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Report 123

Meeting the Growing Demand for Water:
An Evaluation of the Shallow Ground-Water Resources in Will and Southern Cook Counties, Illinois

by
George S. Roadcap, Stuart J. Cravens,
and Edward C. Smith

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MEETING THE GROWING DEMAND FOR WATER: AN EVALUATION OF THE SHALLOW GROUND-WATER RESOURCES IN WILL AND

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RESEARCH REPORT 123

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George S. Roadcap, Stuart J. Cravens,
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Abstract: This study evaluates the heavily used shallow aquifer system in Will and southern Cook Counties and ascertains its ability to meet the present and future water supply needs of the communities it serves. The hydrogeologic evaluation involves an examination of existing data to determine the aquifer's geologic and hydraulic properties as well as the amount of water withdrawn from the aquifer. New data are used to determine ground-water flow directions, existing aquifer recharge rates, potential yield of the aquifer, and general ground-water quality.

Reference: Roadcap G.S., S.J. Cravens, and E.C. Smith. Meeting the Growing Demand for Water: An Evaluation of the Shallow Ground-Water Resources in Will and Southern Cook Counties, Illinois. Illinois State Water Survey, Champaign, Research Report 123, 1993.

Indexing Terms: Will County, Cook County, ground water, aquifer, geology, ground-water use, ground-water recharge, potential yield, water quality, Silurian dolomite aquifer.

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1993

ISSN 1059-826X

Funds derived from grants and contracts administered by the University of Illinois were used to produce this report.

This report was printed on recycled and recyclable papers.

Printed by authority of the Slate of Illinois (8-93-400)

Contents

MEETING THE GROWING DEMAND FOR WATER: AN EVALUATION OF THE SHALLOW GROUND-WATER RESOURCES IN WILL AND SOUTHERN COOK COUNTIES, ILLINOIS

by George S. Roadcap, Stuart J. Cravens, and Edward C. Smith

ABSTRACT

This study evaluates the heavily used shallow aquifer system in Will and southern Cook Counties and ascertains its ability to meet the present and future water supply needs of the communities it serves. The hydrogeologic evaluation involves an examination of existing data to determine the aquifer's geology and hydraulic properties, as well as the amount of water withdrawn from the aquifer. New data gathered for the project include 429 water-level measurements and 186 chemical samples. The new data are used to determine ground-water flow directions, existing aquifer recharge rates, potential yield of the aquifer, and general ground-water quality.

The shallow aquifer system in Will and southern Cook Counties consists of Silurian-age dolomites overlain by Pleistocene-age glacial drift. The dolomites form a large wedge-shaped unit that thins to the west. Transmissivity values were calculated from specific-capacity tests and displayed in a log-normal distribution with a median of 11,800 gallons per day per foot. Sand-and-gravel layers in the glacial drift provide additional water to the shallow system and are thick enough west of Joliet to form a buried valley aquifer.

Ground-water pumpage from the shallow aquifer system totaled 32.52 million gallons a day (mgd) in 1990. The primary users included 56 public and private water utilities located mainly along the Will-Cook County line, several industrial wells, and thousands of individual private wells throughout the study area.

The potentiometric surface measured in the Silurian dolomite aquifer is strongly influenced by the topography and the presence of major rivers. Ground-water pumping centers also influence the surface by creating cones of depression and areas of diversion in the regional flow field. An analysis of the diversion areas reveals that the rate of ground-water recharge increases from roughly 25,000 gallons per day per square mile (gpd/mi^2) under natural conditions to 230,000 gpd/mi^2 in areas of very heavy ground-water pumpage.

The potential yield of the shallow aquifer system for a typical township in the study area is conservatively estimated to be 6.0 mgd, largely based on the calculated maximum recharge rate. Ground-water use in 1990 did not exceed the potential yield in any of the townships or diversion areas. Most of the communities should be able to continue using the aquifer at their expected growth rates well into the next century. Problem areas may develop west of the Des Plaines River where the transmissivity is low.

Water quality within the study area can generally be termed acceptable, although concentrations of some constituents, such as iron, sulfur, and hardness, are sufficiently high to give the ground water in some areas an unpleasant taste, odor, or color.

INTRODUCTION

Purpose and Scope

The purpose of this study is to evaluate the heavily used shallow aquifer system in Will and southern Cook Counties and to ascertain its ability to meet the present and future water supply needs of the communities it serves. With the expansion and population growth of suburban Chicago, many of the public water supplies developed from the shallow aquifers have become inadequate or undesirable, forcing many communities to use Lake Michigan as an alternate source of water. However, the amount of water being supplied from Lake Michigan has approached the maximum withdrawal rate determined for Illinois by a series of U.S. Supreme Court decisions. Therefore, the Illinois Department of Transportation, Division of Water Resources (IDOT/DWR), which is responsibile for overseeing the Lake Michigan allocation, must prudently balance the use of lake water with the use of ground water.

The shallow aquifer system in Will and southern Cook Counties is a vital resource. In 1990 it supplied drinking water for roughly one-third of the local population, or 290,000 of 901,000 residents. Approximately 206,000 of these residents were supplied from one of the 56 public and private water utilities that collectively used water from the aquifer at a rate of 22.35 million gallons per day (mgd). The other 84,000 residents live in rural areas supplied by individual domestic wells, which at average rural consumption rates would have used an additional 7.44 mgd. Of the total remaining 611,000 residents in the area covered by this report, 481,000 are supplied with Lake Michigan water, and 130,000 are supplied from the deep bedrock system known as the Cambrian-Ordovician aquifer.

Relatively little information is available about the geology and ground-water flow characteristics of the shallow aquifer system, except where past over-utilization problems have occurred in Chicago Heights and in the Hadley Valley east of Joliet. To obtain the necessary working knowledge of the aquifer's behavior and its development potential, an extensive program of data collection and analysis was undertaken. This process was divided into seven major steps, each having an accruing goal:

1. Define the geologic extent and character of the dolomites and glacial sands that constitute the aquifer system.
2. Calculate and describe the hydraulic characteristics of the aquifer system.
3. Survey all of the public and industrial water users to determine the location and quantity of ground-water pumpage.
4. Measure the potentiometric surface and relate it to pumpage, the bedrock surface, and historic water-level data.
5. Determine the amount of recharge to the aquifer and the potential yield.
6. Take water quality samples to examine trends in the ground-water chemistry of the aquifer system.
7. Synthesize all of the data to determine how the aquifer is being utilized and to identify any areas of over-development

Study Area

The study area (plate I) is located in northeastern Illinois, adjacent to the Illinois-Indiana state line, and comprises 1,095 square miles of Will County and the portion of Cook County south of the Calumet Sag (Cal Sag) Channel. The southwest corner of Will County has been largely excluded from hydraulic interpretations because the shallow aquifers are present only intermittently. Because the township lines do not have a true north-south orientation, study area maps may appear slightly skewed on the figures.

The topography of the study area is generally flat with very little relief, characteristic of the glaciated till plains throughout Illinois. Low rolling hills occur along moraines in the north-central and east-central portions. A large valley has developed along the Des Plaines River and at the west end of the Calumet Sag Channel. The lowest natural elevation is 504 feet above mean sea level (msl), where the Kankakee and Des Plaines Rivers exit the study area at the west edge. The highest point is 830 feet msl along Interstate 57 near Monee.

Land Use

Land use in the southern half of the study area is dominated by several small communities and agricultural uses (plate I). The northern half of the study area includes large established urban areas mixed with rapidly growing new areas expanding over prime agricultural land. These urban areas include the Joliet metropolitan area, the very southern tip of Chicago and all of its southernmost suburbs, and rapidly expanding southwestern suburbs such as Bolingbrook, New Lenox, Mokena, and Orland Park. The Joliet Arsenal is a U.S. Army ammunition plant that covers more than 40 square miles (mi^2) of southwestern Will County.

Forests are limited to steeply sloping areas adjacent to streams, county forest preserves, and abandoned strip mines. Barren areas shown on the land-use map are primarily quarries or landfills. The principal aggregate operations include several dolomite quarries along the Des Plaines River, the nation's largest dolomite quarry adjacent to Interstate 80 in Thornton, sand-and-gravel quarries around Plainfield, and a large expanse of coal strip mines surrounding Braidwood.

Population

The population of the study area is approaching one million, with approximately 544,000 in south-suburban Cook County and 357,300 in Will County, for a total of 901,000 (Northeast Illinois Planning Commission, 1991). Of the 63 municipalities, the largest city is Joliet with an in-town population of 76,836 and a metropolitan population of approximately 120,000. Considering the municipalities by population size, 8 cities are between 25,000 and 40,000; 16 cities are between 10,000 and 25,000; 28 cities are between 2,000 and 10,000; and 10 cities are less than 2,000.

Population growth through the 1980s was very uneven. Some townships experienced rapid growth, and others slight declines (table 1). Orland Township (T36N, R12E) had the greatest numerical increase, followed by Du Page (T37N, R10E), Homer (T36N, R11E), and Wheatland (T37N, R9E), with the largest growth rate. Thornton Township (T36N, R14-15E) lost the most population, followed by Bloom (T35N, R14-15E), Joliet (T35N, R10E), and Lockport (T36N, R10E).

Population projections for the year 2010 made by the Northeastern Illinois Planning Commission (Kamin, 1990) show increases of 33 percent for Will County and 5 percent for suburban Cook, a total increase of 145,000 people. The towns of Plainfield, Romeoville, Lockport, and Frankfort are projected to triple in size, while Crete, New Lenox, Mokena, and Channahon will double in size. Significant population gains are also projected for Bolingbrook, Joliet, Orland Park, and many of the outer south suburbs such as Richton Park, Matteson, and Sauk Village.

Climate

The study area lies within the humid climate zone of the United States. Mean annual precipitation for the period 1961 to 1990 as measured by the National Weather Service was 35.94 inches at the Joliet station and a slightly higher 36.81 inches at the Park Forest station. Total precipitation for 1990 was unusually high with 46.55 inches at the Joliet station and 47.29 inches at the Park Forest station, the highest total for the last 30 years of record. Figure 1 shows the mean monthly precipitation and the 1990 monthly precipitation totals for the two stations.

The above-normal 1990 precipitation totals for January, February, October, and November likely caused a significant increase in the amount of water infiltrating the soil and recharging the shallow ground water. The extra rainfall in May and August and the shortage of rainfall in September likely had a lesser effect on ground-water recharge due to absorption and transpiration of water by vegetation.

The average daily temperature for the period 1961 to 1990 at the Joliet station was 49.3°F with a January mean of 20.9'F and a July mean of 73.8°F. In 1990 the average daily temperature was slightly higher at 51.6°F. Most of the months were within 1 to 3°F of the 30-year normal, except for January and February, when the mean temperatures ran 13.2 and 6.7"F higher, respectively. These temperatures would have allowed for more than normal infiltration due to less freezing at the ground surface.

Previous Ground-Water Studies

Several previous hydrogeologic investigations by the Illinois State Water Survey (ISWS) have examined small portions of the shallow aquifers in the study area. Cravens and Zahn (1990) looked at ground-water movement and water quality of the Silurian dolomite aquifer in the Lake Calumet, Dolton, and Calumet City area. Prickettetal. (1964) examined the dewatering problems in the dolomite aquifer around Chicago Heights and the availability of ground water from the Hadley Valley sand-and-gravel deposit near Joliet. Woller and Sanderson (1983) described the general characteristics of each public ground-water supply in Will County.

Studies of ground-water resources and water quality of the Silurian dolomite in adjacent counties north of the study area werecompleted by Zeizeletal. (1962) and Sasmanetal. (1981) for Du Page County and by Visocky and Schulmeister (1988) for Kane County. These two reports overlap into the two northernmost townships of Will County. The U. S. Geological Survey (USGS) investigated the hydrogeology of the aquifer at the Argonne National Laboratory, which is immediately north of the study area near Lemont (Knowles et al., 1963).

Beginning at a line two townships south of the study area, Cravens et al. (1990) studied the ground-water resources of the aquifer in Kankakee County and its relation to intense irrigation. Directly east of the study area, the Indiana Department of Natural Resources and the USGS conducted a ground-water study of Lake County, Indiana (Rosenshein, 1961, 1963; Rosenshein and Hunn, 1968). West of the study area, the Silurian dolomite is either nonexistent or too thin to supply significant quantities of water. Numerous other studies by the ISWS and the Illinois State Geological Survey (ISGS) have addressed different hydrogeological aspects of the shallow aquifer systems throughout northern Illinois.

The Cambrian-Ordovician aquifer system has been studied fairly extensively due to the enormous water-level declines caused by the collective overpumpage by many communities throughout northeastern Illinois. Because of the large-scale regional behavior of this aquifer, the Will and Southern Cook County area has always been examined in conjunction with the entire region. In the most recently completed project, Burch

Table 1. Population Statistics for the Study Area

		Total population		*1980-1990 change*	
Area		*1980*	*1990*	*Number*	*Percent*
Total study area		858,460	901,313	42,853	5.0
Southern Cook County*		534,000	544,000	10,000	1.9
Will County		324,460	357,313	32,853	10.1
Cook townships (T,R)					
Bloom	36N, 13E	101,424	95,029	-6,395	-6.3
Bremen	36N, 13E	109,023	107,803	-1,220	-1.1
Calumet*	37N, 14E	1,000	1,000	0	0.0
Lemont	37N, 11E	8,850	11,537	2,687	30.4
Orland	36N, 12E	42,607	69,542	26,935	63.2
Palos*	37N, 12E	9,500	11,000	1,500	15.8
Rich	35N, 13E	58,730	61,478	2,728	4.6
Thornton	36N, 14-15E	191,359	175,896	-15,463	-8.1
Worth*	37N, 13E	12,000	11,500	-500	-4.2
Will townships (T,R)					
Channahon	34N, 09E	4,420	5,386	966	21.9
Crete	34N, 14-15E	20,416	21,512	1,096	5.4
Custer	32N, 09-10E	1,101	1,110	9	0.8
Du Page	37N, 10E	47,088	55,444	8,356	17.7
Florence	33N, 10E	931	720	-211	-22.7
Frankfort	35N, 12E	20,335	25,755	5,420	26.7
Green Garden	34N, 12E	1,420	1,722	302	21.3
Homer	36N, HE	13,441	21,464	8,023	59.7
Jackson	34N, 10E	2,473	2,700	227	9.2
Joliet	35N, 10E	89,566	84,243	-5,323	-5.9
Lockport	36N, 10E	34,641	32,336	-2,305	-6.7
Manhattan	34N, HE	3,386	3,963	577	17.0
Monee	34N, 13E	10,996	10,765	-231	-2.1
New Lenox	35N, 11E	16,574	20,716	4,142	25.0
Peotone	33N, 12E	3,319	3,613	294	8.9
Plainfield	36N, 09E	14,685	15,392	707	4.8
Reed	32N, 09E	3,944	4,086	142	3.6
Troy	35N, 09E	17,939	21,642	3,703	20.6
Washington	33N, 14-15E	3,536	3,724	188	5.3
Wesley	32N, 09-10E	2,397	2,540	143	6.0
Wheatland	37N, 09E	4,491	10,746	6,255	139.3
Will	33N, 13E	1,136	1,323	187	16.5
Wilmington	33N, 09E	5,538	5,736	198	3.6
Wilton	33N, 11E	687	675	-12	-1.7

Note* = estimated.
Source: Northeast Illinois Planning Commission, 1991

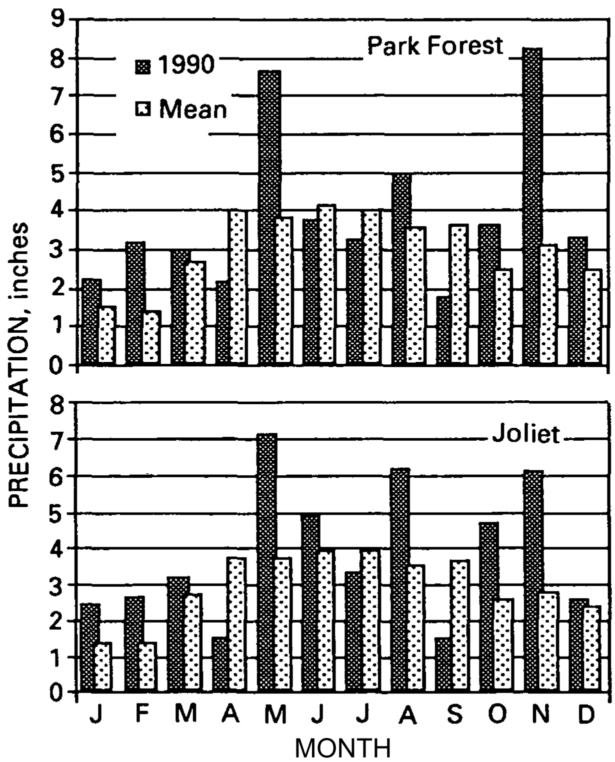

Figure 1. Mean monthly precipitation, 1961-1990, and monthy precipitation, 1990

(1991) used a numerical ground-water flow model to predict possible water-level changes resulting from several different future pumping scenarios.

Acknowledgments

This research was conducted as part of the work of the Hydrology Division of the Illinois State Water Survey, under the general administrative guidance of former Chief Richard G. Semonin. The project was funded by the Division of Water Resources of the Illinois Department of Transportation. Special thanks go to Daniel Injerd and the late Patrick Brady of the Lake Michigan Management Section of the DWR for their assistance in developing this project Additional thanks are extended to Pat for his insight, dedication, and cordiality during the many projects in which Water Survey staff have had the pleasure of working with him.

A special acknowledgment is reserved for Curtis R. Benson for his extensive help in inventorying wells, measuring water levels, and collecting ground-water samples. Technical review of the final report was completed by Water Survey researchers Adrian P. Visocky and Richard J Schicht. Additional review was provided by former Water Survey staff member Robert T. Sasman of Wheaton, Illinois.

Other Water Survey personnel also assisted with the project Brian Kimpel assisted in measuring water levels and analyzing chemical data. Cecille Widolf and Keith Benson also assisted in measuring water levels. Kristopher Klindworth, Dorothy Woller, and Kay Charles provided pumpage data for 1988 and 1990 from the Illinois Water Inventory Program database. Andrew Buck provided the historic water-level data for the hydrographs. Anna Zahn provided computerized maps of the rivers and the geographic and political boundaries. The chemical analyses were completed by the Water Survey's Analytical Chemistry Laboratory under the supervision of Loretta Skowron and with the assistance of Brian Kaiser, Lauren Sievers, and Daniel Webb.

For the Illinois State Geological Survey (ISGS), Robert J. Krumm, Melisa M. McLean, Matthew H.Riggs, and Curtis C. Abert of the Digital Cartography and Geologic Mapping Section provided help with digitizing mapped data, data manipulation, and map production.

John W. Brother, Jr., Linda J. Hascall, and David L. Cox prepared and drafted the figures. Patti Hill and Lori Woller processed the text and entered revisions, and Laurie Talkington edited the manuscript and formatted the final publication.

GEOLOGY

The geology of the study area was examined in detail to define the extent of the major glacial drift aquifers and their relationship to the shallow bedrock aquifer surface. Two principal sand-and-gravel aquifers were identified as a result: an "upper" drift aquifer and a "basal" drift aquifer. Bedrock topography, drift thickness, thickness of the Silurian dolomite, and thickness of the major sand-and-gravel units were mapped to help define the geologic and hydrologic system and the interaction of the upper bedrock aquifer and the drift aquifers.

Data were collected from well records, engineering borings, oil and gas tests, and structure tests on file at the Illinois State Geological Survey to create the various maps. Published reports, manuscripts, and unpublished reports on open file at the ISGS were reviewed to obtain an overall perspective of the geology of the study area. No detailed studies of the hydrogeology of the entire area have been previously undertaken.

Past regional geologic studies of northeastern Illinois that have encompassed the study area include Thwaites (1927), Bergstrom et al. (1955), Bretz (1955), Suter et al. (1959), Hughes et al. (1966), and Willman (1971). Bogner (1976) and Larsen (1976) included interpretive maps of the surficial geology of the area as part of planning studies for northeastern Illinois. Water well and other data were incorporated into a computer database that greatly facilitated map construction. Preliminary maps were developed using Interactive Surface Modeling (ISM) software and the computerized geographic information system (GIS).

Map Construction

More than 10,000 records were reviewed to create the database used in the construction of the geologic maps. Specific data items were input to the PC-based computerized spreadsheetQUATTROPRO®(BorlandInternational,1991),including well ID number, section number, surface elevation, thickness of drift, and depth to top and bottom of the sand layers. Each well log book, which covers a specific range of locations, had its own spreadsheet, allowing for the inclusion of fewer items into the project database, such as well owner, township, and range.

A well record could be located in the log book based on the section number and its location in the spreadsheet. The spreadsheet format allowed for quick calculation of the elevations of the top of the bedrock, tops and bottoms of sand bodies, and thicknesses. Locations were verified wherever possible by using plat books to match either landowners' names or the address location given on the well log. After the data were calculated, they were converted to ASCII text and transferred toadatabase in ARC/INFO (ESRI, 1991). Further data manipulation was performed on Sun Systems Sparc workstations.

More than 5,000 well records were input to the database. Numerous data checks were then performed. Duplicate well IDs were found and corrected, and layer thicknesses and elevations were checked so that 1) the sand thickness reported in the data did not exceed drift thickness or 2) the elevation of a sand body was not below the bedrock surface.

Once inconsistencies in the data were resolved, several preliminary maps were produced. It was necessary to find a grid spacing used by ISM that would fairly well reflect the distribution of the data and provide sufficient detail to depict the geology of the area. Preliminary mapping also allowed for further review of the data, so that wells with poor or highly inaccurate descriptions could be eliminated from the database. Approximately 4,900 records were used to produce the final maps. Editing of the finalized maps was greatly facilitated by the Arcedit feature of the ARC/INFO system. Maps presented in this report have been generalized by contour smoothing to facilitate their overall presentation and to aid in interpretation for the general reader. Detailed maps of the study area and a report describing the map construction process using the GIS system are available on open file at the Illinois State Geological Survey (Smith and McLean, 1992).

Bedrock Geology

All of the sedimentary bedrock units are of the Paleozoic Era. The Paleozoic bedrock is composed of sequences of sandstones, dolomites, limestones, and shales. The vertical succession of the bedrock is illustrated by the stratigraphic column in figure 2. Major tectonic activity of the area includes the formation of the Kankakee Arch in Ordovician time (Ekblaw, 1938) and faulting along the Sandwich Fault Zone. This faulting, which is indicated by the nearly parallel boundary lines of the Silurian dolomite in Channahon and Troy Townships (T34-35N, R9E) in figure 3, may have occurred coincidentally with the formation of the LaSalle Anticlinorum in early Pennsylvanian time (Kolata et al., 1978).

No further faulting has been noted since the deposition of the glacial sediments. Bedrock units dip gently to the east (Willman, 1971). The majority of the area lies on the Niagara cuesta, a south- and west-facing scarp composed of resistant Silurian strata that dip at roughly 15 feet per mile (Horberg, 1950). The Silurian strata are absent west of the Kankakee River and in an area west of the Des Plaines River in west-central Will County (see figure 3). Because this study relates to the hydrogeology of the Silurian strata and the drift materials, units below the Maquoketa Shale Group are summarized only briefly in this report, while the uppermost bedrock units are discussed in detail.

SYSTEM	SERIES	GROUP OR FORMATION	AQUIFER	LOG	THICKNESS (FT)	DESCRIPTION
QUATERNARY	PLEISTOCENE		Sands and Gravels		0 – 250	Unconsolidated glacial deposits-pebbly clay (till), silt, sand and gravel Alluvial silts and sands along streams
PENNSYLVANIAN	DES MOINESIAN	Spoon and Carbondale			0 – 110	Shale, sandstone, clay, limestone, and coal
SILURIAN	NIAGARAN	Racine	Silurian (Shallow dolomite aquifer system)	reef	0 – 350	Dolomite, very pure to argillaceous, silty, cherty, reefs in upper part
		Sugar Run				Dolomite, slightly argillaceous and silty
		Joliet				Dolomite, very pure to shaly and shale, dolomitic, white, light gray, green, pink, maroon
	ALEXANDRIAN	Kankakee			0 – 100	Dolomite, pure top 1' - 2', thin green shale partings, base glauconitic
		Elwood				Dolomite, slightly argillaceous, abundant layered white chert
		Wilhelmi				Dolomite, gray, argillaceous and becomes dolomitic shale at base
ORDOVICIAN	CINCINNATIAN	Maquoketa			80 – 250	Shale, red to maroon, oolites Shale, silty, dolomitic, greenish gray, weak (Upper unit) Dolomite and limestone, white, light gray, interbedded shale (Middle unit) Shale, dolomitic, brown, gray (Lower unit)
	CHAMPLAINIAN	Galena	Galena-Platteville (Cambrian-Ordovician aquifer system)		310 – 380	Dolomite, and/or limestone, cherty (Lower part) Dolomite, shale partings, speckled
		Platteville				Dolomite and/or limestone, cherty, sandy at base
		Glenwood	Glenwood-St Peter		125 – 600	Sandstone, fine and coarse-grained; little dolomite, shale at top
		St Peter				Sandstone, fine to medium-grained, locally cherty red shale at base
	CANADIAN	Shakopee	Prairie du Chien		0 – 410	Dolomite, sandy, cherty (oolitic), sandstone
		New Richmond				Sandstone interbedded with dolomite
		Oneota				Dolomite, white to pink, coarse-grained cherty (oolitic)
		Gunter				Sandstone, medium-grained, slightly dolomitic
CAMBRIAN	CROIXAN	Eminence	Eminence Potosi		0 – 280	Dolomite, light colored, sandy, thin sandstones
		Potosi				Dolomite, fine-grained, gray to brown, drusy quartz
		Franconia	Franconia		110 – 160	Dolomite, sandstone and shale, glauconitic, green to red, micaceous
		Ironton	Ironton-Galesville		135 – 235	Sandstone, fine to coarse-grained, well sorted, upper part dolomitic
		Galesville				
		Eau Claire			390 – 570	Shale and siltstone, dolomitic, glauconitic, sandstone, dolomitic, glauconitic
		Elmhurst Member	Elmhurst-Mt. Simon aquifer system		2200	Sandstone, coarse-grained, white, red in lower half, lenses of shale and siltstone, red, micaceous
		Mt. Simon				
PRE–CAMBRIAN						Granitic rocks

Figure 2. Generalized stratigraphic column of rock units and aquifers (prepared by M.L Sargent, ISGS)

Precambrian bedrock

The Precambrian basement of northern Illinois is composed of granites or granitic rock. Few details as to the nature of the basement rocks are known, because few wells have completely penetrated the sedimentary bedrock of the region. The elevation of the top of the Precambrian basement has been inferred at 4,000 feet below msl in the study area.

Cambrian

The Elmhurst-Mt Simon Sandstone comprises the oldest sedimentary units in Illinois and consists of medium-grained sandstones with a total thickness of approximately 2,500 feet. The upper part of this unit has been utilized as an aquifer in the Chicago region in the past; however, a high mineral content and ground-water mining of the aquifer (a nonreplenished lowering of the static water level) have led to a discontinuation of its use for that purpose.

The Eau Claire Formation, the basal bedrock confining unit (Visocky et al., 1985), consists of dolomitic shale and siltstone with thin beds of sandstone. It has a thickness of 300 to 400 feet and separates the Elmhurst-Mt. Simon aquifer from the Ironton-Galesville aquifer.

The Ironton and Galesville Sandstones have a combined thickness of 150 to 250 feet and are widely utilized as a source of ground water in northern Illinois (Hughes et al., 1966). The Galesville Sandstone is fine-grained, while the Ironton Sandstone is coarser grained and contains more dolomite.

The Knox Megagroup, the middle confining unit (Visocky et al., 1985), consists of all the bedrock units between the Ironton-Galesville Sandstones and the Ancell Group. It includes the Cambrian Franconia Formation, the Potosi Dolomite, the Eminence Formation, the Jordan Sandstone, and the Ordovician Prairie du Chien Group. The Knox Megagroup is primarily dolomitic in composition, though it contains thin sandstones. It ranges in thickness from 400 feet in the northern portion of the study area to about 700 feet in the southernmost tip of Will County. The sandstones tend to be somewhat discontinuous and, where present, are a localized source of ground water. However, the group as a whole acts as a confining unit between the Ironton Sandstone and the Ancell Group.

Ordovician

The Ancell Group, containing the St. Peter Sandstone and Glenwood Sandstones, has a thickness of roughly 200 feet throughout the study area except in north-central Will County, where it thickens to more than 400 feet. The thickness of the Ancell Group varies considerably in northern Illinois because itrests on an erosion surface. The Ancell Group is the shallowest aquifer in this area below the Silurian dolomite aquifer. The top of the Ancell Group can be found at elevations ranging from just over sea level in the northwestern corner of Will County to 500 feet below msl in the southwestern corner of Will County.

The Galena and Platteville Groups are a sequence of carbonate rocks that are primarily dolomitic in composition. The Platteville Group conformably overlies the Ancell Group. The two units have a combined thickness of 350 feet throughout this part of the state. The Galena and Platteville Groups, combined with the overlying Maquoketa Shale Group, act as an aquitard between the Ancell aquifer and the Silurian dolomite aquifer.

Maquoketa Shale Group

Three bedrock units are exposed subaerially in the study area. The oldest of those to be detailed in this report are Ordovician-aged strata, including the Cincinnatian Series Maquoketa Shale Group. The Maquoketa Group has a thickness ranging from 260 feet in eastern Will County to 120 feet in the northwestern corner of Will County and is unconformably overlain by Silurian strata (Kolata and Graese, 1983).

