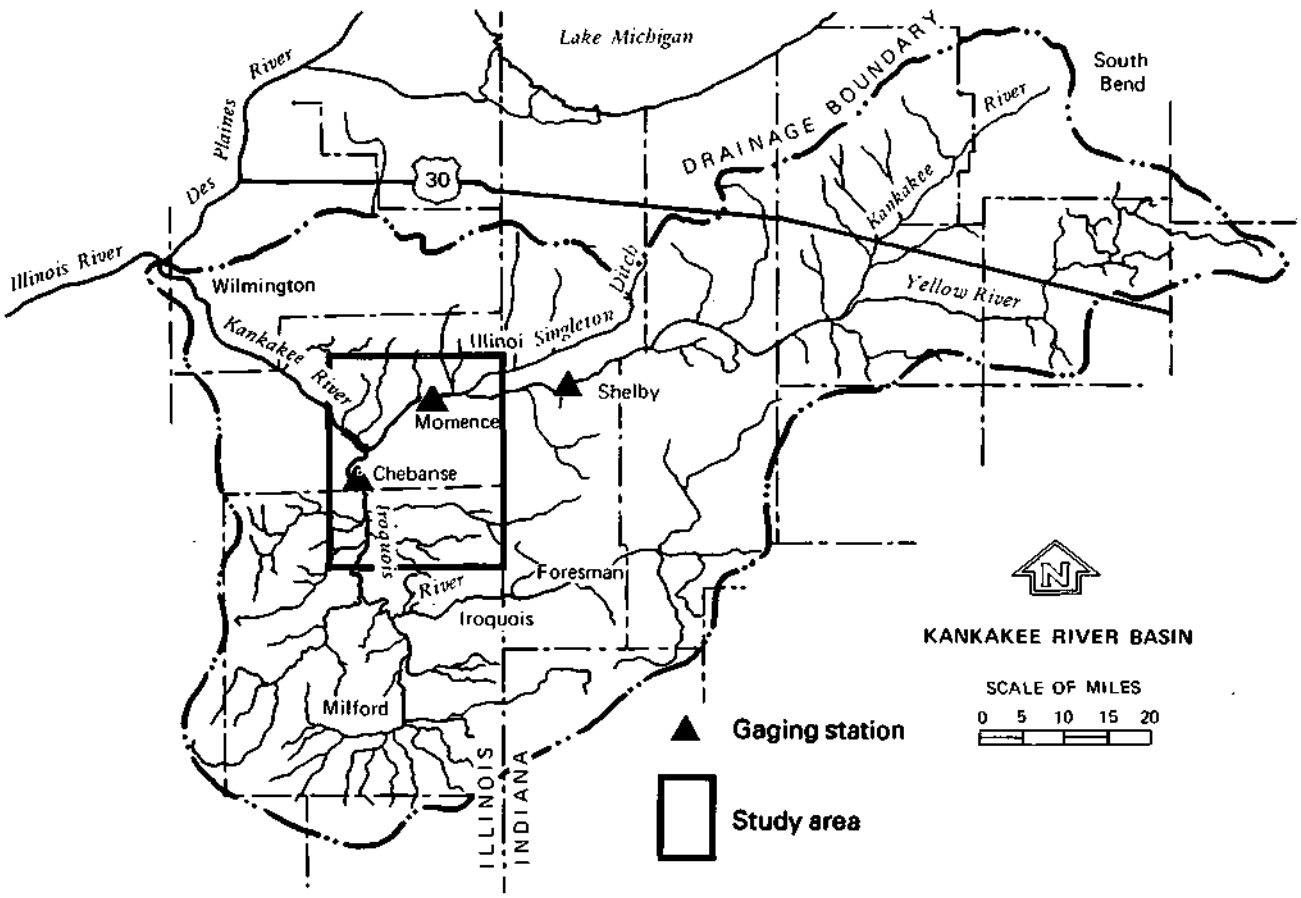


Figure 20. Gaging stations used for baseflow analysis in the Kankakee River basin (after Bhowmik et al., 1980)

The total drainage area of the Kankakee River at its mouth at the Illinois River is 5,165 square miles. The drainage area of the Kankakee River at the Momence gaging station is 2,294 square miles, of which only 154 square miles (7 percent) is in Illinois (Bhowmik et al., 1980). The drainage area of the Iroquois River at the gaging station near Chebanse is 2,091 square miles (Water Resources Data - Illinois, 1987), of which approximately 1,468 square miles (69 percent) is in Illinois.

Previous Work

Several studies have characterized flow patterns in the Kankakee and Iroquois Rivers. A study of streams throughout Illinois by Singh and Stall (1973) determined the lowest flow expected for a 7-day period at a recurrence interval of 10 years. Under these low-flow conditions, the river flow can be assumed to consist entirely of baseflow. The low flow determined for the Kankakee River at Momence is 411 cubic feet per second (cfs) for a drainage basin of 2,340 square miles, or 0.176 cfs/sq mi (table 8). The low flow of the Iroquois River, measured near Chebanse, is 16.6 cfs over 2,120 square miles, or 0.008 cfs/sq mi.

The rate of flow of the Kankakee River is higher than that of the Iroquois River because the surficial drift deposits in the Kankakee River basin are more permeable than the fine-grained materials in the region through which the Iroquois River flows. Extensive sand deposits along the Kankakee River allow less surface runoff and more recharge to the sand and gravel and bedrock. This situation results in high ground-water discharges to the river.

The 1965 Walton study characterized ground-water runoff for the Kankakee and Iroquois Rivers on the basis of cubic feet per second per square mile for three years of below-normal, normal, and above-normal precipitation. These results are presented in table 9. Although precipitation classifications relative to "normal" are rather imprecise, the results do allow comparison with other methods of calculating baseflow.

Methodology

The first method of baseflow separation is referred to as the "fixed base-length" technique. It assumes that runoff contributions to streamflow after a storm event will become negligible at a fixed time after peak flow (Linsley, 1958). To

Table 8. 7-Day, 10-Year Low Flows Adjusted for 1970 Effluent Conditions on the Kankakee and Iroquois Rivers

USGS gaging station	*Drainage (sq mi)*	*7-day, 10-year low flow (cfs)*	*Cfs per sq mile*	*Equivalent inches over drainage area*
Kankakee River at Momence	2,340	411	0.176	2.39
Iroquois River near Chebanse	2,120	16.6	0.008	0.11

Source: After Singh and Stall, 1973.

Table 9. Estimated Ground-Water Runoff for the Kankakee and Iroquois Rivers

USGS gaging station	*Annual ground-water runoff (cfs/sq mile)*		
	Near	*Below*	*Above*
Kankakee River at Momence	0.55	0.40	0.72
Iroquois River near Chebanse	0.24	0.10	0.52

Note: Data are for years of near-, below-, and above-average precipitation.

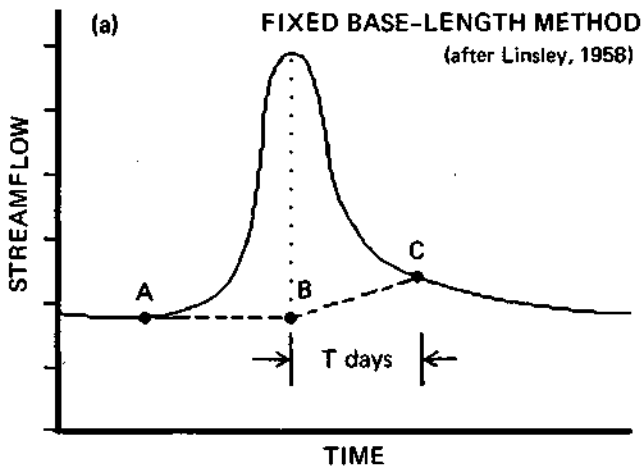
Source: After Walton, 1965.

apply this method, a line is hand-drawn on the hydrograph to extend the decline that had been occurring before the storm event to a point directly below the hydrograph's peak (line A-B in figure 21a, in which point A indicates the end of the recession from a previous storm event and the beginning of a new event). A straight line then connects the end of line A-B with the streamflow hydrograph at a point "T" days after the peak; T is given by the formula:

$$T = A^{0.2}$$

where A is the area of the drainage basin in square miles which is shown as line B-C in figure 21a.

The second method of baseflow separation is known as the "S-curve" or "variable-slope" method (Schulz, 1973). First, the hydrograph is drawn on a semilogarithmic plot. When drawn this way, the decline in streamflow after a storm event levels off rapidly; thus, the plot curve slopes immediately after the storm and later straightens out to decline at a constant (semilogarithmic) rate. Because the rate of decline is assumed to be the same for different storm events, a typical slope for this line can be determined "by eye." Extension lines are then drawn on both sides of the hydrograph for a storm event (figure 21b). The line extends from point A, which is the end of the recession from a previous storm event, to a point directly below the hydrograph's peak (shown as line A-B). Then a line extends backwards from a point after the storm ends to a point directly under the inflection point of the hydrograph's falling limb (shown as line C-D). A straight line then connects the two free ends to complete the baseflow separation (shown as line B-C).



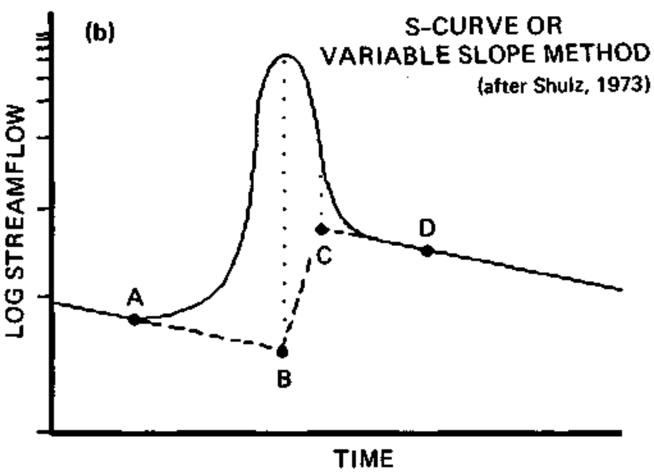


Figure 21. Baseflow separation using
(a) the fixed base-length method and (b) the S-curve method

It is difficult to apply baseflow separation techniques to multiple storm events because hydrographs become too complex when the effects of one storm overlap with those of another. Nevertheless, the drainage basins studied were so large that some form of baseflow separation had to be applied to the frequent periods of overlapping storm activity. As a result, when multiple peaks occurred on the hydrographs, falling limbs were drawn by hand for each discernible peak, which made it possible to approximate each event completely, as if the later storm had not occurred.

The baseflow estimates presented in this report were found by averaging the results of the fixed base-length and variable-slope methods. Although they do not reflect the exact changes in baseflow during individual storm events, they do show general trends and permit reasonably accurate estimates of yearly averages.

Baseflow Results

The streamflow hydrograph for the Kankakee River at Momence is shown in figure 22. Ground-water runoff, as estimated by the baseflow separation technique, is superimposed. The period of record includes water years 1985 through 1987 and the first quarter of water year 1988. A

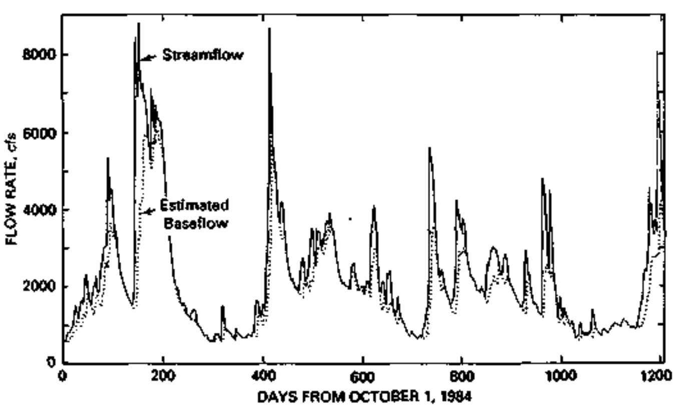


Figure 22. Streamflow and estimated baseflow for the
Kankakee River at Momence, WY 1985-1987 and early 1988

water year (WY) begins on October 1 and ends on September 30 of the following calendar year. Average baseflow for WY 1985 through 1988 was 1,870 cfs (0.83 cfs/sq mi). Table 10 presents the mean and median baseflows for the three water years analyzed.

To judge the accuracy of these baseflow estimates for the portion of the Kankakee River drainage basin in Illinois, the baseflows at Momence were compared to those at Shelby, Indiana, the next gaging station upstream from Momence. Ground-water contributions per square mile were compared for WY 1986 (figure 23). The yearly baseflow average was 0.87 cfs/sq mi for each of the stations. The average dairy difference in baseflow between the two stations was less than 0.005 cfs/sq mi. The close correlation between baseflows suggests that the rate of ground-water recharge does not change significandy in the Kankakee River drainage area between Shelby, Indiana, and Momence, Illinois.

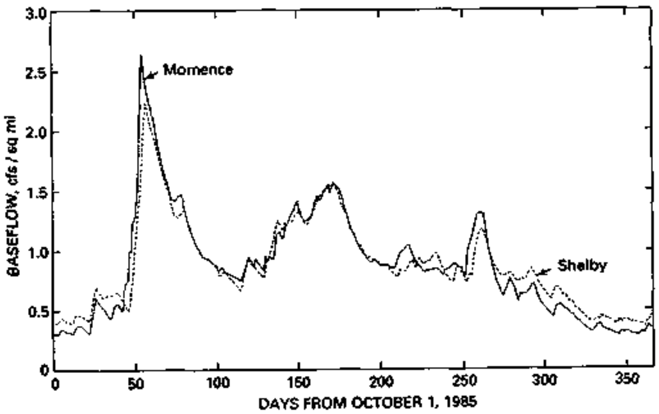


Figure 23. Baseflows for the Kankakee River at Shelby, Indiana, and at Momence, Illinois, WY 1986

Because baseflow into the Kankakee River varies with time, it is useful to plot the cumulative relative frequencies of the baseflow for WY 1985 through 1987 (figure 24). Baseflows calculated for the Kankakee River at Momence were less than 2,000 cfs (0.85 cfs/sq mi) for about 60 percent of the period of record. The frequency at which different rates of baseflow occurred indicates the varying rates at which the sand-and-gravel and Silurian Dolomite aquifers were recharged. Baseflow is derived from ground water, so baseflow increases along with increased recharge to surficial materials and bedrock. The individual cumulative relative frequencies for both the Kankakee and Iroquois Rivers in 1985, 1986, and 1987 are presented in appendix 3.

In contrast to the high baseflow of tie Kankakee River, baseflow into the Iroquois River upstream from the gaging station near Chebanse averaged only 0.36 cfs/sq mi for WY 1985 through 1987. The streamflow hydrograph for the

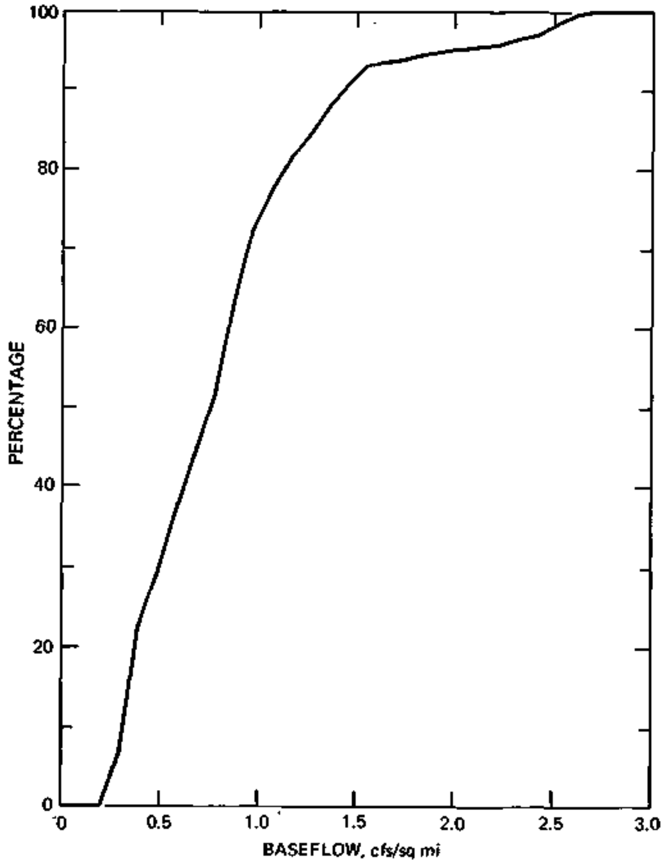


Figure 24. Cumulative relative frequencies of baseflow for the Kankakee River at Momence, WY 1985-1987

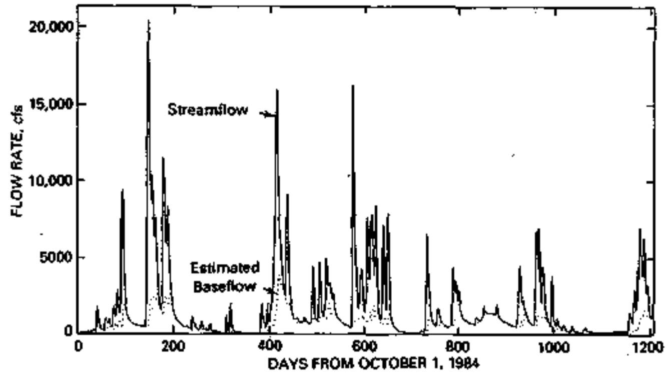


Figure 25. Streamflow and estimated baseflow for the Iroquois River near Chebanse, WY 1985-1987 and early 1988

period, with the baseflow rate superimposed, is shown in figure 25. Comparison of figures 25 and 22 shows that the rate of flow of the Iroquois River varies considerably, ranging from under 50 cfs to more than 20,000 cfs in this three-year period.

The Iroquois River flows through a region that is characterized by fine-grained drift, which causes rapid surface

Table 10. Estimated Baseflow from Hydrograph Separations (cfs/sq mi)

USGS gaging station	*Water year 1985* Mean	*Water year 1985* Median	*Water year 1986* Mean	*Water year 1986* Median	*Water year 1987* Mean	*Water year 1987* Median	*Water years 1985-87* Mean	*Water years 1985-87* Median
Kankakee River at Momence	0.88	0.63	0.87	0.85	0.73	0.74	0.83	0.75
Iroquois River near Chebanse	0.30	0.17	0.44	0.40	0.33	0.31	0.36	0.29

runoff and at the same time limits baseflow contributions to the river. The river responds rapidly to rainfall events, which allows for easier separation of the streamflow hydrograph and more accurate results both at low and high rates of stream discharge. A summary of the mean and median values for baseflow into the Iroquois River is presented in table 10. The cumulative relative frequencies of baseflow for WY 1985 through 1987 are given in figure 26.

Discussion

Average baseflows determined for the Kankakee River in WY 1985, 1986, and 1987 were 0.88,0.87, and 0.73 cfs/sq mi, respectively. Precipitation during these three water years was measured at 40.03, 38.38, and 34.69 inches, respectively, based on measurements at the National Weather Service's Kankakee recording station. Assuming that average annual precipitation is 37.75 inches for the region, WY 1985 through 1987 can all be considered near average in terms of total precipitation. Comparing the baseflow estimates for the Kankakee River to those determined by Walton (1965) for a year of near-average precipitation, the mean baseflows for 1985 through 1987 are greater than Walton's value of 0.55 cfs/sq mi by 33 to 60 percent. If the baseflow estimates are compared to Walton's value of mean baseflow for a year of above-average precipitation, the mean baseflows surpass Walton's value of 0.72 cfs/sq mi by 1 to 22 percent. Since Walton failed to identify the actual amount of precipitation that constituted below-, near-, or above-average precipitation, an absolute comparison between years of similar precipitation could not be made. However, based on the above comparisons and the tendency to overestimate baseflow during periods of large storm runoff using baseflow separation methods, the actual mean yearly baseflows might be as much as 25 percent lower than those estimated.

amount of ground water discharging from both the surficial materials (primarily coarse-grained) and the Silurian Dolomite. However, as shown in figure 18, the Kankakee River may be losing water to the Silurian Dolomite

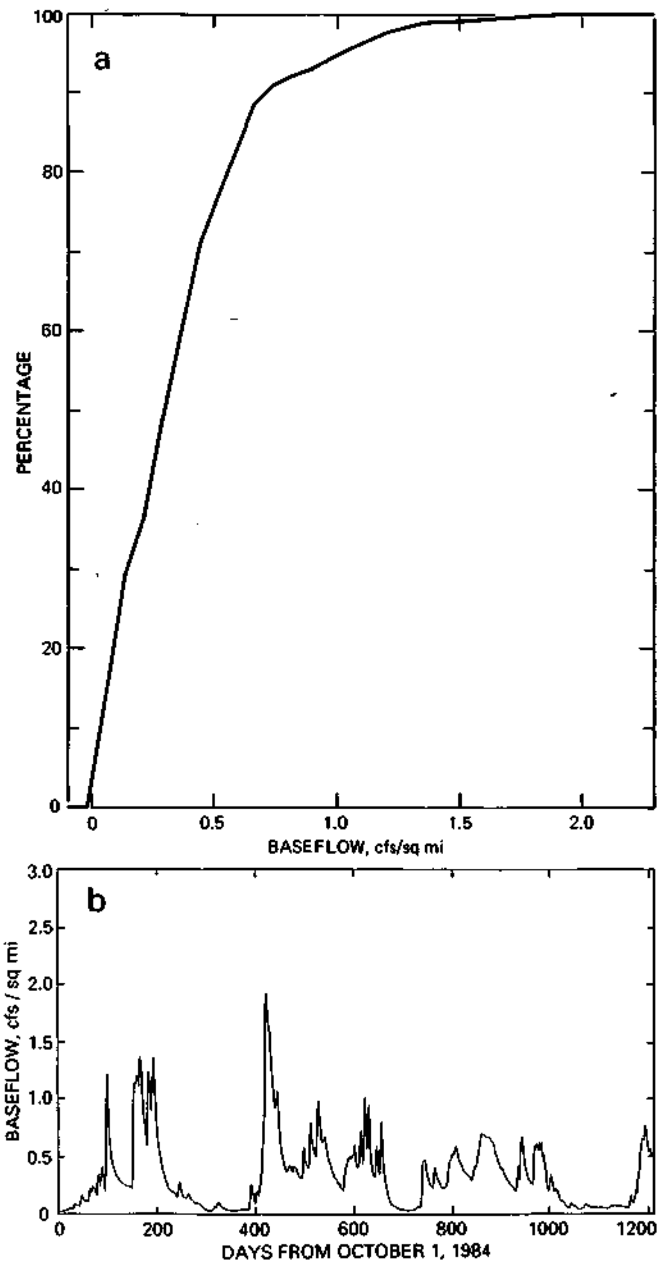


Figure 26. Cumulative relative frequencies (a) and baseflow (b) for the Iroquois River near Chebanse, WY 1985-1987

upstream from Momence during certain periods of the year. Thus, baseflow into the river from surficial materials is occurring over the same stretch of river that is losing water to the Silurian Dolomite. This theory agrees with surface water discharge measurements taken by the U.S. Geological Survey in August 1986. A net loss of streamflow was measured between a point on the Kankakee River four miles east of the state line and the Momence gaging station (Arihood, 1986).

Baseflows determined for the Iroquois River near Chebanse are less than half of those of the Kankakee River. Mean ground-water runoff into the Iroquois River during 1985, 1986, and 1987 ranged from 0.30 to 0.44 cfs/sq mi, well within the values given by Walton (1965) for near-average and above-average levels of precipitation. Surficial deposits of the Iroquois River basin are predominantly fine-grained materials, which restrict ground-water recharge and decrease the basefiow.

Future studies of streamflow and basefiow in the Kankakee and Iroquois County area would be aided by locating stream gaging stations at the Illinois-Indiana state line, on the Kankakee River upstream from Aroma Park, and on the Iroquois River upstream from Aroma Park. These three additional stations would make it possible to monitor both recharge and discharge of the Iroquois and Kankakee Rivers.

6. WATER USE

Ground water used in northern Iroquois and eastern Kankakee Counties is drawn predominantly from the bedrock, although a small percentage of water for rural and domestic use is obtained from unconsolidated materials near the land surface. Of the 2,434 documented water wells within the study area, only 71 wells (less than 3 percent) obtain their water from unconsolidated materials. A more accurate determination of the number of wells being supplied from unconsolidated materials would have to take into account the large number of sandpoint (driven) wells installed throughout the study area, particularly in Pembroke Township.

Ground-Water Use in 1987

Pumpage data were taken from several sources to determine total ground-water use for the study area in 1987. Ground-water use was determined for public, rural-domestic, livestock, industrial, and irrigation purposes. In addition, 1988 pumpage data were compiled for irrigation wells. Because of the small percentage of known wells pumping from unconsolidated deposits, no distinction was made between wells pumping from the bedrock and those pumping from unconsolidated deposits. Water use in 1987 from unconsolidated deposits was estimated at less than 5 percent of the total use in the region.

Ground-water use data show that the Kankakee-Iroquois region received near-average precipitation of 35.15 inches in 1987, including 11.21 inches for June through August. In 1988, a year of record-setting high temperatures and low precipitation, the region received only 5.24 inches of rainfall during the summer months. As of September 1, 1988, the year-to-date precipitation measured at the Kankakee recording station was only 14.37 inches.

Public Supplies

Public water supplies accounted for approximately 15.7 percent of total ground-water use within the study area (table 11) in 1987. All of the public supply wells, except those in the village of Donovan, obtain their water from the bedrock. Based on the pumpage totals derived from the Water Survey's Water Inventory Program (Kirk, 1986), public supply wells in northern Iroquois and eastern Kankakee Counties withdrew an estimated 33.23 and 493.77 million gallons, respectively, from ground-water sources.

Rural-Domestic Supplies

Rural-domestic ground-water use was determined by using 1986 population figures from the Illinois Bureau of the Budget for Kankakee and Iroquois Counties and interpolating township populations from 1980 census data (U.S. Dept. of Commerce, 1982). Assuming ground-water use is 72 gallons per day per capita, total rural-domestic use was estimated at 586 million gallons per year, which is 17.4 percent of the total yearly withdrawals within the study area.