The Maquoketa Group is composed of four formations. The Scales Shale forms the lowermost unit and consists of gray to brown dolomitic shale. Thin layers with phosphatic nodules and pyritic fossils occur near the top and base of the unit The Scales Shale may attain a thickness of up to 120 feet in this region (Kolata and Graese, 1983). The Fort Atkinson Limestone, coarse-grained crinoidal limestone to fine-grained dolomite, may range up to 60 feet thick (Kolata and Graese, 1983). The Brainard Shale is composed of greenish-gray dolomitic shale and has a thickness generally less than 100 feet (Willman et al., 1975).

The Neda Formation is the youngest formation in the Maquoketa Group and is relatively thin, usually less than 10 feet. In some places it may attain a maximum thickness of 15 feet. The Neda is exposed along the Kankakee River and is typically overlain by the Silurian-aged Kankakee Formation. The Neda Formation consists mostly of red and green shale with interbedded goethite and hematite oolite beds (Willman, 1971; Willman et al., 1975).

Silurian *System*

Silurian-aged rocks consist almost solely of dolomites and dolomitic limestones. The Silurian is divided into the Alexandrian and Niagaran Series. The Alexandrian Series is about 25 feet thick and is represented by the Kankakee, Elwood, and Wilhelmi Formations, which are fine to medium-grained, white or gray to pinkish-gray dolomites. The Kankakee Formation is exposed along the Kankakee River in the southern portion of Will County (Willman, 1973).

The Niagaran Series constitutes much of the bedrock surface of the study area and includes three formations. The Joliet Formation is characterized by a lower member of dolomite with interbedded red and green shale, and two upper members with an increasingly pure dolomite towards the top of the formation (Willman, 1971). The Sugar Run Formation, formerly termed the Waukesha Formation (Willman, 1973), is an argillaceous, fine-grained, medium to thick-bedded brownish-gray dolomite (Willman, 1971). The Racine Formation is the thickest unit in the Niagaran Series, sometimes as much as 300 feet (Willman, 1973). The Racine Formation contains large reefs of vugular gray dolomite that grew to as much as 100 feet high. The interreef rock consists of dense, cherty, gray dolomite. The Racine Formation is exposed in the bluffs along the Des Plaines River from Joliet to Blue Island (Willman, 1973).

Figure 3 is an isopach map of the Silurian dolomite indicating the thickness of the unit in the study area and the boundary of the Silurian rocks. The Silurian dolomite aquifer has a maximum thickness of just more than 500 feet in the southeastern comer of Will County, and it becomes even thicker east and south of the study area. It rapidly increases in thickness from its margin along the western border of Will County, where it has been eroded away. The contact between the Silurian dolomite and the underlying Maquoketa Shale Group has relatively little relief; the major differences in thickness of the unit are the result of erosion of the bedrock surface. Joints and fracture patterns within the upper bedrock have a dominantly northwest-soutiieast and northeast-soudiwest orientation (Foote, 1982).

Pennsylvanian System

Pennsylvanian-age bedrock is found in the southwestern portion of Will County west of the Kankakee River with an outcropping at the confluence of the Des Plaines and Kankakee Rivers. The lowermost unit, the Spoon Formation, is very thin and consists of clay beds with scattered occurrences of coal formed in channel-like depressions (Smith, 1968). It overlies the Maquoketa Shale Group.

The overlying Carbondale Formation may attain a thickness greater than 100 feet in the southwestern corner of Will County. The Carbondale Formation consists of shale with thin limestone beds. The lowermost unit, the Colchester (No. 2) Coal Member, outcrops in this area and attains a thickness of up to 3 feet. It has been extensively mined along the Will-Grundy-Kankakee County line, where large areas of strip-mined land are found. Most of the available coal has been mined out, and numerous gob piles can be found in the area of Braidwood.

The No. 2 Coal is overlain by the Francis Creek Shale Member, which constitutes the remainder of the Pennsylvanian units in the study area. The Francis Creek Shale Member is gray with numerous flattened concretions that contain the Mazon Creek flora of Pennsylvanian-aged fossils (Smith, 1968). Fossiliferous concretions may be exposed in the gob piles due to weathering of the mine slag materials (Willman, 1971).

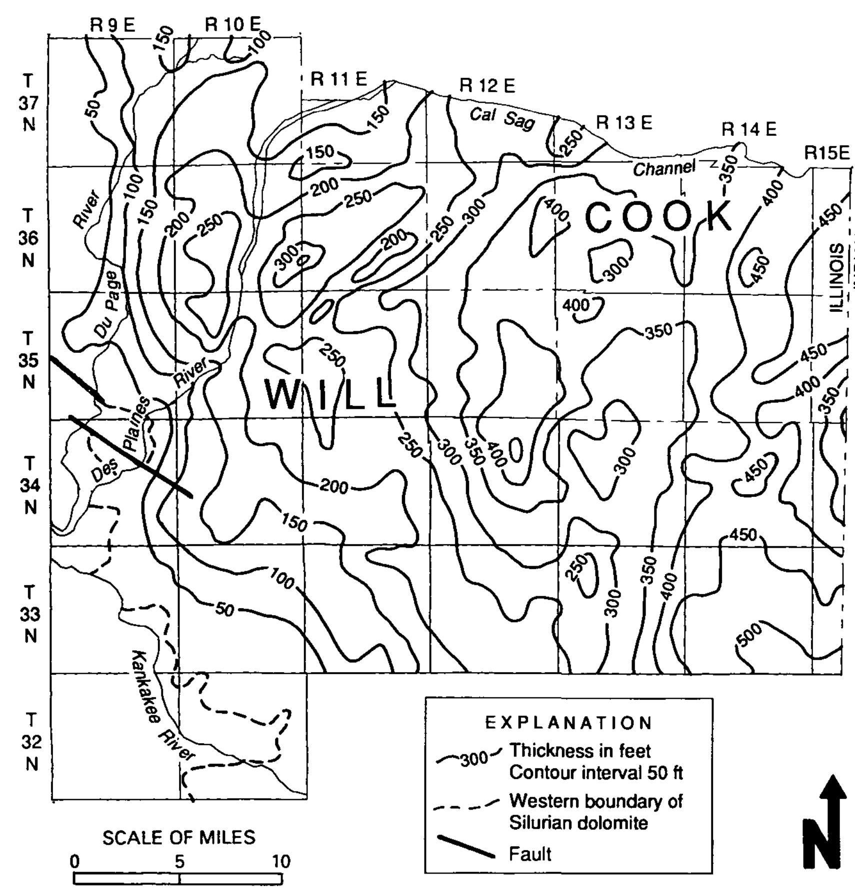

Figure 3. Thickness of the Silurian dolomite

Bedrock Topography

The highest bedrock elevations are found in east-central Will County, where the bedrock rises more than 700 feet above msl (plate II). Bedrock uplands with elevations consistendy rising beyond 650 feet above msl occur as a broken curved ridge from the soudieast to the northwest. The bedrock surface slopes from the bedrock upland westward to the Des Plaines River. It also has regional downward slopes to the soudi into Kankakee County, northeastward into the Lake Michigan basin, and east into Indiana. Westof the Des Plaines River, the bedrock surface rises higher than 650 feet above msl in northeastern Kendall County. Elsewhere, the surface has relatively low relief.

The dominant features of the bedrock surface are the river valleys. The Des Plaines River valley is better expressed than the Kankakee River valley, in part because it is older and acted as a drainageway for glacial meltwater, which caused it to become more entrenched in its present valley. The Kankakee River valley may be less well expressed, partly due to the extent of scouring over the area during the Kankakee Flood event, which occurred as glacial meltwaters built up behind a constriction at the Marseilles Morainic System westof the study area (Gross and Berg, 1981). As a result, the river is not entrenched in most places. Also, smoothing of the contours on the maps used in this study has generalized some of the detail.

The buried Hadley Bedrock Valley, described initially by Horberg and Emery (1943), was probably formed prior to glaciation and existed concurrently with the preglacial Des Plaines River. The valley may have acted as a drainageway for glacial meltwaters until it was buried by glacial debris. The valley was believed to have been formed originally by glacial scouring, although evidence presented by McConnel (1972) indicates a fluvial origin. Also, the base of the Hadley Valley does not overhang or lie much below the Des Plaines River valley, but rather joins it at a smooth juncture.

The bedrock surface contains a number of sinkholes or closed depressions, which are expressions of karst development that predate continental glaciation. Karst, a terrain developed on limestone or dolomite by solution or dissolving of the rock, is characterized by closed depressions and cavities along joints and fractures. Karstfeatures were first noted by Fisher (1925) in the Joliet area, where early Pennsylvanian sediments of shale and clay were found filling cavities in the upper bedrock. Buschbach and Heim (1972)indicatedclosed depressions in the Silurian dolomite surface in their bedrock topography map for the Chicago region, which they speculated were expressions of karst develop ment McConnel (1972) demonstrated the existence of sinkholes in the area of the buried Hadley Bedrock Valley northeast of Joliet by using data from a seismic refraction survey.

Glacial Geology

The sediments overlying the bedrock are composed of tills, sands and gravels, lacustrine deposits from glacial lakes, and surficial eolian deposits of loess and sand. The unconsolidated deposits are more than 150 feet thick along the crest of the Valparaiso Morainic System. Principal moraines are shown in figure 4. In the area of the Hadley Valley, the deposits are more than 175 feet thick. Bedrock is mainly exposed along the Des Plaines River valley and its tributaries, and in isolated areas in southeastern Cook County. The drift thickness map (plate III) indicates the distribution of the earth materials overlying the bedrock and the locations of bedrock outcrops.

Erosion of the glacial sediments was a major factor in controlling the drift thickness of the area. Previously deposited sediments were scraped off by succeeding glaciers, but glacial meltwaters, which came from the east and north along the river channels, caused much of the erosion. Both the Kankakee and

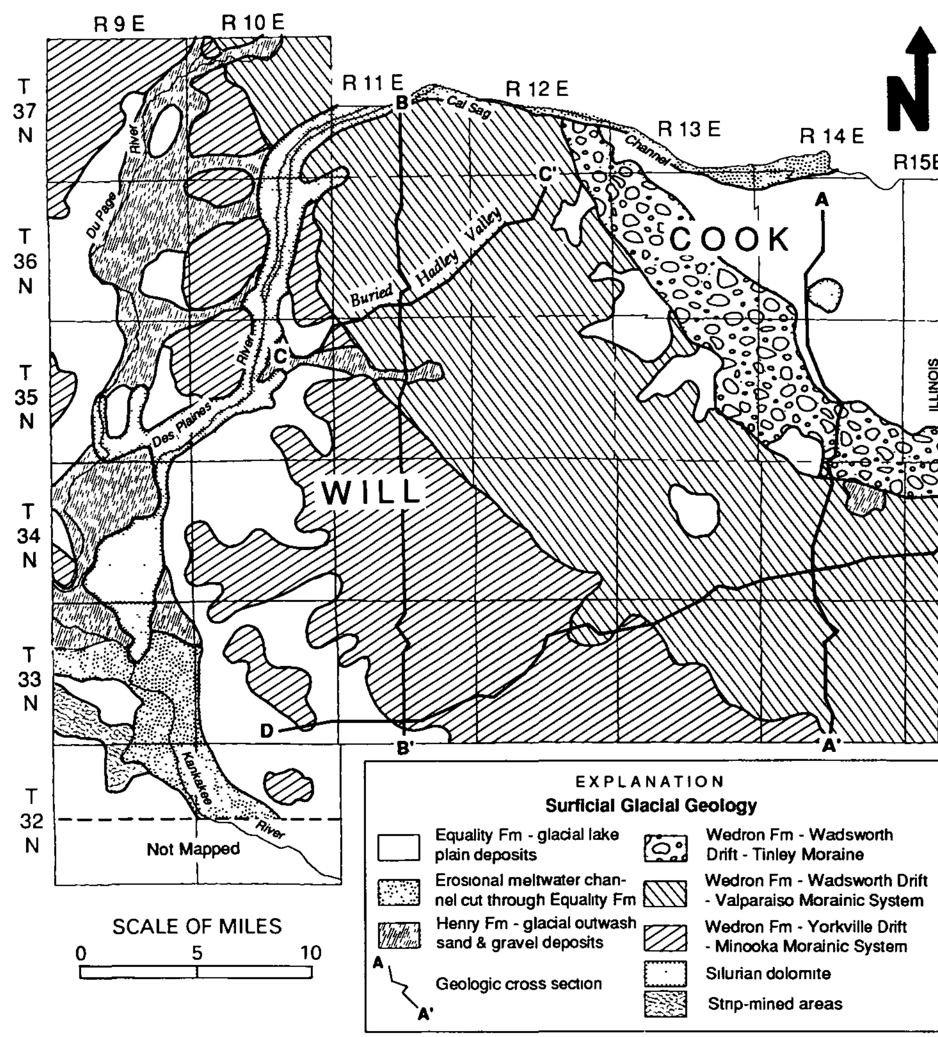

Figure 4. Surficial glacial geology (after Willman and Lineback, 1970). Cross-sectional lines are shown in figure 5.

Des Plaines Rivers acted as meltwater channels as the glaciers melted. The Du Page River acted as a minor drainageway and was most active during large-scale flooding events.

The thickness of the drift also varies in the area due to the topographical control exercised by the bedrock on the overlying sediments. The crest of the Valparaiso Moraines coincides with the topographic high in the bedrock surface, as shown on the geologic cross sections (figure 5). The bedrock high may have forced late Woodfordian glaciers to stall repeatedly in the same area, causing moraines to be built atop one another sequentially (Hansel and Johnson, 1987).

Few variations in the character of the unconsolidated sediments are noted in well drillers' descriptions, so no attempt was made to correlate these deposits. The drift materials present in the study area are late Wisconsinan or younger. Though this region was glaciated repeatedly prior to the Wisconsinan glacia-

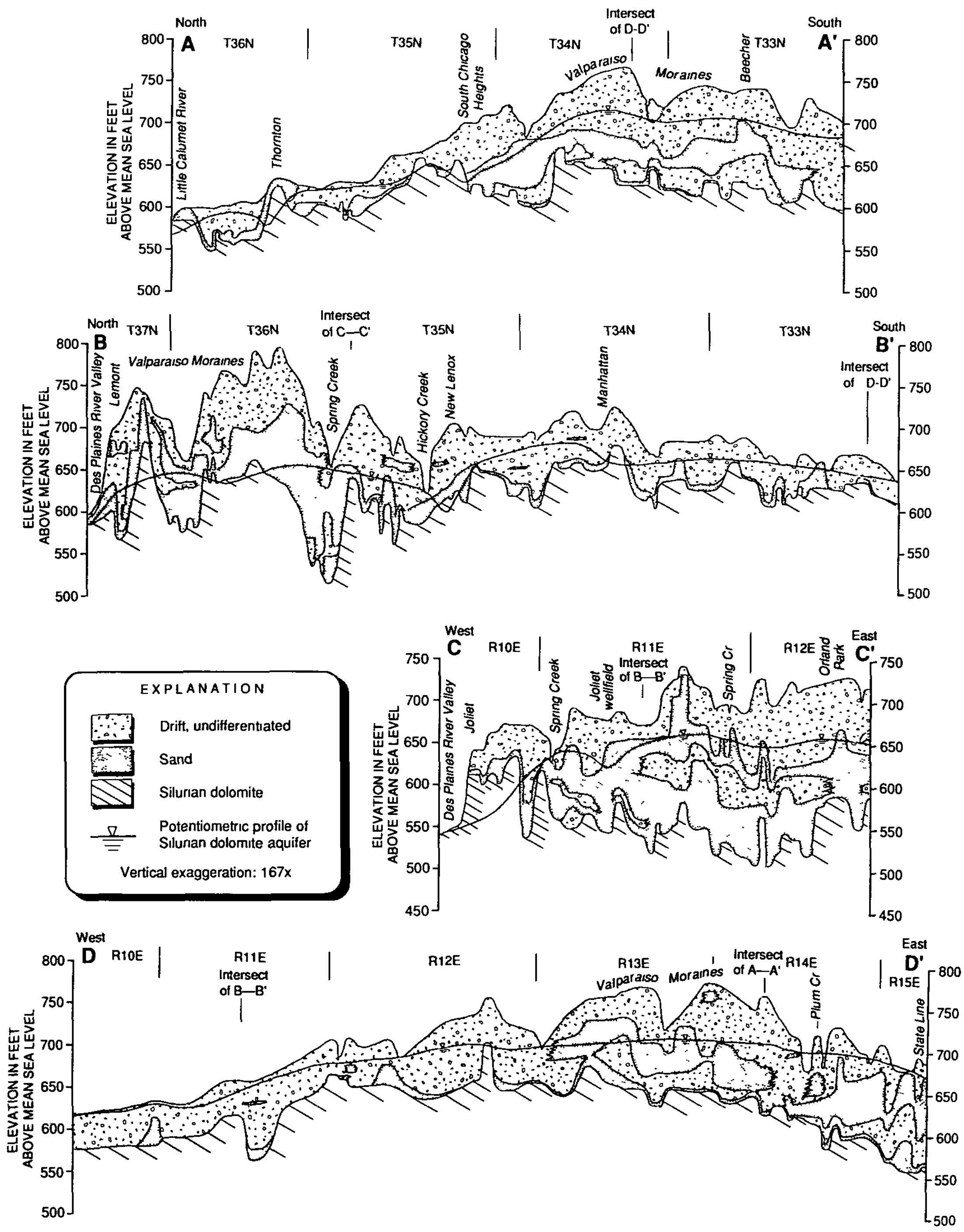

Figure 5. Geologic cross sections of the glacial drift and potentiometric profile of the Silurian dolomite aquifer

tion, no Illinoisan or pre-Illinoisan deposits have been identified (Horberg, 1953).

The drifts have been divided into three main units: the Lemont Drift, the Yorkville Drift, and the Wadsworth Drift (Johnson and Hansel, 1985). The three drift units are all part of the Wedron Formation of Wisconsinan age. The Lemont Drift has a dolomitic character, because the source material for the diamicton was glacially eroded Silurian dolomite. The Lemont Drift is the oldest of the three units and is found only underlying the Wadsworth Drift.

The extent of the Yorkville Drift, a silty gray diamicton, is indicated on figure 4. The Yorkville Drift, the only drift unit west of the Valparaiso Morainic System boundary within the study area, overlies the bedrock surface wherever the basal sand unit is not present

The Wadsworth Drift is composed of silty and clayey diamictons and is the youngest of the drifts (Johnson and Hansel, 1985). It overlies the Lemont Drift and the upper sand unit. The cross sections (figure 5) show how the upper sand unit, where present, roughly corresponds to the boundary between the Lemont and Wadsworth Drifts. The gradation between the different drift units at the Valparaiso System boundary is not well defined. The Wadsworth Drift appears to grade into the Yorkville Drift, and both are very similar in composition near the boundary (Larsen, 1976).

Extensive sand-and-gravel and lacustrine sediments were deposited along the Kankakee and Des Plaines Rivers during the Kankakee Flood. Large glacial lakes developed during the flood and then emptied into the Illinois River valley after a breach developed in the moraines. The erosive force of the floodwaters eroded the glacial deposits along the river valleys, flattening the surface of the drift and in places exposing the underlying bedrock. Thin, dispersed lake plain deposits of silt, clay, and sand were formed in soudiwestem Will County during the flood event Some lacustrine deposits are found between morainic ridges in southern Cook County, where small glacial lakes developed as the Valparaiso Moraines were being deposited (Bogner, 1976). Figure 4 shows the locations of some of the surficial materials.

Sands and gravels were also deposited along tributary creeks and in abandoned channels that once connected the Du Page and Des Plaines Rivers north of their present juncture. Wind has reworked the surficial sand deposits, forming low dunes along the Kankakee River in soudiem Will County. Masters (1978) classified the sand-and-gravel deposits of the area by their origin, indicating Uiat most of the deposits in the valley of the Des Plaines River were formed as well-sorted valley train deposits. In the Kankakee River valley, the sands and gravels were primarily deposited as riverine sediments during the Kankakee Flood.

Sand-and-Gravel Isopachs

The sand-and-gravel isopach maps (figures 6 and 7) indicate the variations in thickness of the upper and basal sand-and-gravel units. The most extensive deposits of both are found throughout the area overlain by the Valparaiso Morainic System. This may be associated with bedrock control on the

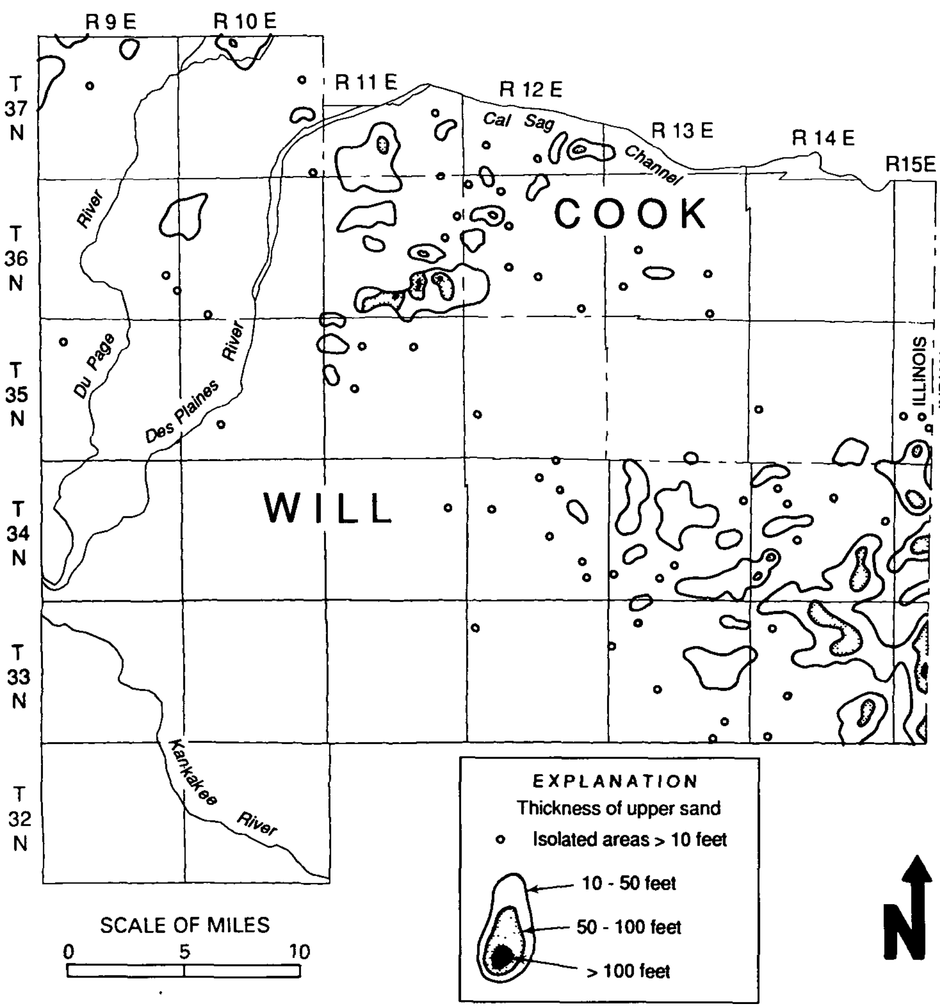

Figure 6. Thickness of the upper sand unit

formation of the moraines and the associated deposits referred to earlier. The thickest deposits are found in the buried Hadley Bedrock Valley, where thicknesses of both units can exceed 100 feet The upper sand unit can be found in the glacial drift across a wide range of elevations. For mapping purposes, the upper sand unit was defined as a sand unit more than 10 feet thick, whichoccurs between two fine-grained layers (figure 6). A minimum thickness of 10 feet was chosen because of the scale of the resultant maps.

The basal sand unit is composed entirely of coarse-grained materials that overlie the bedrock surface (figure 7). Most of the basal sands west of the Des Plaines River were formed as valley train deposits along the river channels as the glaciers melted back. The origin of the extensive deposits underlying the Valparaiso Moraines is not clear. They may have been formed during early Wisconsinan glacial events as outwash plain deposits, or they may have been deposited subglacially. The cross sections (figure 5) indicate the variability and complexity of the sand-and-gravel deposits as they occur within the drift These deposits are very seldom utilized as aquifers in this region because almost all wells are completed in the Silurian dolomite aquifer. Quite clearly, figures 6 and 7 indicate the possibility of some ground-water resource potential within these deposits.

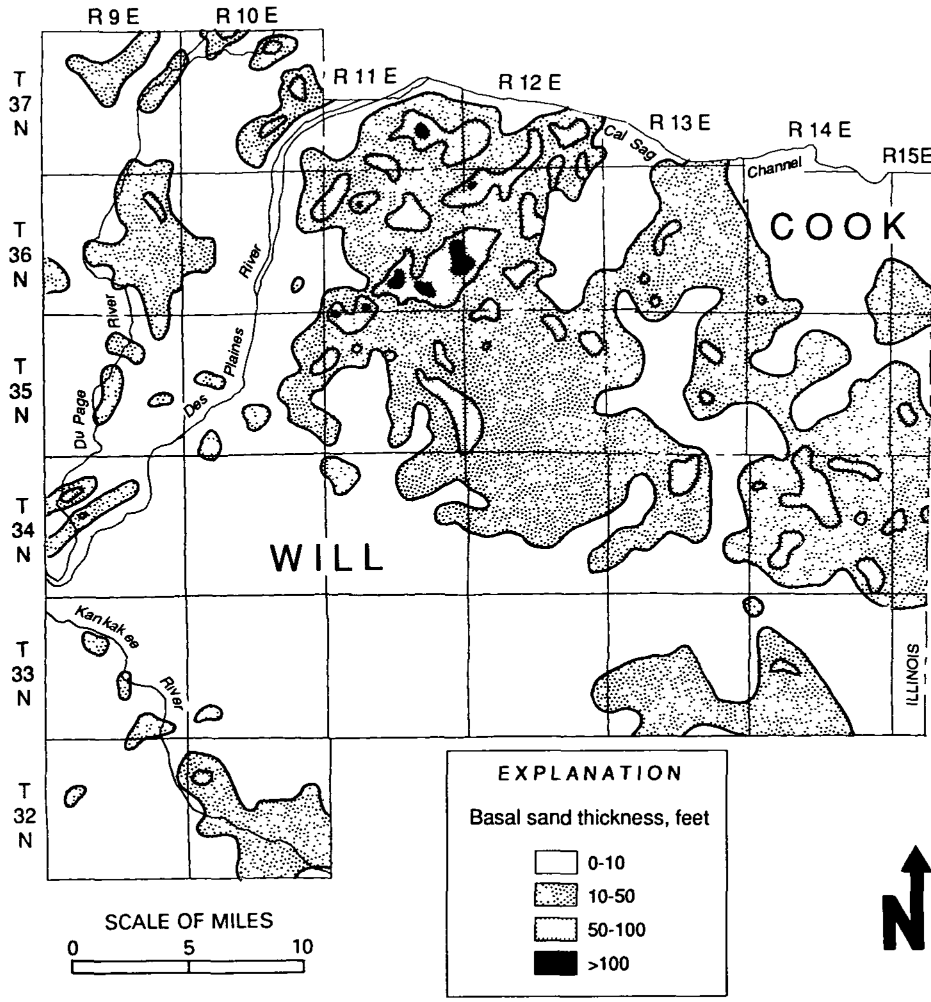

Figure 7. Thickness of the basal sand unit

AQUIFER HYDRAULICS

The location and depth of plentiful shallow ground-water supplies in Will and southern Cook Counties is dictated by the layering of geologic materials with high and low permeabilities. The uppermost aquifers, or high-permeability units, are contained in the glacial sand-and-gravel deposits (figures 6 and 7). Water entering these aquifers generally passes through a low-permeability aquitard formed by clay-rich till in the surficial layer of undifferentiated drift (figure 5). In the sand aquifers, ground water flows either laterally towards discharge areas or downwards towards the next aquifer in the Silurian dolomite.

Water enters the Silurian dolomite aquifer from the sand-and-gravel aquifers either directly or through more drift with low permeability. A small amount of water may also enter the aquifer directly from bedrock outcrops in recharge areas, such as the ones shown in plate III in Bloom Township (T35N, R14-15E). Most of the ground water in the Silurian dolomite aquifer moves laterally towards discharge areas along rivers or to production wells, although a small amount of water leaks downward through the Maquoketa Shale aquitard and into the Cambrian-Ordovician aquifer. Walton (1965) estimated the flow rate through the Maquoketa Shale to be a very low 2,100 gallons per day per square mile (gpd/mi^2).

Occurrence of Ground Water in the Silurian Dolomite Aquifer

Ground water in the Silurian dolomite aquifer occurs in cavities formed by the chemical dissolution of the rock along horizontal bedding plains and vertical stress fractures. The ability of water to flow through these cavities is known as the "secondary permeability." The primary permeability of the rock matrix is so low that it does not contribute to the overall productivity of the aquifer, although it is high enough to play an important role in the sorption of contaminants moving through the fractures and bedding planes.

The major water-bearing cavities formed in the vertical fractures are characteristically hundreds of feet long, while the width decreases from a few inches at the top of the dolomite to almost nothing at the bottom. These enlarged fractures are generally subparallel with spacings that range from a few feet to tens of feet wide. They are typically interconnected with smaller fractures that have more random orientations. A water-supply well fortunate enough to intersect a significantly enlarged vertical fracture will usually have a high capacity. However, a well located a few feet away from the fracture may be unusable for a supply unless there is significant dissolution along the horizontal bedding planes.

The frequency and size of the water-bearing openings is greatest at the top of the dolomite where preglacial weathering was greater. Historic preglacial water levels were below the top of the dolomite. This allowed carbonic acid formed from dissolved carbon dioxide and organic matter to penetrate into the rock and cause dissolution along fractures and bedding planes. The greater the depth to water, the deeper the dissolution occurred and the greater the resulting secondary permeability. As a general rule in designing and operating municipal well fields, it is very important to keep static water levels above the top of the bedrock. When the water level falls below the top of the dolomite aquifer and dewatering begins, many of the larger dissolution cavities near the top of the aquifer will no longer contribute water to the well, causing the production capacity to drop off and drawdown to increase greatly.

By reviewing tests of specific capacity (discharge per foot of drawdown) for nearly 800 wells in northern Illinois, Csallany and Walton (1963) examined the relationship in well productivities versus different geologic factors. The specific-capacity values used for these comparisons ranged over two to three orders of magnitude, and the differences for each comparison are quite discernible. Results of the study show that the specific capacities of wells located on bedrock uplands are three to four times higher than for wells located in bedrock valleys. A similar study in Chicago Heights by Prickett et al. (1964) also showed that given an equal saturated thickness, the specific-capacity values for wells in areas of partial dewatering are three to four times less than the values for wells outside these areas.

Overlying glacial materials contribute to the specific capacity of a well by providing extra water, or leakage, through the openings in the top surface of the dolomite. Csallany and Walton (1963) found that wells in portions of the aquifer overlain by sand and gravel have a specific capacity three to four times higher than wells in portions overlain by till. The data also show that the thickness of the sand and gravel is not a factor for wells with high specific capacity. However, as the lower end of the specific-capacity distribution is approached, areas with less than 10 feet of overlying sand and gravel become progressively less productive than areas with more than 10 feet.

Hydraulic Properties of the Silurian Dolomite Aquifer

Two hydraulic properties, transmissivity and storage, are used as quantitative measures of permeability and yield of an aquifer and are essential for determining the economic usefulness of a particular well or aquifer. Transmissivity (T), the ability of an aquifer to transmit water, is defined as the rate of flow through a unit width of the aquifer under a unit hydraulic gradient. In common units, transmissivity is expressed as gallons per day per foot (gpd/ft,) which is equivalent to discharge divided by width. 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 water level. The storage coefficient is unitless.

If the water level in a well does not rise above the top of the aquifer, the aquifer is under unconfined conditions and yields water almost entirely through gravity drainage. The unconfined storage coefficient generally ranges from 0.01 to 0.30 and is roughly equal to the specific yield. Specific yield is the ratio of the volume of water that will drain by gravity out of saturated aquifer material to the total volume of that aquifer material.

Storage coefficients of 10^{-5} to 10^{-3} usually indicate that an aquifer is confined underpressure between two units of material that are of low 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. Similar storage coefficient values are found in leaky-confined aquifers, in which additional water is added to the aquifer from overlying confining materials. Ground water in the Silurian dolomite aquifer is generally under leaky-confined conditions throughout the study area.

Transmissivity is a less predictable parameter, especially in fractured bedrock aquifers where values often range over several orders of magnitude. The two major methods of determining transmissivity are aquifer tests and specific-capacity tests. An aquifer test is a controlled experiment that monitors the effect of a discharging well on water levels in both a pumped well and nearby observation wells. Data on drawdown versus time from the observation wells are examined with an analytical equation to determine the transmissivity and storage coefficient between one of the observation wells and the pumped well. Observation well data are preferred to pumping well data due to the complications associated with a pumping well, such as frictional well losses and variable pumping rates.

If no observation wells are available for monitoring, which is the case with all the tests on file for the study area, then a production test is conducted on a pumping well. Production tests provide less information than aquifers tests but are still very valuable for use in specific-capacity analyses.

Specific capacity is the rate of discharge from a well divided by the drawdown of the water level within the well. Although subject to many sources of error, transmissivity can be estimated from specific capacity by treating a specific-capacity test as a short nonequilibrium aquifer test. This method requires an assumed value for the storage coefficient, minimal well losses, and the well must fully penetrate the aquifer. Detailed descriptions of specific-capacity analyses used for determining transmissivity are found in Csallany and Walton (1963), Theis (1963), Peters (1987), and Brown (1963).

Transmissivity values for the study area were calculated from 248 specific-capacity tests with a computer program written by Bradbury and Rothschild (1985). When the data are available, the program corrects for partial penetration, well diameter, and well loss. The partial penetration of wells was adjusted to a standard aquifer thickness of 100 feet (Bergeron, 1981). Although the Silurian dolomite aquifer may be as thick as 450 feet in places, the predominant water-yielding openings typically occur in the upper 100 feet. The storage coefficient of the aquifer is assumed to be 0.0001, based on studies discussed later in this section. The actual storage coefficient 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 this parameter.

The 248 specific-capacity values were obtained from tests on file at the Illinois State Water Survey and from data published in Prickett et al. (1964), Csallany and Walton (1963), Woller and Sanderson (1983), and Cravens and Zahn (1990). The variations in specific capacity were dramatic, ranging from 0.012 to 1000 gallons per minute per foot of drawdown (gpm/ft). The median specific capacity was 4.5 gpm/ft. The calculated transmissivities also varied dramatically, with log-normally distributed values ranging from 16.6 ($10^{1.22}$) to 2,750,000 ($10^{6.44}$) gpd/ft, as shown by the histogram of log values plotted in figure 8. The median transmissivity value of 11,800 ($10^{4.07}$) gpd/ft is a better quantitative measure of the aquifer than the mean value of 68,700 gpd/ft because of this log-normal distribution. The standard deviation of 0.94 log units means that values within one standard deviation of the median range from 1,350 to 102,000 gpd/ft.

A plot of the transmissivity distribution (figure 9) shows an area trending northwest-southeast along the Will-Cook County line where higher transmissivity values are concentrated. This region roughly corresponds to an area of higher bedrock elevation and steeper bedrock topography (plate II). Dissolution of the dolomite was probably greatest here, and the

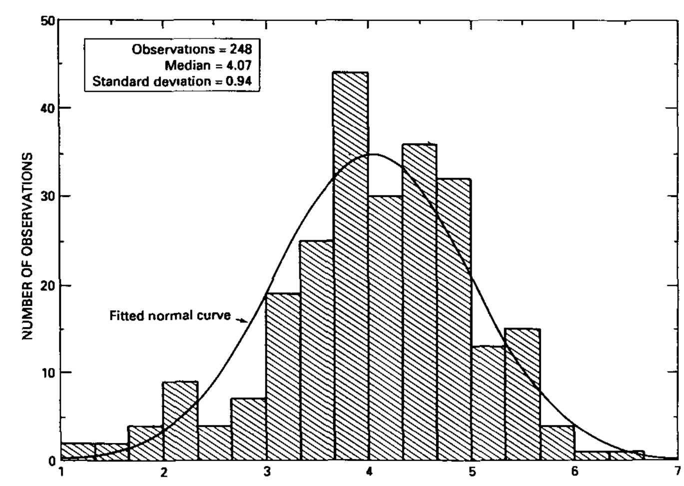

Figure 8. Histogram for the log_{10}-base transmissivity values

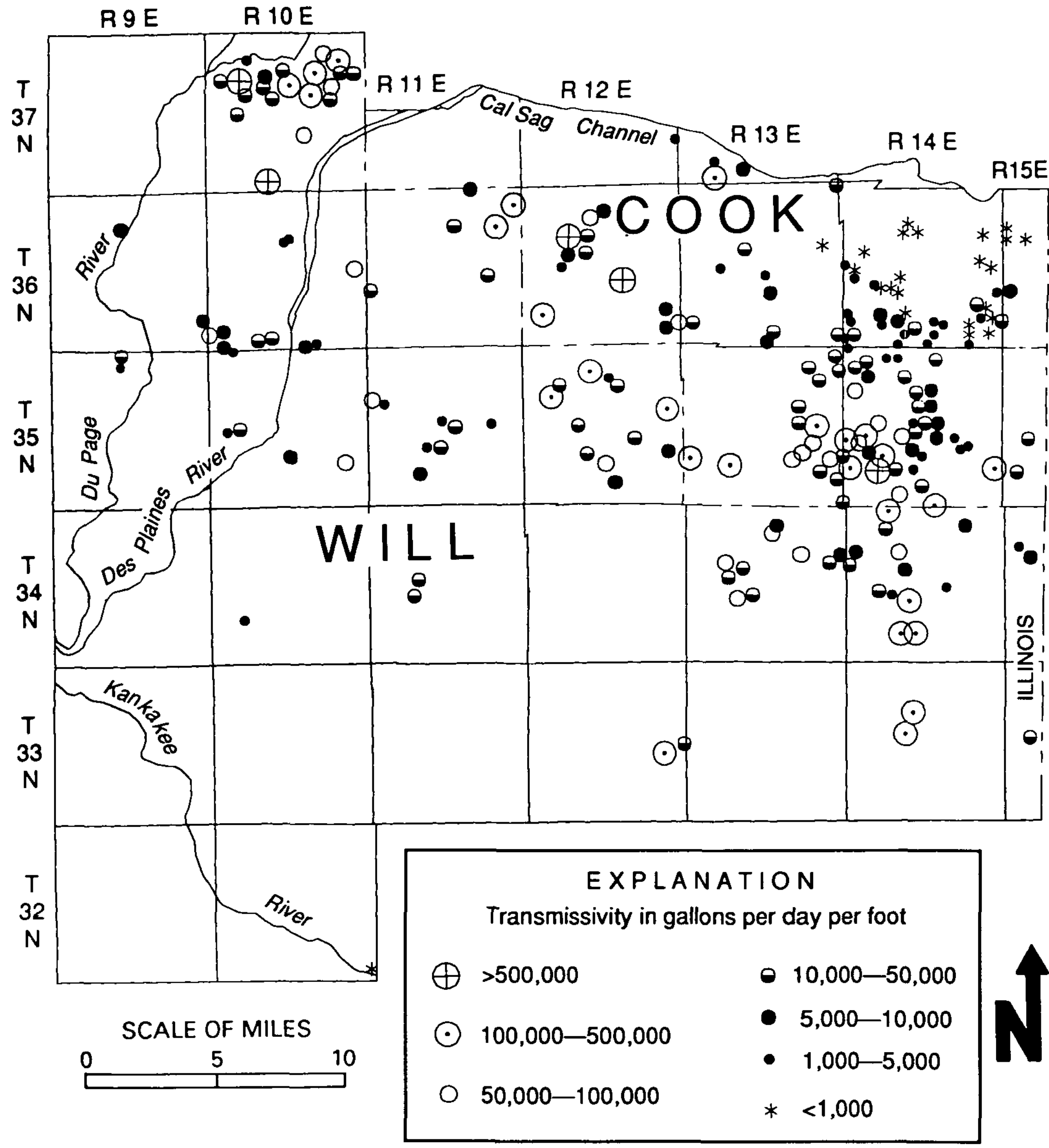

Figure 9. Distribution of transmissivity values for the Silurian dolomite aquifer

interconnection between enlarged fractures and bedding planes is such that a well encountering any one of these features would be fairly productive. Although it is possible to drill an essentially dry hole, Csallany and Walton (1963) estimated that where the dolomite has a high transmissivity and a thickness greater than about 150 feet, the chances are good of drilling a well that will produce more than 500 gallons per minute (gpm). The trend in higher transmissivity values also corresponds roughly with the distribution of basal sands that contribute additional water, or leakage, to the aquifer directly above the point of withdrawal. Exceptionally high values greater than 500,000 (10 5.6^{9}) gpd/ft are likely due to the tested well intersecting very large dissolution features.

Northeast of this area, transmissivity begins to drop off rapidly towards Calumet City, where values are generally less than 1,000 gpd/ft. Factors that may contribute to this decrease include lower bedrock elevations and overlying clay-rich materials that have washed into the fractures and clogged them. The decrease also may be due in part to lithologic and structural changes associated with reef and interreef zones in the dolomite, which Lowenstam (1957) observed north of the large quarry in Thornton Township (36N, 14-15E). Although fewer data points are available southwest of the Will-Cook County line, a general drop in transmissivity also occurs in the area around Crest Hill, Shorewood, and Elwood, where the Silurian dolomite is thinner.

The range of transmissivity values determined in this study is corroborated by data from two other studies. For the Silurian dolomite aquifer in eastern Kankakee and northern Iroquois Counties, Cravens et al. (1990) found transmissivity from 885 specific-capacity analyses to be log-normally distributed with a median value of 7,244 gpd/ft, with minimum and maximum values of 18 and 244,881 gpd/ft Data analyzed by Zeizel et al. (1962) from 130 specific-capacity tests in Du Page County produced a higher median transmissivity of 39,000 gpd/ft, with minimum and maximum values of 1,000 and 5,000,000 gpd/ft. Together these studies may indicate a general trend of decreasing aquifer productivity towards the south.

Hydraulic property data for the Silurian dolomite aquifer are also available from several aquifer tests conducted by Cravens et al. and Zeizel et al. In Du Page County, Zeizel et al. (1962) analyzed data from aquifers tests at Argonne National Laboratory (T37N, R11E) and Wheaton (T39N, R10E), both of which showed leaky-confined aquifer behavior. The Argonne test produced a transmissivity value of 44,000 gpd/ft, with a storage coefficient of 0.00009 and a leakage coefficient of 0.001 gpd/ft^3. The leakage coefficient gives a measure of how much water the overlying confining materials can contribute to the system. It is defined as the vertical permeability of the confining layer divided by its thickness. Hydraulic properties from the Wheaton test were slightly higher, with transmissivity, storage coefficient, and leakage coefficient of 61,000 gpd/ft, 0.00035, and 0.0065 gpd/ft^3, respectively. In Kankakee County, Cravens et al. (1990) ran six aquifer tests, which resulted in transmissivities ranging from 14,200 to 122,000 gpd/ft and storage coefficients ranging from 0.00004 to 0.0006.

Occurrence of Ground Water in Sand-and-Gravel Aquifers

The occurrence of ground water is more straightforward in a sand-and-gravel aquifer than in a fractured dolomite aquifer. In a sand-and-gravel aquifer, water is stored in the pore spaces between individual sand grains. Porosity generally ranges from 15 to 35 percent The rate of ground-water flow, or permeability, is controlled by the size of the openings between the grains. A sand deposit with large sand grains of fairly uniform size will have a high permeability. If the deposit has a fine silt or clay content greater than 5 to 10 percent, permeability will be greatly reduced. The transmissivity of a sand-and-gravel aquifer, therefore, is highly dependent on the geologic mechanisms that formed the deposit. Unlike transmissivity in a fractured dolomite aquifer, the distribution in sand and gravel is continuous, and values generally change slowly with the gradational changes in grain size distribution and total thickness of the layer.

Hydraulic Properties of Sand-and-Gravel Aquifers

Transmissivity and storage coefficient data are not available for the sand-and-gravel aquifers in the study area, except in the Hadley Valley area where Prickettetal.(1964)reanalyzed two 1950 aquifer tests conducted in wells operated by the city of Joliet. The two Prickett analyses produced very similar hydraulic property values and showed that the aquifer locally has a leaky-confined behavior. The average computed values for transmissivity, hydraulic conductivity (transmissivity divided by thickness), storage, leakage, and vertical permeability of the confining layer were 186,000 gpd/ft, 3,100 gpd/ft^2, 0.0015,0.034 gpd/ft^3, and 1.02 gpd/ft^2, respectively.

Rosenshein and Hunn (1968) mapped the distribution of transmissivity values based on specific-capacity measurements of the sand-and-gravel aquifer in neighboring Lake County, Indiana. Although it is probably more geologically continuous, the aquifer in Indiana is very similar to what it is in the adjacent sand-and-gravel deposits in the eastern part of the study area. Where the aquifer is confined, Rosenshein and Hunn (1968) found the transmissivity to range from less than 10,000 to more than 50,000 gpd/ft, while the regional average is estimated at 24,000 gpd/ft. The storage coefficient was estimated to average 0.003. In the southern part of Lake County near the Kankakee River, the aquifer becomes unconfined; the estimated average transmissivity drops to 15,000 gpd/ft, and the storage coefficient increases to 0.12.

GROUND-WATER USE

Water for public or industrial supplies in Will and southern Cook Counties originates either as ground water from one of the three aquifer systems or as surface water from Lake Michigan or the Kankakee River. Location and need largely control which water supply source is used. In 1990 all of the major public water supplies in Will County used ground water, with the exception of Wilmington, which has converted to Kankakee River water. Originally, most of the water supplies in southern Cook County were developed from ground water. But as the population of the area greatly expanded in the last 40 years, the aquifers became overused, and many communities had to switch to Lake Michigan water.

In the eastern and central portions of the study area, the Silurian dolomite aquifer serves as the primary water source. In the western portion of Will County, this aquifer becomes too thin for some of the large demands, so water must be withdrawn from the deeply buried Cambrian-Ordovician aquifer. Joliet supplements its deep aquifer supply by using water from the highly productive sand-and-gravel deposits buried in the Hadley Valley. Although the Cambrian-Ordovician aquifer is not the topic of this report, water use in this aquifer will be discussed because it is important to an understanding of the overall water use in the study area.

Ground-water use in the study area totaled 55.90 mgd in 1990, with 30.72 mgd and 23.38 mgd coming from the Silurian dolomite aquifer and the Cambrian-Ordovician aquifer, respectively. The remaining 1.8 mgd was derived from shallow sand-and-gravel aquifers. The distribution of pumpage from the two shallow aquifers is shown in figure 10. This distribution generally follows a band from the northwest to the southeast, corresponding to the municipalities on the outer fringes of the Chicago and Joliet metropolitan areas that have not switched to Lake Michigan water. The diversion areas indicate how the aquifer is affected by pumpage, which will be discussed in the chapter on recharge and potential yield. The 1990 data were supplied from a database maintained at the Illinois State Water Survey as part, of the Illinois Water Inventory Program (IWIP), which monitors public and industrial water users for total annual use from each of their wells or surface water intakes.

Per-capita water use in Will County was 118 gallons per day (gpd) in 1990. This figure is based on a collective pumpage of 34.3 mgd by the public water suppliers and an estimated

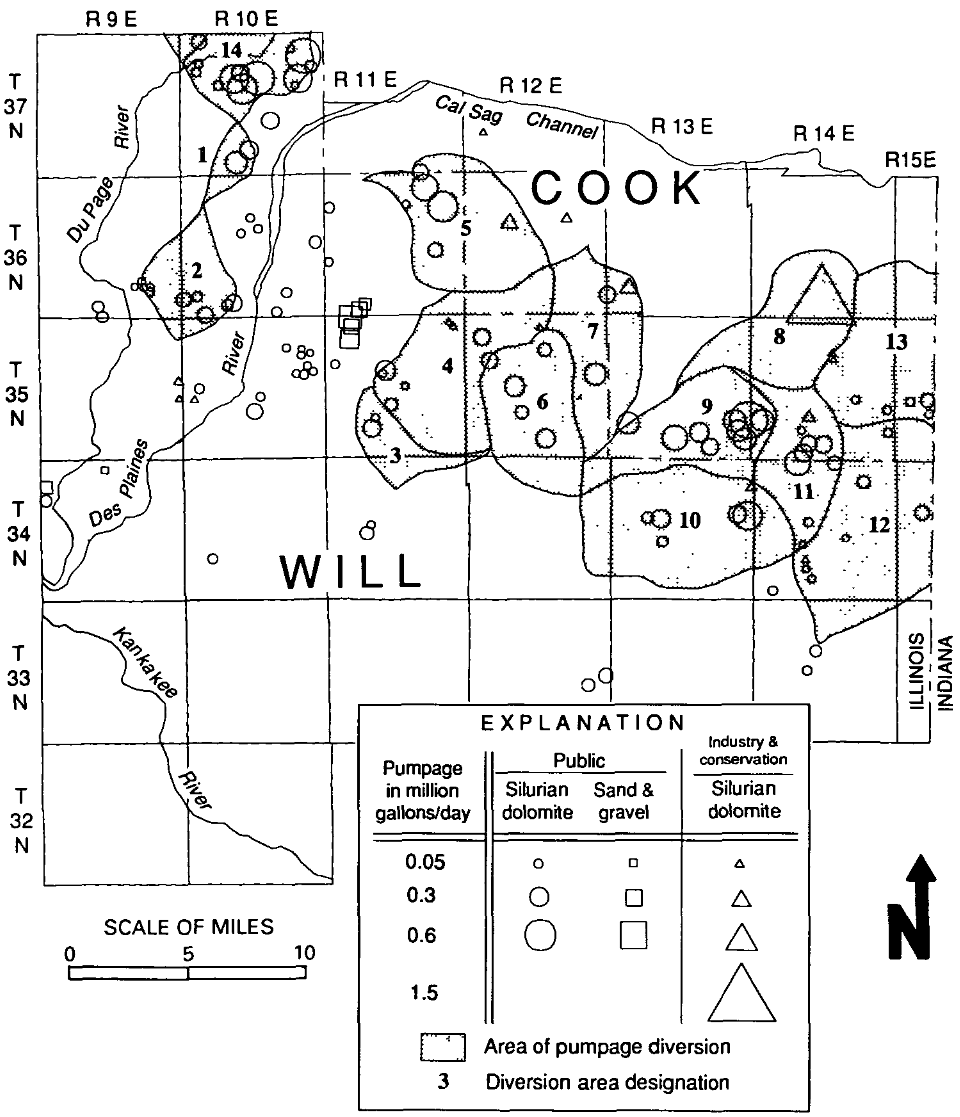

Figure 10. Distribution of ground-water pumpage and diversion areas, 1990

population served of 290,000 people. The population total was derived from the 1990 census (Northeast Illinois Planning Commission, 1991) for residents living in incorporated municipalities, and from figures published by Woller and Sanderson (1983) for residents living in unincorporated areas served by water utilities. This same average consumption was calculated from figures in Kirk (1987) for the statewide average.

Individual Water Users

Silurian Dolomite Aquifer

Listed in table 2 are the individual users of water from the Silurian dolomite aquifer as shown on figure 10. The largest ground-water withdrawals occured in the clustered suburbs of Park Forest, Steger, University Park, Crete, Richton Park, Sauk Village, South Chicago Heights, and Monee which withdrew a total of 6.57 mgd from 31 wells in 1990. The biggest single water user was Bolingbrook, which withdrew 3.66 mgd from seven city wells and seven wells owned by Citizens Utility. Nearby Romeoville used an additional 0.91 mgd. In the north-central portion of the study area, the communities of Frankfort, Mokena, and New Lenox collectively used 3.20 mgd, while the two utilities in Homer Township, Derby Meadows and Metro Chickasaw Hills, used an additional 1.54 mgd. Although Joliet and Lockport use the Cambrian-Ordovician aquifer, the adjacent towns of Crest Hill, New Lenox, Rockdale, and Shorewood and many small subdivisions and utilities, including Crystal Lawns, collectively used 3.16 mgd from the Silurian dolomite aquifer in 1990. Of the communities not listed in table 2, Wilmington used Kankakee River water, and all others received water from Lake Michigan in 1990. Small parts of some communities not listed on table 2 may have received water from neighboring communities also using ground water.

Industrial water use from the Silurian dolomite aquifer is very light, and relatively few suburban industries use this aquifer. Several industrial ground-water users are located in communities whose public supplies are furnished with Lake Michigan water. The large quarry in Thornton Township (T36N, R14-15E) is responsible for most of the industrial

Table 2. 1990 Ground-Water Use

Silurian Dolomite Aquifer

Public water use	*Location (T,R)*	*Pumpage (mgd)*	*Active wells*
Beecher	33N, 14E	0.262	3
Bolingbrook	37N, 10E	0.968	7
Citizens Utility, Arbury Hills	35N, 12E	0.163	1
Citizens Utility, W. Suburban	37N, 10E	2.692	7
Consumers IL Wtr, Univ. Park	34N, 13E	1.198	4
Crest Hill	36N, 10E	0.878	5
Crete	34N, 14E	0.381	3
Crystal Lawns Subdivision	36N, 09E	0.095	5
Derby Meadows Utility Co.	36N, HE	0.591	1
Elwood	34N, 10E	0.074	4
Frankfort	35N, 12E-13E	1.943	6
Howe Developmenl: Center	36N, 12E	0.238	1
Kankakee Wtr Co, Willow Brook	34N, 15E	0.202	2
Lockport	36N, HE	0.049	1
Manhattan	34N, 11E	0.203	2
Metro Utility, Chickasaw Hills	36N, HE	0.951	4
Minooka	34N, 09E	0.133	1
Mokena	35N, 12E	0.473	2
Monee	34N, 13E	0.178	4
Naperville	37N, 10E	0.215	1
New Lenox	35N, 11E	0.786	5
Park Forest	35N, 13-14E	2.228	6
Peotone	33N, 12E	0.350	2
Richton Park	35N, 13E	1.046	3
Rockdale	35N, 10E	0.069	1
Romeoville	37N, 10E	0.914	3
Sauk Village	35N, 14E	0.151	3
Shorewood	35-36N, 09E	0.222	2
South Chicago Heights	35N, 14E	0.518	3
Steger	34-35N, 14E	0.750	2
Small systems near Joliet	35N, 10-11E	0.527	13
Small systems near Lockport	36N, 10-11E	0.536	9
Small systems near Crete	34N, 14E	0.123	5
Small systems near Lynwood	35N, 15E	0.288	7
Subtotal		20.56	**128**
Industrial water use by township			
Monee	34N, 13E	0.075	1
Crete	34N, 14-15E	0.030	1
Troy	35N, 09E	0.084	2
Joliet	35N, 10E	0.077	3
New Lenox	35N, 11E	0.023	3
Frankfort	35N, 12E	0.012	1
Bloom	35N, 14-15E	0.209	4
Orland	36N, 12E	0.349	4
Bremen	36N, 13E	0.282	1
Thornton	36N, 14-15E	1.616	1
Palos	37N, 12E	0.018	1
Subtotal		**2.721**	**22**
Domestic Use Subtotal		**7.44**	.
Total		30.72	**150**

Table 2. Concluded

Sand-and-Gravel Aquifer

Public water use	*Location (T,R)*	*Pumpage (mgd)*	*Active wells*
Minooka	34N, 09E	0.174	1
Treasure Is. Mobile Home Park	34N, 09E	0.023	1
Joliet	35-36N, HE	1.596	5
Total		1.797	7

Cambrian-Ordovician Aquifer

Public water use			
Braidwood	32N, 09E	0.303	3
Camelot Utilities Inc.	35N, 09E	0.047	1
Channahon	34N, 09E	0.046	1
IL Youth Ctr. - Kankakee School	32N,10E	0.010	1
Imperial Mobile Home Park	35N,09E	0.023	3
Joliet	35-36N, 09-11E	10.164	10
Joliet Correctional Center	35N,10E	0.278	1
Lakewood Shores Imprvmt. Assn.	32N,09E	0.042	3
Lemont	37N, HE	0.687	2
Lewis University	36N,10E	0.044	1
Lockport	36N,10E	0.909	2
Naperville	37N, 10E	1.627	2
Plainfield	36N, 09E	0.676	2
Rockdale	35N,10E	0.296	1
Romeoville	37N, 10E	0.571	2
Shorewood	35N, 09E	0.111	1
Stateville Correctional Ctr.	36N, 10E	0.532	2
Treasure Is. Mobile Home Park	34N, 09E	0.031	1
Subtotal		16.389	39
Industrial water use by township or facility			
Wesley-Custer	32N, 10E	0.054	1
Joliet Army Ammunition Plant	33-34N, 09-10E	0.515	4
Channahon	34N, 09E	2.990	9
Jackson	34N, 10E	0.233	3
Joliet	35N,10E	2.372	10
Lockport	36N,10E	0.646	2
Wheatland	37N, 09E	0.033	1
Lemont	37N, 11E	0.161	2
Subtotal		7.004	32
Total		23.393	71

water use, but this supply is pumped from a sump at the bottom of the quarry where ground water collects along with surface runoff from direct rainfall. Quantifying these two components is very difficult, and past pumpage from the sump has been omitted from ground-water use totals. However, due to the influence of the quarry on regional water levels, it is reasonable for illustrative purposes to include this pumpage in the 1990 use total.

Sand-and-Gravel Aquifer

The shallow sand-and-gravel aquifer is very geologically discontinuous through the study area. Nevertheless, moderate water supplies could be obtained in areas where the total thickness of sand and gravel exceeds 50 feet. Joliet is the only major water user taking advantage of this aquifer, with an average pumpage of 1.6 mgd and past pumpages as high as 5.9 mgd. Prickett et al. (1964) estimated that 6.5 mgd could safely be withdrawn from the aquifer along the buried Hadley Valley. Rosenshein and Hunn (1968) estimated that 4 mgd was pumped during the 1960s from sand-and-gravel deposits in Indiana that are either similar to or continuous with deposits along the eastern edge of Will County.

Cambrian-Ordovician Aquifer

In 1990 the Joliet public water supply system relied primarily on the deep bedrock aquifer, consuming 10.1 mgd, or nearly half of the total ground water withdrawn from the Cambrian-Ordovician aquifer. Lockport, Plainfield, and other communities located along or west of the Des Plaines River used an additional 6.23 mgd from this aquifer. Included in this subtotal is 1.6 mgd withdrawn by the Du Page County community of Naperville, a small portion of whose total population and ground-water use are located in Will County. Industrial water use from the Cambrian-Ordovician aquiferreached 7.00 mgd in 1990. The largest users were chemical and energy utility companies, which withdrew totals of 3.1 and 2.2 mgd, respectively.

Overpumpage of the Cambrian-Ordovician aquifer throughout the Chicago area has caused water levels to drop several hundred feet, posing great concern for the long-term ability of the aquifer to supply the communities dependent on it. To secure stable water supplies, many south-suburban Cook County communities such as Homewood switched to Lake Michigan water in the early 1980s. Communities in western Will County are also looking for alternative water supplies, either additional Lake Michigan allocations or new supplies developed from the Kankakee River. Burch (1991) summarized the current condition of the aquifer and used a numerical flow model to predict the future condition of the aquifer based on different water-use scenarios.

Domestic Water Use

Another major component of the total ground-water withdrawal from the shallow aquifers is domestic use by rural homeowners and fanners with private wells. These wells are widely scattered, generally have low capacities, and are completed almost exclusively in the Silurian dolomite. Where the dolomite is thin or absent along the western edge of the study area, domestic wells are completed either in sand-and-gravel deposits or in thin limestone layers of the Maquoketa Formation.