Livestock Supplies

The most recent township data available for Illinois livestock populations were taken in 1976. Those data were interpolated into 1986 Illinois agricultural statistics from

Table 11. Major Ground-Water Uses in Northern Iroquois and Eastern Kankakee Counties, 1978

Use	*Percentage of total use*	*Quantity used (millions of gallons)* Northern Iroquois County	Eastern Kankakee County
Public	15.68	33.23	493.77
Rural-domestic	17.44	65.27	520.68
Livestock	2.09	33.88	36.26
Industrial	1.63	0	54.86
Irrigation	63.15	82.21	2,040
Totals	100	214.59	3,145.57

the Illinois Cooperative Crop Reporting Service. Together they reflect 1986 county livestock summaries. A range of daily water use was estimated at 0.06 gallon per day (gpd) for poultry to 35 gpd for dairy cattle, which amounts to a total annual water use of 70.14 million gallons. This accounts for about 2.1 percent of total ground-water use in the study area in 1987.

Industrial Supplies

With estimated total ground-water use of 1.6 percent, industries are a minor user of the ground-water resources of the predominandy rural study area. Total ground-water withdrawals by industry in eastern Kankakee County are estimated at 54.86 million gallons. There is no industry within the study area in Iroquois County.

Irrigation Supplies

Detailed information and data on the number of irrigation wells, the types of irrigation systems, irrigated crops, and methods of determining water use are provided in the section on Ground-Water Development for Irrigation. Irrigation accounted for an estimated 63.2 percent of total ground-water use in 1987, when an estimated 2,122 million gallons were used to irrigate 10,278 acres. Unlike the industrial, livestock, rural-domestic, and public supplies, irrigation water use is entirely seasonal. Most irrigation water withdrawals occur between early June and late August. Only sod, which is irrigated as early as April and as late as November, accounts for significant ground-water use outside of the three-month irrigation season.

Ground-Water Use in 1988

Ground-water pumpage rose dramatically for most users in 1988. Although 1988 pumpage data were not available for most users, irrigation pumpage was monitored throughout the summer irrigation season. By July 7, 1988, total ground-water withdrawals for irrigation amounted to 2,227 million gallons. Thus, by mid-summer 1988, ground water pumped for irrigation already exceeded the irrigation pumpage for all of 1987 by 105 million gallons. By season's end 1988, total ground-water use for irrigation was estimated at 5,658 million gallons.

Ground-Water Development for Irrigation

Ground water is used extensively for irrigation in portions of eastern Kankakee and northern Iroquois Counties. In this part of Illinois, irrigation has a long history: the first development was reported as early as 1926, and 100 irrigation systems were in place by 1950 (Roberts, 1951).

Irrigation was developed on the sandy soils of the region to protect crops during periods of low precipitation and to maximize crop production. Vegetable, sod, and gladiola crops are particularly susceptible to wilting in periods of low rainfall. Even short periods of high temperatures and wind can cause large production losses on vegetable and gladiola farms unless the crops can be cooled with water. The amount of irrigation pumpage varies considerably from year to year, reflecting precipitation patterns and the number of acres irrigated.

Installation of Irrigation Wells

The rate at which irrigation has developed in the study area can be traced by looking at the drillers' logs for each year's construction of new irrigation wells (figure 27). From 1937 through 1987 documented construction dates are recorded for 153 irrigation wells. No documented construction dates are available for an additional 84 irrigation wells. The largest increases in new installations occurred in the mid-1940s, the mid-1960s, and in the period 1984 to 1987. The largest single period of irrigation well construction occurred between 1963 and 1968, when 62 irrigation wells were installed in six years. New well construction in 1988 and 1989 probably exceeded the rate of construction of the mid-1980s, but field data are not available.

Historically, irrigation predominandy served the thriving gladiola farms in Kankakee County, which centered about the city of Momence. Through the 1960s most of the irrigation wells installed in Kankakee and northern Iroquois Counties served gladiola, vegetable, and sod farms. More recendy, irrigation water has been used widely for field corn production, which accounts for many of the irrigation wells constructed in the 1980s.

Well Construction Features

Wells constructed within the dolomite aquifer in the study area range in depth from 14 to 700 feet. Based on logs

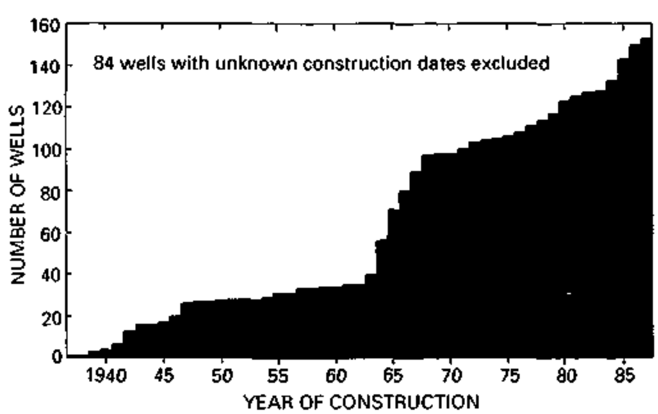


Figure 27. Irrigation wells constructed in northern Iroquois and eastern Kankakee Counties, 1937-1987

for 2,667 wells penetrating into the bedrock, the average depth is 121 feet. Other than about 300 irrigation, municipal, and industrial wells, most of these wells fulfill domestic and livestock uses.

The casing passes first through unconsolidated deposits to the bedrock. Casing depths range from several feet, where the bedrock is near the land surface, to a maximum depth of 231 feet. Where large thicknesses of dune sand, till, and outwash deposits are present, casings must be installed to greater depths in order to reach the bedrock aquifer. Average casing depth for the study area is 51 feet. Well-bore diameters range from 1 to 24 inches; most domestic wells range from 4 to 6 inches in diameter, while irrigation wells are generally 8 inches or more.

Wells constructed in the dolomite aquifer for domestic or livestock use must generally yield 5 to 10 gallons per minute (gpm). Discharge rates of irrigation wells operated in 1987 ranged from 80 to 1,975 gpm, and the average well pumped at a rate of 658 gpm. Most irrigation wells require large diameters and penetrate deep into the bedrock, whereas domestic wells make only shallow penetrations into the bedrock. The mean thickness of the dolomite penetrated by domestic and livestock wells is 50 feet, based on 2,082 well records. The mean thickness of the dolomite penetrated by 111 documented irrigation wells is 223 feet, ranging from a minimum penetration of 12 feet to 685 feet.

Irrigation Well Locations

Although more than 200 irrigation wells have been drilled into the Silurian Dolomite of eastern Kankakee and northern Iroquois Counties, many wells have been abandoned, sealed, or converted to observation wells. In 1987 a total of 96 irrigation wells provided water to approximately 130 irrigated plots of varying size (figure 28). During the 1988 drought, 133 irrigation wells were used to irrigate 165 plots (figure 29).

Irrigation wells are scattered throughout eastern Kankakee County and the northeast corner of Iroquois County, but the highest concentration of wells is found north of St. Anne. This area consists primarily of smaller irrigated plots of vegetables, gladioli, and melons, although other irrigated crops are also present.

To the east of St. Anne, toward Leesville, irrigated plots become larger, and center-pivot and subsurface irrigation systems predominate. Subsurface systems are used for irrigating corn, and center pivots are used primarily for irrigating corn and potatoes. Southeast of Momence, sod

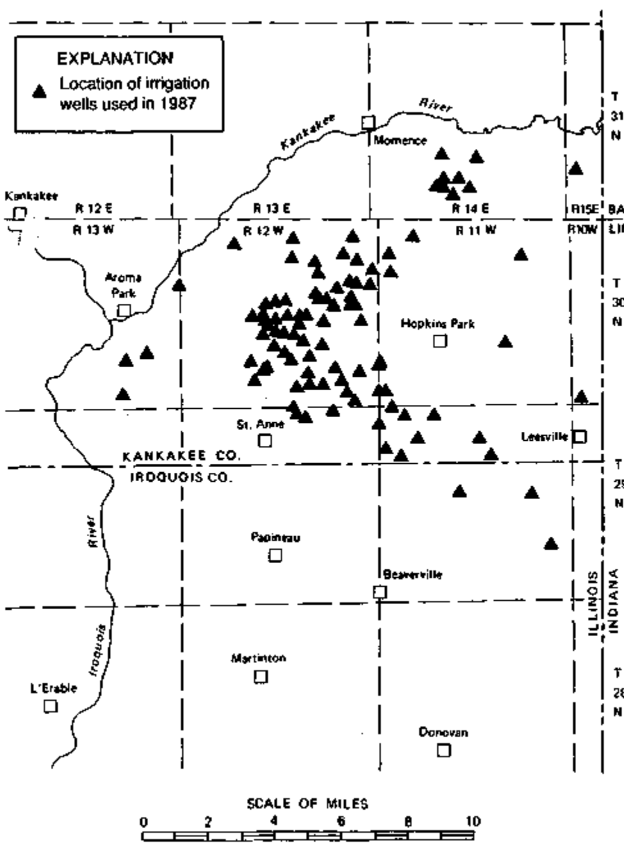


Figure 28. Irrigation wells active during the 1987 irrigation season

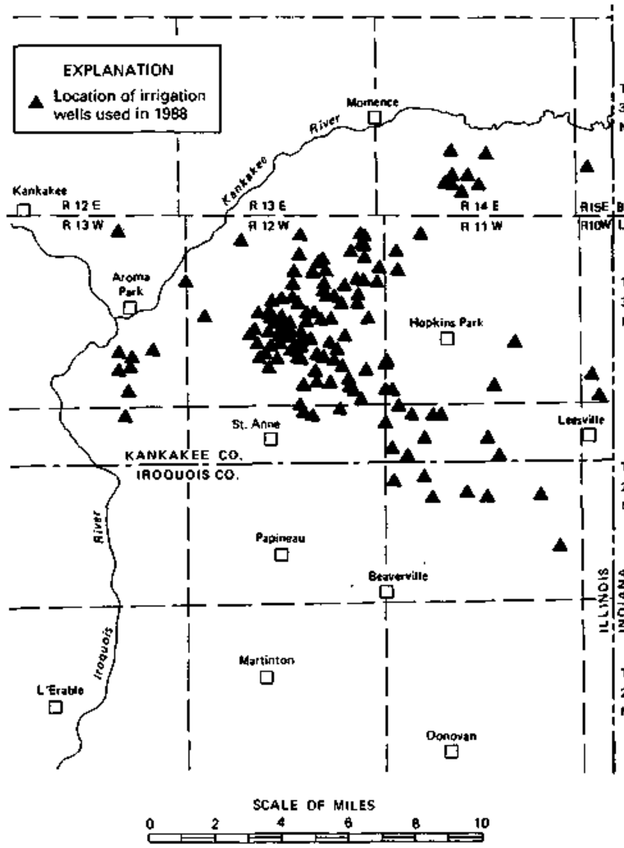


Figure 29. Irrigation wells active during the 1988 irrigation season

and corn are the primary crops. Sod requires more water than all other crops grown in the region.

Irrigated Acreage and Crop Types

The amount of cropland irrigated with ground water was estimated at 10,278 acres for 1987 and at 12,143 acres for 1988. These totals were determined by using August 1986 aerial photographs (1:25,000 scale) provided by the Illinois Department of Transportation; records from the U.S. Department of Agriculture's Agricultural Stabilization and Conservation Service; field sitings; and interviews with fanners in the study area.

Irrigated plot sizes range from just a few acres for small gladiola or vegetable plots to 640 acres for field corn with center-pivot irrigation. Average plot size served by one irrigation well is approximately 79 acres, based on a 1987 survey of all 130 irrigated plots in the study area. In 1988 average irrigated plot size decreased slightly to 74 acres.

Both crop type and irrigation method must be determined for an accurate estimate of the ground water used for irrigation. Because of the large variety of irrigated crops grown in Kankakee and northern Iroquois Counties, crops were divided into seven groups to help estimate irrigation water use. The seven major irrigated groups are gladioli (and other flowers), field corn, melons, nursery crops, potatoes, sod, and vegetables. The vegetables grown include squash, peppers, onions, tomatoes, cabbage, green beans, peas, sweet corn, okra, chives, and more.

Of the 10,278 acres in the study area that were irrigated with ground water and monitored in 1987, field corn was grown on 5,918 acres, which is equal to 57.6 percent (tables 12 and 13). The next largest tracts of land irrigated by ground water were planted in vegetables and sod, which accounted for an estimated 1,163 and 1,006 acres, respectively. No other tracts planted in a single crop exceeded 1,000 acres.

During the drought of 1988 the total area irrigated with ground water expanded to 12,143 acres. Irrigated acreage of corn expanded by 25 percent over 1987. Approximately 7,451 acres of corn were irrigated in 1988, which amounts to 61.4 percent of all land irrigated with ground water. Melon and vegetable acreage expanded by more than 20 percent from 1987, while potato and gladiola acreage declined by 20 and 36 percent, respectively.

Irrigation Systems

Of all the irrigation regions in Illinois, the Kankakee and Iroquois County areas use the largest variety of application methods. This diversity of irrigation methods reflects the various crop types and their differing water requirements. Five major types of irrigation systems are used in the study area: center-pivot, subsurface, periodic lateral-move, solid-set, and traveling gun. Because they apply similar rates of water and because they are used for similar crop types, the periodic lateral-move and solid-set methods were grouped together for crop water-use determinations. Table 13 lists each crop type and the number of acres according to the method of irrigation employed in 1987 and 1988.

Center-pivot irrigation systems consist of a single sprinkler lateral; one end is anchored to a fixed pivot structure, and the other end applies the water while moving continuously around the pivot (Addink et al., 1980). The lateral pipes in the study area ranged from 660 to 2,640 feet in length. Of the 130 plots irrigated with ground water in the study area in 1987, center-pivot systems were used on

Table 12. Inches of Irrigation Water Applied to Various Crops and Acreages, 1987 and 1988

Crop	*Average inches of water*		*Percentages of total acres irrigated*		*Percentages of total ground water used*	
	1987	*1988*	*1987*	*1988*	*1987*	*1988*
Gladioli	12.1	33.4	6.03	4.07	9.58	7.87
Field corn	3.3	12.4	57.58	61.36	24.80	44.00
Melons	0.5	4.4	4.95	5.02	0.30	1.29
Nursery crops	9.2	11.0	2.34	4.81	2.82	3.06
Potatoes	3.4	15.3	8.00	4.34	3.56	3.85
Sod	39.5	47.7	9.79	8.77	50.81	24.25
Vegetables	5.5	23.3	11.32	11.63	8.14	15.68

Table 13. Acres Irrigated with Ground Water, 1987 and 1988

Irrigation Method	*Gladioli*	*Corn*	*Melons*	*Vegetables*	*Potatoes*	*Nursery*	*Sod*	*Total acres*
1987								
Center-pivot	-	3,302	-	-	629	30	-	3,961
Solid-set and lateral-move	620	-	244	670	193	110	1,006	2,898
Traveling gun	-	378	210	493	-	100	-	1,181
Ditch	-	2,238	-	-	-	-	-	2,238
Total	620	5,918	504	1,163	822	240	1,006	10,278
1988								
Center-pivot	-	3,682	40	-	307	30	-	4,059
Solid-set and lateral-move	494	270	436	1,010	180	114	1,065	3,569
Traveling gun	-	885	134	402	40	400	-	1,861
Ditch	-	2,614	-	-	-	40	-	2,654
Total	494	7,451	610	1,412	527	584	1,065	12,143

29 plots, for a total coverage of 3,961 acres, or 38.5 percent of the total acreage irrigated with ground water. In 1988, 30 plots amounting to 4,059 acres were irrigated with center pivots, and the predominant crop type was field corn. Seven of the 29 plots irrigated with ground water through a center-pivot system in 1987 were planted in potatoes, but in 1988 only 3 of 30 such plots were planted in potatoes. Another center-pivot system dispersing ground water was used to irrigate nursery crops in both 1987 and 1988, and one more was used on a melon plot in 1988 only.

Subsurface irrigation is the least familiar system to most persons. This method of irrigation usually operates by pumping water into ditches bounding a field. By maintaining the water level in the ditches, the water-table elevation under the enclosed field can be raised and maintained at a desired level. Subsurface irrigation makes water available to the root zone of the crop being grown, usually field corn. The water table for subsurface irrigation systems should be about 2 feet below the land surface for maximum value to the crop. Subsurface irrigation was used on approximately 2,238 acres of field corn in 1987, which is 21.8 percent of the total acreage monitored that was irrigated with ground water. Subsurface irrigation use expanded to 2,654 acres in 1988. Forty of those acres were planted in nursery crops, and the remainder were corn.

Periodic lateral-move and solid-set irrigation systems consist of above-ground, portable aluminum pipe systems with regularly spaced sprinkler heads. These systems are ideal for irrigating vegetables, gladioli, sod, and other crops of low height. In 1988 these systems were used for almost every crop type, including corn. Because of their similar rates of water usage and application, these two systems have been grouped together for purposes of predicting water use. The periodic lateral-move and solid-set systems were used on an estimated 68 plots (2,898 acres) in 1987 and on 87 plots (3,569 acres) in 1988. All seven of the major crops grown in the study area were irrigated with one of these two systems.

Solid-set systems are left in place in the fields during the irrigation season. They are typically laid out with laterals parallel to the crop row and the main water line perpendicular to the row. Gladioli, potatoes, and vegetables are the major crops irrigated with this system. In 1988, however, solid-set systems were used to irrigate every type of crop, including corn during its early growth stages.

In periodic lateral-move systems, the sprinkler laterals are moved between applications, although they remain stationary while irrigating. These systems work well for large irrigated fields, because they cost less than covering entire fields with solid-set systems. The periodic lateral-move systems also allow for more thorough overlap of irrigation water than solid-set systems (Addink et al., 1980). The most common lateral-move system in the Kankakee-Iroquois area is the side roll, a wheel-move system in which wheels are mounted on a lateral pipe that serves as the axle. Sprinkler laterals may be up to one-fourth mile in length. Sod farms are the most common users of side-roll systems.

Also used in Kankakee and Iroquois Counties is the traveling gun system, a high-capacity sprinkler mounted on a chassis and connected to a flexible hose up to 1,320 feet long. The chassis is connected to a rotating cable reel and pulled along travel lanes. Water is supplied to the sprinkler gun by a flexible hose, which is reeled in with the traveling chassis (Addink et al., 1980). This type of system can adapt to a variety of field shapes and topography and can apply large amounts of irrigation water in a relatively short time.

In 1987 traveling guns were used on an estimated 25 of the 130 plots irrigated with ground water, which amounts to approximately 1,181 acres. In 1988, 30 plots totaling 1,861 acres were irrigated with traveling guns. The major crop types irrigated with this system are field corn, melons, and vegetables, as well as some nursery crops and potatoes.

Irrigation Ground-Water Use Determinations

Estimates of ground water used for crop irrigation in the study area were developed through a variety of qualitative and quantitative techniques. Standard methods for estimating ground-water pumpage for irrigation include measuring power consumption, crop-consumptive use, and instantaneous discharge. Detailed accounts of each of the above methods and some variations are found in Frenzel (1984,1985). The diversity of crop types and irrigation systems made it necessary to use more than one method to estimate ground-water use. In addition, the large number of irrigated plots and the variety of power sources limited the value of power-consumption and crop-consumptive use estimates.

Five methods were employed to develop ground-water use estimates: 1) measurement of pumpage periods using hour meters and 2) measurement of the instantaneous discharge at the irrigation well; the less quantitative methods included 3) interviews with irrigators, 4) extrapolation from known data, and 5) need-based estimates from raingage data and interviews.

Hour Meters

The study found that the most reliable method for estimating irrigation ground-water use was to monitor hour meters that record the operating time of an irrigation system. Discharge rate of the irrigation well was determined directly using a nonintrusive ultrasonic flowmeter. The product of total pumping time and discharge rate provides total ground-water pumpage for the irrigation well

In 1987, this method was used for 18 sites planted in either field corn or potatoes: 11 were irrigated with center-pivot systems, while wells at 7 sites discharged to subsurface irrigation systems. The known water-use data for these crop types and the number of acres irrigated were then extrapolated to irrigated fields for which direct measurements could not be collected.

Center-pivot systems are usually equipped with their own hour meters in the form of clocks built into the control boxes. They record the total time that the pivot is moving. Errors can occur if the pivot is being moved to a new position when water is not being pumped to the system. No compensation was made for such errors in the total hours, but they would contribute only a small percentage of error to final water-use determinations. Several irrigation wells that pumped water to subsurface irrigation systems also used hour meters. These meters record the working time of the pumping well itself, eliminating the error inherent in meters that monitor travel time as well as pumping time.

Ultrasonic flowmeters, also called acoustic flowmeters, measure the velocity of liquid flow through a pipe of known diameter. In a properly calibrated and correctly operated flowmeter, the maximum error is within about 5 percent. In most cases in the current study, flowmeter discharge measurements were within a reasonable range of the discharges estimated by owners and drillers' logs.

In addition to the existing hour meters used in 1987, four new hour meters were installed by the Illinois State Water Survey on plots being irrigated with solid-set irrigation systems. Two of them were installed on systems pumping water for sod, one on a system for vegetables and melons, and one on a system irrigating gladioli.

Owner-Estimated Hours

A second method of determining total ground-water use by an irrigation system relied on direct ultrasonic flowmeter readings of the irrigation well discharge, along with the hours of operation as supplied by the owner. When hour meters were not available, owners were asked to provide the total number of hours irrigated during the growing season. Although subject to greater error than direct hour meter readings, irrigator-supplied operating times are preferable to need-based estimates for specific crop types.

Owner-Estimated Application

The third method for determining water use required the irrigator to determine the number of inches of water in each irrigation application and the total number of applications for the irrigation season. The total inches were then calculated into total water use for the number of acres irrigated. Although large errors can occur when water use is estimated from irrigator-supplied information, this method is often the only one available for some irrigated plots. Traveling gun irrigation systems are especially difficult to monitor for water use.

Of the 130 plots irrigated with ground water in 1987, water-use estimates for 11 plots depended entirely on owner-supplied information. In 1988, water-use estimates at only 9 of 165 plots were wholly dependent on owners' estimates.

Data Extrapolation

This method involves extrapolating water-use data taken from irrigated plots with direct measurements to irrigated plots with no directly measured quantitative data. Extrapolation was required for 14 locations in 1987 and 19 locations in 1988. These plots were irrigated primarily with center-pivot and subsurface irrigation systems, and data could not be collected directly from the irrigation well or the irrigation system. In such cases, data were collected by measuring pumpage rates and operation times. These measurements were then used to determine quantities of water applied to unmonitored plots.

Crop-Consumptive Use

The final and most frequently used means of determining water use was to make an estimate based on the water requirements of the specific crop being irrigated. This need-based water estimate was used predominantly with plots irrigated by periodic lateral-move and solid-set systems. Water requirements of the various crop types, chiefly vegetables, potatoes, gladioli, melons, and sod, were determined from raingages placed both adjacent to and in the irrigated fields. Irrigators were interviewed on their methods of applying water to different crop types, and this information as well was used to formulate standards for the rate and frequency of irrigation. Irrigation pumpage was observed by field personnel as a third means of checking the information derived from raingages and irrigators.

Raingage data, interviews, and field observation are all necessary to estimate the quantity of irrigation water used on the basis of crop requirements. Weighing-bucket and Trucheck® raingages were used to collect data in 1987 and 1988. Thirty-one Trucheck® raingages were located in irrigated plots within the study area to measure irrigation water applications. Using the raingage data, total water use per week was established for each crop type monitored. The total number of irrigation weeks was determined by interviewing the irrigator of each plot and by conducting field observations throughout the growing season. The total seasonal water use for each crop type was then computed.

The weekly water use for each crop type was derived from the Trucheck® raingages and from interviews. The total inches of irrigation water applied weekly during the irrigation season were then calculated by subtracting each week's natural precipitation from the total inches of irrigation water and precipitation that each monitored field received weekly. Rainfall data were collected by using weighing-bucket raingages to monitor the quantity and duration of each rainfall event. Three weighing-bucket raingages were used in 1987 and eleven in 1988. Distribution of the raingages is shown in figure 30. Rainfall distribution may be highly variable over the region, particularly during summer thunderstorm activity, so average rainfall was calculated for the region from the weighing-bucket raingage charts.

Interviews with irrigators provided much insight into the methods by which different crops, especially vegetables and sod, are irrigated. Each crop has specific water needs, often at specific stages of development, and these are often ignored in estimating crop-consumptive use. To keep them

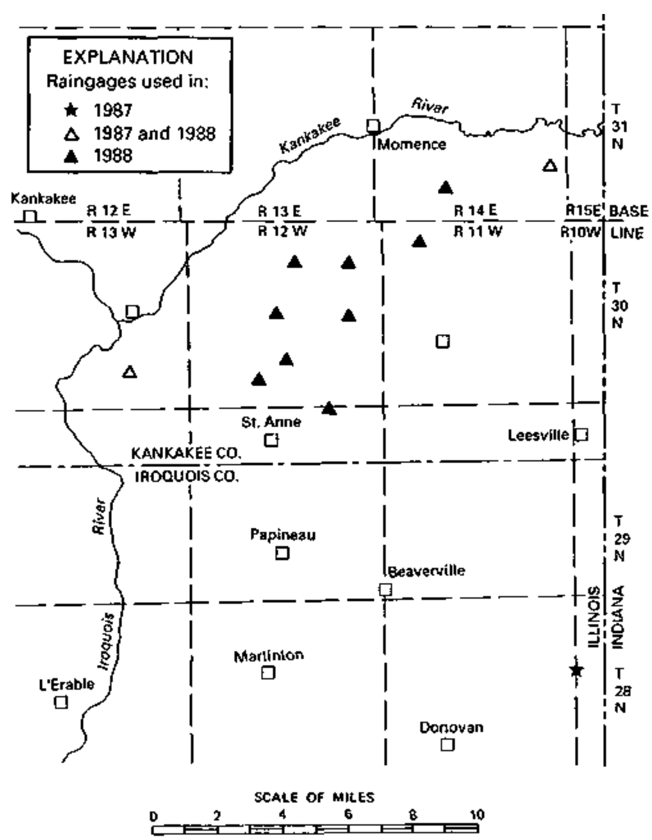


Figure 30. Weighing-bucket raingages, 1987 and 1988

cool, gladioli are irrigated even when the soil is wet. A hot, dry, windy day can devastate a gladiola crop, even if it has a fully wetted root zone. Sweet corn is also a special case: unlike most other crops, it is often double-cropped with another vegetable, allowing for a second planting during the growing season. Without field interviews and observation, crop-consumptive use models would fail to consider the irrigation methods used on some crop types.