Because pumpage records are not kept for private wells, total domestic use must be approximated. Kirk (1987) estimated that the per-capita consumption of the average resident served by a private well in northeastern Illinois is 83 gpd. This is 25 gpd lower than the municipal consumption rate because the water use of rural self-supplied industries and schools is reported separately. With roughly 67,000 rural residents in Will County and 17,000 rural residents in southern Cook County, estimated domestic use is 6.97 mgd in the study area.

Agricultural water use in Will County also adds to this figure. Using published daily consumption rates and 1986 animal populations, Kirk estimated that 0.36 mgd was used for livestock production. Bowman (1991) calculated that the three irrigation systems in Will County use 0.434 mgd for the 92-day irrigation season, or 0.109 mgd when averaged over the whole year. Totaling these figures produces an estimated total domestic use of 7.44 mgd for the study area.

Ground-Water Use Trends

Joliet developed the first public ground-water supply in the early 1880s from wells completed in the shallow sand-and-gravel deposits and in the Cambrian-Ordovician aquifer. In 1894 Chicago Heights developed the first water supply using the Silurian dolomite aquifer. Sasman (196S) and Sasman et. al. (1974) chronicle the development of public, industrial, and domestic water supplies and their respective ground-water use for regions of northeastern Illinois from 1864 to 1970. Total ground-water use in the study area gradually increased from approximately 2 mgd in 1890 to 5 mgd in 1910. World War I caused a large jump in use, reaching 12 mgd by 1920. Throughout the 1930s use remained fairly constant at 16 mgd due to reduced industrial activity during the Depression. World War II caused another increase in ground-water use, and the subsequent growth of the suburbs extended this trend until the early 1970s. By 1950, ground-water use had reached 24 mgd. It soared to 55 mgd in 1960 and 78 mgd in 1974.

To aid in analyzing recent trends in ground-water use, the total pumpage for the entire study area, each county, and each township have been plotted on figures 11 and 12. Pumpage data for 1974 were drawn from Schicht et al. (1976); for 1980-1986

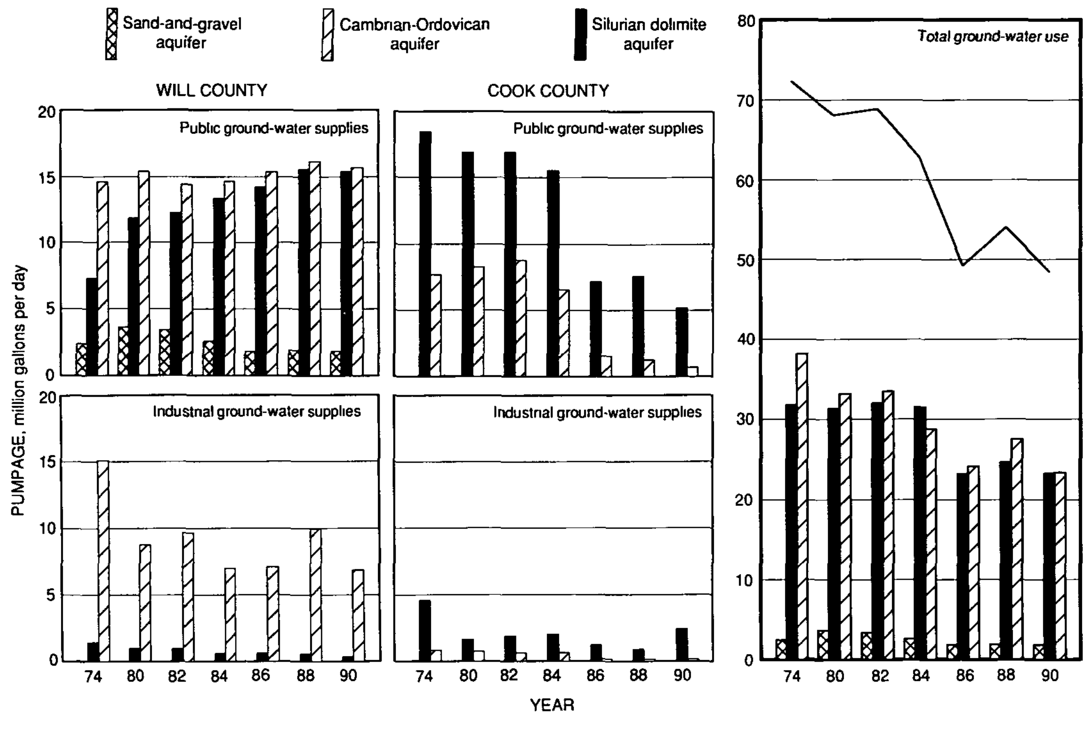

Figure 11. Major ground-water use trends in Will and southern Cook Counties, 1974-1990

from Kirk et al. (1982, 1984, 1985) and from Kirk (1987); and for 1988 and 1990 from the IWIP database. Domestic water use is not included in the figures, although it probably remained fairly stable at 7.44 mgd from 1974 to 1990, similar to the trend estimated by Sasman et al. (1974) for the 1960 to 1970 period.

The total public and industrial ground-water pumpage for the study area has dropped dramatically from 72.3 mgd in 1974 to48.4 mgd in 1990. Southern Cook County accounts for almost all of this 23.9 mgd drop, since many industries and communities such as Chicago Heights have switched to water from Lake Michigan. These Lake Michigan allocations occurred mainly in 1985, resulting in total ground-water pumpage decreases of 8.38 mgd from the Silurian dolomite aquifer and 4.98 mgd from the Cambrian-Ordovician aquifer. Industrial pumpage also dropped in Cook County by 3.1 mgd between 1974 and 1980. The increase in industrial water use for 1990 reflects the

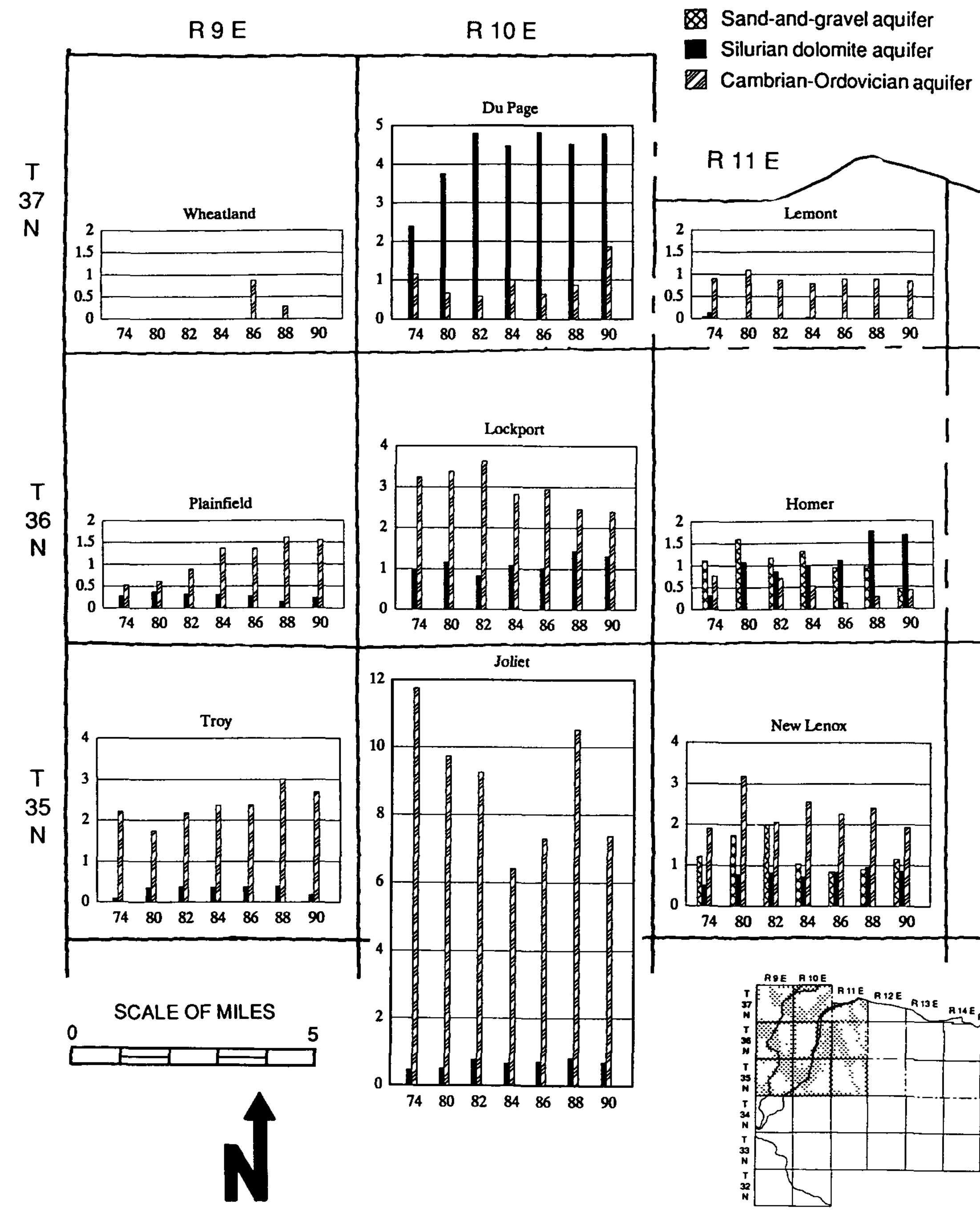

Figure 12a. Ground-water use trends for the townships in the northwest quadrant of the study area, 1974-1990

inclusion of pumpage from the sump at the large quarry in Thornton Township.

Total public and industrial ground-water use in Will County for all three aquifers remained fairly constant for the 16-year period of 1974-1990 at approximately 40 mgd. Pumpage declined slightly in 1984 and 1986 and rose somewhat in the drought year of 1988. The population of the county grew by about 85,000 during this period and increased demand for publicly supplied water, although this increase was offset by equal reductions in industrial demands.

The new or expanded public supplies tend to withdraw water from the Silurian dolomite aquifer in the growing suburban townships of Du Page, Homer, and Frankfort, while the declining industrial needs require less water from the Cambrian-Ordovician aquifer in Joliet and Channahon Townships (figure 12). Between 1974 and 1990 a fairly constant 15 mgd

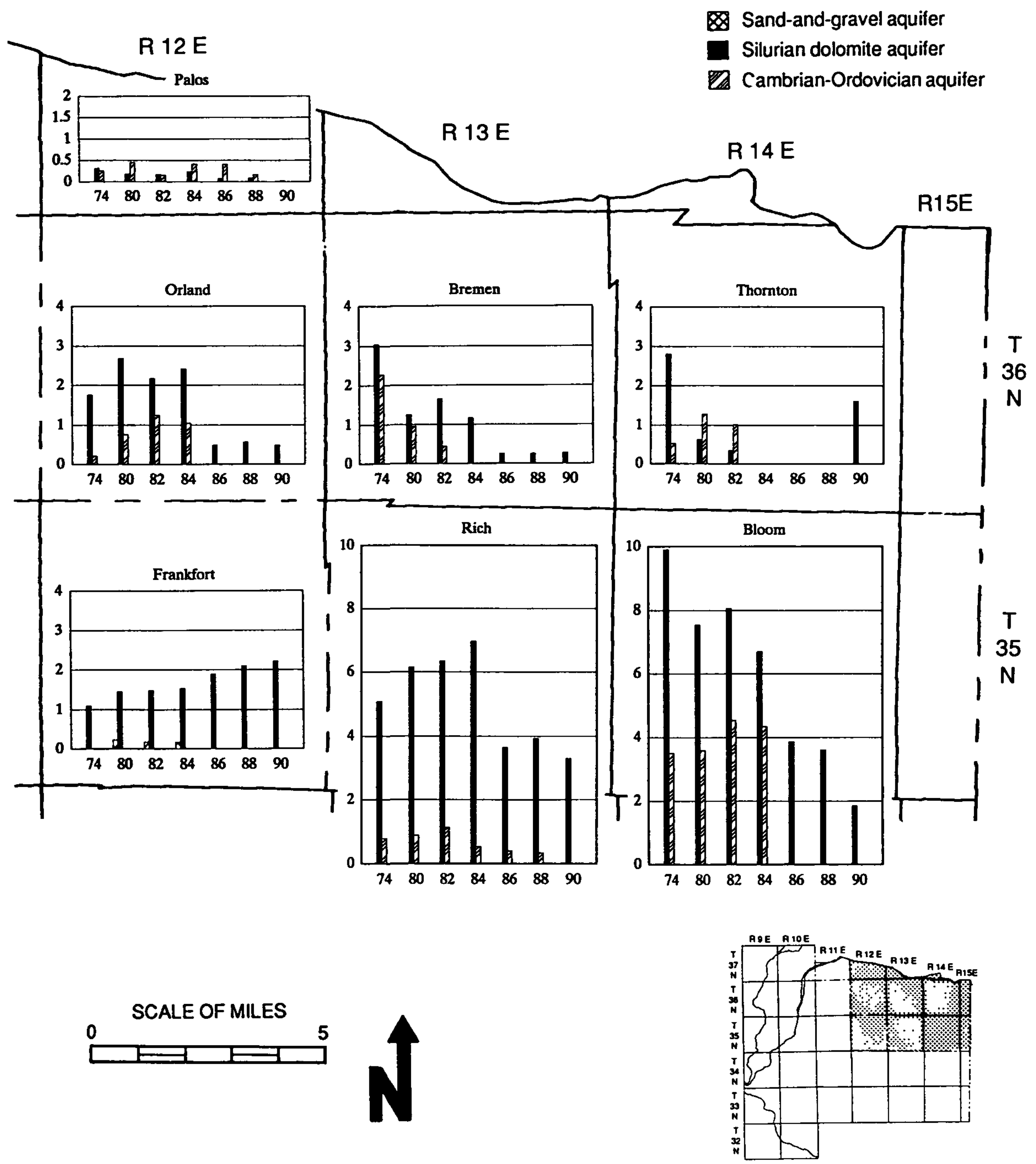

Figure 12b. Ground-water use trends tor the townships in the northeast quadrant of the study area, 1974-1990

was pumped from the Cambrian-Ordovician aquifer for public water supplies (figure 11), although a population shift during this period has increased pumpage in Troy, Plainfield, and Du Page Townships and decreased pumpage in Joliet and Lockport Townships (figure 12).

Trends in total water use for New Lenox and Homer Townships are complicated by the city of Joliet, which pumps from both the sand-and-gravel and Cambrian-Ordovician aquifers. In Homer Township, pumpage for local demand from the Silurian dolomite aquifer increased by 1.37 mgd between 1974 and 1990. Meanwhile, Joliet reduced pumpage from the sand-and-gravel and Cambrian-Ordovician aquifers by 0.67 mgd and 0.35 mgd, respectively, increasing total water use by a relatively small 0.36 mgd. In New Lenox Township, total pumpage dropped 1.76 mgd after 1980. Local demand increased the use of the Silurian dolomite by a slight 0.09 mgd, while Joliet reduced pumpage in the sand-and-gravel and Cambrian-Ordovician aquifers by 0.60 mgd and 1.25 mgd, respectively.

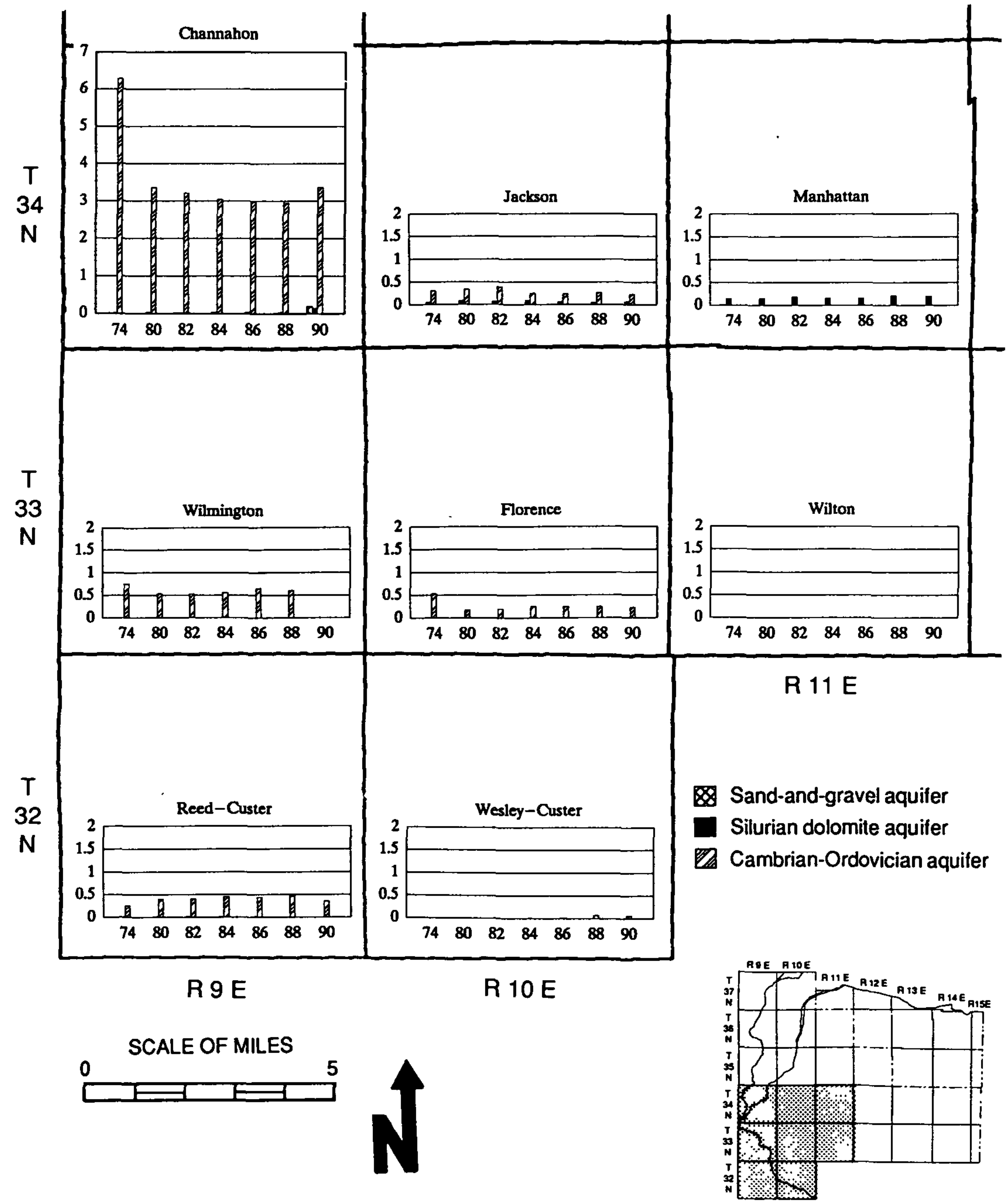

Figure 12c. Ground-water use trends for the townships in the southwest quadrant of the study area, 1974-1990

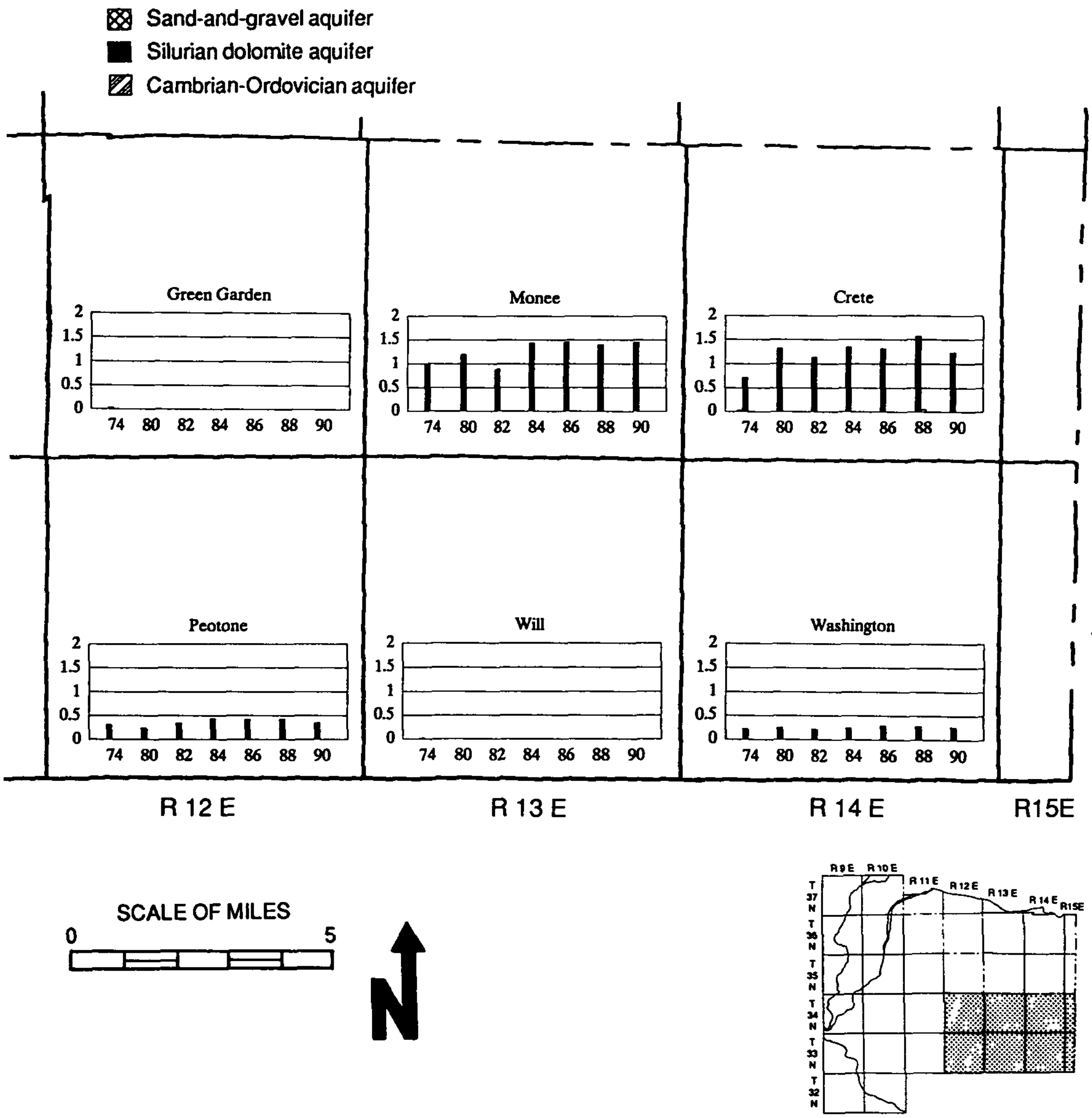

Figure 12d. Ground-water use trends for the townships in the southeast quadrant of the study area, 1974-1990

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POTENTIOMETRIC SURFACE OF THE AQUIFER

Water levels in the Silurian dolomite aquifer were measured in summer and fall 1989 and fall 1990. The 1989measurements were taken as part of a reconnaissance effort to locate and characterize wells that could be used for a 1990 mass measurement. The mass measurement involved taking depth-to-water readings at 429 public, private, and industrial wells (figure 13) over a three-week period to produce an instantaneous view of water levels in the aquifer, free of any temporal variation.

All measurements were taken while the wells were not pumping and were preceded by several measurements to ensure that water levels were static and not changing significantly. The depth-to-water readings were then subtracted from surface elevations estimated from USGS topographic maps. The resulting water-level elevation represents what is called the aquifer's "potentiometric" or "hydraulic" head, that is, the level to which water will rise in a properly constructed well.

A preliminary potentiometric surface map was developed by contouring the water-level elevations with the computer program SURFER® (Golden Software, 1989). Additional contouring points were added to represent surface water elevations where they are considered to indicate the hydraulic head in the aquifer, such as along the Des Plaines River.

A statistical analysis of the uncertainty in the water-level data was performed using the program GEO-EAS (Englund and Sparks, 1988). The analysis showed that the network of water-level measurements is dense enough to define the regional potentiometric surface accurately.

The final potentiometric map (plate IV) was constructed by manually changing and adding contours along the study area boundaries and some of the streams where data were insufficient to allow the contouring algorithms in SURFER to properly function.

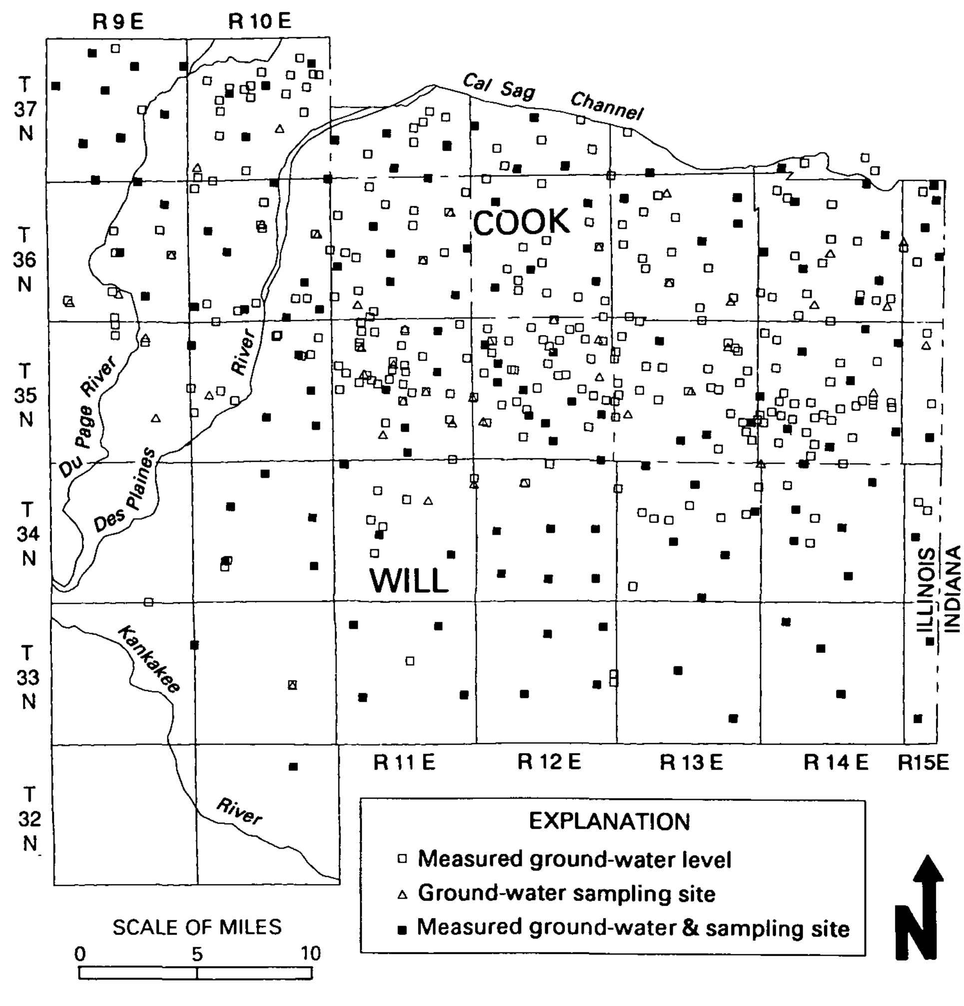


Figure 13. Water-level measurement and ground-water sampling sites in the study area

Potentiometric Surface

The topography of the study area and the location of surface water streams work together to control the shape of the potentiometric surface. Surficial geology and public and industrial ground-water pumpage additionally influence this surface. The highest point in the potentiometric surface occurs in Green Garden Township (T34N, R12E) with an elevation just over 720 feet above msl. The lowest point occurs at the floor of the quarry in Thornton Township (T36N, R14-15E) with an approximate elevation of 350 feet above msl. A major ground-water divide separates westward flow towards the Des Plaines and Kankakee Rivers from northeastward flow towards the Calumet River system and Lake Michigan. The divide generally follows the topographic high formed by the Valparaiso Morainic

System, extending from the high point northward to Orland Park and southeastward towards Beecher in the southeast portion of the study area (plate IV).

Western Portion of the Study Area

The Des Plaines River is the dominant hydrologic feature in the western half of the study area. The river forms a large valley that cuts through the glacial material and into the Silurian dolomite. Because the river is in direct connection with the aquifer, the potentiometric level of the aquifer is approximately equal to the elevation of the river. The river serves as a major discharge area for the aquifer, reflected by the potentiometric contours that parallel the river and the river's 75-foot in drop elevation as if flows through the study area. Abundant recharge maintains the potentiometric level in the aquifer at a relatively high elevation until ground-water flow approaches the river. Here the head begins to drop rapidly due to the rapidly declining ground levels in the river valley.

In the southwestern portion of the study area, the Silurian dolomite is either very thin or absent (figure 3). As ground-water flow moves to the southwest though this progressively thinning aquifer, water is diverted into the geologic material above and below the dolomite, or it is discharged directly into streams and wetlands at the surface. In some areas, flow in the aquifer reaches the Kankakee and Des Plaines Rivers, but the quantity is very small because the aquifer is so thin.

Several small creeks along the eastern sides of the Des Plaines and Kankakee Rivers form additional discharge areas where they have eroded through the glacial material. As with the large rivers, the potentiometric level of the aquifer at these isolated bedrock outcrops (plate III) is equal to the elevation of the creeks. Hickory Creek, the largest of these small creeks (plate IV), forms a valley that causes a deep cut in the potentiometric surface around New Lenox due to several discharging aquifer outcrops. The effect of Hickory Creek is further exacerbated by ground-water pumpage in New Lenox, Mokena, and the buried Hadley Valley.

Northwestern Portion of the Study Area

West of the Des Plaines River, the ground-water flow system becomes very complicated due to the influences of the Du Page River. Ground-water discharge into the Du Page River varies along its length due to changes in the surficial geology. Near Naperville, at the northern edge of the study area, the river crosses over several aquifer outcrops, allowing for some direct ground-water discharge. Because the hydraulic connection between the river and the aquifer is only spotty, ground water can also flow beneath the river from Naperville to the well fields in Bolingbrook.

Between Naperville and Plainfield, the aquifer appears to be flowing into sand-and-gravel deposits immediately east of the Du Page River, where it then discharges into small streams, sand-and-gravel quarries, or the river itself. From Plainfield to Shorewood, the aquifer continues to discharge through overlying material, but the discharge has become recentered over the river. South of Shorewood, the potentiometric surface had to be estimated due to a lack of measurable wells, but ground-water likely is discharging into the river, as well as to a small creek to the west and to the Illinois and Michigan Canal.

The ground-water divide between the Du Page and the Des Plaines Rivers is very meandering due to the valleys formed by three glacial outwash channels at Romeoville and Crest Hill that once connected the two rivers (figure 4). Municipal pumpage at Bolingbrook, Romeoville, and Crest Hill has also affected the position of the potentiometric divide. The northwestern corner of the study area sits on another ground-water divide that separates flow towards the Du Page River from flow in neighboring Kendall County, which moves toward the Fox River, according to a map by Visocky and Schulmeister (1988).

Southern Portion of the Study Area

Along the southern edge of the study area, ground water flows to the south into Kankakee County. Approximately 10 miles south of the county line, ground water discharges into the Kankakee River, which flows roughly east to west. Cravens et al. (1990) showed that in 1989 ground water flowed into the river at an elevation of 620 feet above msl near the town of Momence(T31N,R13E).

Northeastern Portion of the Study Area

North and east of the major divide underlying the Valparaiso Morainic System, ground water flows northeast towards the Calumet River system at the north end of the study area. In Palos and western Worth Townships (T37N, R12-13E) the potentiometric surface follows the surface topography into the Calumet Sag Valley. Flow ends at the channel with a hydraulic head several feet above the elevation of the surface water. Along the channel, ground water in the Silurian dolomite aquifer flows upwards into the channel or one of the surrounding creeks, either directly or through surficial materials. There are no published potentiometric surface maps for the area north of the Calumet Sag Channel, but in September 1990 the water level in a USGS observation well a mile north of the channel and a quarter-mile south of the Des Plaines River showed an elevation of 583 feet above msl (Richards et al., 1992). This level is approximately 5 feet above that of the rivers.

The potentiometric surface in the northeastern corner of the study area is complicated by four ground-water depressions. Beneath the channel in eastern Worth and western Calumet Townships (T37N, R13-15E) is a large combined sewer overflow tunnel constructed several hundred feet below the surface. It is operated by the Metropolitan Water Reclamation District of Greater Chicago (MWRDGC) as part of the Tunnel and Reservoir Project (TARP). Cravens and Zahn (1990) mapped the potentiometric surface around the TARP tunnel in as much detail as possible as part of a study that covered the Lake Calumet area between the Little Calumet River and the mouth of the Calumet River at Lake Michigan.

These water-level measurements show that a steep localized gradient has developed towards the tunnel and that the water level has been lowered by approximately 60 feet. The gradient is a result of the tunnel being dewatered except during storm events when it may be full and under pressure for periods of several hours. Cravens and Zahn (1990) postulated that the low transmissivity of the area contributes to the steepness of the gradient, and that the long screens of the deep MWRDGC observation wells may show lower heads than typical domestic wells completed in the first 20 feet of the dolomite aquifer. In plate IV the depression around the tunnel follows the 560-foot contour in Calumet Township (T37N, R14E).

As flow enters Thornton Township (T36N, R14-15E) much of the ground water is diverted into a large quarry and is discharged by the quarry sump. The flow into this quarry is much smaller than to a comparable quarry elsewhere in the study area because the local transmissivity is much lower and the surrounding bedrock elevations are much higher. This has allowed for greater dewatering of the more permeable upper portions of the aquifer.

Directly east of the quarry is Thorn Creek, which passes over a bedrock outcrop where water discharges into the aquifer and causes a ground-water mound. East of Thorn Creek is an unexplained depression that may or may not have resulted from activity at the quarry.

Farther to the northeast, the potentiometric surface intersects the Little Calumet River. The river does not appear to affect the shape of the potentiometric surface, so flow between the river and the aquifer is probably minimal. In the very northeasternmost corner of the study area, a depression occurs where the water-level elevation drops to 500 feet above msl, 80 feet below the level of Lake Michigan. The cause of this large depression is unknown, but it is not due to public or industrial pumpage. Two possible explanations involve water seeping through the Maquoketa Shale to the Cambrian-Ordovician aquifer, where the hydraulic head is several hundred feet lower. This could be caused either by the presence of extensive fractures in the shale or, more likely, by an improperly abandoned well that opens to both aquifers and facilitates the large transfer of water between them.

Along the eastern edge of the study area, ground water flows toward Indiana. In 1960 the USGS mapped the potentiometric surface of the Silurian dolomite aquifer in neighboring Lake County, Indiana (Rosenshein, 1963). This map shows a continuation of the major ground-water divide that meanders eastward at a latitude equivalent to the northern half of township row 33N. Ground water entering from Illinois will flow either due north to the Calumet River system and Lake Michigan or due south to the Kankakee River. The Lake County, Indiana, potentiometric surface matches fairly well with that of the study area, except near its intersection with Will and Cook Counties, where the 1960 hydraulic heads were 10 to 20 feet higher.

Effect of Pumping Centers on the Potentiometric Surface

Each well that removes ground water from the aquifer reduces the hydraulic head in the surrounding area, forming a cone of depression in the potentiometric surface. The drop in hydraulic head, or drawdown, depends on the pumping rate and its duration and on the aquifer transmissivity and storage coefficient. Several cones of depression have a pronounced effect on the potentiometric surface in the study area, such as the ones at South Chicago Heights, Park Forest, Peotone, Frankfort, New Lenox, and Crest Hill. Several pumping centers with cones of depression do not appear on plate IV due to physical reasons such as low discharge rates, high transmissivity, or proper well spacing; or for mapping reasons such as the location of observation wells with respect to the pumping well or the contour interval of the map.

Pumping centers remove water from the aquifer, thus diverting water out of the regional flow .field. This diversion area becomes a new independent flow system that is separated from the rest of the flow system by a continuous ground-water divide. The diversion areas for most of the pumping centers in the study area are shown in figure 10. Assuming conditions are not changing, all of the water within a particular diversion area will eventually be discharged from the aquifer through a pumping well. For example, all of the recharge entering diversion area 6 will be consumed by Frankfort, Arbury Hills, or one of the Mokena wells.

Relationship of the Potentiometric Surface to the Geology

The relationship of the potentiometric surface to the bedrock topography, glacial geology, and land surface can be observed through potentiometric profiles and elevation difference maps. The potentiometric profiles superimposed on the geologic cross sections (figure 5) give a vertical perspective of the regional ground-water flow. The profiles show that the aquifer is mostly under leaky-confined conditions except near some of the pumping centers and streams where the aquifer becomes unconfined. A confining condition means that the water in the aquifer is under pressure due to the presence of overlying, low-permeability material. This causes the water level of a well completed in the dolomite to rise above the top of the bedrock. Under leaky-confined conditions, the overlying materials can contribute water to the aquifer, which recharges the aquifer and builds up the potentiometric surface under topographic highs.

If the flow system was strictly confined, the potentiometric surface would be much flatter, and the gradients would be controlled by bedrock outcrops and penetrating streams. Due to the variable nature of the glacial deposits, stricter confining conditions can occur such as at Plum Creek in cross-section D (figure 5). Where the potentiometric profile is within the drift layers on the figure, it represents the hydraulic pressure heads of the confined aquifer and not the physical location of ground water moving within the flow system.

Figure 14 shows the difference in elevation between the potentiometric surface of the aquifer and the bedrock topography. In most of the study area, the potentiometric surface is above the dolomite bedrock surface, reflecting the confined behavior shown in the profiles. The greatest positive elevation differences tend to occur where the glacial drift is thickest, such as along the Valparaiso Moraines and the buried Hadley Valley. The greater the elevation difference, the greater the allowable drawdown. Thus more water can be withdrawn from a water supply well before productivity drops significantly.

Although not enough wells are available to measure the potentiometric surface of the sand aquifers, their hydraulic heads, gradients, and flow directions may be quite different than those of the Silurian dolomite aquifer. Prickett et al. (1964) found that in the Hadley Valley, the potentiometric surfaces of the two aquifers are very similar due to the good hydraulic connection between them. Conversely, Rosenshein (1963) shows that beneath the Valparaiso Moraines in Indiana, where the two aquifers are separated by materials with low permeability, the hydraulic head of the sand aquifer is 20 feet higher. In Kankakee and Iroquois Counties, Cravens et al. (1990) also found the head in the sand-and-gravel aquifers to be higher, providing further evidence that water moves downward through the glacial drift, recharging the dolomite aquifer.

In areas where the potentiometric surface is below the Silurian dolomite bedrock surface, the aquifer has been partially dewatered. Under these conditions, flow in the aquifer is unconfined. Measured water levels represent the true water table, and decreases in water levels physically drain the aquifer. Because the more permeable portion of the Silurian dolomite aquifer tends to be near the bedrock surface, it is important to know the extent to which the aquifer has been dewatered.

A large area of naturally dewatered aquifer occurs along the Des Plaines and Kankakee River valleys, where the relatively lower elevations of the rivers and creeks have caused the surrounding bedrock uplands to become unsaturated (figure 14). This relationship can be observed at the west end of cross-section C in figure 5. Ground-water pumpage at Crest Hill, Romeoville, and the three bedrock quarries also have contributed to the dewatering. In New Lenox, the small area of dewatered aquifer can be attributed to the close proximity of the pumping wells to the bedrock out-

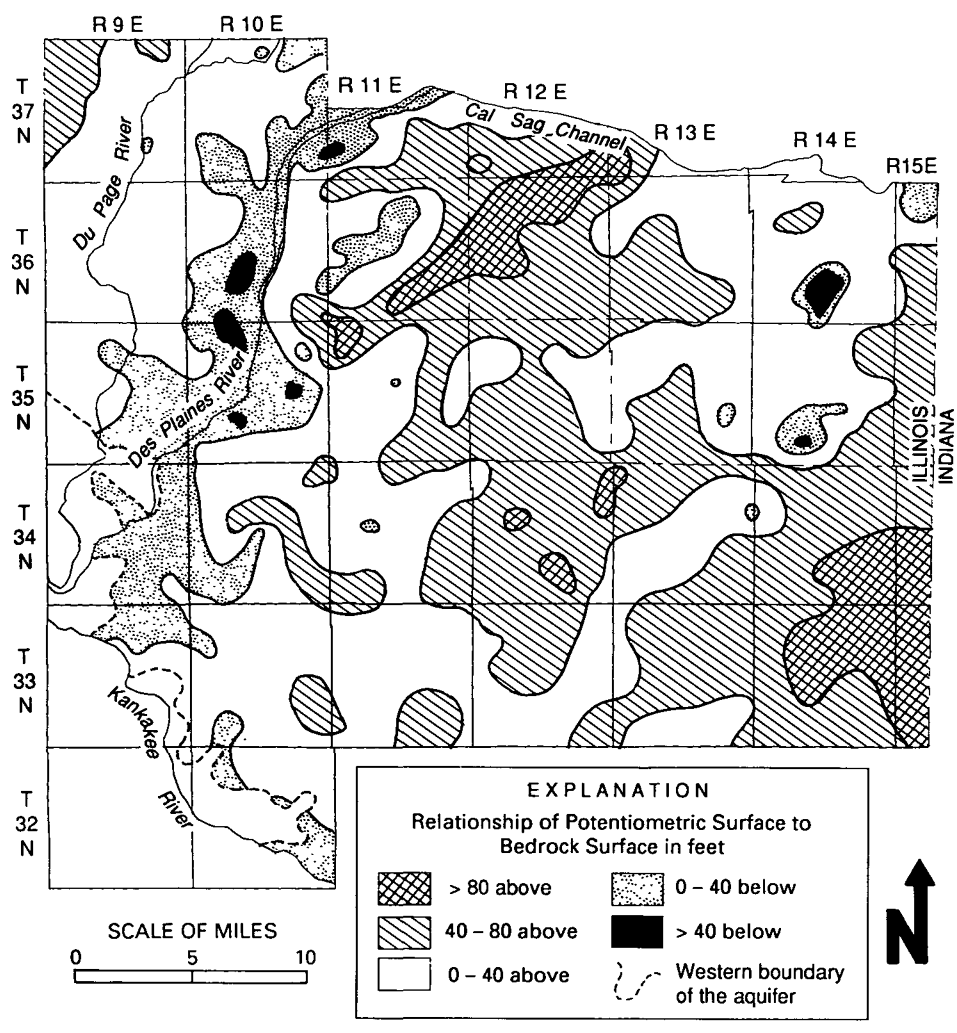


Figure 14. Relationship of the potentiometric surface to the bedrock surface

crops along Hickory Creek. Although separated from the main area, the dewatered portions of Homer Township (T36N, R11E) and northeastern Bolingbrook are due to relatively high bedrock elevations and low surface water elevations. Pumpage in Homer Township may have contributed slightly to the dewatering. Bolingbrook was also affected in 1990 by local pumpage and by pumpage in the neighboring Du Page County town of Woodridge.

The remaining areas of aquifer dewatering in South Chicago Heights, Park Forest, University Park, and Manhattan (figure 14) are caused by the potentiometric cones of depression created when ground-water pumpage intersects highs in the bedrock topography (plate II). The dewatered area around South Chicago Heights in Bloom Township (T35N, R14-15E), shown as cross-section A in figure 5, has probably been enlarged by the bedrock outcrops in the northeast part of the area and by past dewatering in Chicago Heights. The large dewatered area in Thornton Township (T36N, R14-15E) is due to the large quarry excavation.

Historic Changes in the Potentiometric Surface

Historic water-level data are available for three portions of the study area, including the Chicago Heights area, the Bolingbrook area, and the Hadley Valley area. Previously measured potentiometric surfaces are available for all three areas, and in two of these areas water-level hydrographs also are available from ISWS observation wells.

Chicago Heights Area

Water levels in the Silurian dolomite aquifer have fluctuated dramatically during the twentieth century in response to changes in pumpage and precipitation. Prickett et al. (1964) summarized the relationship between these parameters and made several conclusions about the flow system. Between 1894 and 1952, daily public and industrial ground-water pumpage increased by about 1.3 mgd per decade, reaching a total of 8 mgd. During this period, the water level in Chicago Heights production well T35N, R14E-21.7e15 fluctuated between 50 and 140 feet below the land surface and ended at 55 feet below the land surface.

By examining precipitation records, Prickett et al. (1964) identified aclose relationship between water levels and precipitation changes and noted that heavy spring rains cause a rapid rise in water levels. He also concluded that water was taken from storage within the aquifer during years of below-normal precipitation and replenished during years of normal and above-normal precipitation.

In 1952, daily ground-water use began a dramatic increase of 0.6 mgd per year, reaching a total of 14 mgd in 1962. The extra pumpage caused a decrease in regional water levels of about 25 feet and a 100-foot decrease at well T35N, R14E 21.7e15. Prickett et al. constructed a potentiometric surface map using 1961 and 1962 water-level measurements. It shows a large cone of depression in Chicago Heights with the water level in the center below 500 feet above msl. Within the cone of depression, dewatering had occurred over an area of 9 square miles with an average dewatered thickness of 36 feet and a maximum of 174 feet.

Prickett et al. also showed that the average transmissivity of the aquifer (estimated from specific-capacity data) drops from 65,000 gpd/ft in areas with no dewatering to 22,000 gpd/ft in extensively dewatered areas, which in turn contributes to further water-level declines. It was concluded that ground-water withdrawals could continue from the existing pumping center because water levels in Chicago Heights had not reached a critical stage, and other areas were far from approaching one.

Just outside the main Chicago Heights cone of depression, a mile to the southwest of well 21.7e15, is an ISWS observation well in section 29.6e. The hydrograph of the observation well (figure 15) shows the regional water-level changes, including the sharp drop in the late 1950s and early 1960s. In the mid 1960s ground-water pumpage from the Silurian dolomite aquifer began to stabilize, and rose only 2 mgd by 1984 to approximately 16 mgd. During this period the water level in the observation well dropped by about one foot

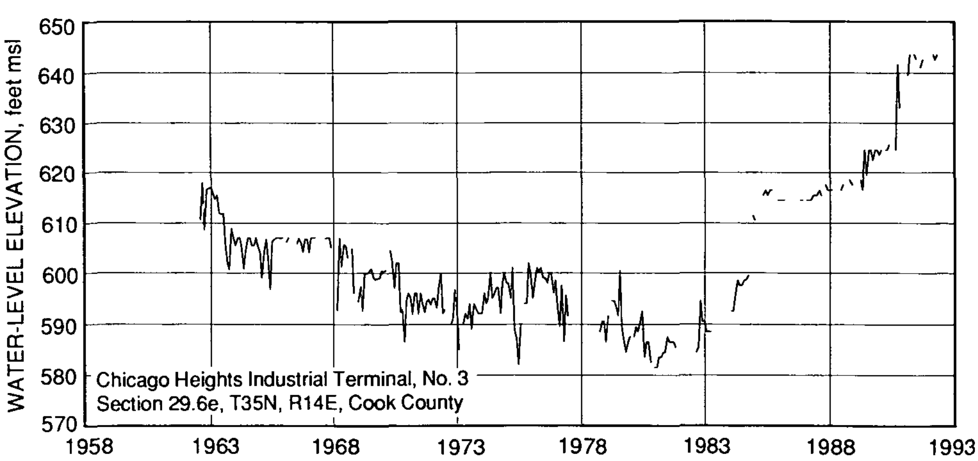


Figure 15. Hydrograph of observation well in Chicago Heights

per year. In 1985 Chicago Heights switched to Lake Michigan water, and the total area water use for the Silurian dolomite aquifer dropped by 5.5 mgd. This caused the water level to begin a rapid recovery, maintaining an average rate of 10 feet per year until 1990, when the water level appears to have restabilized at the 1958 level.

By subtracting the 1962 potentiometric surface from the 1990 surface (plate IV), a difference map was created showing the spatial distribution of water-level change (figure 16). The most dramatic change occurs at the Chicago Heights well field, where water levels have recovered more than 140 feet since 1962, and more likely 160 to 200 feet when the lower water levels of the early 1980s are considered. Future data will determine whedier the recovery is continuing and expanding in area. Another center of recovery occurs northwest of Chicago Heights where a pre-1985 cone of depression was formed by pumpage from the village of Flossmoor.

In Park Forest, 1990 pumpage was equal to 1962 pumpage, but the location of the pumpage has shifted to the west where it has caused the water level to decline. Additional declines have occurred in South Chicago Heights, Steger, Crete, and Sauk Village, where pumpage has increased; and in University Park, where two new well fields have been developed towards the eastern and western edges of town.

Some of the water-level differences shown in figure 16 may be due to differences in how the potentiometric surface maps were constructed, such as the location and numbers of observation points. The 1962 maps were affected by seasonal fluctuations because the water-level measurements were taken over a period of 20 months. Yearly fluctuations in precipitation may have caused additional water-level differences, aldiough it is difficult to determine exactly what their effect is without a hydrograph that is unaffected by pumpage. The 1990 precipitation total at the Park Forest station set a 30-year high at 47.29 inches, while the 1962 total set the corresponding 30-year low of 24.56 inches. However, 16.65 inches of precipitation fell during the critical fall recharge months of 1961, a 30-year high.

Bolingbrook Area

Sasman et al. (1981) conducted a study of the Silurian dolomite aquifer in Du Page County that included a potentiometric surface map constructed in summer 1979 showing Wheatland Township (T37N, R9E) and Du Page Township (T37N, R10E) in Will County. This potentiometric surface agrees very well with the 1990 potentiometric surface; most of the differences in water levels are less than 5 feet. Differences approaching

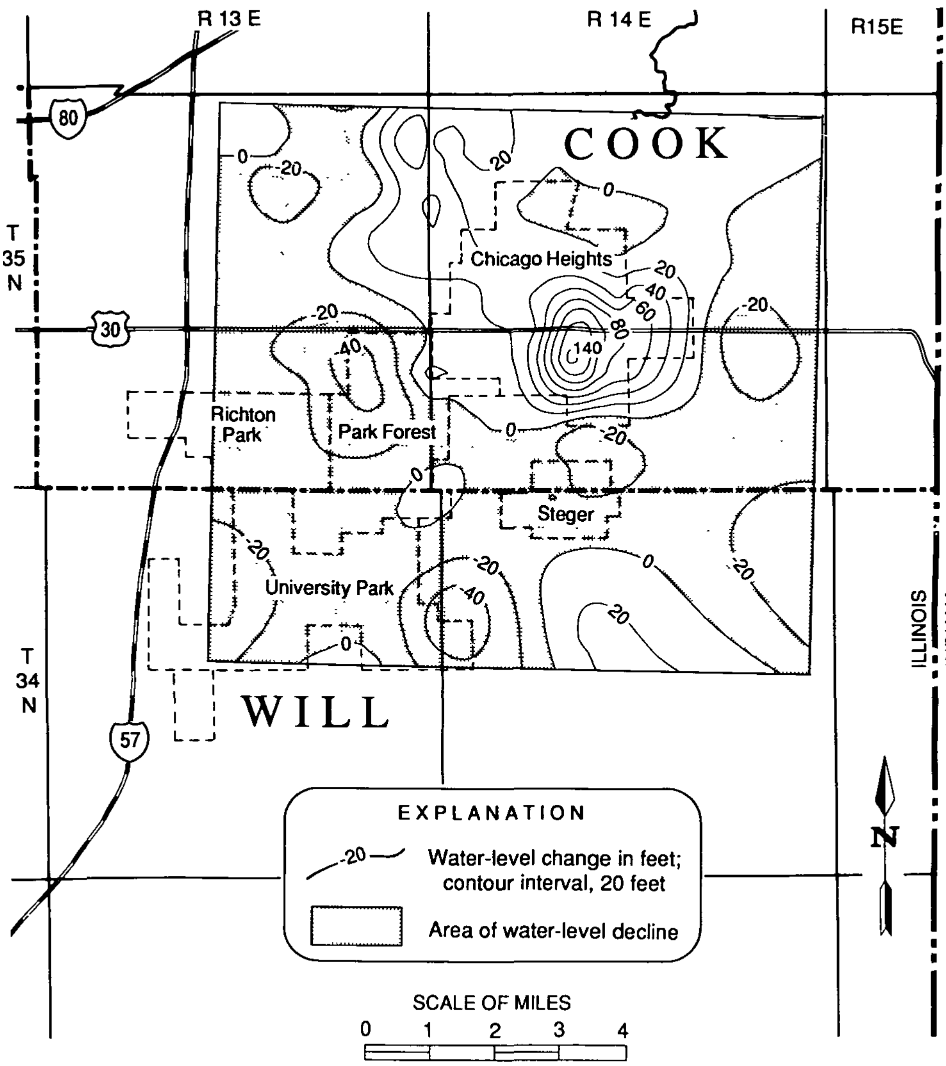


Figure 16. Water-level changes in the Chicago Heights area, 1962-1990

10 feet occur in small areas of east-central Wheatland Township and west-central Du Page Township. The 1979 map showed more local variations in northern Wheatland Township, which may be due to a greater density of measuring points. A dewatered aquifer map from the same study showed less dewatering in northeastern Bolingbrook, but this is probably the result of using a less accurate bedrock surface map for Du Page Township.

Figure 17 shows a water-level hydrograph for observation well T37N, R10E 11.6d in central Bolingbrook, which is surrounded by nine production wells, all between a half-mile and a mile away. The hydrograph is strongly affected by seasonal changes: water levels generally rise during the winter recharge season and fall during the summer discharge season when plants intercept most of the precipitation. An overall decline of roughly one foot per year occurred between 1984 and 1989. However, a redistribution of pumpage in late 1989 prevented further regional water-level declines in the area around this well.

Hadley Valley Area

In the early 1940s, Horberg and Emery (1943) mapped out the buried bedrock valleys east of Joliet in the hope of finding a sand-and-gravel aquifer suitable for supplying water to the city. What they found was a large, saturated sand-and-gravel deposit in a buried glacial outwash channel that was later named the Hadley Valley aquifer after a local crossroads. This valley is overlain by the present-day Spring Creek. In 1950, the city of Joliet installed five production wells in the aquifer and in 1952 began withdrawing water at a rate of 3.0 mgd.

Prickettet al. (1964) examined water-level changes through the first ten years of use and on May 24-25,1962, mapped the potentiometric surface of the Hadley Valley aquifer. By comparing these water levels with those in wells completed in the Silurian dolomite, it was concluded that the two aquifers are well connected and that they generally have very similar potentiometric surfaces. Detailed hydrographs show that ground-water levels respond rapidly to heavy spring rains and to changes in total pumpage. Using streamflow hydrograph separation methods, Prickett et al. determined that in 1962, ground-water discharge to Spring Creek ranged from about 20 mgd during peak flows in the winter and spring, to 1.2 mgd during low flows in early September. A network of seven streamgaging stations showed that ground-water discharge varied dramatically along the creek, and that in two stretches the creek actually was losing water into the sand-and-gravel aquifer.

Figure 18 is a water-level difference map for the Silurian dolomite aquifer constructed by subtracting the May 1962 map from the September 1990 map (plate IV). Over most of the area, water levels declined about 10 feet between 1962 and 1990. The seasonal recharge-discharge cycle probably explains much of this decline, because measurements were made at different times of the year. Another factor is that 21.4 inches of precipitation, a 30-year high, fell during the recharge months in fall 1961 and January 1962. In the area around the Joliet well field, 1990 water levels were about the same as in 1962, because the regional decline had been roughly offset by a 1.6-mgd pumpage reduction, which halved the well field's production rate. The additional water-level declines in the northeastern portion of this study area are most likely due to pumpage from the dolomite aquifer by nearby public water supply utilities.

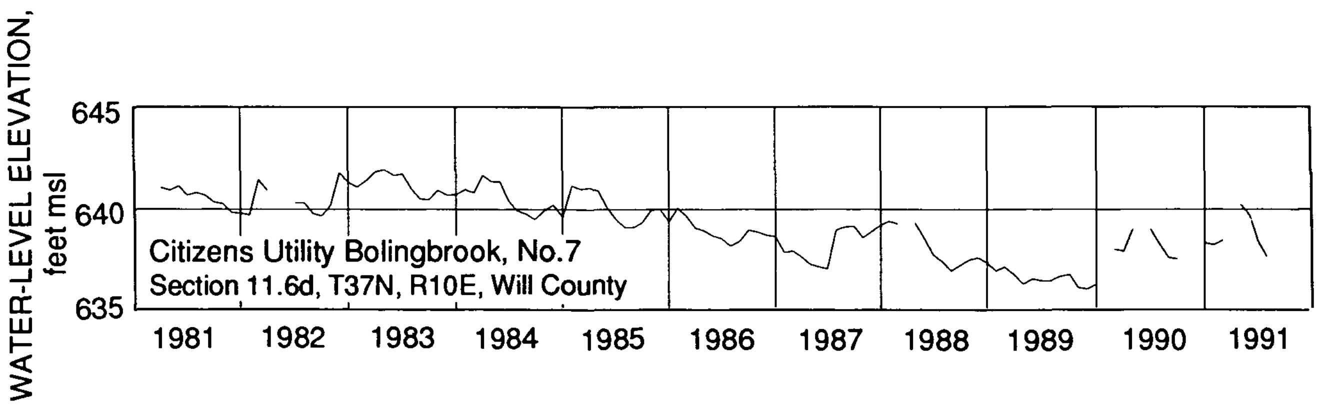


Figure 17. Hydrograph of observation well in Bolingbrook

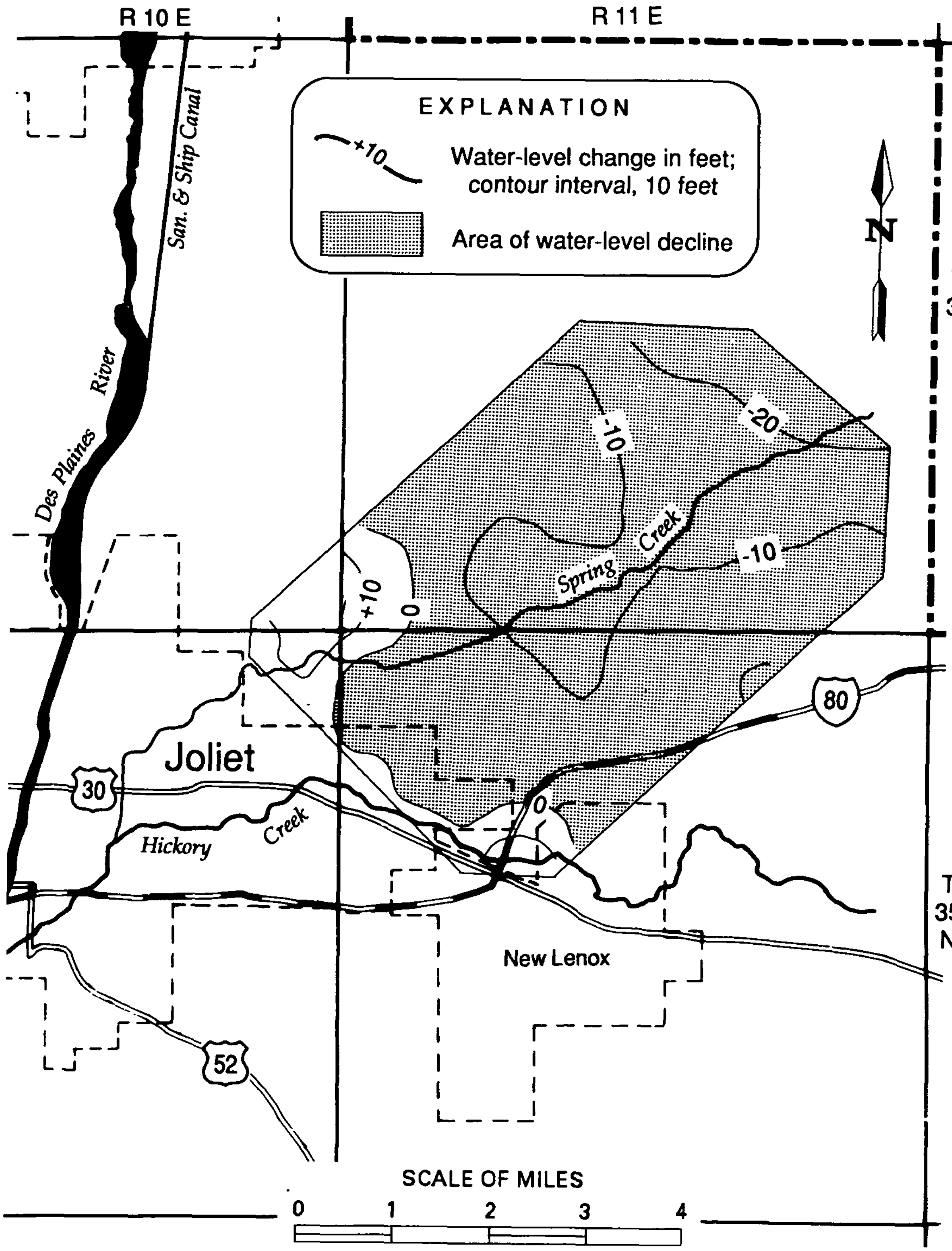


Figure 18. Water-level changes in the Hadley Valley area, 1962-1990

RECHARGE AND POTENTIAL YIELD OF THE SHALLOW AQUIFER SYSTEM

Recharge of the shallow aquifers in northeastern Illinois primarily occurs as precipitation percolates downward through the topsoil, past the root zone of the overlying vegetation, and into the drift deposits. The Silurian dolomite aquifer is subsequently recharged by the vertical leakage of ground water through the overlying drift deposits. The rate at which the dolomite is recharged depends on 1) the presence, permeability, and thickness of the overlying unconsolidated materials, and 2) the hydraulic head differential between the water table in the overlying materials and the potentiometric level of the dolomite.