Ground-Water Use

Most crop-consumptive use methods are intended to determine the optimal amount of water needed by specific crops with an eye to conserving water as well. Even for specialty crops such as vegetables or gladioli, few irrigators follow specific formulas. Actual water needs of specific crops are more correctly termed "assumed water needs," since they are based on the individual's method of irrigation. The seven crop groupings in the study area each have distinct water needs. Total ground water used for crops in 1987 was determined to be 2.1 billion gallons. In 1988 this number increased to 5.7 billion gallons. It should be noted, though, that in 1988 final determinations were made by mid-September, before all irrigation had ceased for the season. Ground-water use according to crop type and method of irrigation is presented in table 14.

Throughout the study, no correlation was found between the concentration of irrigation wells and ground-water pumpage. Five irrigation wells in one location might pump less water than one well in another location. The percentage of ground water applied to each category of crops in 1987 and 1988 was presented in table 12. As a percentage of the total ground water pumped for irriga-

Table 14. Ground-Water Use for Irrigation
(millions of gallons)

Irrigation method	*Gladioli*	*Corn*	*Melons*	*Vegetables*	*Potatoes*	*Nursery*	*Sod*	*Total pumpage*
1987								
Center-pivot	-	324.3	-	-	52.6	-	-	376.9
Solid-set and lateral-move	203.7	-	2.2	98.2	23.0	57.2	1,080.0	1,464.3
Traveling gun	-	20.2	4.1	74.9	-	2.7	-	101.9
Ditch	-	182.6	-	-	-	-	-	182.6
Total	203.7	527.1	6.3	173.1	75.6	59.9	1,080.0	2,125.7
1988 (through 7/7)								
Center-pivot	-	495.7	2.4	-	96.3	39.0	-	633.4
Solid-set and lateral-move	191.6	27.8	26.2	305.0	38.5	58.3	831.4	1,478.8
Traveling gun	-	103.8	8.1	116.9	8.6	33.7	-	271.1
Ditch	-	477.4	-	-	-	-	-	477.4
Total	191.6	1,104.7	36.7	421.9	143.4	131.0	831.4	2,860.7
1988 (through 9/16)								
Center-pivot	-	1,275.9	4.8	-	128.4	50.2	-	1,459.3
Solid-set and lateral-move	447.6	38.6	152.5	644.5	74.1	86.3	1,379.3	2,722.9
Traveling gun	-	140.9	16.1	247.4	16.5	33.7	-	454.6
Ditch	-	1,046.7	-	-	-	3.6	-	1,050.3
Total	447.6	2,502.1	73.4	891.9	219.0	173.8	1,379.3	5,687.1

tion, corn and sod are the largest users, followed by vegetables and gladioli. As a consequence of the drought, corn irrigation increased from about 25 percent of total ground-water pumpage in 1987 to 44 percent of total pumpage in 1988. Ground-water use on vegetables also rose, increasing from 8 percent of total pumpage in 1987 to almost 16 percent in 1988. Conversely, sod consumed an estimated 51 percent of the ground-water used for irrigation in 1987, and in 1988 it used only 24 percent. This figure does not reflect a decrease in water use by sod growers in 1988, but rather a substantial increase in irrigation water use for other crops.

The acres irrigated and the amount of ground water applied to each crop are discussed below. Table 15 shows the inches of ground water applied to each crop according to the method of irrigation used in 1987 and 1988. A comparison of the average number of inches of ground water applied to each type of crop for 1987 and 1988 is shown in table 12.

Gladioli

Gladioli and other flower varieties accounted for approximately 620 and 494 of the total acres irrigated with ground water in the study area in 1987 and 1988, respectively. Irrigation water use was estimated using raingages, interviews with irrigators, and hour meters. In 1987 approximately 12.1 inches of ground water were applied to gladioli. The hot, dry conditions of 1988 required irrigators to apply an average of 33.4 inches of water, and applications occurred almost every other day during some periods.

Field Corn

Irrigated acreage of corn increased from 5,918 to 7,451 acres from 1987 to 1988. Water use for corn was estimated primarily by using hour meters. Where hour meters were unavailable, the hours were either obtained from the irrigator or they were interpolated. Ground-water pumpage for corn irrigation increased from an average of 3.3 inches in 1987 to 12.4 inches in 1988.

Melons

Most farmers do not normally irrigate melons such as pumpkins, squash, watermelons, and other specialty varieties unless extremely dry conditions prevail. Some farmers irrigate melons at the start of the season, but most melons growers use no irrigation systems whatsoever. Based on information provided by field observation and interview, an average of 0.5 inch of water was applied to 509 acres of melons in 1987. In 1988, 4.4 inches of water were applied to 610 acres of melons.

Nursery Crops

A large variety of small plants, shrubs, and trees are grown in nurseries, and irrigation varies according to specific crops. Estimates of irrigation water use for nursery crops were based entirely on assessments by the irrigators. Approximately 9.2 inches of ground water were applied to 240 acres of nursery crops in 1987. In 1988 irrigated nursery acreage expanded to 584 acres, and irrigation rose to an estimated 11.0 inches of water.

Table 15. Ground-Water Use for Irrigation (inches)

	Center-pivot		Solid-set & lateral-move		Traveling gun		Ditch		Average	
Crop	*1987*	*1988*	*1987*	*1988*	*1987*	*1988*	*1987*	*1988*	*1987*	*1988*
Gladioli	-	-	12.1	33.4	-	-	-	-	12.1	33.4
Corn	3.6	12.8	-	5.3	2.0	5.9	3.0	14.7	3.3	12.4
Melons	-	4.4	0.3	4.4	0.7	4.4	-	-	0.5	4.4
Vegetables	-	-	5.4	23.5	5.6	22.7	-	-	5.5	23.3
Potatoes	3.1	15.4	4.4	15.2	-	15.2	-	-	3.4	15.3
Nursery	-	61.6	19.1	27.9	1.0	3.1	-	3.3	9.2	11.0
Sod	-	-	39.5	47.7	-	-	-	-	39.5	47.7
All crops	6.7	94.2	80.8	157.4	9.3	51.3	3.0	18	7.6	17.3

Potatoes

Irrigation use on potatoes was determined using raingages and hour meters. Their water need is greatest during the flowering stage, but overall potatoes use less water than most crops. Irrigation water use for potatoes was determined to be approximately 3.4 inches on 822 acres for the entire 1987 growing season. Total ground water used for the 527 acres of potatoes grown in the study area in 1988 was 15.3 inches.

Sod

Water use for sod was determined from interviews, observation, raingage data, and hour meters. Irrigation was observed as early as April 15 and as late as November 1 during 1987, for an irrigation period of 200 days. Based on interviews with sod farmers, the crop requires 1.0 to 1.5 inches of water per week. The limited raingage data collected indicated applications of 1.5 to 2.0 inches of irrigation water per week, so a value of 1.5 inches was assumed to be the average water need per week in 1987. A total of approximately 39.5 inches of ground water was applied to 1,006 acres of sod grown in 1987. Through September 15, 1988, about 47.7 inches of ground water was pumped for 1,065 acres of sod.

Vegetables

Based on raingage data, interviews, and hour meters, an average of 5.5 inches of ground water was used to irrigate 1,163 acres of assorted types of vegetables in 1987. The number of irrigated acres increased to 1,412 in 1988, and each received an average of 23.3 inches of water.

7. EFFECTS OF GROUND-WATER DEVELOPMENT

Potentiometric Surface Maps

Water levels in the carbonate bedrock were measured in the spring and summer of 1987 and 1988. A set of 226 private, industrial, and public wells throughout the study area were used for the water-level measurements (figure 31). During the same period, each wellhead was surveyed from benchmark locations to determine water elevations over mean sea level Potentiometric surface maps were developed by contouring the water-level elevations with a personal computer-based contouring package. The potentiometric surface represents the static head in an aquifer, that is, the levels to which water will rise in tightly cased wells. Surface water levels along the Kankakee and Iroquois Rivers were not included as data points for the contouring. Future mass water-level measurements should incorporate surface water levels along river stretches hydrologically connected to the dolomite aquifer.

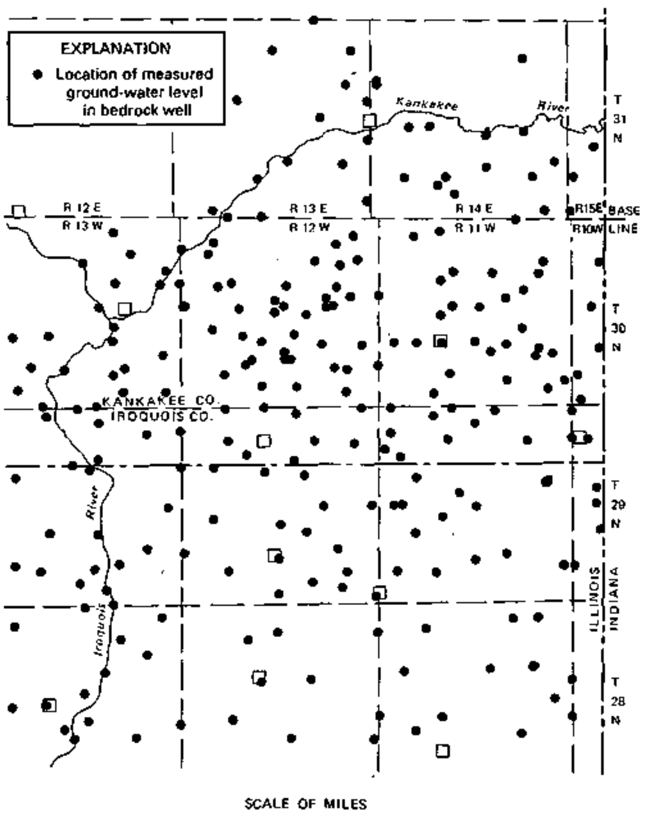


Figure 31. Silurian and Devonian Dolomite wells used during mass measurements, 1987 and 1988

Spring 1987Potentiometric Surface Map

The potentiometric surface map created from 226 water-level measurements taken May 25-28, 1987, shows water levels within a few feet of the maximum within the carbonate aquifer in 1987 (figure 16). Water levels in both the unconsolidated deposits and the underlying carbonate bedrock normally reach their yearly peaks in late April to early June, after being recharged throughout most of the late fall, winter, and spring. At locations northwest of Hopkins Park and four miles north of Leesville, adjacent to the state line, the carbonate aquifer had achieved maximum water levels.

The rise in the potentiometric surface northwest of Hopkins Park occurred because: 1) the land surface rises in this area, creating the potential for higher ground-water levels within the unconsolidated deposits; 2) the bedrock surface rises at this location; and 3) the bedrock is mantled by 25 to 75 feet of sand with no intervening clay layer, so that ground water can recharge the bedrock aquifer directly from the sand. The potentiometric high remains at this location year-round, even during periods of high ground-water pumpage from the dolomite.

High ground-water levels in the bedrock four miles north of Leesville are also related to a rise in the land surface and bedrock elevations as well as thick sand deposits, which are in excess of 75 feet. However, between the bedrock and the sand is more then 20 feet of clay, which limits the leakage of ground water down to the Silurian Dolomite aquifer. During periods of high ground-water discharge during summer months, the ground-water peak declines at this location and tends to migrate northward toward the Kankakee River.

A third and final regional high in the potentiometric surface occurs northwest of Momence. The potentiometric surface of the Silurian Dolomite in this area is constant throughout the year. The elevations of both the land surface and the Silurian Dolomite rise northwest of Momence, accounting for the commensurate rise in water levels.

Potentiometric gradient changes across the study area indicate large variations in permeability within the carbonate aquifer. Along the Kankakee River east of Aroma Park, the potentiometric gradient is very steep — approaching 20 feet per mile — as indicated by the closely spaced contour lines in figure 16. This steep incline might be related to a bedrock valley southeast of Aroma Park, where the bedrock elevation drops from 600 feet above mean sea level to 525 feet in less than one-half mile. Public water supply pumpage for the village of Aroma Park and changing permeability fields may also explain the steep potentiometric gradient in the area.

The lowest potentiometric gradients are found in the southern part of the study area. In the vicinity of Beaverville, gradients approach 1 foot per mile as water flows toward the Iroquois River to the southwest. To the north, gradients between Hopkins Park and the Kankakee River generally range from 3 to 10 feet per mile as water flows north from the two potentiometric surface highs toward the Kankakee River.

Southwest of Momence the potentiometric contour lines deflect upstream on the Kankakee River. This deflection indicates ground-water flow into the Kankakee River and/or to the Momence pumping center. A slight contour deflection is also noted upstream on the Iroquois River south of Aroma Park. Although surface water interacts with the carbonate bedrock elsewhere along the Kankakee and Iroquois Rivers, the scale of the potentiometric surface mapping is insufficient to detail all areas of stream loss and stream gain from the bedrock. Ground-water interactions between the bedrock and the Kankakee and Iroquois Rivers are discussed in detail in section 5.

Summer 1987 Potentiometric Surface Map

The potentiometric surface map was created from 219 water levels measured August 17-19, 1987. Its most salient feature is a regional cone of depression centered south of Leesville (figure 32). This regional depression in the potentiometric surface extends north of Hopkins Park, west toward St. Anne, and south toward Beaverville. Groundwater flow around Beaverville has reversed direction from the southwesterly flow seen in May to northeasterly in August. The steep potentiometric gradients near Aroma Park are still present, as are subdued forms of most other potentiometric surface features outside of the Leesville-Hopkins Park-Beaverville region.

Gradients that were 1 to 2 feet per mile in the spring increased by August to become the regional cone of depression with gradients as high as 15 feet per mile. The large increase can be attributed to the volume of ground water being pumped from the Silurian Dolomite by irrigation wells. Increased discharge from the bedrock aquifer causes the potentiometric gradient to steepen and increase recharge to the aquifer.

East of Momence and south of the Kankakee River, in the area of the 620-foot elevation contour, the gradient of the potentiometric surface of the Silurian Dolomite was more level in August than it was in spring. The Kankakee River and the dolomite are hydraulically connected along this stretch, and the low gradient suggests that the river may control water levels in the local dolomite. Another factor affecting water levels in this area is, of course, irrigation.

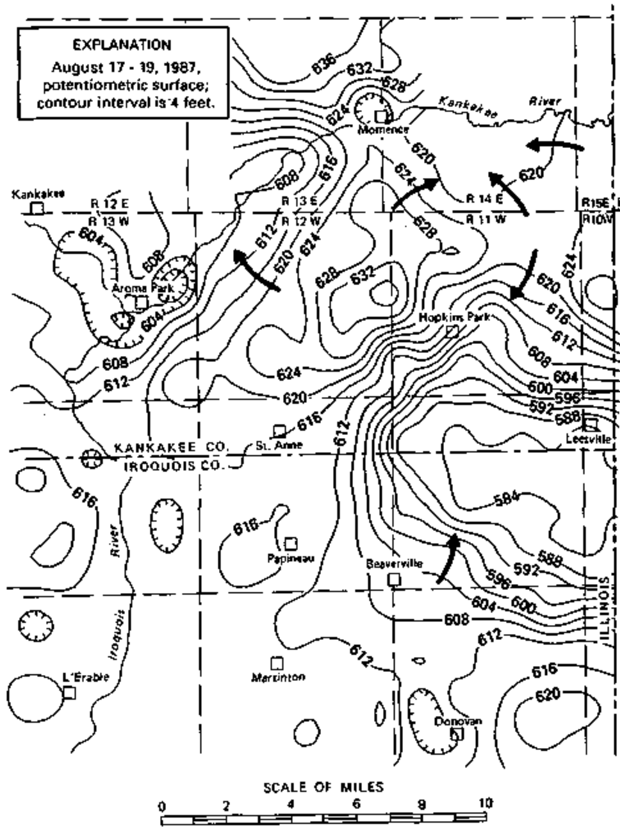


Figure 32. Potentiometric surface of the dolomite aquifer, August 17-19, 1987

Figure 33 is a difference map showing the change in the potentiometric surface within the carbonate aquifer between May 28 and August 19, 1987. Although water levels declined more than 44 feet south of Leesville, the potentiometric surface was above the top of the Silurian Dolomite. Large water-level declines in this corner of southeastern Kankakee County and northeastern Iroquois County are the result of several factors. The carbonate aquifer in the Beaverville-Leesville area is overlain by thick confining layers of semipermeable to impermeable clays and tills that limit the ability of water to move downward and recharge the bedrock aquifer. In addition, artesian storage coefficients on the order of 0.0001 were determined for the Silurian Dolomite aquifer, and these cause large drawdowns with high rates of discharge. Under artesian conditions, water that is removed from storage can affect much larger volumes of the aquifer than water kept under water-table conditions. As a result, the drawdown and lateral extension of the cone of depression is significantly greater under confined than unconfined conditions.

In the heavily irrigated areas of Township 30N., range 12W. (north of St. Anne), and Township 31N., range 14E. (southeast of Momence), water levels declined from 4 to 8 feet. Larger water-level declines were not observed be-

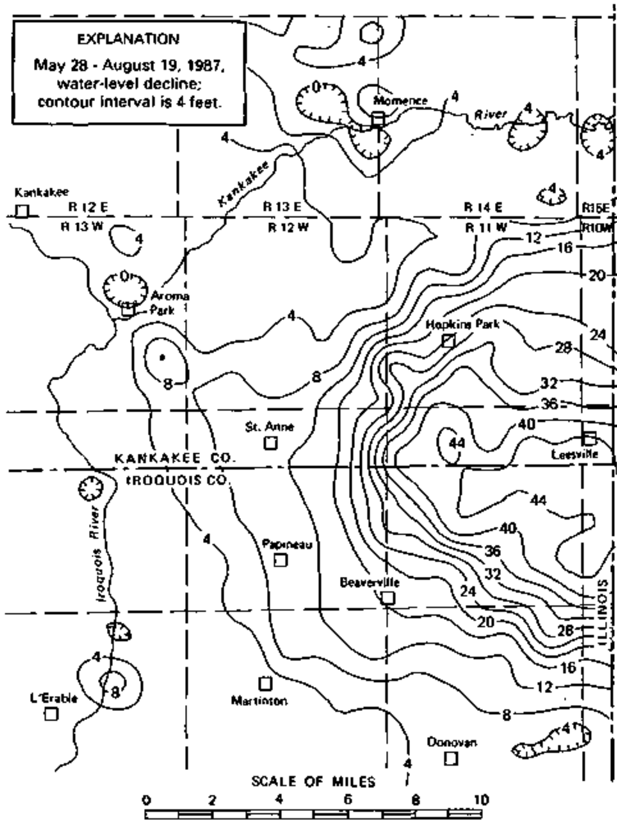


Figure 33. Water-level difference map showing the change in the potentiometric surface of the dolomite aquifer, May 28-August 19, 1987

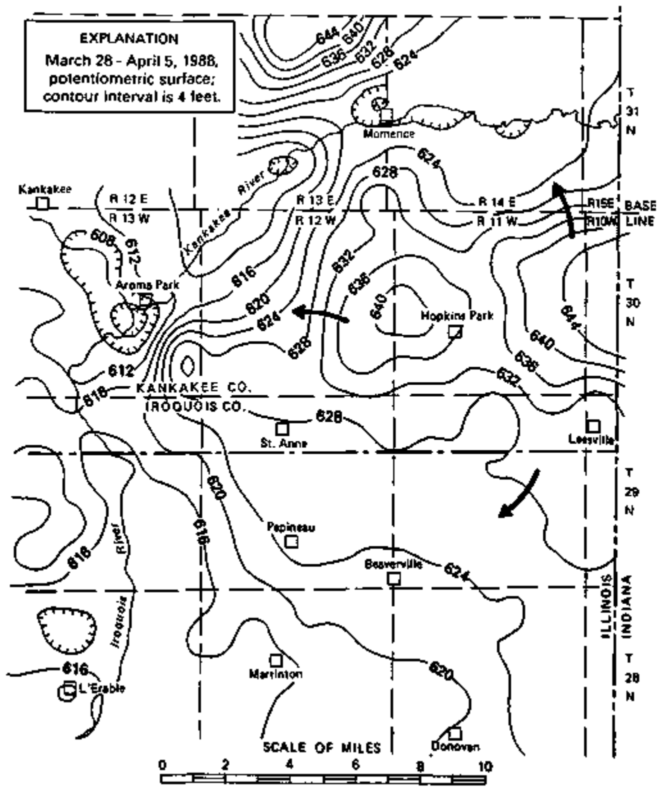


Figure 34. Potentiometric surface of the dolomite aquifer, March 28-April 5,1988

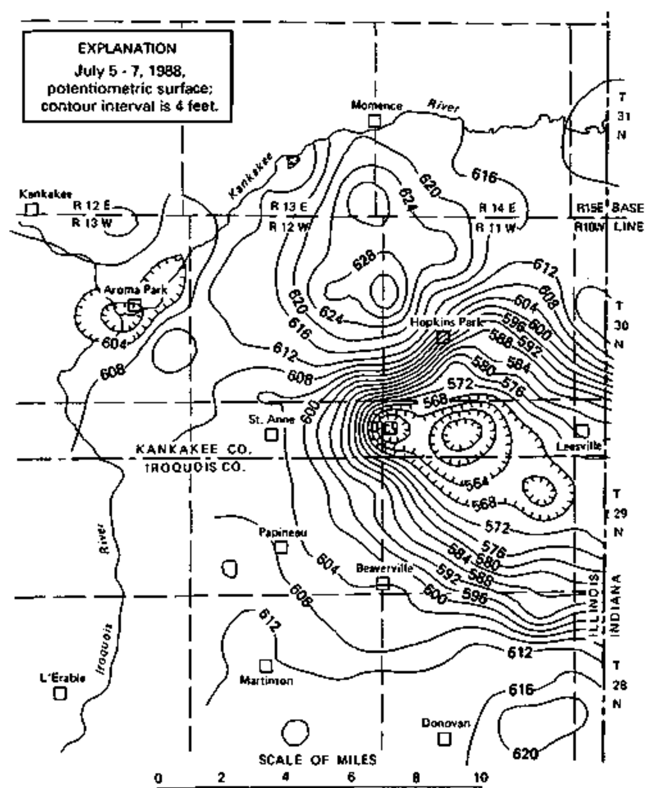


Figure 35. Potentiometric surface of the dolomite aquifer, July 5-7, 1988

cause the bedrock aquifer in these areas is semiconfined to unconfined. In addition, the close proximity of the Kankakee River, some stretches of which are hydraulically connected to the Silurian Dolomite, restricts water-level changes within the aquifer.

Spring 1988 Potentiometric Surface Map

As shown in figure 34, the water-level elevations measured at 173 locations in the carbonate aquifer between March 28 and April 5, 1988, were usually within 1 to 2 feet of water levels recorded the previous May. The proximity of the elevations indicates that the aquifer was fully recharged over much of the region through the fall, winter, and spring. Water levels recovered from the declines of the previous irrigation season primarily through vertical leakage. Discharge from the dolomite aquifer from the end of May 1987 through the beginning of April 1988 did not exceed recharge.

Summer 1988 Potentiometric Surface Map

Figure 35 shows the water levels in the carbonate aquifer July 5-7, 1988. As discussed earlier, the record-setting low precipitation and high temperatures of summer 1988 also resulted in record-setting ground-water use for private, public, and irrigation purposes. As of July 1, ground-water use for irrigation in the study area had already surpassed the total irrigation withdrawals of 1987. The large regional cone of depression observed in 1987 reappeared in an expanded form in 1988 and shifted about three miles to the west of Leesville. The water-level difference map (figure 36) contouring the change in the potentiometric surface from April 5 through July 7 shows a maximum decline of 72 feet west of Leesville.