The recharge rate is a dynamic variable that can change as conditions change. For example, an increase in pumping in the dolomite aquifer will increase the gradient through the overlying material and thus increase the recharge rate. The recharge rate is commonly referred to in units of gallons per day per square mile, (gpd/mi^2) or in millions of gallons per day (mgd) if discussing the recharge rate for a 36-square mile township. To convert gpd/mi^2 to inches per year, multiply by 2.1×10^{-5} (i.e., 100,000 gpd/mi^2 = 2.1 in/yr).

The rate at which an aquifer is recharged is difficult to estimate because it does not lend itself to direct measurement by any kind of field test. However, recharge rates can be indirectly estimated by analyzing:

1. Diversion areas created by ground-water pumpage.
2. Flow channels in the potentiometric surface.
3. Baseflow discharge of surface streams.

A recharge rate calculated according to these methods is valid for the conditions under which the analyses were made. Numerous investigations conducted around the state by Illinois State Water Survey researchers have used these methods to determine recharge rates. Several studies have employed the first and third methods in the shallow aquifers of northeastern Illinois.

The potential yield is an important parameter for quantitative analysis of available ground-water resources because it tells ground-waters managers how much water can be safely withdrawn from an aquifer. Potential yield is defined as the maximum amount of ground water that can be developed from a reasonable number of wells and well fields without creating critical water levels or exceeding the maximum recharge rate. The potential yield of an aquifer is generally greater than any calculated recharge values because it postulates that an aquifer is under maximum-use conditions. However, the potential yield may be lower than the calculated recharge rate in areas where all of the recharge cannot be diverted into cones of depression, such as in a low transmissivity zone.

Recharge Estimates Using Diversion Area Analyses

As mentioned previously, a diversion area is a subarea of an aquifer, defined by the potentiometric surface. All of the ground water contained in a diversion area flows towards a discharge point such as a municipal wellfield. Under equilibrium conditions, recharge is the only source of new water to the diversion area. Therefore, a recharge rate can be calculated by dividing the total pumpage by the land surface extent of the diversion area. If equilibrium conditions do not apply, such as when regional water levels are dropping, the calculation also must take into account changes in the amount of water stored in the aquifer.

*Previous Estimate in **the** Chicago Heights **Area***

In the Chicago Heights area, Prickett et al. (1964) computed a recharge rate of 225,000 gpd/mi^2 for a 60-mi^2 diversion area determined from the August 1962 potentiometric surface map. Recharge was assumed to be balanced by 13.5 mgd of discharge. The general area analyzed for this study is shown in figure 16. Because the recharge rate varies with the vertical head loss associated with water leakage through overlying materials, Prickett computed the average vertical head loss between the potentiometric surface of the Silurian dolomite aquifer and the shallow deposits at about 25 feet in 1961-1962. The average recharge rate per foot of head loss was approximately 9,000 gpd/mi^2.

*New Estimates Using **1990 Data***

Eleven diversion areas in Will and southern Cook Counties were identified by conducting a particle tracking analysis of the 1990 potentiometric surface using the software program GWPATH (Shafer, 1990). Figure 10 shows the boundaries of the major areas of diversion and the locations of the pumping centers contained within each diversion area. An additional 9,000 gpd/mi^2 was added to the pumpage total for each diversion area to account for domestic pumpage (6,900 gpd/mi^2) and for leakage into the underlying Maquoketa Shale (2,100 gpd/mi^2). The total pumpage for diversion area 8 had to be approximated to account for the surface water component of the pumpage from the sump at the large quarry in Thornton Township (T36N, R14-15E).

Equilibrium conditions were assumed to exist throughout the study area because pumpage from the aquifer has remained fairly constant, and only small portions have been artificially dewatered. The recharge rate to the Silurian dolomite required to balance discharge was determined by dividing the total pumpage in each diversion area by the land surface area. Table 3 lists the computed recharge rates, which ranged from 33,500 to 167,000 gpd/mi^2 with a median value of 65,900 gpd/mi^2.

Table 3. Recharge Rates Calculated from 1990 Diversion Areas and Pumpage, Will and Southern Cook Counties

Diversion area designation	*Area (mi^2)*	*1990 pumpage (mgd)*	*Recharge rate (gpd/mi^2)*
1	4.2	0.701	167,000
2	12.9	1.113	86,300
3	7.1	0.361	50,800
4	32.3	1.081	33,500
5	28.1	2.048	72,900
6	25.2	1.438	57,100
7	22.6	1.489	65,900
8	20.7	1.186	57,300
9	24.5	3.496	142,000
10	35.5	1.771	49,900
11	17.8	1.867	105,000
12*	38.7	0.878	—
13*	25.5	0.600	—
14*	16.1	4.022	—

* Partial diversion areas; land area and pumpage are only for the portion of the diversion area located within the study area.

A detailed analysis of the data in table 3 reveals that the computed recharge rate increases as the pumpage in a diversion area increases. Figure 19 is a plot of pumpage versus recharge constructed with the software program GRAPHER® (Golden Software, 1988). It shows a linear relationship and a best-fit line with a slope of 0.0306 and a zero pumpage intercept of 23,600 gpd/mi^2. The slope implies that for every 1-mgd increase in total pumpage, the average recharge rate in the diversion area will increase by 30,600 gpd/mi^2. The intercept implies that under nonpumping conditions, the recharge rate needed to maintain the natural steady-state flow in the aquifer averages 23,600 gpd/mi^2. The increase in recharge with total pumpage is a result of the greater vertical gradients across the glacial overburden caused by the additional drawdown in the aquifer. However, the additional drawdown also will cause the diversion area to expand, offsetting some of the potential recharge rate increase and forcing the diversion area's recharge value to migrate along the best-fit line with increasing pumpage.

Due to variable geologic and hydraulic conditions, several of the computed recharge rates lie either above or below the best-fit line. The recharge rates in diversion areas 1,2, and 11 are higher than expected because the expansion of these areas with increased pumpage has been constricted by pumpage in surrounding diversion areas or by discharge into nearby rivers. This constriction creates greater vertical gradients across the drift, resulting in a higher recharge rate. That rate in turn compensates for the decreased contribution of regional flow to the pumping centers.

Conversely, diversion area 10 and to some extent areas 4, 5, and 6 fall below the best-fit line because the pumping centers in these areas can capture more water from the regional flow field. The natural recharge rates in areas 1,2, and 11 also may be greater than elsewhere because of less overlying clay-rich till in areas 1 and 2 and thicker overlying sands in area 11. Diversion area 1 is very small compared to the spatial distribution of water-level measurements; it was therefore left out of the best-fit calculation due to the uncertainty of the diversion area delineation.

It appears from figure 19 that recharge rates may increase indefinitely with increasing pumpage. But, in reality, recharge rates will reach a maximum value because of physical constraints placed on the flow system. These constraints include the low vertical permeability of the widespread glacial tills, the maximum vertical gradient across the drift, and the finite amount of precipitation that can infiltrate the root zone in the soil. Determination of the maximum aquifer recharge rate would require several diversion area analyses to take into account heavy pumping or maximum use conditions, such as the previously mentioned analysis by Prickett et al. (1964) for Chicago Heights.

Assuming that the hydrogeologic conditions of the Silurian dolomite aquifer in Du Page County are similar to those in Will County, 12 additional recharge values from diversion area analyses can be included in the maximum rate determination. Three of these values were calculated by Zeizel et al. (1962) from the 1960 potentiometric surface, while the remaining nine values were derived from diversion areas delineated by Sasman etal. (1981) from the 1979 potentiometric surface. The Du Page County recharge data range from 15,700 to 230,000 gpd/mi^2 with a median value of 136,000 gpd/mi^2.

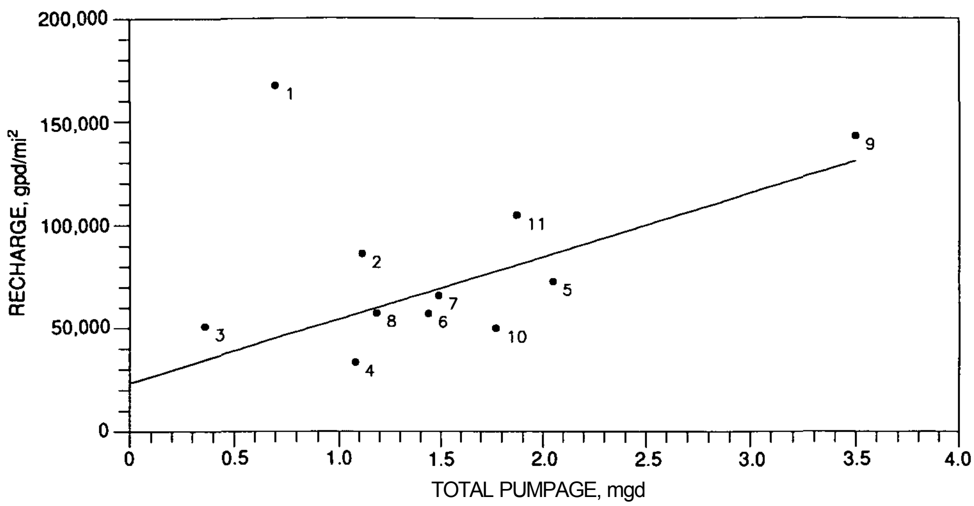


Figure 19. Relationship of the total pumpage to the computed recharge rate for the diversion areas, as determined from 1990 data

The median recharge value for Du Page County is significantly higher than that of Will and southern Cook Counties and may reflect more intensive aquifer use and/or higher vertical permeability of the glacial drift. In light of declining regional water levels, Sasman et al. (1981) showed that the aquifer was not under equilibrium conditions and that an estimated 1.2 mgd was being removed from storage. However, much of the decrease in storage came from diversion areas not included in the calculations for this report. The remaining decrease in storage would lower the calculated recharge rates for a few of the included diversion areas, but then by less than 10 percent.

A plot of the relationship of pumpage and recharge for all 24 diversion area analyses (figure 20) shows that the best-fit trend in the data is actually defined by a curve, not a straight line. The GRAPHER® (Golden Software, 1988) defined the best-fit curve as a third-power polynomial with a zero pumpage intercept of 27,100 gpd/mi^2. For total pumpages less than 3.0 mgd, the curve essentially follows the straight best-fit line defined by the Will and southern Cook County data. After 3.0 mgd, the curve begins to fall progressively farther beneath this line, eventually leveling off at a recharge value of about 230,000 gpd/mi^2. This value becomes the average maximum recharge rate, although the actual rate may vary across a diversion area, increasing close to any pumping centers and decreasing along the outer fringes.

The calculated maximum recharge rate also can be analyzed by comparing it to permeability values. A vertical permeability value of 0.00825 gpd/ft^2 for the glacial overburden can be calculated from Darcy's Law by assuming a downward vertical discharge of 230,000 gpd over a square-mile area with a hydraulic gradient of 1.0 foot per foot (ft/ft). Under maximum ground-water use conditions, the potentiometric surface of the dolomite aquifer would likely be below the top of the dolomite, creating a gravity drainage situation in the overlying materials and thus a vertical gradient of 1.0 ft/ft.

The calculated permeability value falls within the range of glacial till permeabilities given in a number of studies that are summarized in Walton (1965) and Fetter (1988). This would imply that the low permeability of the till controls the amount of recharge that can enter the aquifer, and that the presence of basal or interbedded sands is not important as long as some till is present. This is consistent with the widely accepted theory that the effective vertical permeability of a layered system is the harmonic mean of the permeabilities, which is controlled by the lowest value. Because almost all of the study area is covered

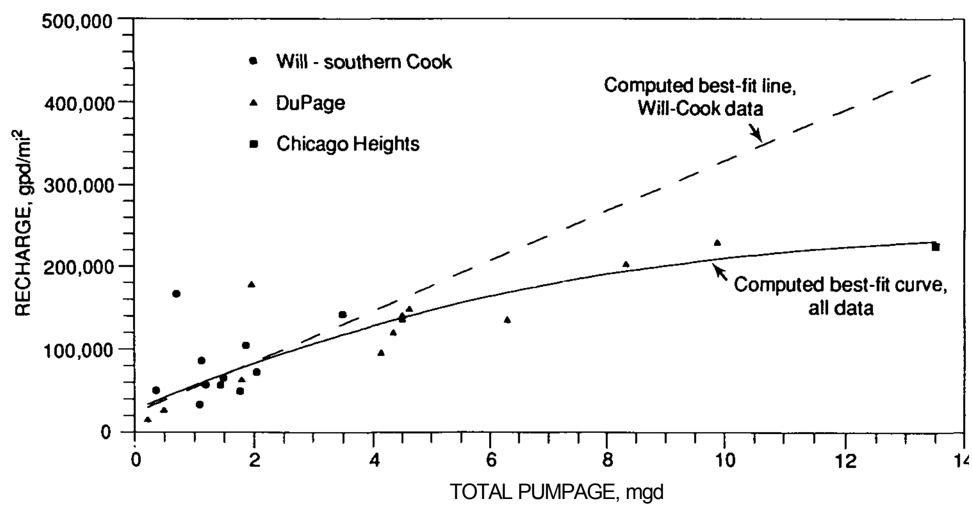


Figure 20. Relationship of total pumpage to the computed recharge rate for diversion areas, as determined from 1990 data, Du Page County data, and previous Chicago Heights diversion data

with some till, a maximum recharge rate of approximately 230,000 gpd/mi^2 would seem to be applicable overall.

Recharge Estimates Using Flow-Channel Analyses

Recharge rates were determined for selected areas of Will and southern Cook Counties using flow channels that also were derived from the particle tracking analysis of the 1990 potentiometric surface. A flow channel is a wedge-shaped section of the aquifer defined by two parallel flow paths that start at the same location on the peak of a ground-water mound and diverge hundreds or thousands of feet apart at some distance downgradient. The flow paths run perpendicular to the potentiometric contours shown in plate IV.

Assuming no changes in storage, the flow channel is a closed system, and recharge is the only source of added water causing the flow paths to diverge. Therefore, a recharge rate can be calculated by dividing the quantity of flow through a perpendicular slice of a flow channel by the upstream area of that flow channel. The value of the recharge rate depends on how fast the flow paths diverge and how fast the gradient increases. The methods used to calculate recharge rates by a flow-channel (flownet) analysis are described in detail by Walton (1965) and Cedergren (1967). The flow channels chosen for computing recharge rates are shown in figure 21.

Based on the configuration of the potentiometric surface, 12 flow channels were delineated, constituting 3.3 percentof the land surface of the study area. Starting locations were placed at the zero discharge points along the major ground-water divides. For flow channels 1, 2, 3, and 8, the zero discharge points appear as lines because the local divides have a constant maximum elevation. The quantity of water discharging through the perpendicular slice at the end of each flow channel was calculated using Darcy 's Law; the median transmissivity of 11,800 gpd/ft was determined for the study area from the specific-capacity analyses. Recharge rates for the selected flow channels (table 4) range from 33,200 gpd/mi^2 along the divide beneath the Valparaiso Moraines to ten times that or 339,000 gpd/mi^2 along the Des Plaines River valley.

The wide distribution of recharge values can be attributed mainly to the position of the flow channels with respect to discharge areas. The low recharge values in flow channels 1,2, and 3 along the divide are a result of low horizontal hydraulic gradients in the aquifer, which limit the amount of recharge that can enter the aquifer and travel towards a discharge area. Flow channels 4 through 8 are located closer to pumping centers, causing both the horizontal and vertical gradients to increase to the point where significantly greater amounts of recharge enter the aquifer. The steep gradients along the Des Plaines River valley essentially act as a very large pumping center. This causes the calculated recharge rates for flow channels 9 through 12 to be very high, depending on their proximity to the river. Because of the unconfined flow conditions along the river, changes in aquifer storage also may affect the computed recharge rate. Beneath and adjacent to the river, the recharge

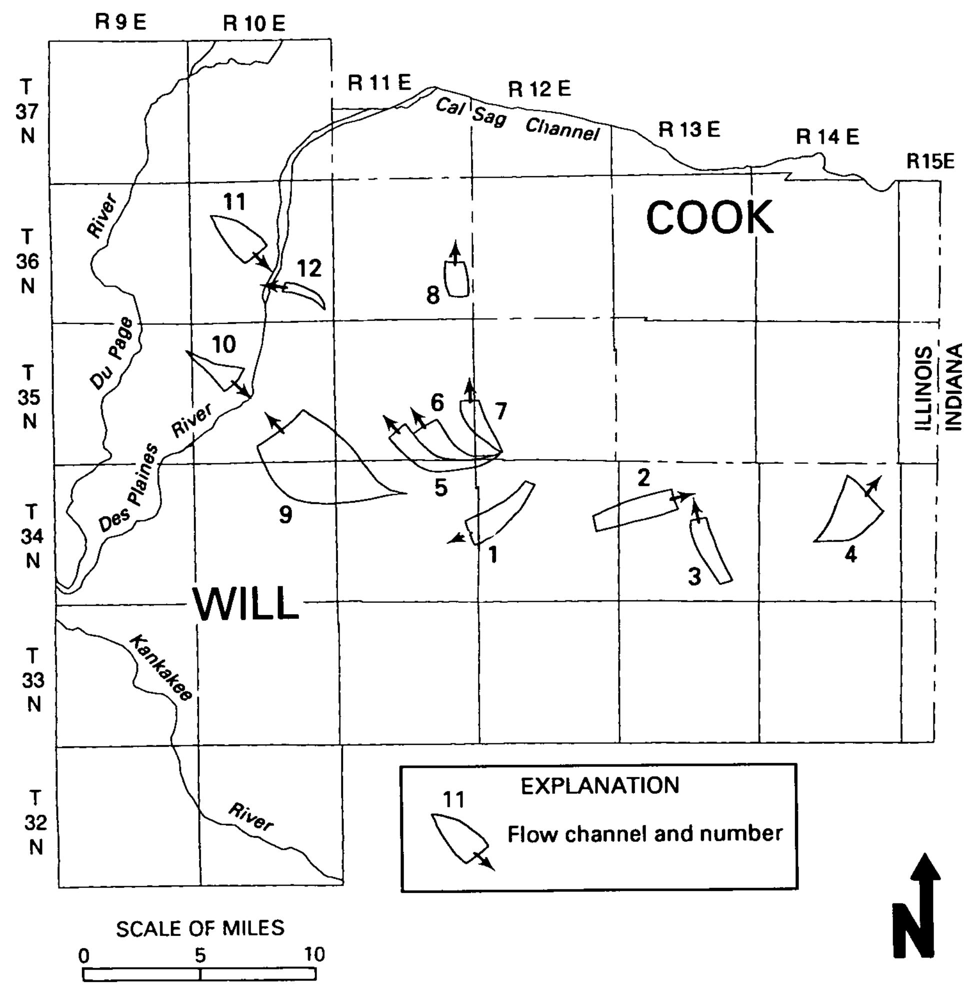


Figure 21. Location of flow channels used to determine recharge rates in the study area

Table 4. Recharge Rates to the Silurian Dolomite for Selected Flow Channels

Flow channel number	*Channel discharge (gpd)*	*Area (mi^2)*	*Recharge (gpd/mi^2)*
1	135,000	2.76	48,900
2	101,000	3.04	33,200
3	77,700	1.77	43,900
4	682,000	3.83	178,000
5	227,000	2.81	80,800
6	261,000	2.00	130,000
7	219,000	1.50	146,000
8	95,600	1.36	70,300
9	1,134,000	12.64	90,000
10	408,000	1.35	302,000
11	339,000	2.44	139,000
12	251,000	0.74	339,000

rate may become very negative due to the upward movement of ground water into the river.

Other factors also contribute to the variation in calculated recharge rates, including the heterogeneity of both the Silurian dolomite and the overlying unconsolidated deposits, the length of the defined flow channel, and the precision of the flow-path determination. A major assumption in calculating the recharge rates was that the transmissivity in the vicinity of each flow channel was equal to the median transmissivity for the whole study area. In actuality, though, transmissivity can vary dramatically. However, the lack of sufficient aquifer property data near the flow channels necessitated the use of a median value. The effective vertical permeabilities of the overlying glacial deposits also are spatially variable and will differentially affect the calculated recharge rate.

Recharge rates increase and decrease along the length of a flow channel as hydraulic conditions change. Therefore the arbitrarily defined length of the flow channel will affect the resultant recharge value. For example, if only the first third of channel 2 were examined, the average recharge rate would be 58,000 gpd/mi^2, instead of 33,200 gpd/mi^2. The flow-channel method is also very sensitive to the exact definition of the potentiometric surface. The relatively small size of the flow channels compared to the distribution of water-level measurements may have introduced additional error to the values listed in table 4.

Recharge Estimates Using Baseflow Analyses

Two sources of water contribute to the discharge of a stream: ground-water runoff and stormwater runoff. Ground-water runoff, or baseflow, is derived from ground water seeping into a stream. Stormwater runoff is the portion that falls during a storm event, either directly into surface water bodies or onto land, from which it subsequently flows through gullies or storm sewers and then into creeks and rivers. Stormwater runoff usually contributes to a stream several days after the storm event, while baseflow accounts for the flow at all other times, even when there has been little rain.

In a baseflow analysis, hydrograph separation techniques are used to calculate a baseflow value, which is then divided by the drainage basin area to produce a value for the recharge rate. However, unlike the recharge rate estimates derived from the diversion area and flow-channel methods, a baseflow-derived recharge rate is a measure of ground-water recharge to the shallow glacial deposits, as well as to the Silurian dolomite. Water that enters the shallow material during a storm also can contribute to ground-water runoff by moving laterally through this material and into a surface stream without ever entering the dolomite aquifer. Additional ground-water runoff results from the release of water stored along the banks of a stream during a storm event (bank storage) when surface water levels may be higher than surrounding ground-water levels.

The relation between baseflow and the actual aquifer recharge rate is further complicated when ground-water pumpage diverts water away from the discharge areas along streams. In many cases this diverted water will later appear in the stream as sewage discharge, although the volume will be less due to evaporative uses such as lawn watering. Baseflow estimates are also complicated if pumpage is drawn from a different basin or a deep aquifer or if the sewage discharge is directed to a different basin.

Baseflow Analyses by Zeizel et al. and Walton

Utilizing streamflow and flow-duration data collected by the USGS, Zeizel et al. (1962) estimated baseflow from hydrographs of the Du Page River at Shorewood. Walton (1965) similarly estimated the baseflow of Hickory Creek at Joliet. In both studies, baseflow was computed for years with below-normal precipitation (1953 or 1956), near-normal precipitation (1948), and above-normal precipitation (1942 or 1951). The drainage basins, as generally defined, are shown in figure 22.

The Du Page River drainage basin (1) upstream from Shorewood in Will County encompasses 325 square miles, more than 60 percent of which is located in Du Page County. Parts of five townships in the northwestern corner of Will County are also within the drainage basin. Baseflow estimates based on hydrograph separations for years of below-normal, near-normal, and above-normal precipitation resulted in recharge rates of 136,000,259,000, and 449,000 gpd/mi^2, respectively. Averaging this near-normal rate with a similar rate from Salt Creek in Du Page County produces a baseflow value of 247,000 gpd/mi^2. Zeizel et al. compared this average with the 140,000 gpd/mi^2 recharge rate computed from the diversion area analysis in Du Page County and concluded that only 58 percent of the total baseflow component was being diverted into cones of depression to recharge production wells in deeply buried glacial drift aquifers and presumably, the Silurian dolomite aquifer.

Walton (1965) also estimated baseflow for 21 Illinois drainage basins by using streamflow hydrograph separation techniques. One of these, the Hickory Creek drainage basin (2), encompasses 107 mi^2 in parts of seven townships in Will and southern Cook Counties. Baseflow estimates of recharge based on hydrograph separations for years of below-normal, near-normal.andabove-normal precipitation were 110,000,181,000, and 284,000 gpd/mi^2, respectively. Using this method, Walton also revisited the data from the Du Page River and found values very similar to those computed by Zeizel et al.

*Baseflow Analyses by O'Hearn **and** Gibb*

The method of hydrograph separation applied by O'Hearn and Gibb (1980) to determine baseflow is essentially the same as that applied by Zeizel et al. and Walton, except in the definition of normal flow conditions. For the four drainage basins wholly or partly located in the study area (table 5 and figure 22), a 20-year record of mean daily discharge measurements (1957-1976) was used to arrive at average baseflow estimates during median streamflows (50 percent frequency or probability of occurrence). The authors also determined average baseflow for 10 and 90 percent probabilities. The averages for the baseflow estimates for each basin were divided by their respective drainage areas to arrive at the average median baseflow per square mile, or average recharge rate.

Comparing the baseflow values in table 5 to those previously discussed for the Hickory Creek and Du Page River drainage basins, it is clear that the estimates differ. For the Hickory Creek drainage basin, the Walton baseflow estimate for a near-normal year is 47 percent higher than O'Hearn and Gibb's median baseflow. Similarly, the Zeizel et al. baseflow estimate for the Du Page River basin is 21 percent higher than the O'Hearn and Gibb median baseflow. One factor to consider when comparing baseflow data is that the use of ground water from the shallow aquifers in these areas increased dramatically between 1948, when Walton's (1965) near-normal baseflows were computed, and 1957-1976, which was used by O'Hearn and Gibb for their baseflow calculations. Baseflows within the Hickory Creek and Du Page River drainage basins would be expected to decrease as more ground water was diverted to wells and well fields, particularly those supplying the municipalities of New Lenox, Mokena, and Frankfort in the

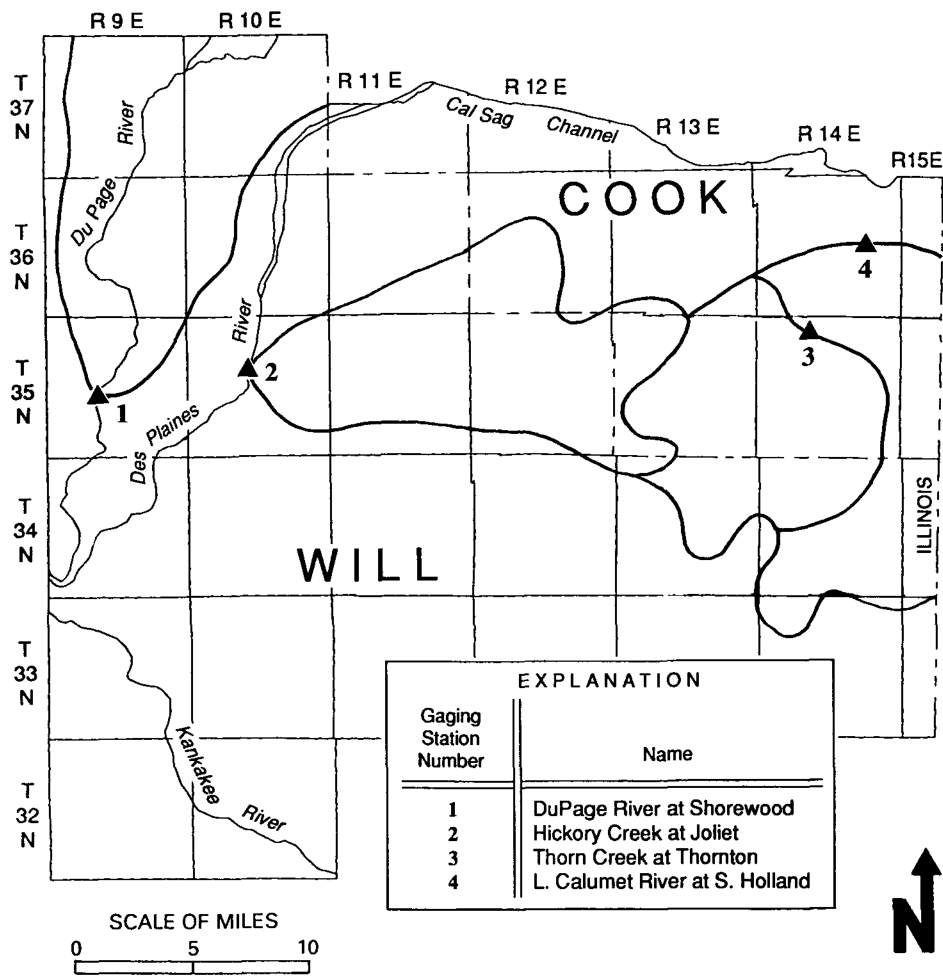


Figure 22. Drainage basins used for baseflow analysis

Table 5. Average Baseflows **for Four Drainage Basins in Will and Southern Cook Counties, 1957-1976**

Station number and name	*Drainage area (mi²)*	*Average baseflows* Median (50% frequency)	Low (90% frequency)	High (10% frequency)
1 DuPage R. at Shorewood	324	213,309	77,567	775,669
2 Hickory Creek at Joliet	107	122,814	32,320	633,463
3 Thorn Creek at Thornton	104	226,237	116,350	723,958
4 Little Calumet R. at South Holland	205	200,381	96,959	698,102

Source: After O'Hearn and Gibb, 1980.