Water levels were measured a final time between August 29 and September 2 to compare with the April and July water-level measurements. Figure 37 is the potentiometric surface map from the August-September measurement of 173 wells, and figure 38 is the water-level difference map for the period of April 5 through September 2. The maximum drawdown occurred between Leesville, Papineau, St. Anne, and Hopkins Park. Less than 10 percent of the total drawdown for summer 1988 occurred after the first week of July. Figure 39 shows the change in water levels in the bedrock between July 7 and September 2. At this time, water levels over much of the region declined by 0 to 4 feet, although declines greater than 4 feet generally occurred

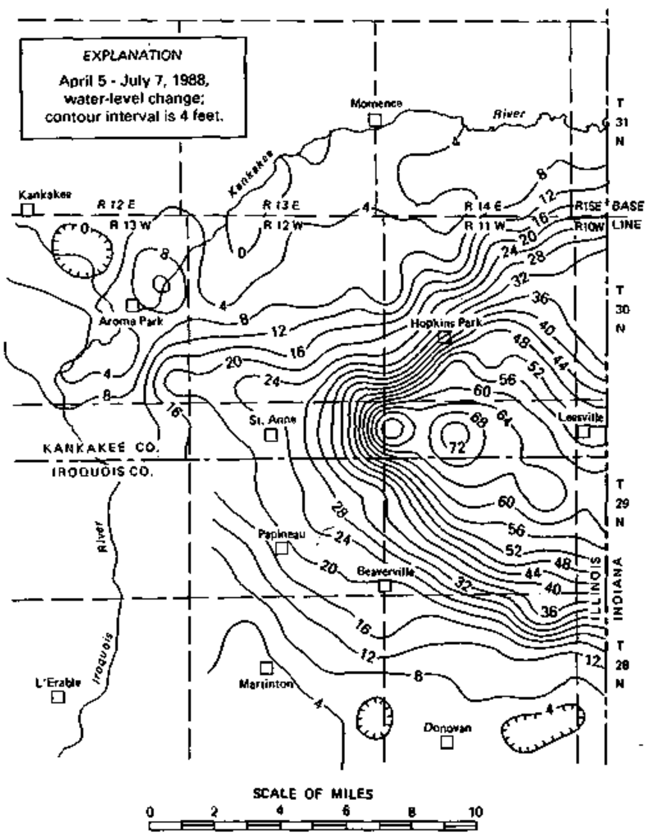


Figure 36. Water-level difference map showing the change in the potentiometric surface of the dolomite aquifer, April 5-July 7,1988

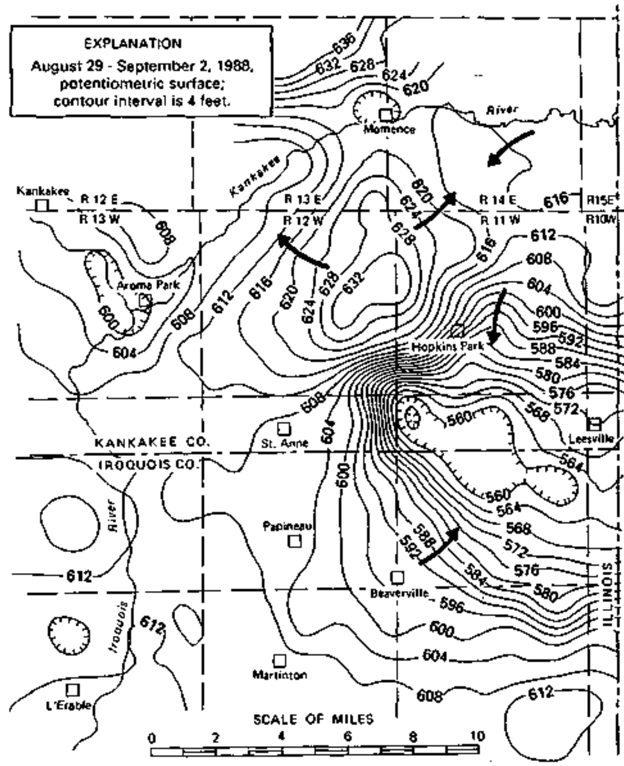


Figure 37. Potentiometric surface of the dolomite aquifer, August 29-September 2, 1988

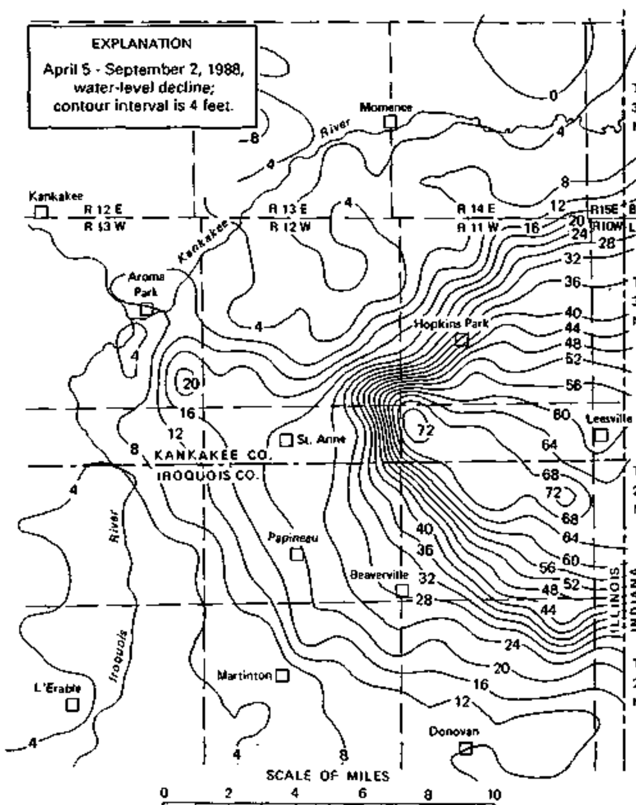


Figure 38. Water-level difference map showing the change in the potentiometric surface of the dolomite aquifer, April 5-September 2, 1988

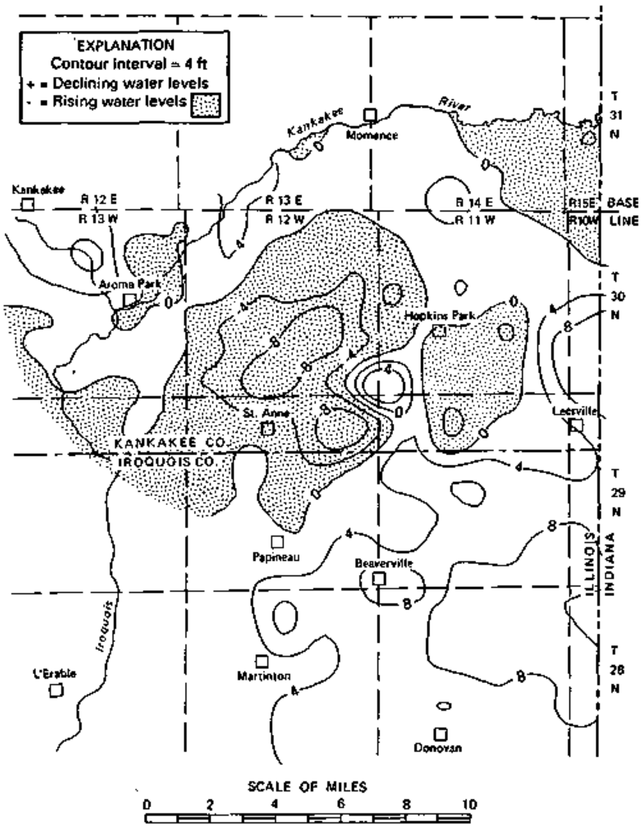


Figure 39. Water-level difference map showing the change in the potentiometric surface of the dolomite aquifer, July 7-September 2, 1988

north of Leesville and in eastern Iroquois County. In contrast, water levels recovered by more than 4 feet over a large area north and east of St. Anne. Irrigation withdrawals in this area slowed in late August, allowing water levels some time to recover before mass measurements were completed on September 2.

The greatest drawdown during July and August occurred south and southeast of Beaverville, in the southeastern part of the study area. After July, declines in this area generally ranged from 8 to 12 feet. Drawdown in July and August was greater in this area than in areas closer to the irrigated region because of the time lag associated with the expanding regional cone of depression. Closer to the irrigated region, most drawdown in the bedrock aquifer occurred early in the season. The potentiometric surface of the bedrock aquifer in areas farther from the irrigated region experienced greater drawdown later, as the area of ground-water diversion slowly expanded outward.

Ground-Water Divide

A ground-water divide is an imaginary boundary that separates the directions of ground-water flow. The ground-water divide for the dolomite aquifer in the study area was identified from potentiometric surface maps for 1987 and 1988, as shown in figure 40. Ground water on the north side of the divide flows north and west toward the Kankakee River. To the south of the divide, ground water flows south and west toward the Iroquois River.

The ground-water divide in this area lies very close to the surface water divide, which is a static line governed by topography that separates the drainage area of the Iroquois River to the south from the drainage area of the Kankakee River to the north.

As seen on the map, the ground-water divide is not static; it moves in response to the recharge and discharge of the Silurian Dolomite. Under natural conditions, the ground-water divide passes through the two potentiometric surface highs located four miles north of Leesville and northwest of Hopkins Park and continues westward toward the confluence of the Iroquois and the Kankakee Rivers. During periods of high irrigation discharge from the dolomite to the south, the ground-water divide migrates northward as ground water is diverted into the irrigated region. The northward movement of the divide was particularly dramatic along the state line in 1988: by the end of August it had migrated 4.5 miles.

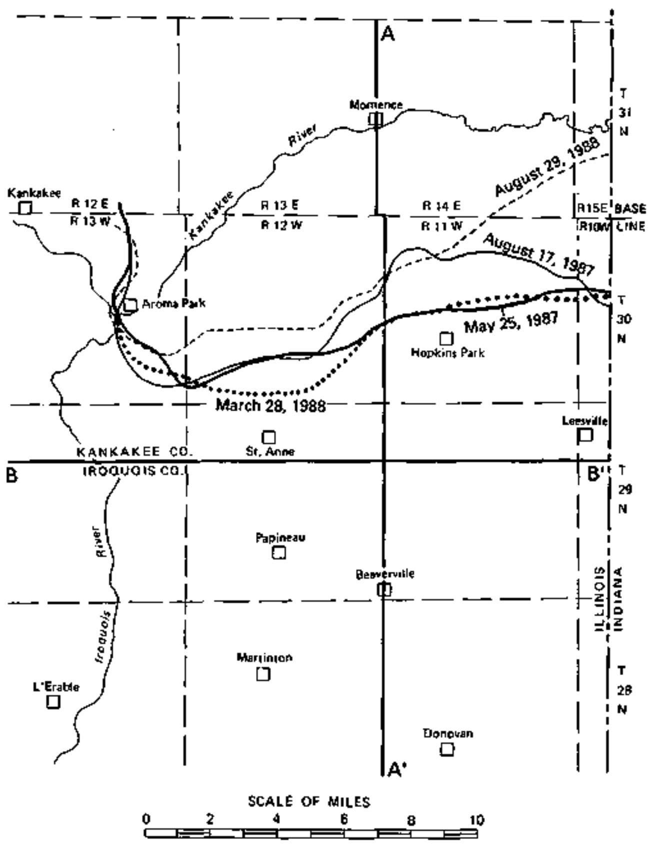


Figure 40. Movement of the ground-water divide as shown in the potentiometric surface of the dolomite aquifer, 1987-1988

Potentiometric Profiles

Figure 41 shows cross-sectional profiles of the potentiometric surface maps for spring and summer 1987 and 1988 along lines A-A' and B-B' of figure 40. The potentiometric profiles are presented relative to both the land surface and the topography of the bedrock.

Areas where the potentiometric profile drops below the top of the bedrock surface indicate dewatering of the bedrock. Ordinarily, much of the bedrock in the study area is under confined conditions, but when water levels fall below the top of the bedrock, the aquifer becomes unconfined and water-table conditions prevail. Under these conditions, the storage coefficient increases significantly, resulting in a sharp decrease in the rate of drawdown of water levels in the aquifer. As discussed earlier, the 1964 study by Prickett et aL determined that the specific yield of the upper portion of the Silurian Dolomite aquifer was 0.03 in northeastern Illinois.

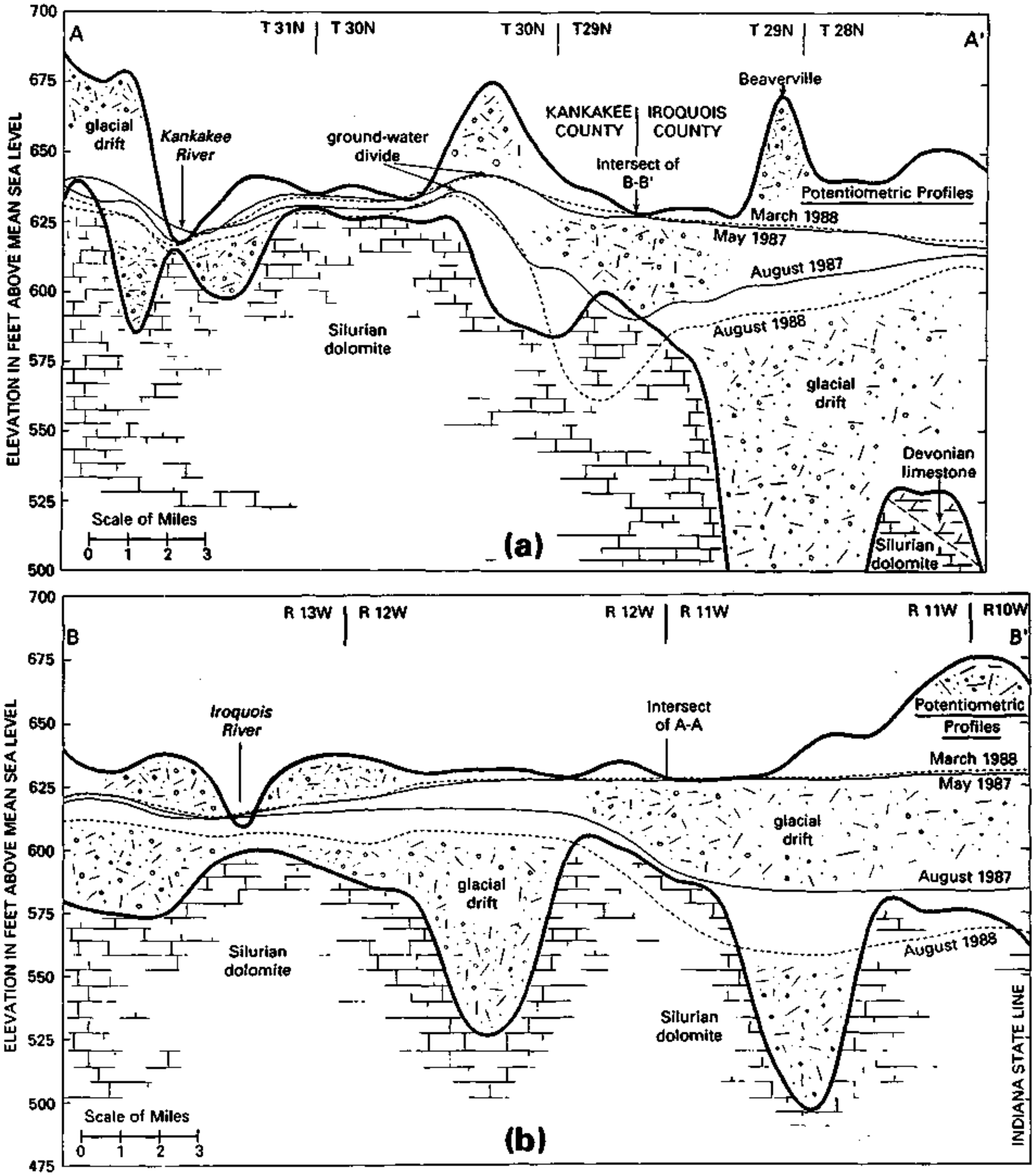


Figure 41. Cross section of the potentiometric surface of the dolomite aquifer along a) line A-A' and b) line B-B'

In 1988 the bedrock aquifer was dewatered primarily in confined sites with high bedrock elevations near areas of substantial ground-water discharge. Although localized dewatering of the bedrock may have occurred in scattered parts of the study area near high-capacity wells, most of the dewatering occurred within three to four miles of the Kankakee-Iroquois county line in ranges 10W., 11W., and the eastern end of 12W. The potentiometric surface of the aquifer was nearly at or below the top of the bedrock in an estimated 18 to 20 square miles of the region during 1988. In most wells in the area, the rate of water-level decline slowed sharply once the potentiometric surface reached the bedrock, and further declines were limited to less than a few feet. Conversely, water levels dropped in some areas to 10 to 25 feet below the top of the bedrock.

If 20 square miles of dolomite were under water-table conditions, a drop of 1 foot below the top of the bedrock would release approximately 125 million gallons of ground water over a period of months to years. This represents 4.5 percent of the ground water discharged within the study area between July 7 and August 30, 1988. If water levels declined 5 feet below the top of the dolomite over 20 square miles, 625 million gallons of ground water would be released, or 22.5 percent of the ground water pumped between July 7 and August 30. The high yield from the dolomite under water-table conditions helped slow the rate at which the potentiometric surface declined late in the 1988 irrigation season.

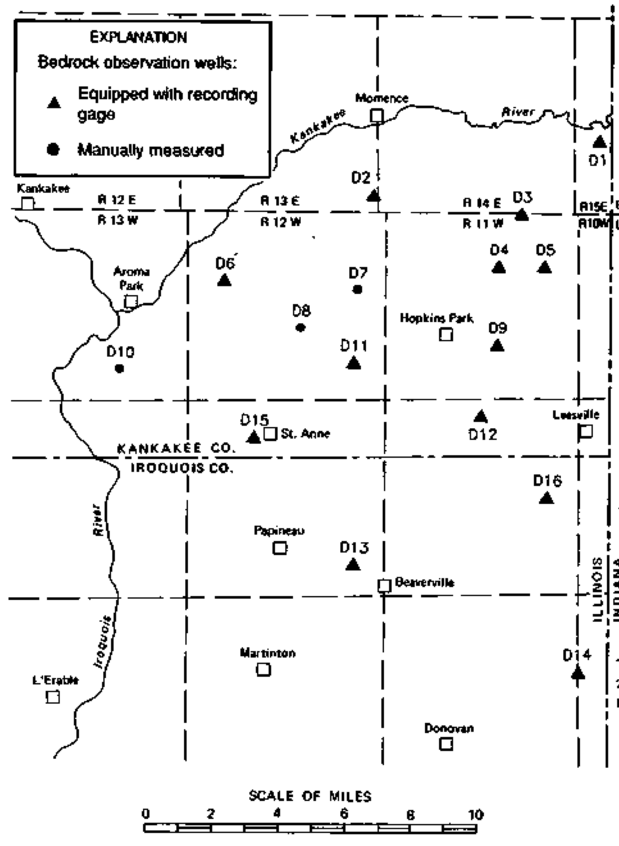


Figure 42. Silurian Dolomite observation wells

Ground-Water Hydrographs

A ground-water hydrograph is used to chart water-level changes over a period of time in an observation well that penetrates an aquifer. Sixteen such wells were monitored during the study (figure 42). Three of the wells, D4, D5, and D11, were already being monitored as part of the Water Survey's statewide ground-water observation well network, and they were subsequently incorporated into the study. Cooperating land owners provided nine additional wells for use during the study. In order to achieve more complete coverage of the impacted bedrock aquifer in the southern part of the study area, four new bedrock observation wells were constructed at a depth of 200 feet and numbered D13 through D16. Information about each observation well is presented in table 16, and hydrographs from wells D1 through D14 are presented in appendix 4.

Historical Water-Level Records

Observation well D11, located in the center of the study area, has been monitored continuously since 1968, providing a historical look at water-level changes in the irrigated region of southeastern Kankakee County. As seen in figure

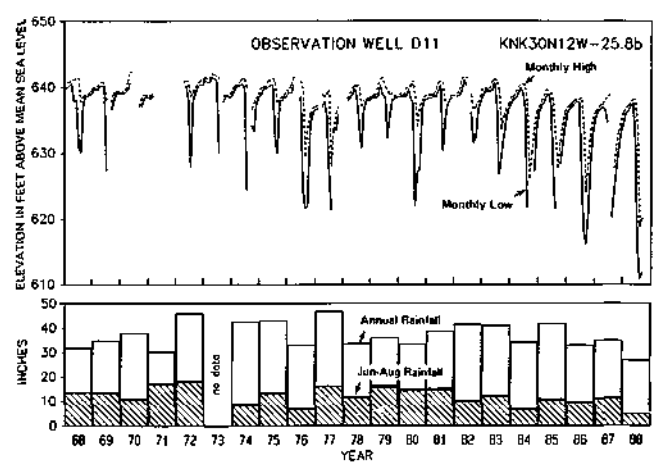


Figure 43. Hydrograph of ground-water levels at observation well D11 and precipitation, 1968-1988

43, water levels in the Silurian Dolomite aquifer at this location have fluctuated seasonally since monitoring first began. The hydrograph pattern shows summer drawdown and subsequent water-level recovery in fall, winter, and spring each year. This cyclical pattern of drawdown and recovery occurs in direct response to ground-water withdrawals by irrigation wells and subsequent recharge of the aquifer.

Table 16. Silurian Dolomite Observation Wells

Observation well	Location	Depth of well (ft below land surface)	Measuring point elevation (ft above msl)	Land surface elevation (ft above msl)	Bedrock surface elevation (ft above msl)
D 1	KNK 31N15E-19.3B	91	629.88	628.9	588
D 2	KNK 31N13E-36.1E	226	638.22	635.5	618
D 3	KNK 30N11W-02.6H	156	635.01	634.1	556
D 4	KNK 30N11W-10.4A	200	663.86	661.2	583
D 5	KNK 30N11W-11.1A	150	668.10	665.9	587
D 6	KNK 30N12W-17.8F	604	625.93	624.6	571
D 7	KNK 30N12W-13.7D	?	643.19	642.2	?
D 8	KNK 30N12W-22.5C	127	630.86	630.3	611
D 9	KNK 30N11W-27.5E	700	667.77	666.7	582
D10	KNK 30N13W-27.1A	625	626.00	625.6	576
D11	KNK 30N12W-25.8B	220	647.99	645.9	595
D12	KNK 29N11W-03.8D	642	654.54	652.0	552
D13	IRO 29N12W-25.8A	200	658.97	656.3	558
D14	IRO 28N11W-13.1E	200	696.16	694.7	548
D15	KNK 29N12W-09.8H	200	648.06	644.9	521
D16	IRO 29N11W-23.1H	200	668.73	666.1	565

In addition to short-term fluctuations in the observation well due to seasonal irrigation, the hydrograph also shows long-term trends. In observation well D11, long-term water levels are subject to change as a result of precipitation and temperature, installation of new irrigation systems, changing crop types, and other factors related to the amount of water recharged to and discharged from the aquifer each year.

Annual precipitation is the primary factor affecting both the magnitude of water-level declines during the summer and the recovery of water levels in fall, winter, and spring. Several seasons of low summer precipitation, as in 1982 through 1986, produced a five-year trend of declining water levels. However, in 1987 water levels had recovered before they dropped again in the record drought year of 1988.

Unlike observation well D11, water levels in well D4 (figure 44) showed significantly less drawdown during the summers of 1986 and 1987. Water-level recovery in the Silurian Dolomite in this area can be attributed to the end of ground-water withdrawals for corn irrigation by the neighboring landowner, the Prudential Insurance Company of America. Prudential continued the moratorium on irrigation in 1988, but water levels in the well again declined nonetheless, demonstrating that they fluctuate seasonally in response to both nearby irrigation wells and more distant wells that use the same ground-water resource.

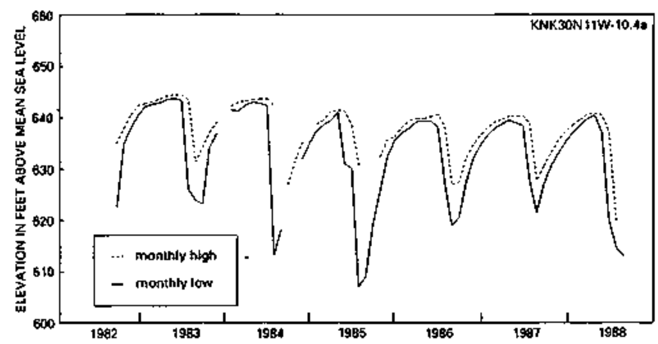


Figure 44. Hydrograph of ground-water levels at observation well D4, 1982-1988

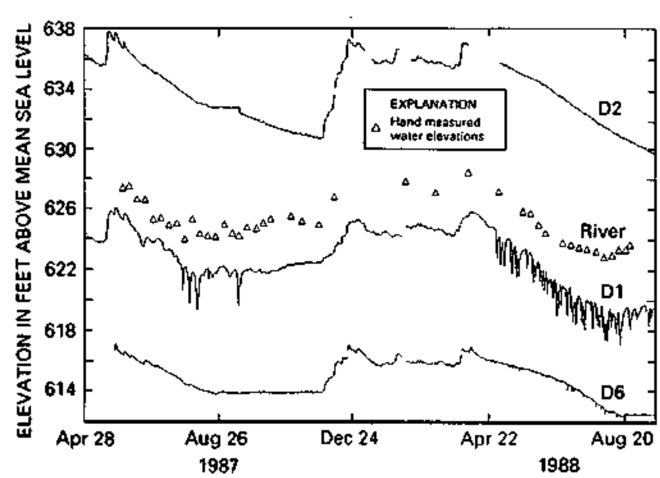


Figure 45. Hydrograph of the Kankakee River at the state line and ground-water levels at observation wells D1, D2, and D6, April 28, 1987-August 20, 1988

Northern Observation Wells

Three Silurian Dolomite observation wells are located within a few miles of the Kankakee River, and hydrographs are shown in figure 45. Also shown are periodic hand-measured water elevations of the Kankakee River at the state line. Although they are located at varying distances from the Kankakee River, water levels in all three wells correlate closely to changes in the river's elevation.

Observation well D1, located within a mile of the Kankakee River, mirrors the changes in the level of the river most closely. Since the water elevation of well Dl is below that of the river, it can be inferred that the Kankakee River contributes to the ground-water flow regime in this area. Water levels in wells D2 and D6 are not directly correlated with the river elevation because of their distance from the river's measuring point. However, the similarities between the hydrograph patterns from these wells and the changes in river elevation demonstrate that the Kankakee River closely interacts with the ground-water flow in the local Silurian Dolomite. More information on this interaction is presented in section 5.

Southern Observation Wells

During the summers of 1987 and 1988, the ground-water divide was located north of observation wells D5, D9, and D12 (figure 46). As a result, neither these three wells nor any other observation wells south of the ground-water divide responded with the Kankakee River. Only the ground-water levels in those wells located north of the ground-water divide followed changes in the river elevation (as shown in appendix 4).

The magnitude of the drawdown in wells D5, D9, and D12 is partly a function of their location: they are situated at progressively greater distances from the ground-water divide, which is in an area that provides significant recharge for the carbonate bedrock aquifer. Water levels in well D5, which was south of the ground-water divide during summer 1988, dropped approximately 40 feet between April and mid-August. Water levels in wells D9 and D12, located approximately 2.25 and 4.5 miles to the south of well D5, dropped 47 and 73 feet, respectively, during the same period. The large declines in wells D9 and D12 can be attributed to increased ground-water withdrawals to the south and greater confinement of the bedrock aquifer beneath the glacial drift.

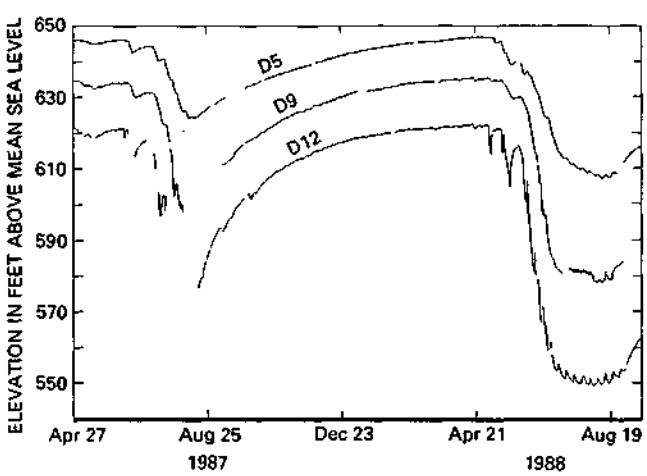


Figure 46. Hydrograph of ground-water levels at observation wells D5, D9, and D12, April 27, 1987-August 19, 1988

Dewatering of the Bedrock Aquifer

Sixteen observation wells monitored water levels in the Silurian Dolomite bedrock during summer 1988, and water levels dropped below the top of the bedrock in three of them. Hydrographs from wells D9 and D12 (appendix 4) showed that dewatering of the bedrock occurred for a period of approximately 41 and 55 days, respectively. From early July through late August, water levels in these wells dropped approximately 3 to 5 feet below the top of the bedrock. In well D16, located in the Iroquois County Conservation Area, water levels dropped as much as 15 feet below the top of the bedrock for a period of about 80 days from late June through mid-September. Each of these three observation wells is located within one-half mile of an active irrigation well.

According to Prickett et al. (1964), when nonpumping ground-water levels drop below the top of the Silurian Dolomite aquifer, yields from production wells will decrease for two reasons: 1) partial dewatering of the dolomite reduces transmissivity, and 2) well loss in dolomite wells accelerates when water levels drop below the top of the aquifer. The practical sustained yield of high-capacity wells is thus affected when drawdown reaches the top of the Silurian Dolomite in the aquifer.

Use/Yield of the Dolomite Aquifer

One method of evaluating the long-term viability of the dolomite aquifer is to compare yearly ground-water use with the available yield of the aquifer. In 1987, a near-normal year in terms of precipitation, the average ground-water pumped from the dolomite over the 414 square miles of the study area was 22,400 gpd/sq mi, or approximately 0.47 inch of water per year. Assuming an average yield of 180,000 gpd/sq mi, equal to 3.8 inches of water over the study area, the use/yield ratio was 0.12. Conversely, average water use during the drought year of 1988 amounted to 45,800 gpd/sq mi, or about 0.96 inch of water. The use/yield ratio for 1988 was 0.25.

A second method of evaluating the use/yield of the dolomite aquifer is to look at the seasonal impacts occurring in the region from which ground water is diverted to the irrigated area. During a 90-day irrigation season in 1987, the average water use over an area of 217 square miles was 58,000 gpd/sq mi. The use/yield ratio for this 90-day period was 0.32. In 1988, ground-water use for a 90-day period during the irrigation season amounted to 139,200 gpd/sq mi from a ground-water diversion area of 271 square miles. The use/yield ratio for this period was 0.77.

A third and final method of comparison is to consider only the use/yield of the irrigated lands. In 1987, approximately 10,278 acres were irrigated with 2.12 billion gallons of ground water. Assuming that the dolomite aquifer yields an average of 180,000 gpd/sq mi, the use/yield ratio for each irrigated acre was 2.00 for the entire year. In other words, the quantity of ground water applied to each irrigated acre exceeded yearly recharge to the dolomite aquifer by 100 percent. In 1988, an estimated 12,143 acres of land were irrigated with 5.66 billion gallons of ground water. Therefore, the use/yield ratio for each irrigated acre in 1988 was 4.54.

Although the above use/yield analyses aid in understanding the quantities of ground water discharged and recharged from the dolomite aquifer, they cannot be used for ground-water resource management without further interpretation by a hydrogeologjst. The use/yield analyses are an average of recharge and discharge over large areas. The volumes of recharge and discharge at different locations within the study area may vary greatly. Recharge of the dolomite is much greater in areas where sand directly overlies the bedrock than in areas with clay or till above the bedrock. The presence of influent stretches of the Kankakee or Iroquois Rivers near discharging wells also reduces the drawdown of water levels. Moreover, in areas nearer the rivers, water levels generally recover much more rapidly after the irrigation season ends.

8. NUMERICAL MODELING

A model is designed to represent a simplified version of reality. Using a set of differential equations that are known to govern the flow of ground water, numerical models can be designed to simulate a real aquifer system. Numerical models simulate real situations by replacing the partial derivatives in the ground-water flow equation with known discretized equations requiring matrix solution. The equations can then be solved using numerical iteration and several simplifying assumptions. This numerical simulation requires the use of a computer because of the large number of equations that must be solved.

A two-dimensional digital model was used to simulate the dolomite aquifer during the 1987 irrigation season. This model, the Prickett-Lonnquist Aquifer Simulation Model (PLASM), uses finite difference methods along with the Iterative Alternating Direction-Implicit Method (IADI) for solving the ground-water flow equations (Prickett and Lonnquist, 1971).

Background Data and Assumptions

The PLASM model was designed to simulate water levels in the dolomite aquifer underlying the study area. It was verified using ground-water data collected from May through August of 1987. The May mass measurement was entered as the initial potentiometric surface of the dolomite aquifer, and steady-state conditions were assumed. The transient simulation consisted of four time steps of one month each. The simulation continued until the end of August. The output was calibrated against the August mass measurement data, which was considered to be the end of the irrigation pumping season.

Because of limited data and a lack of clearly defined hydrologic boundaries within the study area, "no-flow boundaries" were used on all sides of the model. Existing hydrologic boundaries of the dolomite flow system include the Kankakee River in the northern part of the study area and a short segment of the Iroquois River south of Aroma Park. Due to uncertainty regarding the extent to which these hydrologic boundaries affect flow within the dolomite, no-flow boundaries were used beyond the area of hydrologic interest. Boundaries must be used in order to solve the series of equations governing the numerical model. The area of the model was extended well beyond the main area of interest to minimize the effects of the model boundaries. No-flow boundaries do not limit the areal recharge to the source bed above the dolomite, however, because the source-bed head is assumed to be constant throughout the simulation.

Several simplifying assumptions must be made in order to solve the equations that govern ground-water flow in two dimensions:

1. At the start of the simuladon, the dolomite aquifer is at steady-state conditions.
2. The source-bed head for each time step is constant.
3. The dolomite aquifer has a uniform thickness of 100 feet.
4. The dolomite aquifer is a porous medium, with heterogenous, isotropic transmissivity.
5. Any horizontal leakage into the aquifer system from outside the model boundaries is ignored.

The primary stresses on the dolomite aquifer occur as a result of vertical leakage from overlying unconsolidated deposits and from ground-water pumpage. Leakage discharges and recharges the dolomite aquifer by varying degrees, depending on the source-bed head, the dolomite aquifer head, and the thickness of the clay. Leakage was calculated based on a leakage factor. The leakage factor at each model node was determined by dividing the hydraulic conductivity of the clay aquitard (which was estimated from values presented earlier) by the clay tiiickness. The leakage was then calculated using a form of Darcy's Law, in which the amount of leakage at each node was considered to be dependent on the leakage factor and the difference in head between the source bed and the dolomite aquifer.

Other parameters included the transmissivity of the dolomite, the source-bed head of the sand and gravel, the bedrock surface elevations, and withdrawals from the dolomite. Transmissivity values were determined from the specific-capacity analyses presented in section 4 (see figure 10). Aquifer test data were not used for the transmissivity estimates because of a bias towards high-yielding irrigation and municipal wells. On the other hand, specific-capacity data incorporate all types of water wells that penetrate into the dolomite. Source-bed head was assumed to be 7 feet below the land surface elevation, as determined from USGS topographic maps. Although highly generalized, a uniform source-bed head located 7 feet below land surface is based on sand-and-gravel observation well readings for the study area. Bedrock surface elevation estimates were determined from ISGS maps (Kempton, unpublished). Ground-water withdrawals from the dolomite in Illinois were estimated with the water-use data presented earlier. Wididrawals for irrigation in Indiana were compiled and made available for use by the Indiana Department of Natural Resources (Basch, 1988).

Model Results

The results of the model calibration are shown in figure 47. Comparing the model results to the actual potentiometric surface measured between August 17 and 19, 1987 (figure 48), shows that only a few areas of the model deviate significantly from the real data. The two areas of greatest deviation between the predicted and actual potentiometric surfaces are located south and southwest of Leesville and between St. Anne and Hopkins Park. In the area of deviation near Leesville, approximately 23 square miles, the model predicted the potentiometric surface to be 5 to 15 feet higher than the actual potentiometric surface. Between St. Anne and Hopkins Park, in an area of about 16 square miles, the model predicted the potentiometric surface to be 5 to 20 feet below the actual potentiometric surface.

The above model was designed to simulate the effects of pumpage from the dolomite aquifer during the 1987 irrigation season; it was then modified to simulate the effects of two hypothetical pumping wells located in two different locations within the study area (figure 49). The two wells were modeled to pump at a continuous rate of 2,000 gpm for a period of 120 days. Although unrealistically high in terms of both the pumping rate and the duration of an actual high-capacity well, the simulation was conducted

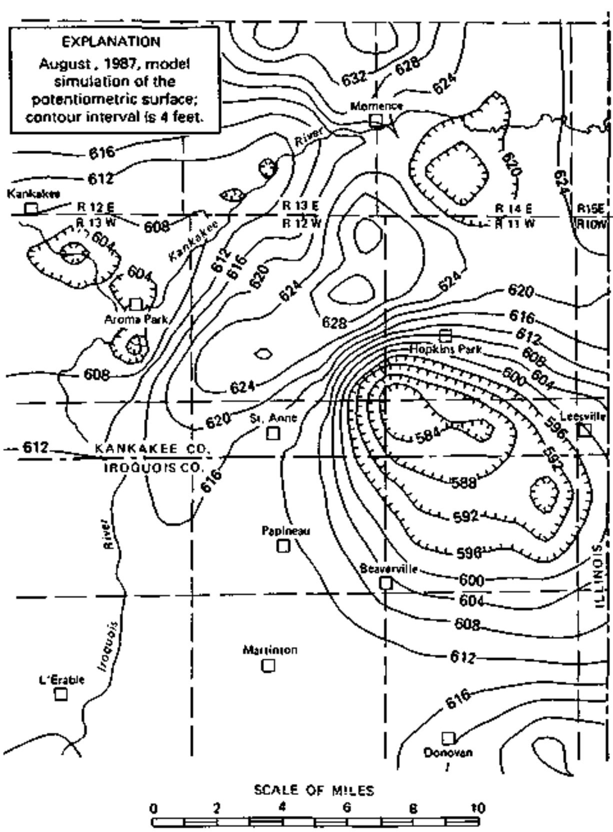


Figure 47. Model simulation of the potentiometric surface of the dolomite aquifer, August 1987

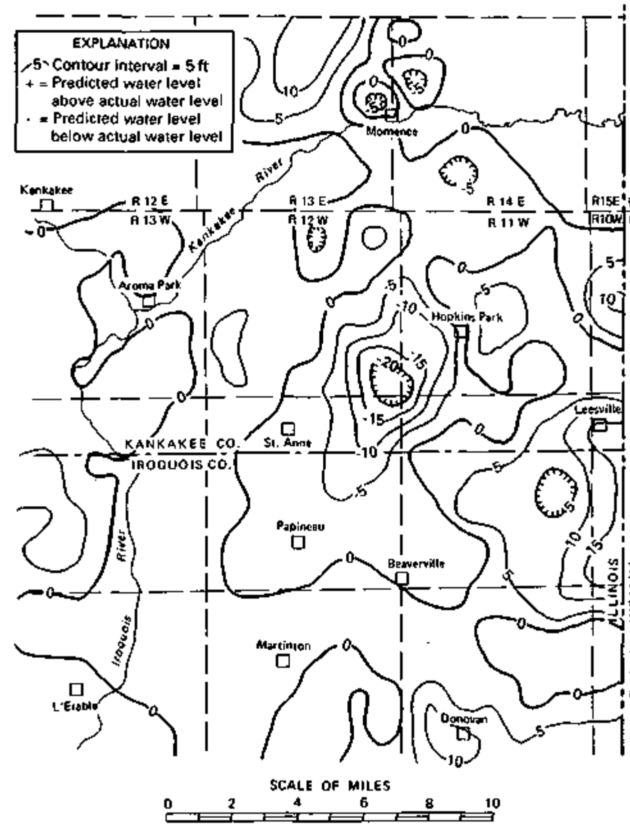


Figure 48. Difference map between simulated and actual potentiometric surfaces of the dolomite aquifer, August 1987

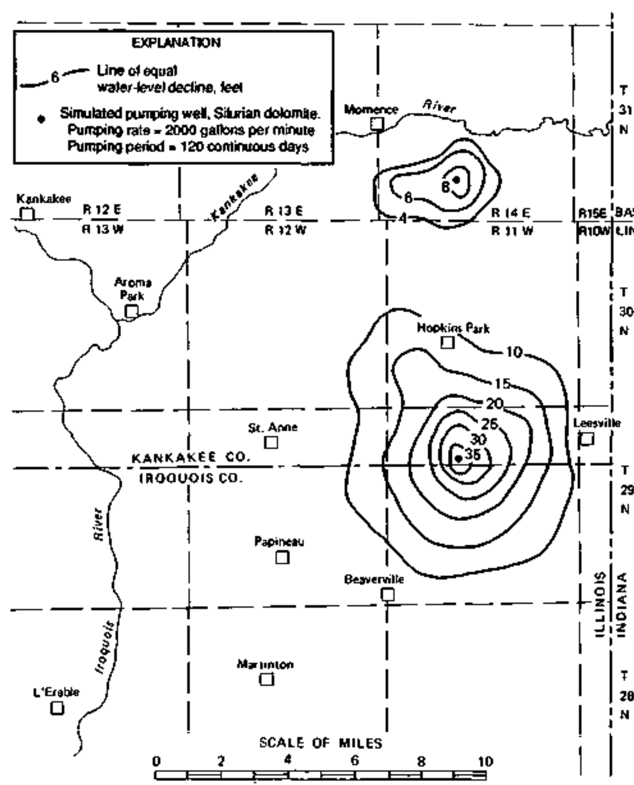


Figure 49. Model-simulated water-level declines

to demonstrate the large differences in drawdown among pumping wells located southeast of Momence versus wells located in the southern part of the study area.

It is interesting to note the large difference in drawdown between the two simulated pumping wells. Drawdowns near the northern well do not exceed 10 feet. This well is in an area of high transmissivity, very high recharge, and a relatively thin clay layer. Conversely, drawdown around the southern well shows a large areal extent; drawdowns near the well exceed 35 feet. A thick clay layer in this area decreases the vertical leakage and limits the recharge available to the dolomite aquifer. While the northern well is recharged primarily from above, recharge in the southern well relies on lateral movement of ground water from the surrounding dolomite.

Conclusions

The dolomite aquifer and overlying unconsolidated deposits constitute a three-dimensional system: the two-dimensional model used here is an attempt to simulate the vertical components of a three-dimensional system using a simple approximation of leakage. The leakage values used in the model do not account for any changes in water levels within the overlying source bed.

A second major limitation of the model simulation is the assumption of uniform pumping during each of the one-month time steps. Most pumping wells cycle on and off at irregular intervals. An irrigation system applying water to vegetables, for example, may operate only two days out of seven. During the remaining five days, the pump is inactive and therefore not influencing the ground-water system.

Design of the numerical model was based on five simplifying assumptions. The degree to which each of these assumptions deviated from the actual behavior of the aquifer system is discussed below:

1. Because of the cyclic nature of the aquifer system from year to year, the system may not have been in a steady-state condition at the beginning of the simulation.
2. The source-bed head is not constant. Measurements from sand-and-gravel observation wells show that in 1988 the head generally ranged from 4 to 10 feet below land surface. These changes in head may cause large changes in the amount of recharge to the dolomite aquifer. The areas of highest recharge occur where the clay or till aquitard disappear. In these areas the source-bed head is essentially equal to the dolomite aquifer head.
3. Although the carbonate aquifer may be as thick as 500 to 600 feet in places, the predominant water-yielding openings occur in the upper 100 feet.
4. At the scale in which the modeling is conducted, the dolomite behaves as a heterogenous, porous medium; the fractures and bedding-plane openings act as interstices between the large dolomite blocks. Aquifer test results confirm that on a large scale, the dolomite aquifer behaves as a porous medium.
5. Horizontal leakage into the dolomite aquifer occurs from outside the model boundaries, but it can be neglected because of the distance of the boundaries from the area of interest. If large withdrawals were continuous instead of seasonal, ground-water movement into the area of interest could become significant as the area of diversion expanded outward. Substitution of the no-flow boundary with a "constant flux boundary" would accommodate the excessive leakage.

Although both the assumptions and the data put into the two-dimensional model are approximations of the actual physical system, the results from these initial modeling efforts have supported the conceptual model developed for the aquifer system. The model simulations conducted as part of this study provide an increased understanding of the hydrologic system in eastern Kankakee and northern Iroquois Counties. The information provided by an improved version of this two-dimensional model or a multi-layered model would allow for efficient ground-water management of the study region.

9. GROUND-WATER CHEMISTRY

Water-quality analyses were compiled for 97 carbonate bedrock wells and 13 wells in unconsolidated deposits in southeastern Kankakee and northeastern Iroquois Counties (appendix 5). Because the water samples were collected over a period of 50 years, some samples may not represent the current quality of ground water at some locations. The recommended upper limits of the various chemical parameters are outlined in the U.S. Public Health Service Drinking Water Standards of 1962. The standards may be used as a guide for interpreting the concentrations of the chemical constituents. They recommend upper limits of: iron 0.3 milligrams per liter (mg/L); sulfate 250 mg/L; nitrate 45 mg/L; magnesium 250 mg/L; chloride 250 mg/L; manganese 0.05 mg/L; and dissolved solids not to exceed 1,000 mg/L, although less than 500 mg/L is preferred.

Carbonate Bedrock

Water quality statistics for samples collected from the carbonate bedrock are presented in table 17. Water from the Silurian Dolomite and Devonian Limestone is high in calcium and magnesium, although less than 7 percent of the water samples had magnesium concentrations in excess of the U.S. Public Health Service standard of 250 mg/L.

Table 17. Water Quality Statistics for Samples from the Silurian and Devonian Dolomite

	Number of cases	*Minimum*	*Maximum*	*Mean*	*Median*	*Standard deviation*
Well depth (ft)	93	53	540	202	181	104
Calcium	45	27	167	78	75	33
Magnesium	45	9.6	352.7	57.2	38.4	82.0
Sodium	38	3.5	90.0	29.4	23.7	20.6
Chloride	91	1.0	207.0	25.6	17.6	30.6
Sulfate	48	1.0	263.0	90.1	82.6	70.4
Nitrate	46	0.0	66.4	5.5	0.7	13.4
Iron	92	0.0	33.0	1.70	0.48	3.89
Fluoride	38	0.1	1.2	0.42	0.40	0.23
Manganese	28	0.0	0.1	0.40	0.02	0.03
Alkalinity	93	102	524	290	280	86
Hardness	92	108	808	324	317	143
TDS	92	142	815	437	409	156
pH	31	6.9	8.0	7.4	7.5	0.4

Note: Dissolved constituent concentrations and hardness are in mg/L; hardness is measured as $CaCO_3$.
Results of 0.0 indicate that concentration was below method detection limit.

Sulfate, another dominant ground-water constituent, tends to be directly proportional to changes in the calcium concentration. The Pearson correlation coefficient for calcium and sulfate in water sampled from the carbonate bedrock is 0.78, which represents a fair correlation between the two parameters.

Magnesium and nitrate are the, only other mineral constituents with good correlations. Concentrations of magnesium and nitrate are directly proportional to one another, with a correlation coefficient of 0.79. No nitrate concentrations were found to exceed the recommended limits.

Iron was the only parameter to exceed the drinking water standard in most wells tested. Iron levels surpassed 0.3 mg/L in 67 percent of the water samples. Although not detrimental to water quality, high levels of iron may cause reddish-brown stains on porcelain fixtures and laundry.

Hardness, measured as calcium carbonate concentrations within the water samples, does not have a recommended upper limit. Hardness is generally important to users because it affects the consumption of soap products and may produce scale in water heaters and distribution pipes. Of the 92 water samples analyzed, 27 percent were categorized as "very hard" (greater than 400 mg/L), and 37 percent were "hard" (250 to 400 mg/L). The remainder were categorized as "moderately hard" (125 to 250 mg/L) or "fairly soft" (75 to 125 mg/L).

Total dissolved solids (TDS) is a measure of the total mineral content in the ground water. Concentrations in excess of 500 mg/L will make the water taste slightly mineralized. Generally, the upper limit acceptable to many users is 1,000 mg/L. Above this level, the water may have a disagreeable taste. No samples tested for TDS had concentrations in excess of 1,000 mg/L, although 34 percent of the samples did exceed 500 mg/L.

The lowest TDS values, less than 250 mg/L, occurred in the Hopkins Park area of southeastern Kankakee County (figure 50). This area of low TDS is adjacent to the area of high potentiometric head as shown on the maps made in May 1987 and April 1988 (figures 16 and 34). High recharge rates northwest of Hopkins Park may account for the lower TDS values.

TDS concentrations increase to the north, west, and south of the area of low TDS. This pattern of increasing TDS concentrations appears to be inversely related to the potentiometric surface of the carbonate aquifer, which decreases with distance from the potentiometric high northwest of Hopkins Park. Mineral content gradually increases as ground water flows in porous geologic media such as sand and gravel, sandstone, dolomite, etc. These gradual increases are common and have been observed in many areas of the state (Helfrich et al., 1988). The pattern of increasing mineralization of bedrock ground water is especially noteworthy south of Hopkins Park. Contours of

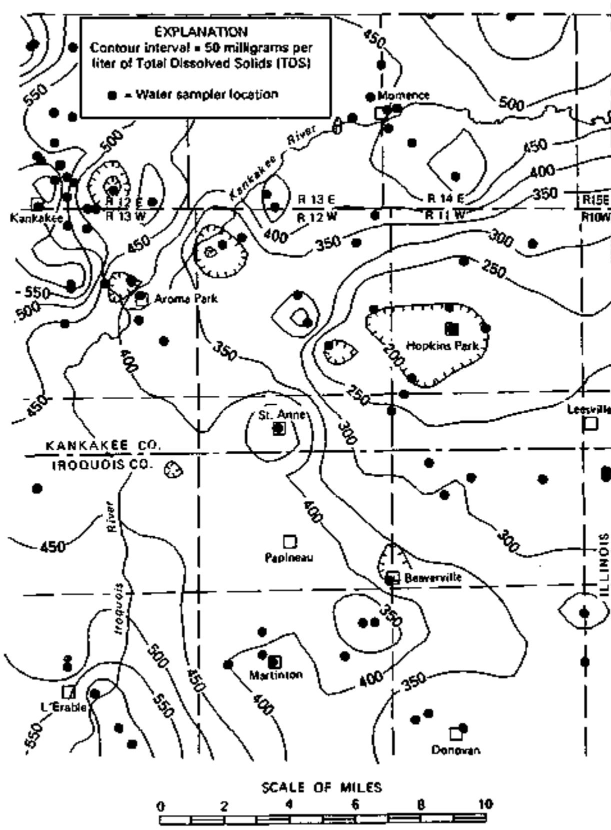


Figure 50. Contour map of total dissolved solids (TDS) distribution in the Silurian and Devonian Dolomite

increasing TDS concentration closely follow the decreasing potentiometric surfaces mapped during the springs of 1987 and 1988.

Some well owners have reported that water quality has declined in those parts of the dolomite aquifer affected by large withdrawals of ground water. In a few localized areas, the ground water obtained from the dolomite has been high enough in dissolved mineral constituents that well owners have turned to shallow sand points as sources for their potable water supplies. To better assess the water quality of the dolomite, water samples should be obtained from uniformly distributed wells over a short time period. In addition, the range of chemical constituents to be analyzed should be expanded beyond those presented in table 17.

Degradation of ground water, either from natural processes or contamination, can be detected by periodic sampling of chemical constituents in three distinct categories (Helfrich et al., 1988): dissolved minerals, trace elements or organic compounds, and contaminant indicator parameters [i.e., pH, TDS, total organic carbon (TOC), and total organic halogen (TOX)]. A ground-water quality monitoring program should be established for eastern Kankakee and northern Iroquois Counties.

Unconsolidated Deposits

Thirteen ground-water samples were taken from wells whose supplies are derived from sand and/or gravel layers within the surficial material mantling the bedrock (appendix 5). The five chemical parameters measured were chloride, iron, total alkalinity, hardness, and total dissolved solids. Iron concentrations exceeded drinking water standards in 12 of the 13 samples taken, accounting for 92 percent of the sampling. All 13 water samples were "moderately hard" to "hard."

Comparison of the mean chemical concentrations in ground-water samples from sand-and-gravel deposits (table 18) with those from the dolomite shows that all parameters are lower in the sand-and-gravel samples. However, because of the statistically small number of samples taken from the sand and gravel, the median concentrations of chloride, iron, and alkalinity are higher in the sand-and-gravel samples than in those from the dolomite.

Based on the available data, the major conclusion to be reached in comparing the ground-water quality from sand-and-gravel sources to water quality from dolomite sources is that hardness and TDS concentrations are generally lower in ground water from the sand and gravel. Expanded water quality monitoring, similar to that discussed for the dolomite aquifer, will be necessary for better characterization of the ground-water quality of the sand-and-gravel aquifers in the region.

Table 18. Water Quality Statistics for Samples from Sand-and-Gravel Aquifers

	Number of cases	*Minimum*	*Maximum*	*Mean*	*Median*	*Standard deviation*
Well depth (ft)	13	15	130	69	65	37
Chloride	13	1.0	31.0	21.5	25.0	10.2
Iron	13	0.2	2.9	1.20	1.00	0.87
Alkalinity	12	136	306	258	282	49
Hardness	13	149	284	214	208	48
TDS	13	211	360	334	346	38

Note: Dissolved constituent concentrations and hardness are expressed in mg/L; hardness is measured as $CaCO_3$.

10. GROUND-WATER MANAGEMENT

Water Use Act of 1983

The Water Use Act of 1983 (P.A. 83-700) was enacted to address public concern over present and future ground-water use in Illinois. It establishes that the "rule of reasonable use" shall apply to ground-water withdrawals. The rule of reasonable use recognizes "the use of water to meet natural wants and a fair share for artificial wants. It does not include water used wastefully or maliciously." The Division of Natural Resources (DNR) of the Illinois Department of Agriculture and the Soil and Water Conservation Districts (SWCD) are assigned administrative responsibility. The act provides mechanisms for 1) notification of proposed new high-capacity wells, 2) review of the ground-water resource impacts from the new wells, and 3) public notification regarding the new wells and their estimated impacts on ground-water resources. The act originally relied on the public notification process to resolve potential use conflicts caused by proposed large ground-water withdrawals.