Hickory Creek basin; and Romeoville, Bolingbrook, and many Du Page County communities in the Du Page River basin.

Evaluation of the Recharge Estimates

Recharge estimates for all the shallow aquifers in the study area, both unconsolidated and Silurian dolomite, are compared in figure 23, along with recharge estimates for the Silurian dolomite aquifer alone. Where sufficient data points were available from an individual study or method, they are represented as box-and-whisker diagrams to show the distribution of the data about the median value. The data in figure 23 show a wide distribution in the estimated recharge values, much of which can be explained by the different recharge calculation methodologies.

As discussed previously, the diversion area and flow-channel analyses produced a wide variation in recharge values because these methods involved taking measurements over relatively small areas. Between each of these areas, especially the small flow channels, the calculated recharge rate can differ considerably due to varying horizontal and vertical flow conditions. For example, both analyses have shown that recharge rates increase in areas of high ground-water pumpage due to the increased vertical gradients caused by additional drawdown in the aquifer. However, the average recharge rate over a diversion area reaches an apparent maximum value of 230,000 gpd/mi^2 as shown by the data in figure 20. Although the flow-channel analyses may be less accurate than the diversion area analyses due to the assumptions and parameter sensitivities previously discussed, recharge rates computed by this method can exceed 230,000 gpd/mi^2, suggesting that the maximum recharge rate can actually be higher.

The baseflow analyses generally produced recharge rates much higher than those from the other two methods because the baseflow measurements include recharge to the glacial deposits that are discharged into the streams before reaching **the** Silurian dolomite aquifer. Baseflow analyses by Walton for basins 1 and 2 (figure 22) are significantly higher than baseflow estimates by O'Hearn and Gibb. As discussed earlier, these differences can be attributed to the years of streamflow analyzed and the different definitions of normal flow conditions. Ground-water use during the years Walton made his baseflow calculations was significantly less than during the years O'Hearn and Gibb used for their calculations. Thus.baseflow estimates for basins 1 and 2 would be expected to decrease as ground-water use increased.

As shown by the baseflow analyses, the calculated recharge rate becomes much higher if recharge to **the** glacial deposits is included. However, in areas of high dolomite ground-water use, more flow normally discharged from glacial deposits directly into streams is diverted into the dolomite aquifer. This diversion causes the recharge rate determined from a diversion area to approximate that of a baseflow analysis, such as the Prickett et al. and O'Hearn and Gibb estimates for the Chicago Heights area.

Potential Yield of the Shallow Aquifers

Previous Potential Yield Estimates by Schicht et al.

Schicht et al. (1976) estimated the potential yield of the sand-and-gravel and shallow dolomite aquifers in northeastern Illinois by constructing recharge-rate distribution maps. The values on these maps were synthesized from all the available

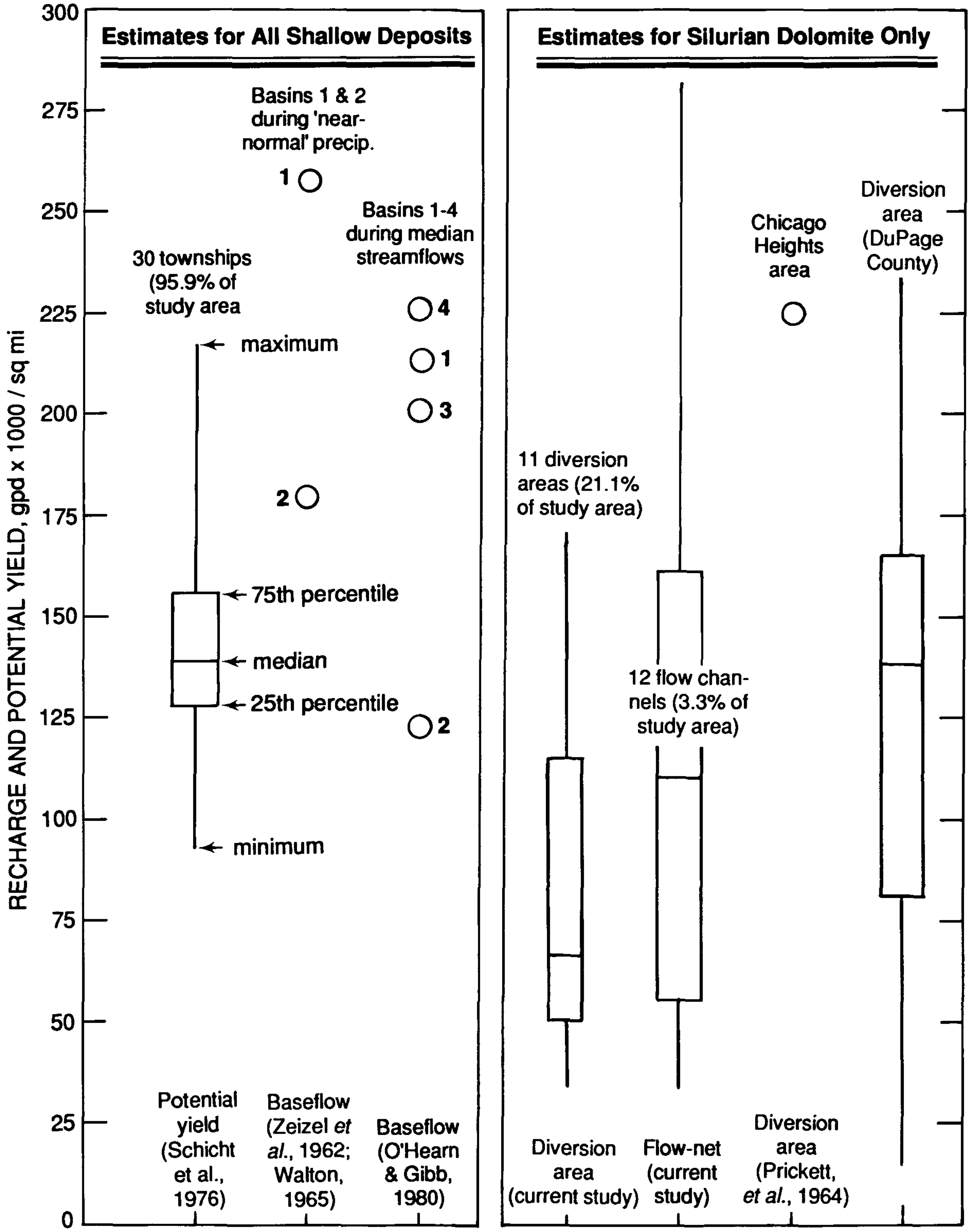


Figure 23. Distribution of recharge values according to various estimating methods

information, including geologic maps of the dolomite and the different units of the glacial drift; vertical permeability and leakage data; water-level, precipitation, pumpage, and streamflow data; and previously estimated recharge values by Zeizel et al. (1962), Prickett et al. (1964), and Walton (1965). In most cases the potential yield of an area was simply the product of the area and the recharge rate, but in some cases the potential yield was limited by the probable yield of wells.

The total potential yield of shallow aquifers was estimated by assuming full developmentof the shallow dolomite aquifers and the supplemental glacial drift aquifers. Supplemental glacial drift aquifers are sand-and-gravel units that are not connected to the Silurian dolomite aquifer, and can therefore be developed without impacting the potential yield of the dolomite. Schicht et al. shows the interbedded, or upper, sand units in Will and southern Cook Counties to be supplemental to the development of the dolomite. Basal sand-and-gravel aquifers, on the other hand, are considered complementary to the dolomite aquifer because of the good connection between them. As a result they are assigned the same recharge rate. Development of a basal sand-and-gravel aquifer will directly impact the potential yield of the dolomite aquifer.

Results of the potential yield analysis by Schicht et al. are presented in table 6 as the total yield for each township in the study area. Reexamination of the potential yield estimates by Singh and Adams (1980) resulted in modification of the estimates for three townships. To show how these potential yield values generally compare with the other recharge estimates, they have been plotted on figure 23 as the average potential yield per square mile. The yield values for several of the townships in the southwestern portion of the study area, such as Wilmington and Channahon, appear far too high because the Silurian dolomite aquiferiseitherabsentor unsaturated. Schicht et al. (1976) probably attributed the high potential yield in this area to sand-and-gravel deposits, but the more recent mapping from this report shows these deposits to be considerably less extensive.

Sasman et al. (1981) attempted to verify Schicht's estimated 44.4-mgd potential yield for the Silurian dolomite aquifer in Du Page County by constructing a water budget from the changes in water levels and pumping rates between 1966 and 1978. The result of this exercise was essentially inconclusive, although Sasman et al. allude to the estimate approximating the real value: when the value was plugged into the water-budget equation, it produced a reasonable specific yield value. Sasman et al. showed that as pumpage doubled from 24.0 to 45.8 mgd in Du PageCounty, water levels declined more than 10 feet over 30 percent of the area, creating several problem areas with concentrated pumpage and high bedrock elevations.

The data in Sasman et al. suggest that if pumpage in DuPage County was more properly spaced out, many of the problem areas would disappear and the potential yield could either meet or exceed the total pumpage. However, in some areas the aquifer still may not be able to meet significantly increased future water demands. The aquifer could potentially yield more water in the western portion of the county, although lower aquifer transmissivity in this area might require a large number of production wells pumping at low rates, a situation that would not be economically feasible. As of early 1992, the public water supplies in Du Page County had switched to Lake Michigan water.

New Estimates Using ***the 1990 Recharge Data***

If the average maximum recharge rate of 230,000 gpd/mi^2 for a diversion area is applied to a 36-mi^2 township, the potential yield of the aquifer would be 8.28 mgd per township. Allowing for errors in methodology, a conservative correction factor of 15 percent is applied, which lowers the potential yield estimate to approximately 7.0 mgd (194,000 gpd/mi^2). Because this number is based on actual measured conditions, many of the uncertainties in the physical flow system have been inherently accounted for, including the aquifer's response to a large pumping stress.

The potential yield estimates based on the recharge data from the current study are listed in table 6. Due to the odd sizes of several townships along the eastern and northern edges of the study area, the potential yield values were proportionally changed. Thornton Township (T36N, R14-15E) had to be assigned a lower value because of lower transmissivities and the likely inability of a production well network to withdraw all of the possible recharge effectively. In the nine townships that constitute the northwest quadrant of the study area (T35-37N, R9-11E), plus Jackson Township (T34N, R10E) and Bloom Township (T35N, R14-15E), the potential yield values have been modestly increased to account for the presence of Silurian dolomite or basal sand outcrops, where the aquifer recharge is not inhibited by low-permeability glacial tills. In the townships along the western edge of the study area where the Silurian dolomite aquifer thins the potential yields had to be readjusted downwards relative to the portion of the township that had saturated dolomite or sand and gravel thicker than 50 feet.

Evaluation of the Potential Yield Estimates

The potential yield values estimated by Schicht et al. are generally lower than the newly estimated values. This may be due to the fact that some of the previously available recharge data were not calculated under maximum recharge conditions, possibly causing Schicht et al. to underestimate the recharge rate for some areas. In addition, some of the higher recharge values, such as those of Prickett et al. for Chicago Heights, may have been attributed to the presence of interbedded glacial sand units, resulting in the assignment of lower recharge rates to areas without these deposits. The data from this study suggest that sand units do not play a major role in determining the local recharge rate. Rather, the vertical permeability of the glacial till is the controlling factor for flow through the glacial overburden.

Table 6. Potential Yield and Ground-Water Use of the Shallow Aquifers in Will and Southern Cook Counties (Listed by Township and Range)

		Potential yield (mgd)				
Township	*(T,R)*	*Total Aquifer Schicht et al. (1976)*	*Current study*	*Composite value*	*ground-water use (mgd)*	*use-to-yield ratio*
Reed/Custer	32N, 09E	6.54	<1.0	<1.0	0.24	>0.24
Wesley/Custer	32N, 10E	5.60*	<1.0	<1.0	0.24	>0.24
Wilmington	33N, 09E	5.09	<1.0	<1.0	0.24	>0.24
Florence	33N, 10E	3.83	4.5	4.2	0.24	0.06
Wilton	33N, 11E	4.83	7.0	6.0	0.24	0.04
Peotone	33N, 12E	4.60	7.0	6.0	0.60	0.10
Will	33N, 13E	4.61	7.0	6.0	0.24	0.04
Washington	33N, 14-15E	5.60	8.7	7.2	0.58	0.08
Channahon	34N, 09E	7.47	<1.0	<1.0	0.39	>0.39
Jackson	34N, 10E	5.62	7.0	6.3	0.32	0.05
Manhattan	34N, 11E	5.02	7.0	6.0	0.45	0.08
Green Garden	34N, 12E	4.60*	7.0	6.0	0.24	0.04
Monee	34N, 13E	4.82	7.0	6.0	1.70	0.28
Crete	34N, 14-15E	5.85	8.7	6.0	1.55	0.26
Troy	35N, 09E	7.81	3.0	3.0	0.44	0.15
Joliet	35N, 10E	7.00	7.5	7.3	0.93	0.13
New Lenox	35N, 11E	4.99	7.5	6.5	2.25	0.35
Frankfort	35N, 12E	4.74	7.0	6.0	2.46	0.41
Rich	35N, 13E	4.57	7.0	6.0	3.53	0.59
Bloom	35N, 14-15E	6.68	8.8	7.7	2.17	0.28
Plain field	36N, 09E	6.38	5.0	5.0	0.48	0.10
Lockport	36N, 10E	6.00*	7.5	7.0	1.56	0.22
Homer	36N, 11E	5.09	7.5	6.5	2.39	0.37
Orland	36N, 12E	4.55	7.0	6.0	0.74	0.12
Bremen	36N, 13E	4.75	7.0	6.0	0.53	0.09
Thornton	36N, 14-15E	4.31	5.0	4.7	1.86	0.40
Wheatland	37N, 09E	5.08	5.0	5.0	0.24	0.05
Du Page	37N, 10E	6.25	7.5	7.0	5.04	0.72
Lemont	37N, 11E**	3.52	3.8	3.7	0.14	0.04
Palos	37N, 12E**	2.21	3.3	2.8	0.14	0.05
Worth	37N, 13E**	0.57	0.8	0.7	0.03	0.04
Total		158.58	175.1	160.9	32.52	0.20

Notes: * Modified by Singh and Adams (1980).
** Partial township.

Overall, the potential yields estimated by Schicht et al. match fairly well with potential yields estimated from the maximum recharge rate data in this study. The potential yields determined from this study are probably closer to the actual potential yields, while the Schicht et al. estimates err on the conservative side. To arrive at a final value for water-use planning, it would be judicious to combine the two estimates to form a composite value (table 6) with more weight given to the new estimates. For a township with typical hydraulic conditions, the composite potential yield is generally 6.0 mgd (167,000 gpd/mi^2). In the southwestern portion of the study area, the new potential yield estimates were relied upon more heavily due to the previously discussed concerns in the Schicht et al. data for this area.

Ground-Water Use versus Potential Yield

The ratio of ground-water use to potential yield gives a measure of the ability of an aquifer to meet current demands and anticipated future demands. The use-to-yield ratio listed in table 6 for the entire study area is 0.20, meaning that only 20 percent of the available water resources are being utilized. At an 80 percent utilization level, ground-water use from shallow aquifers would quadruple to 120 mgd, which in turn could serve four times the number of people, from approximately 290,000 to 1.12 million. This represents a growth of 840,000 consumers, which is more than five times the population growth of 145,000 people estimated by the year 2010. Effectively withdrawing 120 mgd from the aquifer would require numerous wells, properly spaced throughout the study area, operating under a central authority or strategy.

The aquifer use-to-yield ratios listed for each township in table 6 are for illustrative purposes only. The validity of considering each township individually is questionable because ground water does not follow arbitrary political boundaries, as demonstrated by the diversion areas shown on figure 10. For this reason and considering other factors relating to the hydraulic and potentiometric conditions of the aquifer, statements about individual water-use areas will be discussed in the conclusion of this report.

None of the townships in the study area experiencing ground-water depletion where the use-to-yield ratio is greater than 1.0. Du Page Township (T37N, R10E) is closest to approaching the potential yield with a ratio of 0.72. The next highest utilization rate occurs in Rich Township (T35N, R13E) at 0.59, followed by eight townships using between one-quarter and one-half of their potential yield. In 14 townships, amounting to approximately 40 percent of the study area, the use-to-yield ratio is equal to or less than 10 percent.

GROUND-WATER QUALITY

From November 1990 through January 1991, ground-water samples were collected for full inorganic analysis from 186 wells finished in the Silurian dolomite aquifer in the study area (figure 13). The density of wells sampled ranged from as low as 1 per 10 square miles in sparsely populated agricultural areas of southern Will County to 1 per 2.25 square miles in the areas of New Lenox, Mokena, and Frankfort. The purpose of the ground-water sampling was to collect enough ground-water quality data from the Silurian dolomite aquifer to assess the ambient, natural ground-water quality; to prepare statistics and parameter concentration maps to show the distribution of selected inorganic constituents; and to identify any possible areas of ground-water quality degradation due to human impacts.

Sampling Procedure

Water samples were collected from 186 wells in Will and southern Cook Counties. Field duplicate samples were collected at every tenth site for quality assurance and control. Trip blanks were also collected. To assess well water, samples were obtained from a point in the well's piping system upstream of any water treatment devices. Samples were generally drawn from outside faucets at domestic and commercial wells and from inside faucets or sampling taps at municipal wells. When interpreting the results, note that the concentrations of all constituents tested represent untreated water samples. Many municipalities and individual homeowners treat their well water to lower concentrations of some constituents before consumption.

Before ground-water samples were obtained, each of the wells was flushed for at least 15 minutes to purge the well and the plumbing of stagnant water. Samples were collected for metals, anions, and total dissolved solids (TDS) and then filtered using a 0.45-micrometer (uM) in-line disposable filter. Alkalinity and pH samples were not filtered. In addition, samples collected for metals were acidified with 0.5 percent nitric acid to prevent precipitation of the metals. All samples were collected in high-density polyethylene bottles and refrigerated until they reached the Office of Analytical and Water Treatment Services at the Illinois State Water Survey for analysis.

The constituents analyzed in the water samples included 27 cations (metals); the anions fluoride, nitrate, chloride, and sulfate; pH; total alkalinity; and TDS. Of the 27 metals analyzed in the water samples, statistics are provided only for the 18 listed in table 7. Many of the metals omitted, such as molybdenum, thallium, and vanadium, are trace constituents in ground water and did not occur in any significant concentrations.

Of the 186 water wells sampled, approximately 46 percent were domestic; 19 percent commercial or industrial; 23 percent municipal; and 11 percent at schools, parks, or conservation areas. In terms of land use, 56 percent of the sampled wells were in predominantly agricultural areas, 26 percent of the wells were in urban residential areas, 11 percent in nonresidential urban areas (i.e., transportation, industrial, or commercial), and 6 percent in wooded areas such as parks, forest preserves, or conservation areas.

Sampling Results

As shown in the table, water quality within the study area can generally be termed acceptable with some reservations. Although most constituent concentrations are within healthy limits, elevated concentrations of particular inorganic constituents occur in some areas. These include iron, sulfur, and hardness, which can give the ground water an unpleasant taste, odor, or color that may be undesirable to many consumers.

Ground-water quality of the Silurian dolomite is a composite of both the natural or ambient ground-water quality and human influences associated with urban development and agriculture. The human influences may be magnified or minimized, depending on the hydrogeologic conditions of a given area. Thin drift deposits overlying the Silurian dolomite could either limit attenuation of surficial contaminants or allow for those contaminants to enter the dolomite aquifer more rapidly. In contrast, thick drift deposits can allow for greater attenuation of contaminants and slow the downward movement of potential contaminants towards the dolomite aquifer.

Because the natural quality of the ground water in the Silurian dolomite is quite variable, both horizontally and vertically, and because the natural ground-water quality has been affected by human activities that are changing in both time and space, it is difficult to discern to what extent ground-water quality in some areas is naturally occurring versus human-influenced. Where possible, the following discussions of specific inorganic parameters will distinguish between what natural levels should be and, where applicable, how they have been changed by human activities.

Total Dissolved Solids

As seen from table 7, total dissolved solids, which represent the total mineral content of a ground-water sample, ranged from 227 milligrams per liter (mg/L) to 2,515 mg/L. Median TDS for all 186 sampled wells was 670 mg/L. The U.S. Environmental Protection Agency (USEPA) has stated that TDS concentrations in excess of 500 mg/L may have undesirable effects on the aesthetic qualities of drinking water. About 75 percent of the samples exceeded this secondary drinking water standard.

Table 7. Water Quality Statistics for Samples from 186 Wells Penetrating the Silurian Dolomite Aquifer, Winter 1990-1991

									Illinois Water Quality Standards (IPCB. 1984a. 1984b)	
Major constituents (mg/L)	*Method detection limit*	*Samples below detection limit*	*Minimum*	*Maximum*	*Median*	*Average*	*Standard deviation*	*USEPA recommended limits (USEPA, 1982)*	*At point of withdrawal*	*Finished water*
Alkalinity (total)[1]	2	0	121	1,000	339	333.7	82.2			
Calcium	0.03	0	0.6	351	110.4	119.9	63.1			
Chloride	0.3	0	0.3	500	6.2	31.3	65.9	250	250	
Iron	0.01	12	<0.01	7.8	0.61	1.03	1.26	0.3		1.0
Magnesium	0.04	0	0.2	226	51.5	54.3	26.9			
Potassium	1.3	12	<1.3	182	3.7	5.5	13.5			
Silica	0.02	0	3.1	13.3	6.2	6.3	1.6			
Sodium	0.50	0	4.3	404.5	30.1	45.5	50.3	250		
Sulfate	0.9	5	<0.9	1,543	167.5	262.9	281.5		250	
Miscellaneous constituents										
Total dissolved solids'	2	0	227	2,515	669.5	773.4	402.6	500		
Fluoride	0.1	0	0.1	7.3	0.40	0.53	0.69			1.8
Nitrate (NO 3-N)	0.1	139	<0.1	124.	0.1	1.9	10.37		10	10
Hardness[3]	-	-	2.4	1,401	492	522	250.2			
pH[2]	—	—	7.1	8.8	7.6	7.7	0.3	6.5-8.5		

Table 7. Concluded

Trace constituents (µg/L)	Method detection limit	Samples below detection limit	Minimum	Maximum	Median	Average	Standard deviation	USEPA recommended limits (USEPA, 1982)	Illinois Water Quality Standards (IPCB. 1984a. 1984b): At point of withdrawal	Illinois Water Quality Standards (IPCB. 1984a. 1984b): Finished water
Aluminum	17	142	<17	359	<17					
Arsenic	110	183	<110	120	<110	-	-		50	50
Barium	3	4	<3	140	27	38	32		1,000	1,000
Cadmium	17	185	<17	19	<17	-	-		10	10
Chromium	7	110	<7	48	<7	-	-		50	50
Copper	6	171	<6	375	<6	-	-	1,000	-	5,000
Lead	63	186	<63	<63	<63	-	–		50	50
Manganese	4	16	<4	398	13	27	46	50	150	150
Mercury	50	186	<50	<50	<50					2
Nickel	31	178	<31	49	<31					
Strontium	1	0	7	5,240	800	1,070	910			
Zinc	20	69	8	4,986	29	160	491	5,000	-	5,000

Notes:

[1]All constituents are dissolved unless noted as total recoverable.

[2]Measured in standard units.

[3]Hardness in mg/L equivalent to $CaCO_3$ = 2.5 (mg/L Ca) + 4.1 (mg/L Mg).

Duplicate water samples were averaged prior to statistical calculations.

Bruvold (1970) reported an inverse relationship between taste quality and TDS and proposed grades of potability according to TDS levels. Utilizing his method of classification, 41 percent of the water samples from the study area would be termed "good," because they had TDS levels below 600 mg/L. Similarly, 40 percent would be "fair" with TDS levels between 600 and 1,000 mg/L, 8 percent "poor" with TDS levels between 1,000 and 1,300 mg/L, and 11 percent "unacceptable" with TDS levels greater than 1,300 mg/L.

As seen from figure 24, some of the highest TDS concentrations trend along a line through the south-central portion of the study area that lies just to the west of the contact between the Minooka and Valparaiso Morainic Systems (figure 4). This is probably due to the fact that the water in the local drift, composed of the Yorkville Drift of the Wedron Formation, has a naturally higher TDS content. This may be a reflection of the Yorkville having a different mineral and/or formational water composition.

In contrast, many of the lowest TDS concentrations (less than 500 mg/L) are found in the northwest townships and along the western edge of the study area. The surficial geology in this area is composed of a variety of materials, including the Minooka Morainic System, lake plain deposits, and frequent bedrock exposures. Drift thickness in these areas is generally less than 50 feet and in many cases less than 25 feet. Naturally higher recharge rates through the thin to absent drift deposits may account for the low mineral content of the ground water sampled from the Silurian dolomite in these areas.

Sulfate

Sulfate concentrations ranged from below the laboratory instrument detection limit of 0.9 mg/L up to 1,543 mg/L. Median sulfate concentration was 167.5 mg/L. The Illinois Water Quality Standard (IPCB, I984a,b) for sulfate at the point of withdrawal is 250 mg/L. Approximately 36 percent of the samples exceeded this water quality standard (figure 25). Sulfate is one of the major contributors to the overall mineral content of the ground water in the study area, as seen by the similarity of the distributions of sulfate and TDS (figures 24 and 25). The Pearson correlation coefficient for sulfate and TDS is 0.95, which indicates a high degree of correlation between the two parameters. The same reasons for high and low TDS concentrations would also apply for sulfate.

Water with high sulfate content, generally above 250 mg/L, has a medicinal taste. In concentrations of 600 to 1,000 mg/L, the water may have a

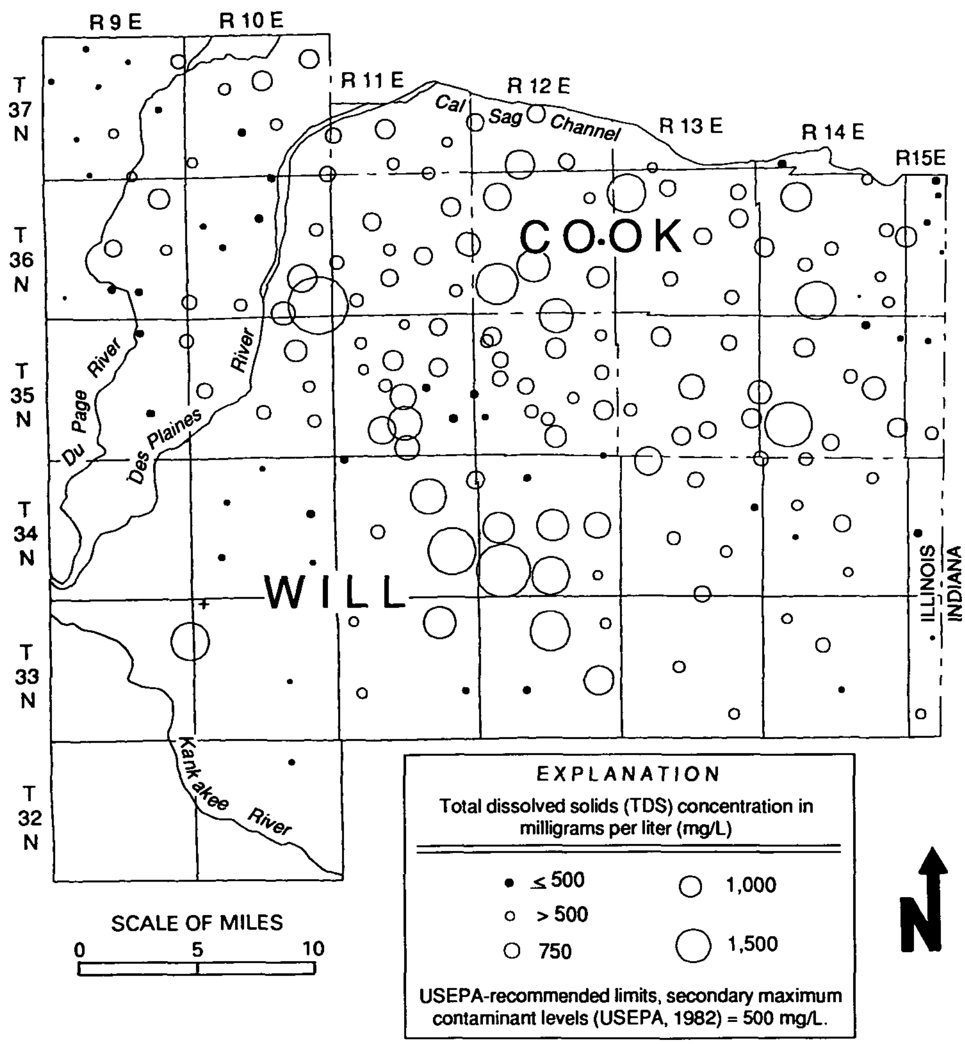


Figure 24. Total dissolved solids distribution in the Silurian dolomite aquifer

pronounced laxative effect on those not accustomed to it. Of the ground-water samples collected from the 186 wells in the study area, 12 percent had sulfate concentrations exceeding 600 mg/L, and 3 percent had concentrations exceeding 1,000 mg/L.