In 1987, the Water Use Act was amended with Public Acts (RA.) 85-483 and 85-905. An additional amendment, RA. 85-1330, became effective on August 31, 1988. The Water Use Act as amended is given in appendix 6. The amendments established a means for conflict resolution between users of ground water in Iroquois, Kankakee, McLean, and Tazewell Counties and stipulated possible restrictions of ground-water withdrawals under emergency conditions. They also provided for the development of recommended well construction guidelines (Illinois Department of Agriculture et al, 1988) and mandatory registration procedures for existing high-capacity wells in these four counties.

Water-Well Supply Interruptions

Domestic water-well supply interruptions have been reported in eastern Kankakee and northern Iroquois Counties since the early 1980s. Until 1988, no accurate figures were maintained on the frequency of water-well supply interruptions. In accordance with the amended Water Use Act of 1983, the Illinois State Water Survey and the State Geological Survey began investigating the supply interruptions that were reported to the Kankakee and Iroquois County Soil and Water Conservation Districts during the drought of 1988.

Approximately 120 complaints of water-well supply interruptions were filed in the study area in eastern Kankakee and northern Iroquois Counties in 1988. Most of the complainants lived in the major-impact area near Papineau, Leesville, and Hopkins Park. By October 1988 detailed investigations had been conducted on 71 of these complaints. Of them, 25 pertained to Silurian Dolomite wells, 37 pertained to shallow sand-and- gravel wells, and 9 were fictitious. Remedial action to reestablish water supplies was taken by the owners of 4 dolomite wells and 4 sand-and-gravel wells. Remediation was accomplished by drilling new wells, deepening existing bedrock wells, or lowering pump intakes.

In numerous cases, particularly for dolomite wells, the interrupted water supply could be reestablished by lowering the pump intake. Many dolomite wells with water supply problems may have water levels below the pump intake but above the bottom of the well In cases where the water level in the dolomite is near the bottom of the well, the only alternatives are to drill the existing well deeper, drill a new bedrock well, or, if a shallow sand-and-gravel aquifer is present, to drill a shallow sand-and-gravel well

Many well owners, particularly those with sand-point wells, may not have the option of lowering their pump intakes. Sand-point wells typically use suction lift pumps, which have an average lift of 20 to 25 feet. If water levels drop below the range of the suction lift, loss of water supply results. The small diameter of these wells generally prohibits the use of pumps with greater lift, such as deep-well jets or submersible pumps.

Reduced water levels in wells and resulting supply interruptions can be traced to several factors. Lowered water levels in an aquifer may have been caused by overpumping, well interference, drought, or any combination of the three. Each of these three factors is discussed below.

Overpumping occurs when one or more wells withdraw more water from an aquifer than can be replenished (recharged) on a long-term basis. Prior to summer 1988, only minor overpumping of the Silurian Dolomite aquifer had occurred in the study area. Although the potentiometric surface of the dolomite aquifer declines regionally during each irrigation season, it had recovered to near-normal levels during the recharge period each fall, winter, and spring. This was not the case in 1988. During the drought of 1988 the potentiometric surface of the dolomite aquifer dropped to the lowest levels ever recorded; water levels were near or below the top of the Silurian Dolomite over a large area of southeastern Kankakee and northeastern Iroquois Counties. Recharge of the dolomite aquifer in this area was insufficient to allow the potentiometric surface to recover fully in 1989.

Water levels in a well may also be lowered by well interference. When pumping wells are spaced relatively close to each other, the cones of depression of those wells often intersect. Thus, the total drawdown in a pumping well is the product of its own drawdown and the drawdowns caused by other pumping wells. The drawdowns in wells caused by withdrawals from other pumping wells are referred to as well interference. Interference between wells is a common occurrence. It becomes a problem only when the total drawdown in a well lowers the dynamic (pumping) water level below the level of the pump or well intake area. In the irrigated region of Kankakee and Iroquois Counties, well interference may account for many of the supply interruptions that occurred in wells deriving their water from the dolomite aquifer.

The third cause of reduced water levels is drought, an extended period during which precipitation is below normal. Drought primarily affects only shallow aquifers that depend on direct recharge from precipitation. Shallow wells drilled in surficial sand-and-gravel deposits are particularly subject to lowered water levels during drought. Many of the supply interruptions reported in the study area occurred with shallow sand-point wells with suction lift pumps. These shallow wells are very susceptible to drought, even though many of them would not be affected by irrigation withdrawals from the dolomite aquifer.

Ground-Water Management Options

Many persons hoped that the hydrogeologic studies conducted in Kankakee and Iroquois Counties in 1986 through 1988 would determine a number for the "safe yield" or "long-term sustained yield" of the dolomite aquifer. Historically, safe yield has been regarded as the amount of water that could be pumped regularly on a long-term basis without seriously depleting the storage reservoir (Fetter, 1980). Through spring 1988, no long-term or excessive depletion of the ground-water resource has been recorded in the irrigated region. The potentiometric surface generally remained above the top of the dolomite bedrock, and there were no significant long-term declines in water levels. However, during the drought of 1988, water levels dropped to record seasonal lows, and water levels were at or below the top of the dolomite over an area of up to 20 square miles.

A safe yield for the dolomite aquifer will vary under different patterns of pumping and development. A high-capacity well in northeastern Iroquois County will cause significantly greater drawdowns than the same well located near St. Anne or near the Kankakee or Iroquois Rivers. More than 2.1 billion gallons of ground water were pumped from the dolomite aquifer for irrigation in 1987. Under the current pumping distribution, that amount can be withdrawn safely, without causing long-term declines or dewatering of the bedrock. The ground water that may be withdrawn from the dolomite in excess of that amount depends on how much seasonal drawdown is acceptable, especially in the high-impact area.

Because of the general lack of consensus regarding a safe yield, the term "optimal yield" is preferable for use in evaluating ground-water management in Kankakee and Iroquois Counties. The optimal yield must be determined by selecting the most favorable ground-water management scheme from a set of possible alternatives. From the optimization viewpoint, ground water has value only by virtue of its use. By the same token, the optimal management scheme is the one that best meets the economic and social objectives associated with the uses for the water (Freeze and Cherry, 1979). In Kankakee and Iroquois Counties this requires balancing the interests of all ground-water users. To achieve an optimal yield, management of the drilling and use of irrigation wells must be considered. Limits on the drilling of new wells may be needed in the area of the Kankakee-Iroquois County line between Leesville and St. Anne, where water levels experience the greatest seasonal drawdowns. Additional development might be permitted north of St. Anne and along the Kankakee River east of Momence, where regional drawdowns from irrigation withdrawals are less than 8 feet.

Before management options for eastern Kankakee and northern Iroquois Counties can be discussed, the purpose behind the aquifer management must be established. Following are several reasons why the dolomite aquifer should be managed:

1. To prevent long-term declines in the potentiometric surface of the Silurian and Devonian Dolomite aquifer.
2. To protect domestic and other wells from excessive regional drawdown and interferences from high-capacity wells.
3. To ensure ground-water quality in the region.
4. To allow for continued "reasonable use" and controlled development of the ground-water resource.
5. To plan for regional ground-water use in accordance with climatic conditions such as drought.

Many plans could be used for effective management of the ground-water resources of eastern Kankakee and northern Iroquois Counties, depending on the management goals set out. The amended Water Use Act of 1983 provides a mechanism for continued ground-water development and protection against long-term depletion of the resource. Central to this plan is the registration of all high-capacity wells and adherence to recommended well construction guidelines for rural domestic wells. The well construction guidelines are intended to promote construction of new wells capable of providing an uninterrupted water supply and to allow for reasonable development of the aquifer. Should a well meet the guidelines and fail to furnish its normal supply of water, a complaint is filed and an investigation of the problem is initiated. If the complaint is deemed valid, restrictions can be placed on the quantity of water extracted from any high-capacity well within the boundaries of the counties.

The amended Water Use Act of 1983 represents *reactive* management; no actions are taken to limit withdrawals from the aquifer until water supply interruptions begin. Several *proactive* alternatives should be considered to manage the ground-water resource:

1. Limit further development of ground water in areas highly susceptible to dewatering of the dolomite bedrock.

2. Institute a ground-water use fee based on the amount pumped. The fee would promote water conservation and provide a contingency fund for domestic well owners, who must either lower their pumps or drill new wells to remedy supply problems.

3. Establish a minimum ground-water elevation, such as the top of the dolomite bedrock, as a trigger mechanism for the initiation of ground-water use restrictions.

4. Establish a more stringent permit system for construction of new high-capacity wells in the management area. Uncontrolled development of new irrigation systems will certainly lead to overdevelopment of the ground-water resource. Well drilling permits for high-capacity wells must be evaluated on the basis of the intended amount and timing of ground-water use.

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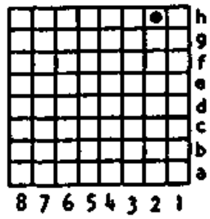
Appendix 1. Well Numbering System

Appendix 1. Well Numbering System

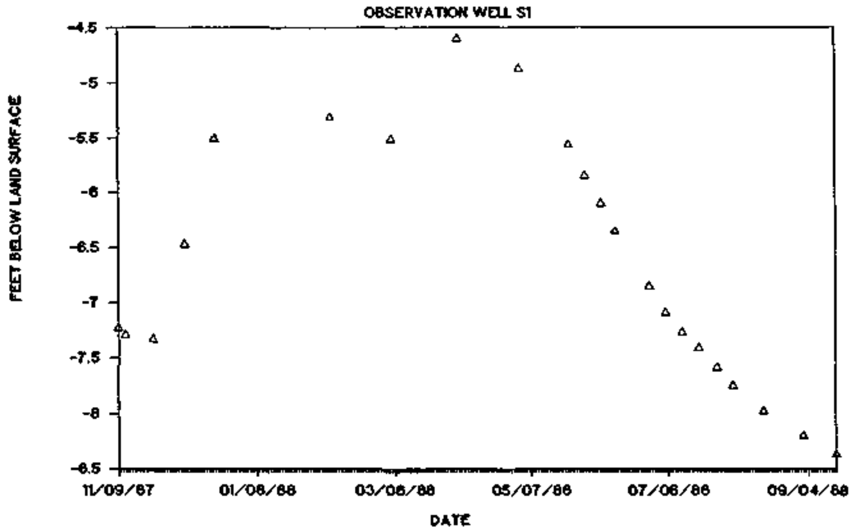
The well numbering system used in this report is based on the location of the well and uses the township, range, and section for identification. The well number may consist of up to five parts: county abbreviation, township, range, section, and coordinates within the section. Sections are divided into rows of 1/8-mile squares. Each 1/8-mile square contains 10 acres and corresponds to a quarter of a quarter of a quarter section. A normal section of one square mile contains eight rows of 1/8-mile squares; an odd-sized section contains more or fewer rows. Rows are numbered from east to west and lettered from south to north as shown below.

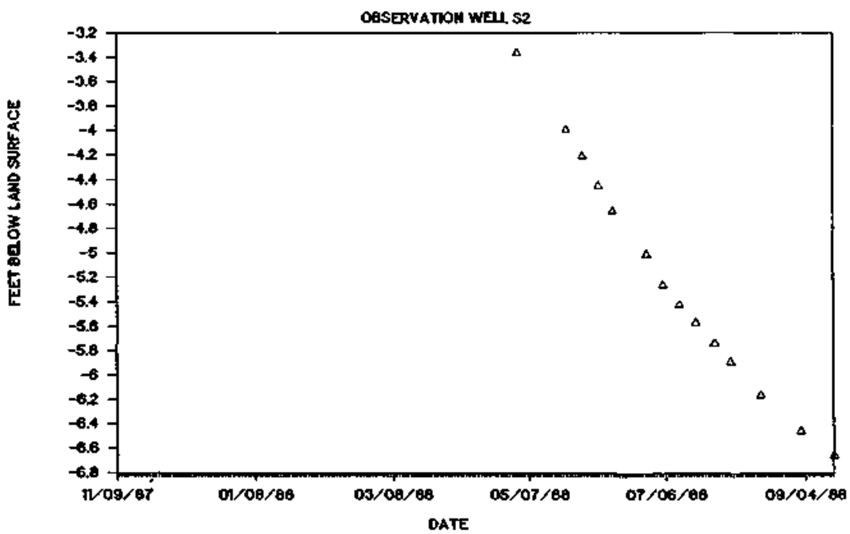
Iroquois County
Township 28N, Range 11W
Section 25

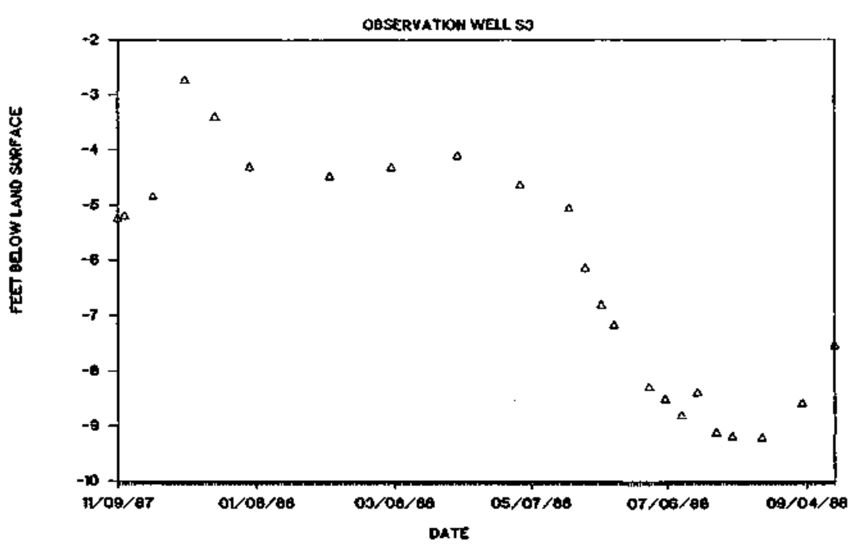


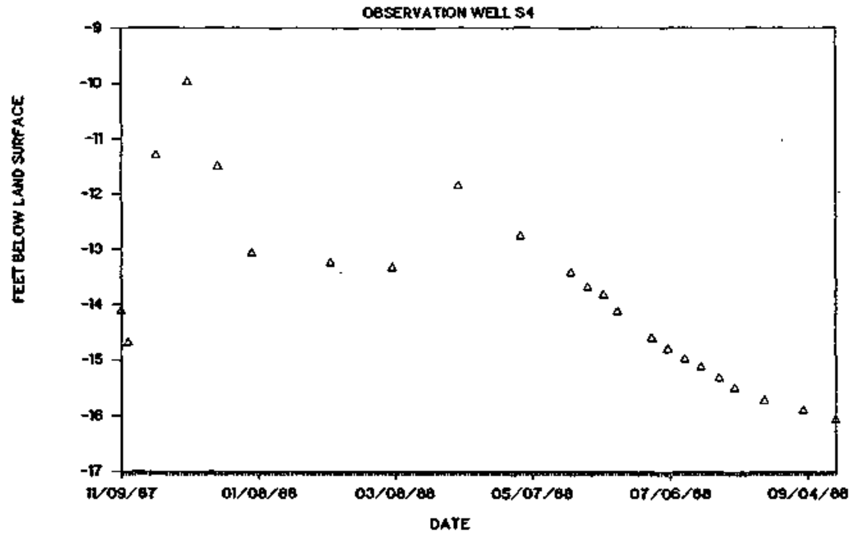
The number of the well above is IRO 28NllW25.2h. Abbreviations for counties discussed in this report are: Kankakee = KNK; Iroquois = IRO.

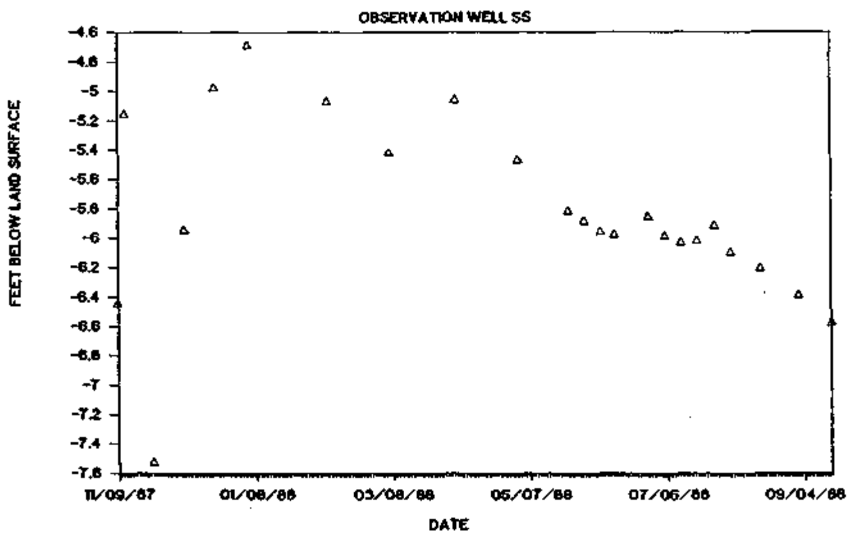
Appendix 2.
Hydrographs for Sand-and-Gravel Observation Wells S1-S8

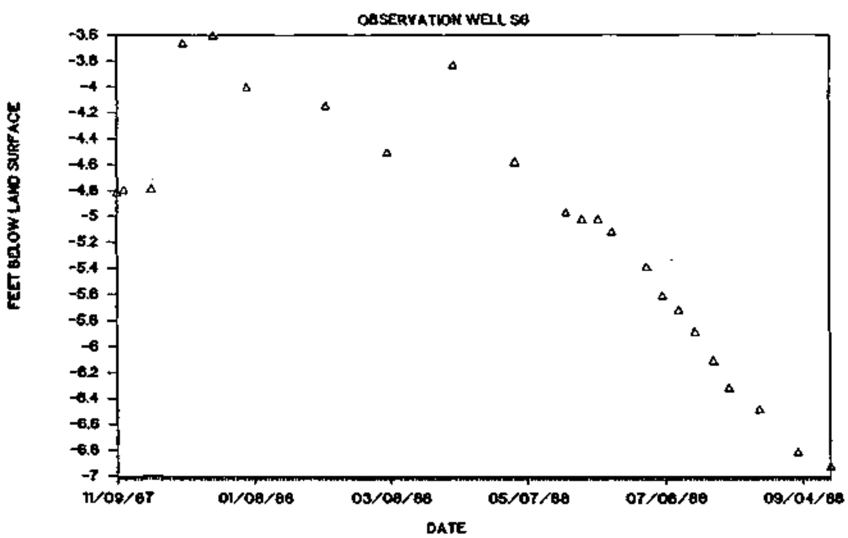

OBSERVATION WELL S1
FEET BELOW LAND SURFACE
-4.5
-5
-5.5
-6
-6.5
-7
-7.5
-8
-8.5
11/09/87
01/08/88
03/08/88
05/07/88
07/06/88
09/04/88
DATE

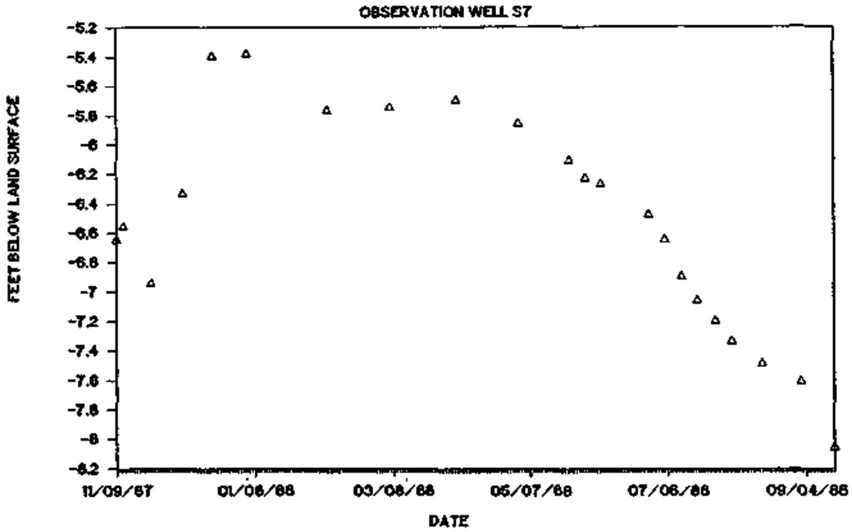

OBSERVATION WELL S2
FEET BELOW LAND SURFACE
-3.2
-3.4
-3.6
-3.8
-4
-4.2
-4.4
-4.6
-4.8
-5
-5.2
-5.4
-5.6
-5.8
-6
-6.2
-6.4
-6.6
-6.8
11/09/87
01/08/88
03/08/88
05/07/88
07/06/88
09/04/88
DATE

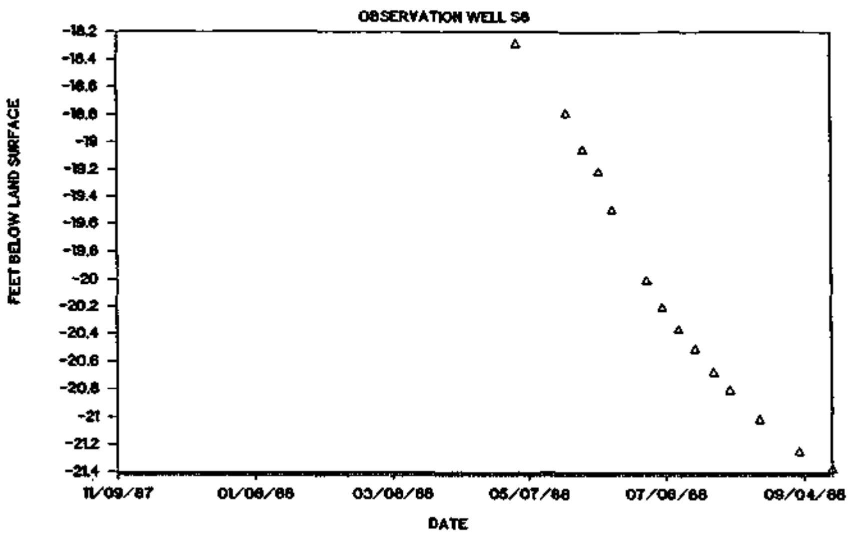

OBSERVATION WELL S3
FEET BELOW LAND SURFACE
-2
-3
-4
-5
-6
-7
-8
-9
-10
11/09/87
01/08/88
03/08/88
05/07/88
07/06/88
09/04/88
DATE


OBSERVATION WELL S4
FEET BELOW LAND SURFACE
-9
-10
-11
-12
-13
-14
-15
-16
-17
11/09/87
01/08/88
03/08/88
05/07/88
07/06/88
09/04/88
DATE

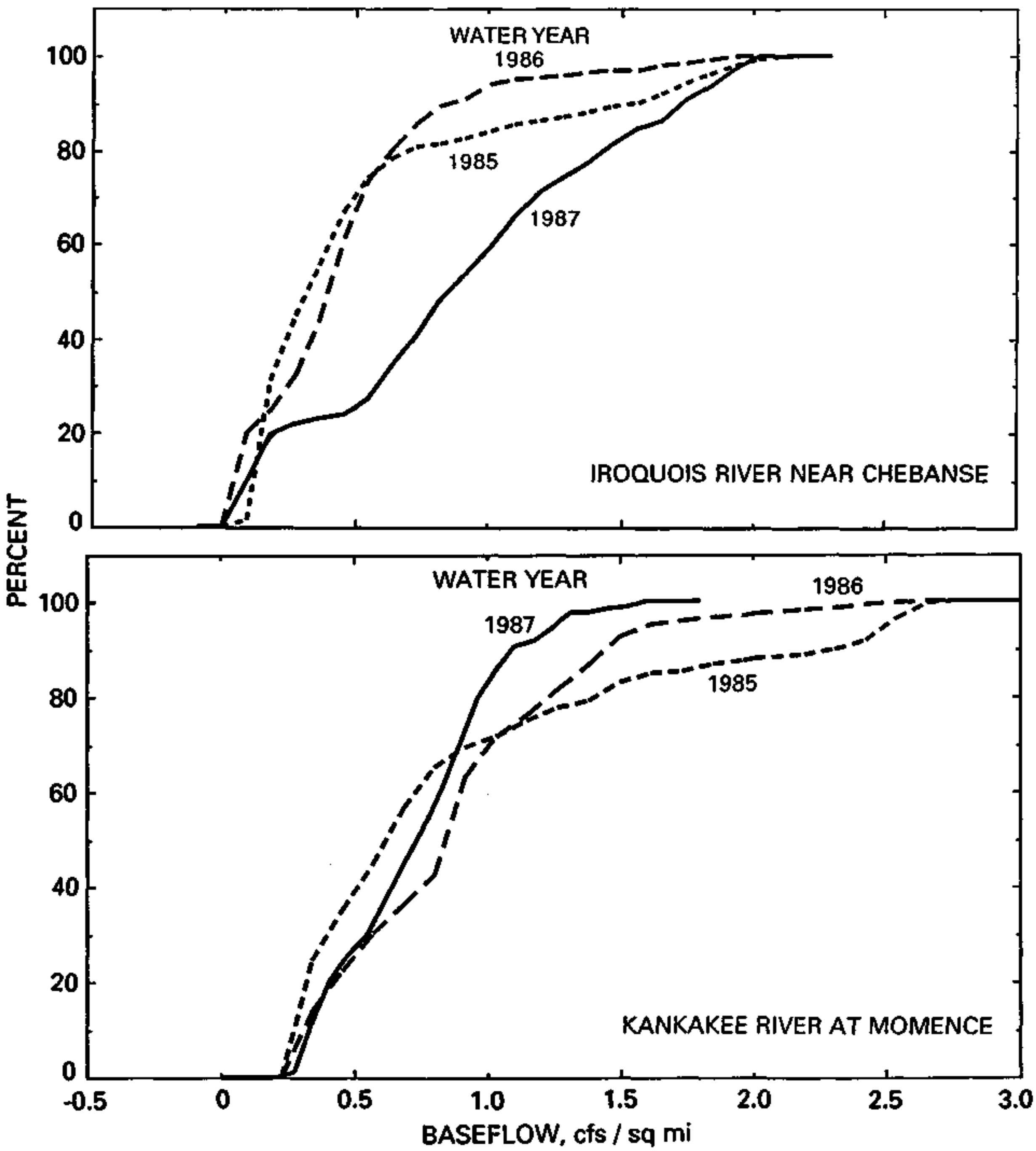

OBSERVATION WELL S5
FEET BELOW LAND SURFACE
-4.6
-4.8
-5
-5.2
-5.4
-5.6
-5.8
-6
-6.2
-6.4
-6.6
-6.8
-7
-7.2
-7.4
-7.6
11/09/87
01/08/88
03/08/88
05/07/88
07/06/88
09/04/88
DATE


OBSERVATION WELL S6
FEET BELOW LAND SURFACE
-3.6
-3.8
-4
-4.2
-4.4
-4.6
-4.8
-5
-5.2
-5.4
-5.6
-5.8
-6
-6.2
-6.4
-6.6
-6.8
-7
11/09/87
01/08/88
03/08/88
05/07/88
07/06/88
09/04/88
DATE

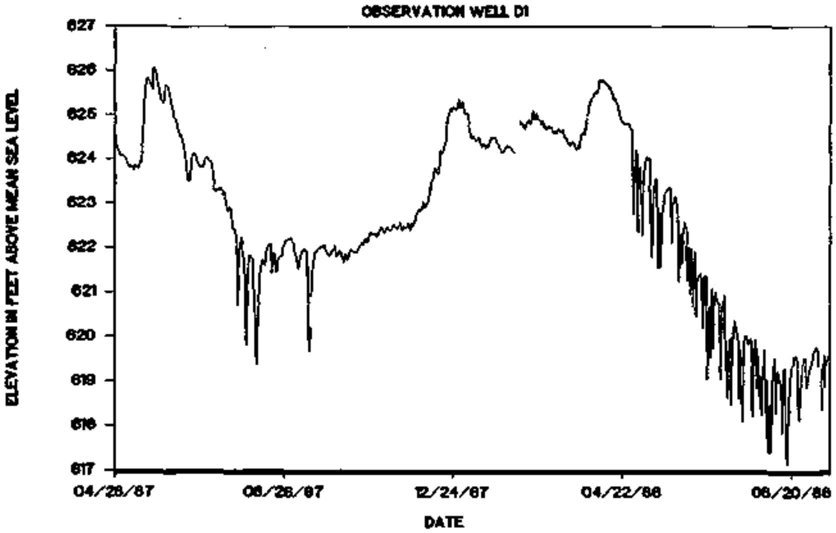

OBSERVATION WELL S7
FEET BELOW LAND SURFACE
-5.2
-5.4
-5.6
-5.8
-6
-6.2
-6.4
-6.6
-6.8
-7
-7.2
-7.4
-7.6
-7.8
-8
-8.2
11/09/87
01/08/88
03/08/88
05/07/88
07/06/88
09/04/88
DATE

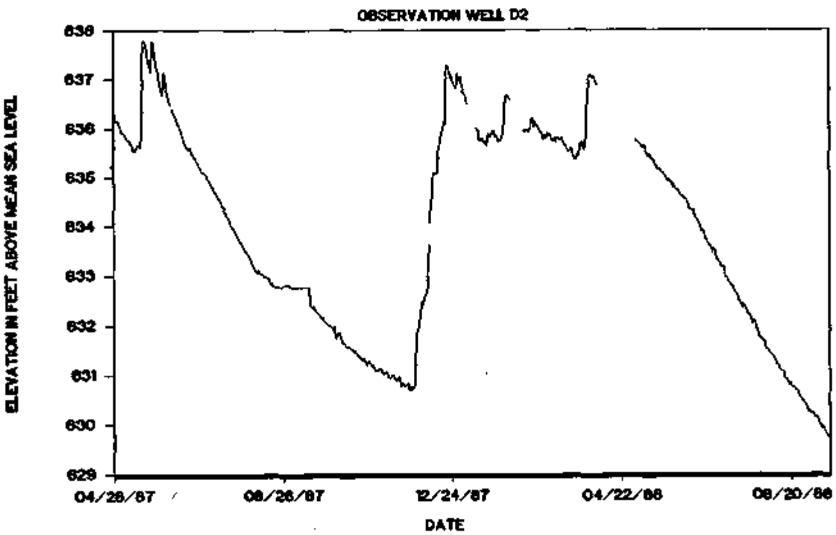

OBSERVATION WELL S8
FEET BELOW LAND SURFACE
-18.2
-18.4
-18.6
-18.8
-19
-19.2
-19.4
-19.6
-19.8
-20
-20.2
-20.4
-20.6
-20.8
-21
-21.2
-21.4
11/09/87
01/08/88
03/08/88
05/07/88
07/06/88
09/04/88
DATE

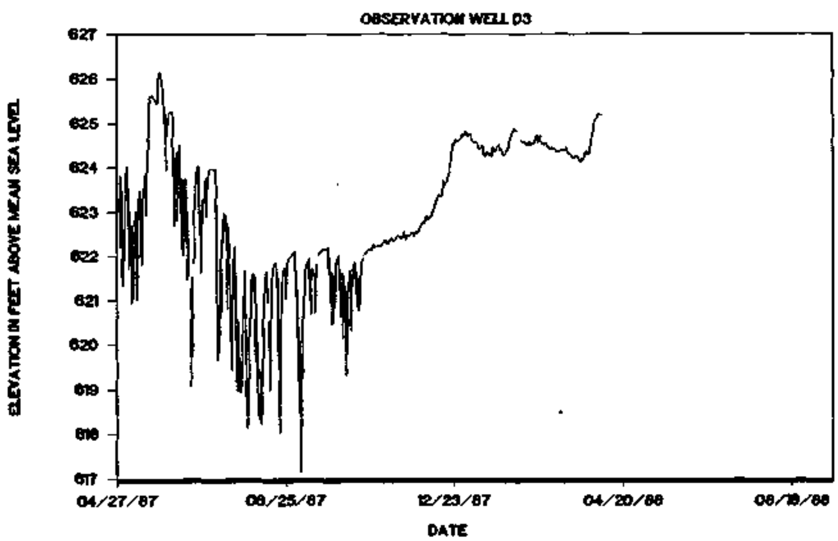
Appendix 3. Cumulative Relative Frequencies of Baseflow
for the Iroquois and Kankakee Rivers,
Water Years 1985, 1986, and 1987

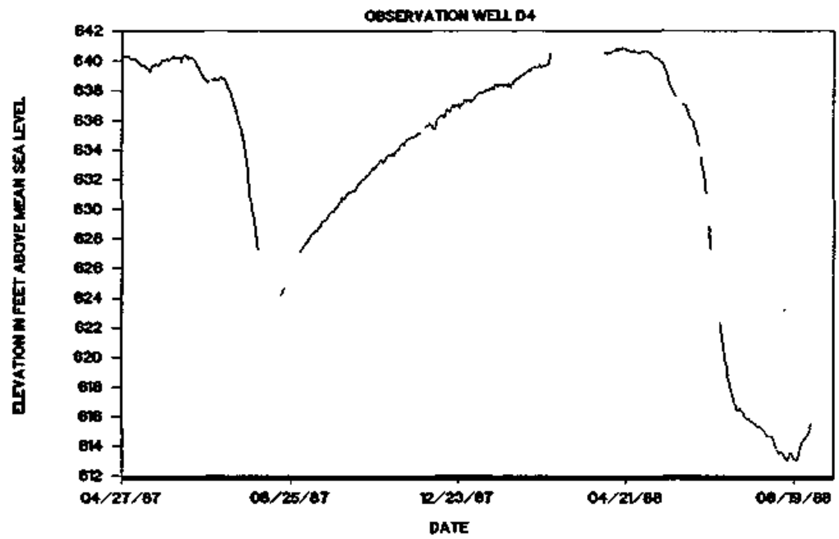

WATER YEAR
1986
1985
1987
IROQUOIS RIVER NEAR CHEBANSE
WATER YEAR
1986
1987
1985
KANKAKEE RIVER AT MOMENCE
PERCENT
100
80
60
40
20
0
-0.5
0
0.5
1.0
1.5
2.0
2.5
3.0
BASEFLOW, cfs / sq mi

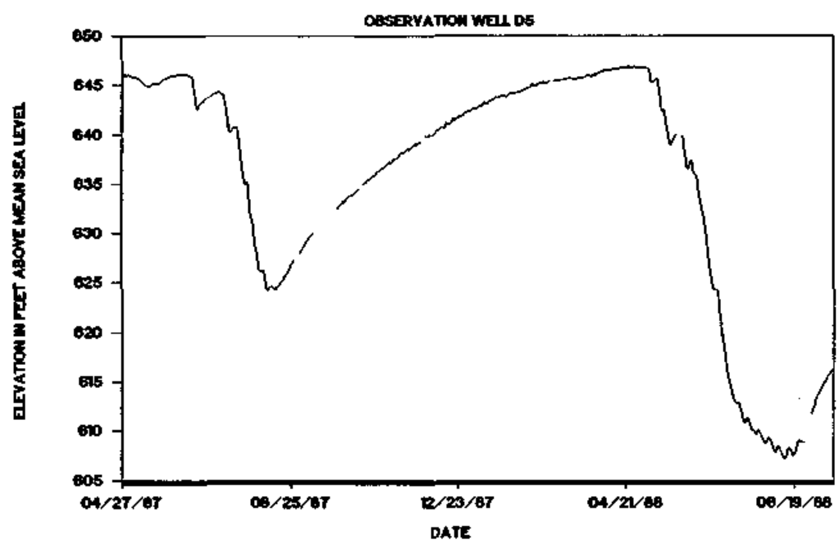
Appendix 4.
Hydrographs of Bedrock Observation Wells D1-D14

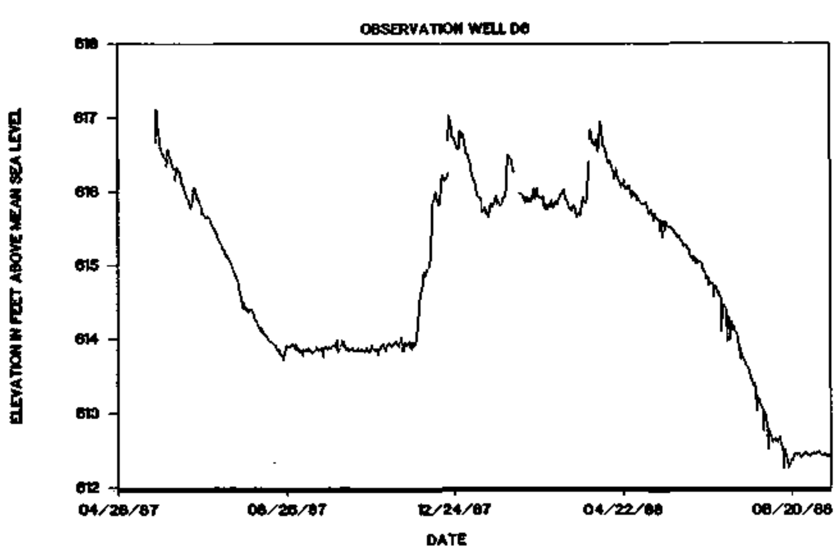

OBSERVATION WELL D1
ELEVATION IN FEET ABOVE MEAN SEA LEVEL
627
626
625
624
623
622
621
620
619
618
617
04/26/87
08/26/87
12/24/87
04/22/88
08/20/88
DATE

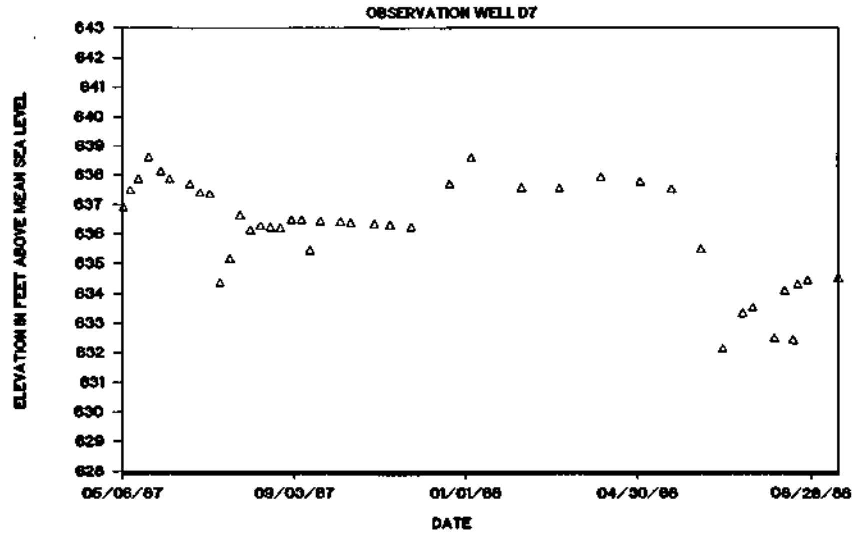

OBSERVATION WELL D2
ELEVATION IN FEET ABOVE MEAN SEA LEVEL
638
637
636
635
634
633
632
631
630
629
04/26/87
08/26/87
12/24/87
04/22/88
08/20/88
DATE

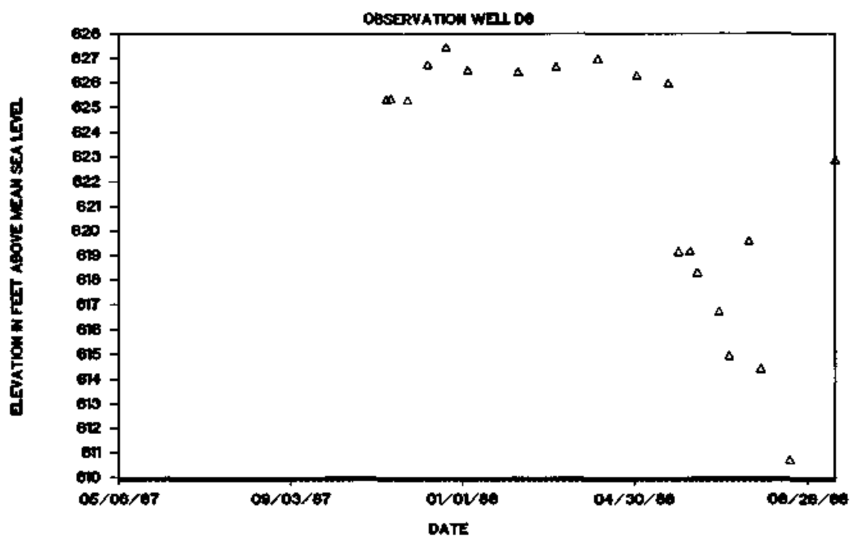

OBSERVATION WELL D3
ELEVATION IN FEET ABOVE MEAN SEA LEVEL
627
626
625
624
623
622
621
620
619
618
617
04/27/87
08/25/87
12/23/87
04/20/88
08/18/88
DATE

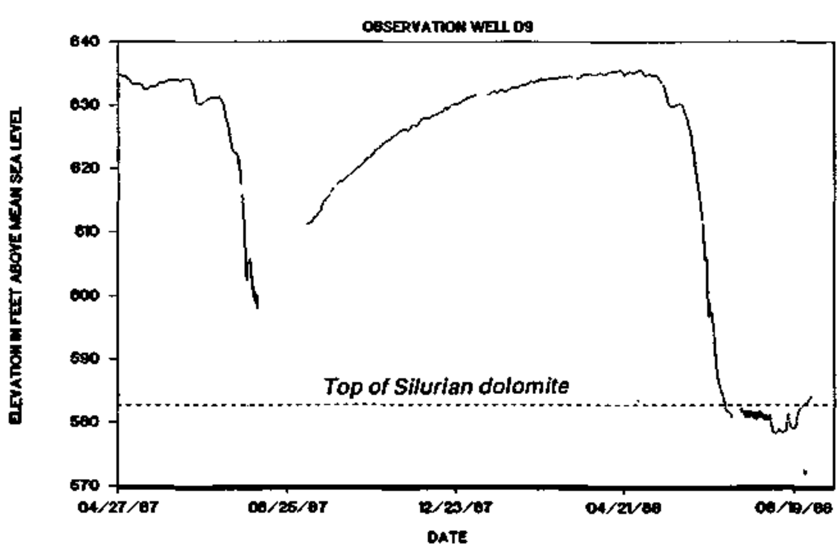

OBSERVATION WELL D4
ELEVATION IN FEET ABOVE MEAN SEA LEVEL
642
640
638
636
634
632
630
628
626
624
622
620
618
616
614
612
04/27/87
08/25/87
12/23/87
04/21/88
08/19/88
DATE

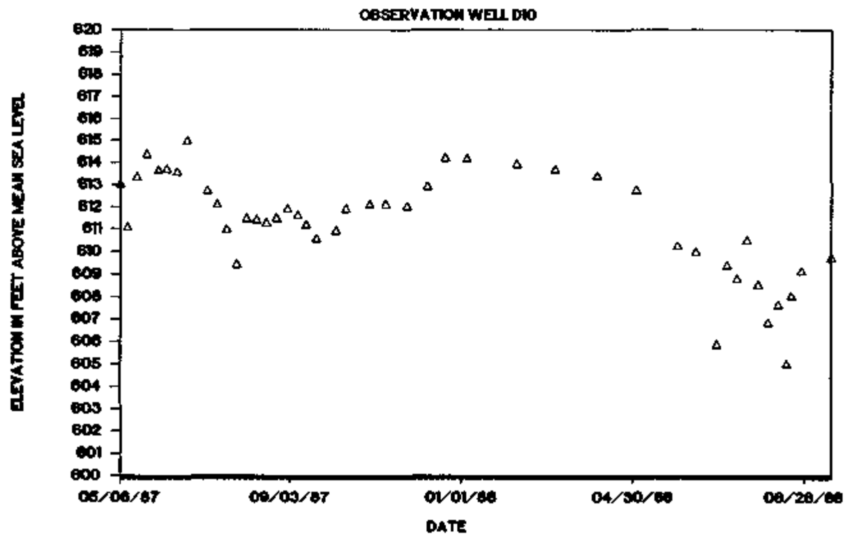

OBSERVATION WELL D5
ELEVATION IN FEET ABOVE MEAN SEA LEVEL
650
645
640
635
630
625
620
615
610
605
04/27/87
08/25/87
12/23/87
04/21/88
08/19/88
DATE

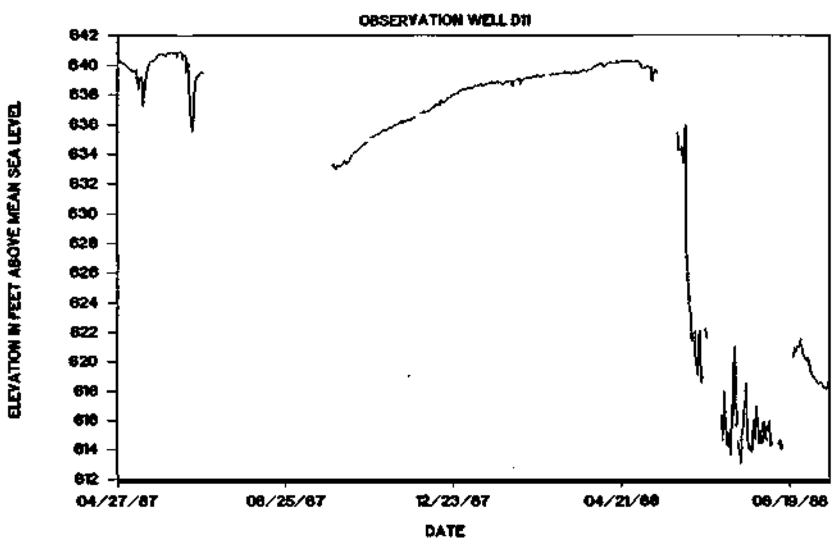

OBSERVATION WELL D6
ELEVATION IN FEET ABOVE MEAN SEA LEVEL
618
617
616
615
614
613
612
04/26/87
08/26/87
12/24/87
04/22/88
08/20/88
DATE

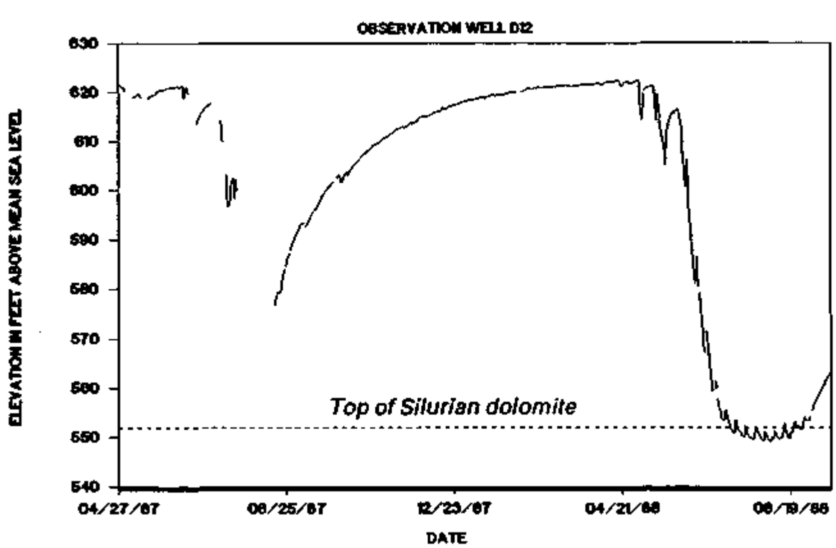

OBSERVATION WELL D7
ELEVATION IN FEET ABOVE MEAN SEA LEVEL
643
642
641
640
639
638
637
636
635
634
633
632
631
630
629
628
05/06/87
09/03/87
01/01/88
04/30/88
08/28/88
DATE

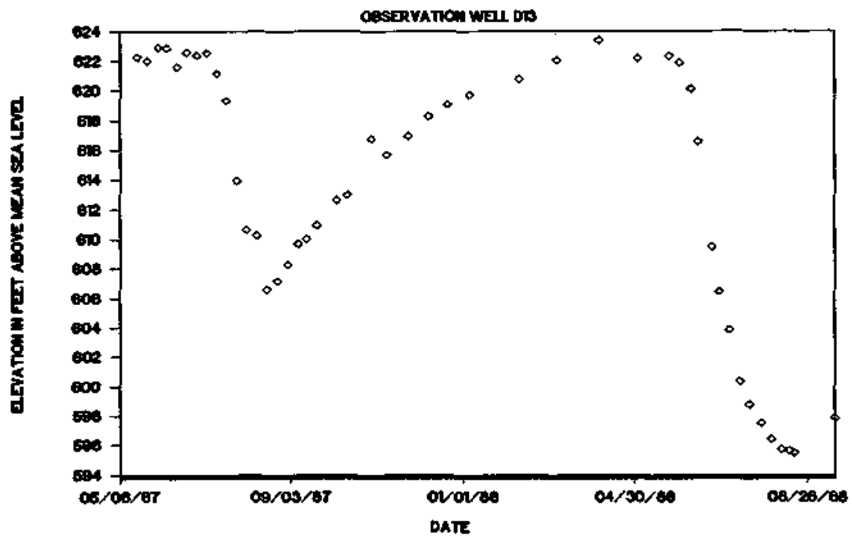

OBSERVATION WELL D8
ELEVATION IN FEET ABOVE MEAN SEA LEVEL
628
627
626
625
624
623
622
621
620
619
618
617
616
615
614
613
612
611
610
05/06/87
09/03/87
01/01/88
04/30/88
08/28/88
DATE


OBSERVATION WELL D9
ELEVATION IN FEET ABOVE MEAN SEA LEVEL
640
630
620
610
600
590
580
570
Top of Silurian dolomite
04/27/87
08/25/87
12/23/87
04/21/88
08/19/88
DATE


OBSERVATION WELL D10
ELEVATION IN FEET ABOVE MEAN SEA LEVEL
620
619
618
617
616
615
614
613
612
611
610
609
608
607
606
605
604
603
602
601
600
05/06/87
09/03/87
01/01/88
04/30/88
08/28/88
DATE


OBSERVATION WELL D11
ELEVATION IN FEET ABOVE MEAN SEA LEVEL
642
640
638
636
634
632
630
628
626
624
622
620
618
616
614
612
04/27/87
08/25/87
12/23/87
04/21/88
08/19/88
DATE


OBSERVATION WELL D12
ELEVATION IN FEET ABOVE MEAN SEA LEVEL
630
620
610
600
590
580
570
560
550
540
Top of Silurian dolomite
04/27/87
08/25/87
12/23/87
04/21/88
08/19/88
DATE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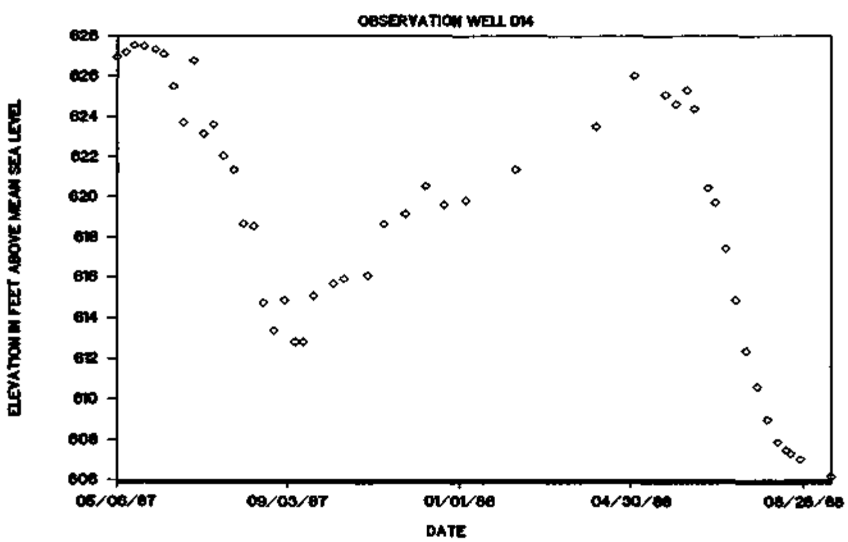
ELEVATION IN FEET ABOVE MEAN SEA LEVEL
624
622
620
618
616
614
612
610
608
606
604
602
600
598
596
594
05/06/87
09/03/87
01/01/88
04/30/88
08/28/88
DATE


OBSERVATION WELL D14
ELEVATION IN FEET ABOVE MEAN SEA LEVEL
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09/03/87
01/01/88
04/30/88
08/28/88
DATE

Appendix 5. Chemistry of Water Samples from Wells in the Unconsolidated and Dolomite Aquifers of Eastern Kankakee and Northern Iroquois Counties

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Explanation: Dissolved constituents and hardness are given in milligrams per liter. Well depth is given in feet. Aquifer abbreviations are as follows: Sil = Silurian Dolomite; Dev = Devonian Limestone; unc = unconsolidated deposits. Results of 0.0 indicate that concentration was below method detection limit.

Location	Date	Lab Analysis	Aquifer	Well Depth	Fe	Ca	Mg	Mn	Na	SO4	Cl	NO3	Fl	Alkalinity	TDS	Hardness	PH
28N 11W 1 1B	6 0 39	1-0085888	Sil	181	0.10	59	25.4	-	35.0	-	22.0	1.4	-	302	370	252	-
28N 11W 20 6B	2 0 71	1-0184989	Dev	253	0.30	41	19.5	-	-	-	34.0	0.8	-	264	319	184	-
28N 11W 20 6C	2 0 71	1-0184990	Dev	230	0.10	48	24.8	-	-	-	32.0	0.6	-	272	332	224	-
28N 11W 28 6F	5 23 79	1-0210920	Dev	267	1.00	-	-	-	46.0	1.2	30.0	1.3	-	260	335	204	-
28N 11W 28 8C	5 24 83	7-B039679	unc	130	0.74	34	17.1	0.0	65.0	10.0	28.0	-	0.73	256	348	149	8.1
28N 11W 30 3H	7 0 66	1-0169203	Dev	210	0.20	-	-	-	-	-	29.0	1.2	0.60	232	304	136	-
28N 12W 1 5A	7 25 74	1-0196418	Sil	287	2.60	-	-	-	-	-	37.0	-	-	472	537	262	-
28N 12W 2 1E	5 21 74	1-0195709	unc	110	1.20	-	-	-	-	-	21.0	-	-	290	333	178	-
28N 12W 8 1A	3 21 75	1-0198134	Sil	169	4.60	-	-	-	-	-	38.0	-	-	372	428	290	-
28N 12W 8 1G	8 0 66	1-0169532	Sil	110	4.40	-	-	-	-	-	42.0	-	-	316	406	236	-
28N 12W 11 4A	11 0 65	1-0167461	Sil	115	2.70	-	-	-	-	-	31.0	-	-	360	407	280	-
28N 12W 12 8H	5 0 70	1-0181556	Sil	150	11.0	-	-	-	-	-	29.0	-	-	476	508	312	-
28N 12W 16 6G	5 17 83	7-B038510	Sil	265	1.50	58	24.5	0.0	48.0	10.0	38.0	-	0.42	320	326	246	8.0
28N 12W 17 8G	8 0 65	1-0167035	Sil	160	1.60	-	-	-	-	-	45.0	-	-	324	398	244	-
28N 12W 21 8H	10 0 69	1-0179717	unc	82	1.00	-	-	-	-	-	25.0	-	-	260	332	178	-
28N 13W 1 5F	6 0 65	1-0166292	unc	56	1.40	-	-	-	-	-	24.0	-	-	288	326	228	-
28N 13W 1 5G	8 22 73	1-0193095	unc	90	0.80	-	-	-	-	-	27.0	-	-	306	344	240	-
28N 13W 11 1E	6 21 88	1-222625	Sil	200	0.41	27	10.8	0.05	73.8	2.1	16.2	0.3	0.90	250	325	111	8.0
28N 13W 16 8G	5 0 70	1-0181737	Sil	190	-	-	-	-	-	70.0	16.0	-	-	304	436	224	-
28N 13W 21 2G	8 0 67	1-0172790	Sil	130	4.30	-	-	-	-	3.0	146.	0.6	0.30	440	651	370	-
28N 13W 23 8H	10 0 62	1-0158889	unc	65	2.90	-	-	0.0	-	-	31.0	-	-	290	356	160	-
28N 13W 26 8D	10 0 62	1-0158888	Sil	134	33.0	-	-	0.1	-	-	71.0	-	-	496	644	346	-
28N 13W 27 4H	4 0 69	1-0177874	Sil	150	7.50	-	-	-	-	-	43.0	1.6	-	524	596	356	-
28N 10W 18 1E	4 15 87	1-222075	Sil	105	2.87	33	11.6	0.0	54.4	13.9	20.4	<0.2	0.40	228	277	132	6.9
29N 10W 18 2C	11 9 87	1-222230	Sil	200	0.56	27	9.6	0.0	61.6	8.1	17.1	<0.1	0.50	232	269	108	7.8
29N 10W 18 2E	11 9 87	1-222321	Sil	220	0.80	27	10.1	0.0	58.8	9.4	17.2	<0.1	0.50	229	272	110	7.9
29N 11W 14 3C	8 0 67	1-0172616	Sil	398	0.80	-	-	-	-	-	14.0	-	-	212	256	182	-

Location	Date	Lab Analysis	Aqui-fer	Well Depth	Fe	Ca	Mg	Mn	Na	SO4	Cl	NO3	Fl	Alkal-inity	TDS	Hard-ness	PH
29N 11W 16 4D	8 0 67	1-0172614	Sil	307	0.20	-	-	-	-	-	20.0	-	-	252	307	220	-
29N 11W 17 7E	8 0 67	1-0172617	Sil	180	0.10	-	-	-	-	-	16.0	-	-	232	297	200	-
29N 11W 20 2H	7 0 67	1-0172334	Sil	329	0.30	-	-	-	-	-	24.0	-	-	264	300	220	-
29N 11W 25 1A	11 23 77	1-0206876	unc	106	1.10	-	-	-	69.0	-	31.0	-	-	278	346	172	-
29N 11W 26 4A	5 0 70	1-0181742	unc	60	2.10	-	-	-	-	3.0	32.0	-	-	292	359	208	-
29N 12W 1 1D	9 30 87	1-222292	Sil	190	0.09	50	18.0	0.0	16.9	60.6	12.1	<0.1	0.40	173	279	201	7.7
29N 12W 4 4A	11 29 82	7-B018507	Sil	257	1.30	76	32.0	0.0	53.0	183.	2.6	-	0.45	256	526	304	8.0
29N 12W 16 5E	9 0 41	1-0091474	Sil	118	7.60	-	-	-	-	-	11.0	-	-	268	690	494	-
29N 12W 28 3E	5 0 70	1-0181643	unc	108	2.90	-	-	-	-	12.0	31.0	-	-	286	355	276	-
29N 12W 36 1C	5 16 83	7-B038211	Sil	203	3.20	57	24.4	0.1	48.0	20.0	29.0	-	0.51	290	314	223	7.9
29N 13W 17 8B	5 0 37	1-0080209	Sil	119	1.00	62	36.1	-	49.0	59.0	11.0	1.3	-	338	418	305	-
30N 10W 30 6C	7 0 68	1-0175558	unc	30	0.20	-	-	-	-	-	12.0	14.	-	136	351	256	-
30N 11W 9 5A	9 29 81	1-0216235	Sil	200	0.30	30	11.9	-	32.5	12.3	8.0	0.5	-	178	241	126	-
30N 11W 11 4E	12 22 81	1-0216524	Sil	455	0.79	69	26.1	-	19.9	10.0	1.0	0.5	-	315	313	282	-
30N 11W 20 1F	2 26 87	1-222011	Sil	210	0.55	32	12.0	0.0	24.4	21.4	9.6	<0.2	0.60	156	221	131	7.8
30N 11W 27 8H	6 25 80	1-0213908	Sil	150	0.30	-	-	0.0	29.5	-	3.0	0.3	0.60	200	210	130	-
30N 11W 28 4H	6 2 77	1-0206105	Sil	300	2.90	-	-	0.1	20.0	-	29.0	0.9	0.80	234	312	156	-
30N 11W 28 8H	2 26 87	1-222010	Sil	201	0.70	32	11.2	0.0	21.2	16.5	6.0	<0.2	0.50	150	204	127	7.9
30N 11W 28 8H	4 25 88	1-222531	Sil	450	0.44	33	11.8	<0.02	33.8	11.5	17.1	<0.1	0.70	181	131	230	7.7
30N 11W 28 8H	4 19 88	1-222521	Sil	445	0.18	27	10.9	<0.02	22.2	12.5	7.2	<0.1	0.60	163	177	112	8.1
30N 11W 31 2E	8 0 67	1-0172618	Sil	245	0.40	-	-	-	-	-	5.0	-	-	136	174	120	-
30N 11W 31 5A	7 0 67	1-0172333	Sil	257	0.30	-	-	-	-	-	8.0	0.8	0.50	184	208	156	-
30N 12W 1 5A	8 0 67	1-0172785	Sil	100	7.40	-	-	-	-	-	15.0	0.0	-	188	815	626	-
30N 12W 7 2G	2 4 72	1-0187679	Sil	320	0.40	-	-	-	-	-	-	0.4	-	128	165	132	-
30N 12W 8 5H	6 14 74	1-0195962	Sil	100	0.80	-	-	-	-	9.5	11.0	0.6	0.90	300	318	192	-
30N 12W 11 1F	7 0 64	1-0163405	Sil	87	1.70	-	-	-	-	-	4.0	0.0	-	282	336	292	-
30N 12W 15 7A	12 0 45	1-0104933	Sil	102	3.80	-	-	-	-	-	8.0	-	-	166	333	287	7.3
30N 12W 20 4B	10 0 64	1-0164403	unc	20	0.40	-	-	-	-	-	8.0	0.8	-	188	360	284	-
30N 12W 22 4G	12 0 45	1-0104932	unc	15	1.50	-	-	-	-	-	8.0	-	-		211	166	-
30N 12W 22 5C	11 4 87	1-222317	Sil	127	1.51	87	22.0	0.1	13.4	145.	36.5	<0.1	0.30	174	455	309	7.4
30N 12W 24 4F	4 0 64	1-0162517	Sil	169	0.40	-	-	-	-	-	1.0	-	-	152	180	156	-

Location	Date	Lab Analysis	Aquifer	Well Depth	Fe	Ca	Mg	Mn	Na	SO4	Cl	NO3	Fl	Alkalinity	TDS	Hardness	PH
30N 12W 26 8E	12 0 45	1-0104934	Sil	185	0.40	-	-	-	-	-	6.0	-	-	102	142	112	7.5
30N 13W 4 1H	4 25 82	1-0217037	Sil	120	0.32	66	45.2	-	23.4	-	1.0	0.5	-	361	390	352	-
30N 13W 4 3B	7 0 40	1-0088365	Sil	100	0.10	94	69.8	-	-	118.	8.0	-	-	454	633	523	7.0
30N 13W 4 3G	5 0 67	5-0171538	Sil	203	0.80	83	25.4	-	13.0	65.0	28.0	0.3	0.10	232	388	312	-
30N 13W 4 5C	7 0 40	1-0088366	Sil	100	0.10	-	-	-	-	-	4.0	-	-	430	571	477	6.9
30N 13W 5 7G	8 0 45	1-0103951	Sil	210	0.60	129	64.0	-	-	-	25.0	-	-	384	697	585	-
30N 13W 14 6A	7 0 50	1-0122329	Sil	181	0.20	-	-	-	-	-	12.0	-	-	328	397	137	-
30N 13W 14 6B	11 3 82	7-B014118	Sil	432	0.01	82	52.0	0.0	21.0	102.	22.0	-	0.30	347	504	397	7.5
30N 13W 14 7E	3 8 76	7-A015386	Sil	299	0.70	68	41.0	0.1	8.5	75.0	13.0	-	0.50	280	400	338	7.5
30N 13W 14 8B	5 0 57	5-0143470	Sil	182	0.20	84	43.1	-	24.0	124.	27.0	3.1	0.30	272	483	388	-
30N 13W 14 8C	7 0 40	1-0088363	Sil	76	0.10	167	43.7	-	-	165.	79.0	-	-	298	776	597	7.1
30N 13W 14 8D	7 0 40	1-0088362	Sil	90	0.00	152	349.	-	-	198.	55.0	-	-	270	730	577	7.1
30N 13W 14 8D	12 0 45	1-0105016	Sil	175	0.90	-	-	-	-	-	7.0	-	-	276	336	270	-
30N 13W 15 7E	6 0 50	1-0121818	Sil	88	0.30	-	-	-	-	60.0	3.0	-	-	268	347	334	-
30N 13W 20 1C	6 0 61	1-0155027	Sil	148	0.90	-	-	-	-	-	1.0	0.8	0.40	316	340	324	-
30N 13W 23 7D	2 0 46	1-0105550	Sil	152	2.10	-	-	-	-	88.0	20.0	-	-	208	353	326	-
30N 13W 25 8G	8 0 67	1-0172784	Sil	520	0.90	-	-	-	-	-	6.0	-	-	324	368	258	-
31N 12E 5 4A	12 0 69	5-0180200	Sil	150	4.20	-	-	0.1	-	-	10.0	0.3	0.20	364	498	450	-
31N 12E 8 6H	5 0 35	1-0076097	Sil	185	1.20	115	56.6	-	90.0	247.	120.	14.	-	278	807	522	-
31N 12E 9 4H	2 0 58	1-0145739	Sil	65	0.00	-	-	-	-	-	15.0	28.	-	330	511	480	-
31N 12E 20 1G	1 0 72	1-0187476	Sil	310	0.10	30	13.6	-	-	-	6.0	-	1.20	408	500	132	-
31N 12E 21 4A	4 0 40	1-0087619	unc	26	0.40	59	33.0	-	-	66.0	1.0	-	-	222	322	284	7.3
31N 12E 21 4G	6 0 64	5-0163071	Sil	279	0.30	-	-	0.1	-	-	12.0	1.1	0.50	320	485	424	-
31N 12E 21 8A	5 0 65	1-0166013	Sil	85	0.10	-	-	-	-	-	11.0	8.7	-	296	408	348	-
31N 12E 28 7C	7 0 68	1-0175690	Sil	315	0.10	120	51.0	-	-	162.	80.0	0.6	0.20	284	613	508	-
31N 12E 28 8C	7 0 68	1-0175691	Sil	310	0.60	112	51.0	-	-	187.	31.0	0.6	0.20	308	605	488	-
31N 12E 29 4D	4 0 43	1-0095981	Sil	212	0.00	107	353.	-	69.0	221.	28.0	-	-	264	601	486	6.9
31N 12E 29 5E	11 0 47	1-0112690	Sil	340	0.20	82	41.0	-	48.0	178.	43.0	23.	0.20	216	580	376	-
31N 12E 32 1G	4 0 47	1-0109812	Sil	90	0.10	-	-	-	-	263.	18.0	-	-	284	744	552	-
31N 12E 33 4G	7 0 46	1-0106903	Sil	300	0.20	-	-	-	-	43.0	4.0	-	-	312	350	290	7.0
31N 12E 33 4H	12 0 59	1-0151119	Sil	325	0.20	99	55.3	0.0	32.0	170.	52.0	38.	0.20	288	635	476	-

Location	Date	Lab Analysis	Aquifer	Well Depth	Fe	Ca	Mg	Mn	Na	SO4	Cl	NO3	Fl	Alkalinity	TDS	Hardness	PH
31N 12E 33 6C	2 0 67	1-0170774	Sil	202	5.20	-	-	-	-	-	40.0	0.9	-	368	668	524	-
31N 12E 34 2A	4 0 40	1-0087730	Sil	106	0.20	75	33.3	-	-	28.0	1.0	-	-	360	390	326	7.2
31N 12E 34 2A	4 0 40	1-0087620	Sil	110	1.60	-	-	-	-	42.0	1.0	-	-	352	412	358	7.1
31N 12E 34 3E	5 0 37	1-0080223	Sil	53	0.20	74	38.5	0.1	5.0	10.0	2.0	-	-	344	357	345	-
31N 12E 35 -0	3 30 78.	7-C003226	Sil	320	0.40	96	48.0	0.0	30.0	146.	13.0	-	0.80	360	584	438	8.0
31N 13E 13 3D	5 12 82	7-B045101	Sil	175	0.01	77	136.	0.0	11.0	86.0	26.0	-	0.22	236	410	337	7.7
31N 13E 24 1G	7 22 71	7-0000483	Sil	135	0.30	96	42.0	0.1	16.0	125.	36.0	4.4	0.30	256	-	404	-
31N 13E 24 7G	11 6 87	1-222318	Sil	200	0.09	64	32.8	0.0	3.5	82.2	15.0	2.2	0.30	217	352	297	7.6
31N 13E 24 7G	2 23 88	1-222435	Sil	200	<0.09	60	34.1	<0.01	3.6	89.8	18.1	<0.1	0.30	210	351	289	7.7
31N 13E 33 3B	4 4 77	1-0204717	Sil	123	5.30	-	-	0.1	-	-	72.0	0.9	0.30	274	518	424	-
31N 13E 33 5D	1 31 84	7-B029334	Sil	475	0.91	75	33.0	0.0	14.0	117.	23.0	-	0.50	220	460	321	7.8
31N 13E 36 5H	11 0 39	1-0086747	Sil	113	1.20	146	17.9	-	32.0	127.	207.	1.3	-	330	685	808	-
31N 14E 2 8H	4 0 64	1-0162694	Dev	540	6.00	-	-	-	-	-	6.0	0.6	-	426	616	572	-
31N 14E 5 5H	8 14 72	7-0097724	Sil	83	0.00	72	54.3	-	5.0	66.0	24.0	44.	0.10	278	516	-	-
31N 14E 7 7D	7 0 63	1-0160652	Sil	173	1.40	-	-	-	-	-	4.0	-	-	296	433	376	7.3
31N 14E 18 4A	5 12 82	7-B045103	Sil	135	0.01	75	38.4	0.0	9.0	83.0	22.0	-	0.27	230	486	330	7.6
31N 14E 18 5A	6 0 47	5-0110831	Sil	150	1.00	98	39.6	0.0	7.0	118.	14.0	-	0.10	260	455	411	7.0
31N 14E 19 1A	5 0 37	1-0080124	Sil	205	0.00	95	348.	-	16.0	91.0	18.0	66.	-	386	503	438	-
31N 14E 19 7D	5 12 82	7-B045104	Sil	150	0.31	77	40.5	0.0	9.0	87.0	26.0	-	0.54	268	481	350	7.6
31N 14E 19 7H	8 0 47	1-0111373	Sil	100	0.10	-	-	-	-	-	16.0	-	-	268	429	387	6.9
31N 14E 33 4H	3 0 70	1-0180895	Sil	390	0.40	-	-	-	-	-	18.0	0.4	-	492	574	444	-

Appendix 6.
Amended Water Use Act of 1983

WATER USE ACT OF 1983

(Illinois Revised Statutes, ch. 5, par. 1601 et seq.)

AN ACT to create the "Water Use Act of 1983". P.A. 83-700, approved Sept. 23, 1983, eff. Jan. 1, 1984.

1601. Short title

Section 1. This Act shall be known and may be cited as the "Water Use Act of 1983".

1602. Declaration of Policy

Section 2. Declaration of Policy. The General Assembly declares it to be in the public interest to better manage and conserve water, to establish a mechanism for restricting withdrawals of groundwater in emergencies, and to provide for public notice of planned substantial withdrawals of water after the effective date of this Act from new points of withdrawal before water is withdrawn.

Amended by P.A. 85-483, eff. Sept. 17, 1987.

1603. Purpose

Section 3. Purpose. The general purpose and intent of this Act is to establish a means of reviewing potential water conflicts before damage to any person is incurred and to establish a rule for mitigating water shortage conflicts by:

(a) Providing authority for County Soil and Water Conservation Districts to receive notice of incoming substantial users of water.

(b) Authorizing Soil and Water Conservation Districts to recommend restrictions on withdrawals of groundwater in emergencies.

(c) Establishing a "reasonable use" rule for groundwater withdrawals.

The requirements of Section 5 and 5.1 of this Act shall not apply to the region governed by the provisions of "An Act in relation to the regulation and apportionment of water from the Lake Michigan watershed", approved June 18, 1929, as amended.

Amended by P.A. 85-1330, eff. Aug. 31, 1988.

1604. Definitions

Section 4. Definitions. As used in this Act, unless the context otherwise requires:

(a) "Department" means the Illinois Department of Agriculture.

(b) "District" or "Soil and Water Conservation District" means a public body, corporate and political, organized under the "Soil and Water Conservation Districts Act".

(c) "Groundwater" means underground water which occurs within the saturated zone and geologic materials where the fluid pressure in the pore space is equal to or greater than atmospheric pressure.

(d) "Land occupier" or "occupier of land" includes any individual, firm or corporation, other than the owner, who is in legal possession of any land in the State of Illinois whether as a lessee, renter, tenant or otherwise.

(e) "Person" means any owner of land or the owners' designated agent including any individual, partnership, firm, association, joint venture, corporation, trust, estate, commission, board, public or private institution, unit of local government, school district, political subdivision of this state, state agency, any interstate body or any other legal entity.

(f) "Point of withdrawal" means that point at which underground water is diverted by a person from its natural state.

(g) "Reasonable use" means the use of water to meet natural wants and a fair share for artificial wants. It does not include water used wastefully or maliciously.

(h) "State" means the State of Illinois.

Amended by P.A. 85-1330, eff. Aug. 31, 1988.

1605. Water Conflict Resolution

Section 5. Water Conflict Resolution. In the event that a land occupier or person proposes to develop a new point of withdrawal, and withdrawals from the new point can reasonably be expected to occur in excess of 100,000 gallons on any day, the land occupier or person shall notify the District before construction of the well begins. The District shall in turn notify other local units of government with water systems who may be impacted by the proposed withdrawal. The District shall then review with the assistance of the Illinois State Water Survey and the State Geological Survey the proposed point of withdrawal's effect upon other users of the water. The review shall be completed within 30 days of receipt of the notice. The findings of such reviews shall be made public.

Amended by P.A. 85-1330, eff. Aug. 31, 1988.

1605.1 Groundwater Emergency Restrictions

Section 5.1. Groundwater Emergency Restrictions.

(a) East District within any county in Illinois through which the Iroquois River flows, and each District within any county in Illinois with a population in excess of 100,000 through which the Mackinaw River flows, is authorized to recommend to the Department of Agriculture restrictions on groundwater withdrawal as provided by this Section.

A land occupier or person who possesses land which contains a point of withdrawal that is capable of producing more than 100,000 gallons of water on any day shall register that point of withdrawal with the District and shall furnish such reasonable data in such form as may be required by the District.

(b) The District, with the assistance and approval of the Department of Agriculture, shall issue recommended guidelines for the construction of points of withdrawal and the type and setting of pumps for use in those points of withdrawal. Copies of the guidelines shall be made available from the District upon request.

(c) Within 2 working days after receiving a written complaint from a land occupier or a person whose point of withdrawal has failed to furnish its normal supply of water, the District shall schedule an on-site investigation. If the investigation discloses (1) that the point of withdrawal fails to furnish its normal supply of water, (2) that the failure is caused by a substantial lowering of the level of groundwater in the area, and (3) that the point of withdrawal and its equipment conform to the recommended guidelines of the District issued under subsection (b), the District may recommend to the Department of Agriculture that the Department restrict the quantity of water that a person may extract from any point of withdrawal within the District's boundaries which is capable of producing more than 100,000 gallons on any day. The restriction shall be expressed in gallons of water, may apply to one or more points of withdrawal within the District, and may be broadened or narrowed as appropriate. The restrictions shall be lifted as soon as justified by changed conditions.

(d) When a District determines that restriction of the withdrawal of water at a particular point within the District is necessary to preserve an adequate water supply for all residents in the District, the District may recommend to the Department of Agriculture that the Department restrict the quantity of water that may be extracted from any point of withdrawal within the District which is capable of producing more than 100,000 gallons of water on any day. The Department shall review the District's recommendation and if it agrees with such recommendation shall restrict the withdrawal of water within the District in accordance with subsection (c) and shall notify each land occupier or person who possesses land which contains a registered point of withdrawal affected by the restriction.

If the Department disagrees with the District's recommendation, it shall notify the District, the land occupier or the person who possesses land which contains a registered point of withdrawal affected by the recommendation and the complainant, giving the reason for the failure to affirm the recommendation. The Department may propose an alternate recommendation.

If the District, the respondent or the complainant disagrees with the decision of the Department, such person may request an administrative hearing to be conducted by the Department in accordance with the Administrative Procedure Act to show cause concerning its decision.

Final decisions of the Department pursuant to this Section may be appealed in accordance with the Administrative Review Law.

(e) The Department is authorized to promulgate rules and regulations, including emergency rules, for the implementation of this Amendatory Act of 1987. The Department may set the general policy for the Districts to follow in the administration of this Act.

Amended by P.A. 85-1330, eff. Aug. 31, 1988.

1605.2. Investigation and review - Entry upon land

Section 5.2. Investigation and review - Entry upon land. Persons investigating a complaint or conducting a review on behalf of the Department or District of the impact of a proposed or existing well that is required to be registered may enter upon private property for the purpose of conducting an investigation and may review any records pertaining to pumping data.

Added by P.A. 85-1330, eff. Aug. 31, 1988.

1606. Reasonable Use

Section 6. Reasonable Use. The rule of "reasonable use" shall apply to groundwater withdrawals in the State.

1607. Penalties

Section 7. Penalties. Any person who fails to register a point of withdrawal pursuant to subsection (a) of Section 5.1, or who fails to notify the District of a proposed new point of withdrawal pursuant to Section 5, or who fails to restrict withdrawals of water pursuant to subsection (b) of Section 5.1 shall be guilty of a petty offense. Any person who is convicted of a second or subsequent offense shall be guilty of a Class C misdemeanor.

Amended by P.A. 85-483, eff. Sept. 17, 1987.