Sulfates are often present naturally in ground water as either magnesium sulfate (also called Epsom salt), as sodium sulfate, or as calcium sulfate or gypsum. Because the aquifer material in this area is dolomite, a calcium-magnesium carbonate rock, the sulfate most likely occurs as calcium sulfate and magnesium sulfate. Both calcium and magnesium concentrations in the ground-water samples were closely correlated with changes in sulfate concentrations. The Pearson correlation coefficient between calcium and sulfate was 0.85, and between magnesium and sulfate 0.74.

Human sources of sulfate are similar to those for chloride, some of which include leachate from solid waste, effluent from sewage disposal, and industrial waste. Because the natural levels of sulfate are so high throughout much of the study area, it would be difficult to discern areas where sulfate concentrations were elevated due to human activities.

Chloride

The concentrations of chloride in the samples from the Silurian dolomite aquifer ranged from 0.3 to 500 mg/L with a median value of 6.2 mg/L. USEPA (1982) and Illinois Water Quality Standards (TPCB, 1984a,b) both recommend an upper limit on chloride of 250 mg/L. Concentrations in excess of 250 mg/L can cause the water to taste salty. Less than 2 percent of the samples have chloride concentrations in excess of the 250 mg/L standard (figure 26). More than 83 percent of the samples have chloride concentrations of less than 50 mg/L, or one-fifth of the recommended upper limit

Chloride occurs naturally in earth materials in a soluble form. However, domestic and industrial wastes, sewage effluent, dumps, mining operations, and road salts all may introduce considerable amounts of chloride in areas where the Silurian dolomite is close to the land surface. Elevated concentrations of chloride occur in the northwest portion of the study area between the Du Page and Des Plaines Rivers where the Silurian dolomite is frequently exposed or is overlain by less than 25 feet of drift deposits. Similarly, the two highest chloride concentrations occur in areas where the bedrock is exposed at the land surface, allowing road salts or other sources of chloride to recharge directly into the aquifer with minimal attenuation.

Iron

Iron concentrations ranged from less than 0.01 mg/L to 7.8 mg/L with a median concentration of 0.61 mg/L. The USEPA (1982) secondary drinking water standard for iron is 0.3 mg/L. The Illinois Water Quality Standard (IPCB, 1984a,b) for iron in finished water is 1.0 mg/L. Approximately 74 percent of the ground-water samples exceeded the 0.3-mg/L standard, and 33 percent exceeded the 1.0-mg/L USEPA standard. As seen on

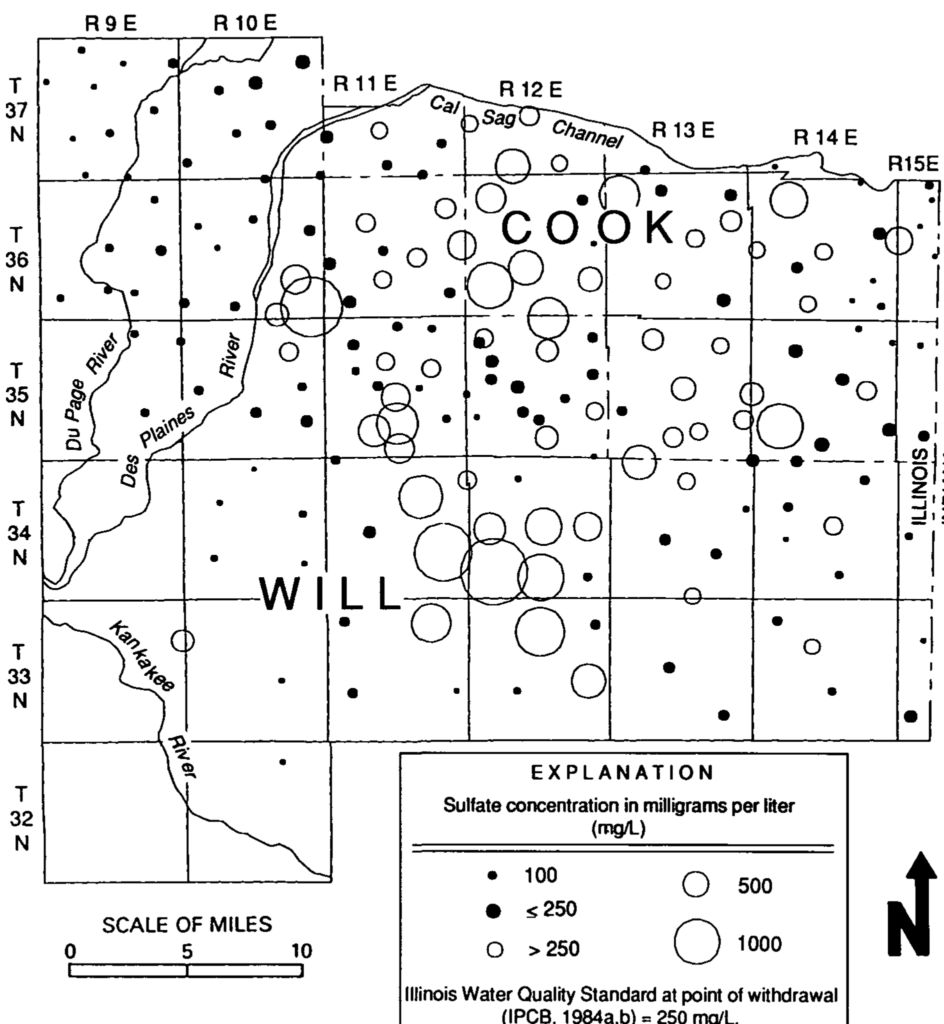
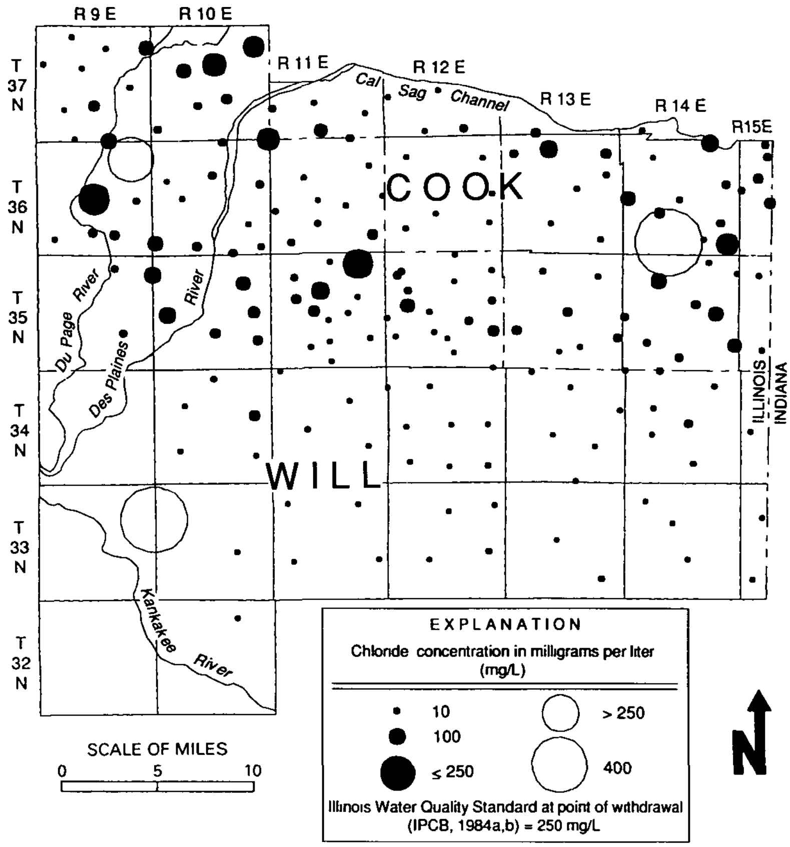


Figure 25. Sulfate distribution in the Silurian dolomite aquifer

Figure 26. Chloride distribution in the Silurian dolomite aquifer



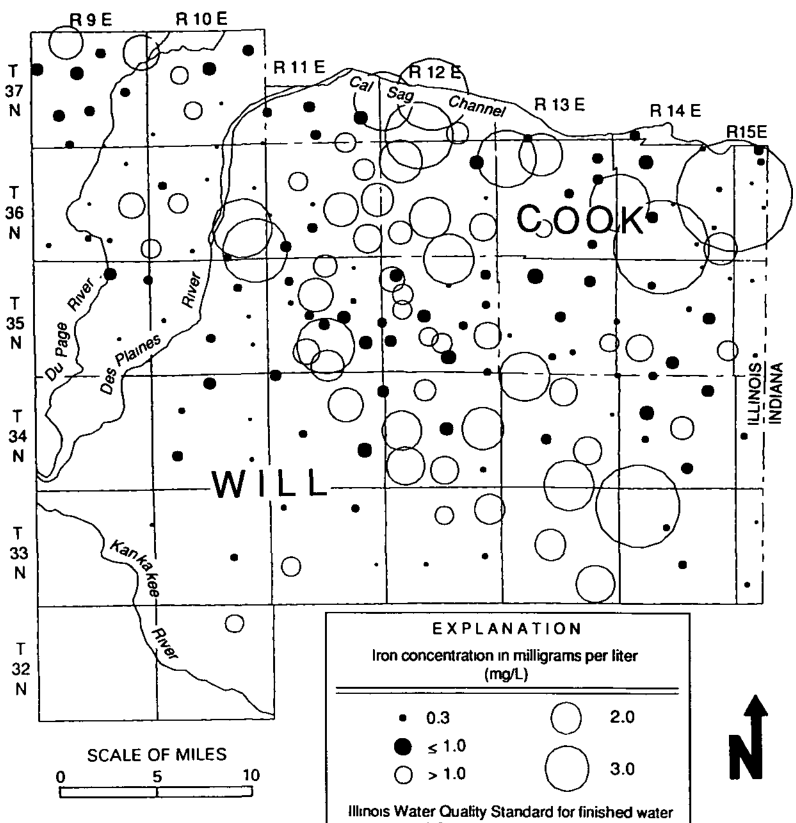


Figure 27. Iron distribution in the Silurian dolomite aquifer

figure 27, iron concentrations are generally greatest where the glacial drift is thick and the TDS concentration is high. Although low concentrations of iron occur throughout the entire study area, the most uniform distribution of low concentrations occurs in the westernmost townships of Will County. This region of low iron concentrations corresponds to similarly low TDS and sulfate values, which occur in areas of thin to absent drift deposits.

Iron is naturally occurring in ground water in the soluble (ferrous) state. However, once exposed to air it oxidizes to the ferric state and forms reddish-brown particles that may stain porcelain fixtures or laundry in concentrations much greater than 0.3 mg/L. In addition, concentrations above 0.3 mg/L may cause a distinctive iron taste in drinking water. The effectiveness of domestic water treatment systems may be dim inished by high concentrations of iron, requiring use of a separate iron removal system prior to water softening.

Fluoride

Fluoride concentrations ranged from a minimum of 0.1 mg/L to a maximum of 7.3 mg/L. The median fluoride concentration for the 186 wells sampled was 0.4 mg/L. Approximately 2 percent, or 4 of the 186 wells sampled, had fluoride concentrations in excess of 1.8 mg/L, the Illinois Water Quality Standard for finished water (IPCB, 1984a,b). All of those wells exceeding the 1.8-mg/L standard are located in the northeastern comer of the study area in Cook County (figure 28). The only hypothesis for naturally occurring high fluoride levels in this area is the thickness of the Silurian dolomite, which exceeds 450 feet. However, prior to development, this region may also have been a natural discharge area for the deeper aquifers that have higher fluoride concentrations.

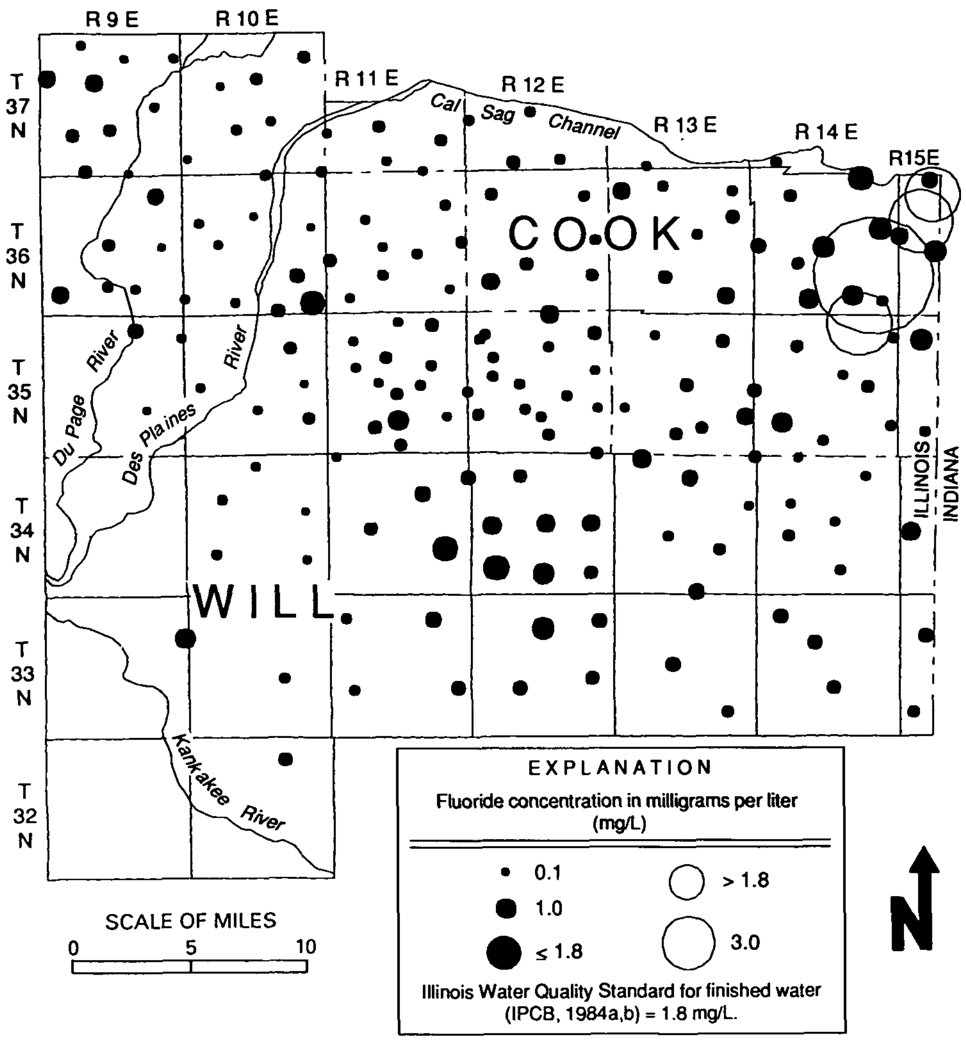


Figure 28. Fluoride distribution in the Silurian dolomite aquifer

Fluoride concentrations up to 1 mg/L have been shown to decrease the occurrence of dental cavities. On the other hand, concentrations greater than 1 mg/L can increase the incidence of fluorosis, which causes darkened and mottled teeth. Human sources of fluoride in ground water can be traced to municipal and industrial wastes. Based on the distribution of fluoride concentrations within the study area, human sources have likely had negligible impacts.

Nitrate

Nitrate concentrations ranged from below the laboratory instrument detection limit of 0.1 mg/L all the way to 124 mg/L. Median nitrate concentration was 0.1 mg/L. Of the 186 wells sampled, 139 had nitrate concentrations below the detection limit of 0.1 mg/L. The Illinois Water Quality Standard (IPCB, 1984a,b) for nitrate at both the point of withdrawal and in finished water is 10 mg/L.

Approximately 4 percent, or 8 of the 186 wells sampled, had nitrate concentrations in excess of the 10-mg/L standard (figure 29). Seven of those eight, with nitrate concentrations ranging from 15.3 to 50.3 mg/L, are located along an 8-mile stretch from the Du Page River north of Plainfield, through Romeoville, to east of the Des Plaines River, southwest of Lemont. This area of high nitrate concentration confirms similar results reported in the ground-water quality study by Sasman et al. (1981). As reported in that study, the highest concentrations of nitrate in samples from Silurian dolomite wells in Du Page and northwestern Will Counties were found in the Romeoville-Bolingbrook-Plainfield region. Nitrate concentrations in samples from this area exceeded 10 mg/L, and three samples exceeded 20 mg/L.

The high nitrate values in northwestern Will County can be attributed to two factors, one geologic and one human. First, the geology in this area is dominated by exposed Silurian dolomite and thin drift deposits less than 25 feet thick. These drift deposits are generally sand and gravel associated with glacial outwash of the Henry Formation. As was the case for the high chloride concentrations also found in ground-water samples from this area, thin drift deposits and bedrock exposures allow for rapid infiltration of rainfall to the aquifer with lower attenuationof contaminants than in areas of thick drift deposits.

The human factor contributing to high nitrate values is the agricultural activity in the area. Nitrates may be leached from soils where nitrogen fertilizer has been applied. Given the high vulnerability of the Silurian dolomite to contamination in this area, nitrate is a threat to the shallow groundwater system.

In addition to agricultural sources, nitrates may also be derived from aerobic bacterial decomposition of organic nitrogenous wastes such as domestic, municipal, and industrial wastewaters. Excessive nitrate concentrations often are found in shallow ground waters near surface sources such as feedlots and septic tanks.

Sodium

Sodium concentrations ranged from 4.3 to404.5 mg/L with a median concentration of 30.1 mg/L. The USEPA (1982) recommends an upper limit of 250 mg/L of sodium in drinking water. About 75 percent of the samples had sodium concentrations below 50 mg/L, and 91 percent had concentrations below 100 mg/L. Only one sample exceeded the USEPA limits; taken in Thornton Township (T36N, R14-15E), it had a sodium concentration of 404.5 mg/L.

The greatest density of high sodium levels in Silurian dolomite samples were found in the northeastern corner of the study area (figure 30), where most concentrations exceeded 100 mg/L. Had similarly high concentrations of chloride also occurred in this area, the source of both the sodium and chloride could be attributed to road salts applied to the dense network of roadways. However, the chloride distribution map (figure 26) does not show a pattern of significantly high chloride concentrations in this portion of Cook County. Although a few of the

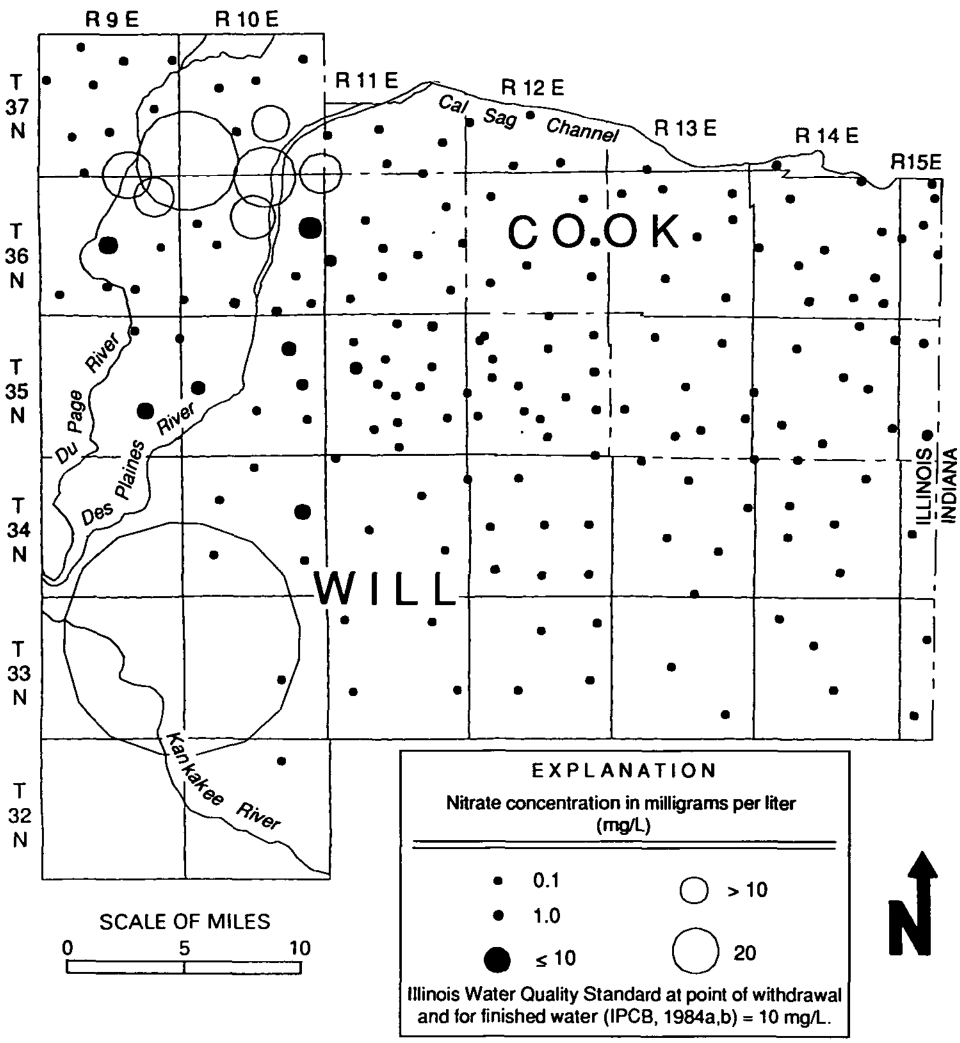


Figure 29. Nitrate distribution in the Silurian dolomite aquifer

high sodium and chloride concentrations in this area may be attributed to road salts, particularly where the drift overlying the bedrock is thin to absent, some of the high sodium concentrations may be naturally occurring.

Sodium levels are also frequently elevated in northwestern Will County between the Du Page and Des Plaines Rivers. These concentrations correspond to similarly high chloride concentrations. Given the thin to absent drift deposits and the increasing density of roadways and urban residential development here, road salting and salt storage may be elevating both sodium and chloride concentrations in the ground water.

Hardness (as $CaCO_3$)

After sulfate, calcium and magnesium are usually the greatest contributors to the mineralization of ground water from the Silurian dolomite in the study area. These two minerals are the primary constituents in what is known as the "hardness" of water. Both minerals are naturally occurring in the dolomite, which is a calcium- and magnesium-rich carbonate rock. The Pearson correlation coefficients between TDS versus calcium and magnesium are 0.84 and 0.82, respectively, which indicate a strong relationship. Similarly, because calcium and magnesium occur in the dolomite together and dissolve into the ground water together, the correlation coefficient between calcium and magnesium is 0.74.

Because the hardness of water is a major contributor to the overall TDS, the mapped distribution of hardness concentrations (figure 31) is very similar to that for TDS (figure 24). Hardness concentrations for the study area ranged from 2.4 to 1,401 mg/L with a median value of 492 mg/L. Using a scale established by the Illinois State Water Survey for designating the relative hardness of Illinois waters, 61 percent of the ground-water samples would be classified as "very hard," or greater than 400 mg/L in concentration. These "very hard" waters occur throughout most of the region, with the exception of the western portion of Will County and the northeastern corner of the study area.

In most of the remaining ground-water samples, about 29 percent, hardness concentrations were 250 to 400 mg/L, and the water would be termed "hard." "Moderately hard" water samples constituted only 5 percent of the 186 wells sampled. The remaining 5 percent, almost exclusively in the northeastern corner of the study area, would be categorized as "soft" to "fairly soft" by the Illinois State Water Survey classification.

Hardness is important because high calcium and magnesium concentrations affect the consumption of soap products and produce scale in water heaters, pipes, and elsewhere in water distribution systems. Neither the IEPA nor the USEPA drinking water standards set an upper limit for hardness.

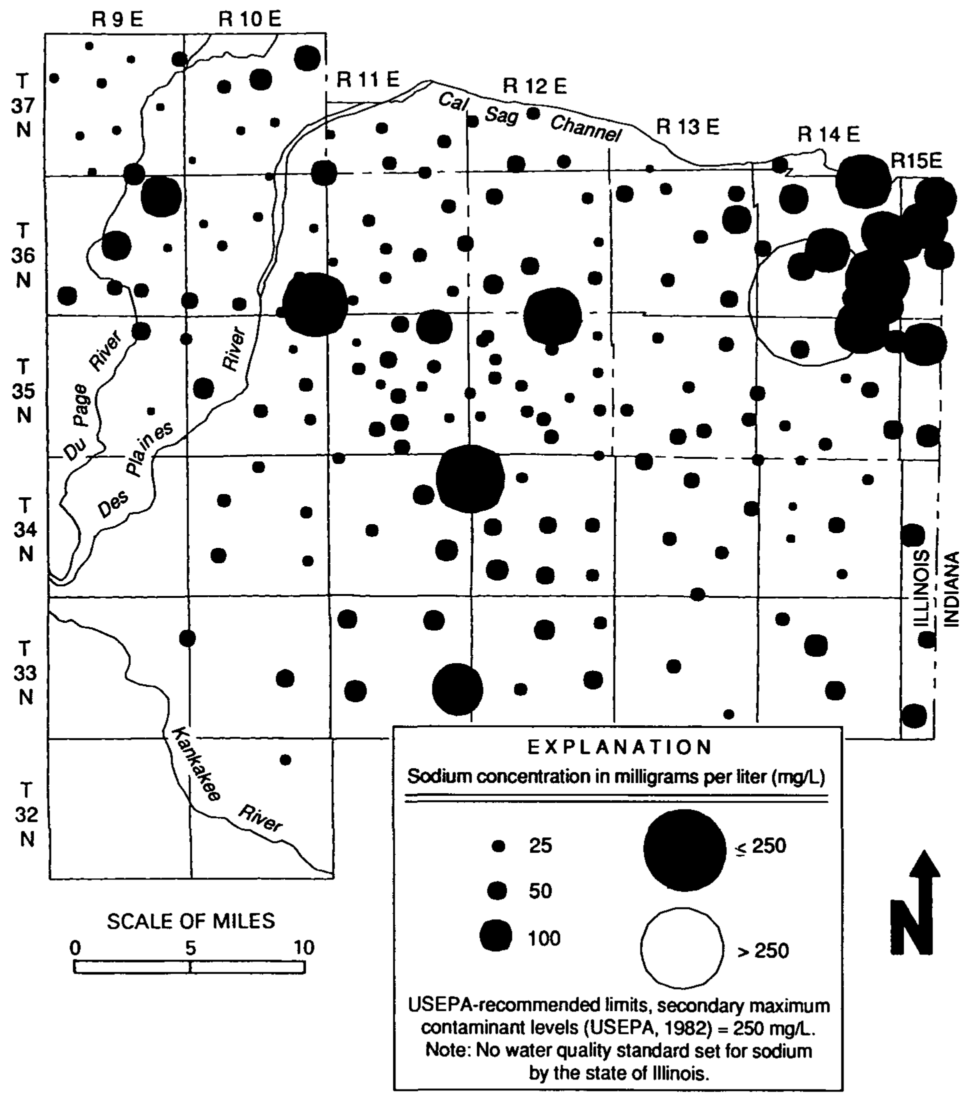


Figure 30. Sodium distribution in the Silurian dolomite aquifer

Trace Constituents

Statistics for twelve trace inorganic constituents analyzed in the water samples are presented in table 7. Other than one sample with a cadmium concentration of 19 micrograms per liter (µg/L) and 21 samples with manganese concentrations exceeding the 50-µg/L recommended upper limit (USEPA, 1982), all of the samples had either trace constituent concentrations below USEPA and Illinois Water Quality Standards or below the instrument detection limit for that constituent.

Generally, the samples collected and analyzed from 186 wells in the study area had acceptable levels of trace constituents. The main constituent of concern is manganese. In concentrations over 50 µg/L, it stains clothing and fixtures black.

Synthetic Organic Compounds

The presence of highly toxic, synthetic organic compounds in the ground water is difficult to assess because the sample procedure is very expensive, time consuming, and impractical for domestic wells. Because these compounds are not naturally occurring, most of the samples would likely come up negative. Fortunately, the IEPA requires regular organic sampling for most of the state's public water supply wells. These samples provide a somewhat good assessment of organic water quality because the wells draw water from large areas and are generally situated in urban areas where most of the potential contamination sources are located. However, the dilution caused by the large pumping rate of a production well can make small areas of highly contaminated aquifers appear to be nothing more than minor problems.

The production well sampling summarized in the Illinois Water Quality Report (IEPA, 1992) shows four confirmed sites with organic contamination, Crest Hill, Crestwood, New Lenox, and South Chicago Heights, and two additional unconfirmed sites in Elwood and southeastern Joliet. The principal organic compounds detected at the sites included petroleum components and several chlorinated industrial solvents, such as trichloroethylene (TCE). Concentrations generally were near the detection limits, but less than 10 parts per billion (ppb = µgL).

The New Lenox contamination was in a production well along Hickory Creek where the glacial drift is very thin and the aquifer is more susceptible to contamination. Well samples showed decreasing TCE levels in recent years, from 60 ppb in 1985 to 3 in 1988 (IEPA, 1989). The South Chicago Heights contamination involved low levels of solvents, petroleum components, and vinyl chloride, some of which have been been attributed to a nearby landfill (IEPA, 1992). Sampling at Crestwood was discontinued in 1987 after the town switched to Lake Michigan water.

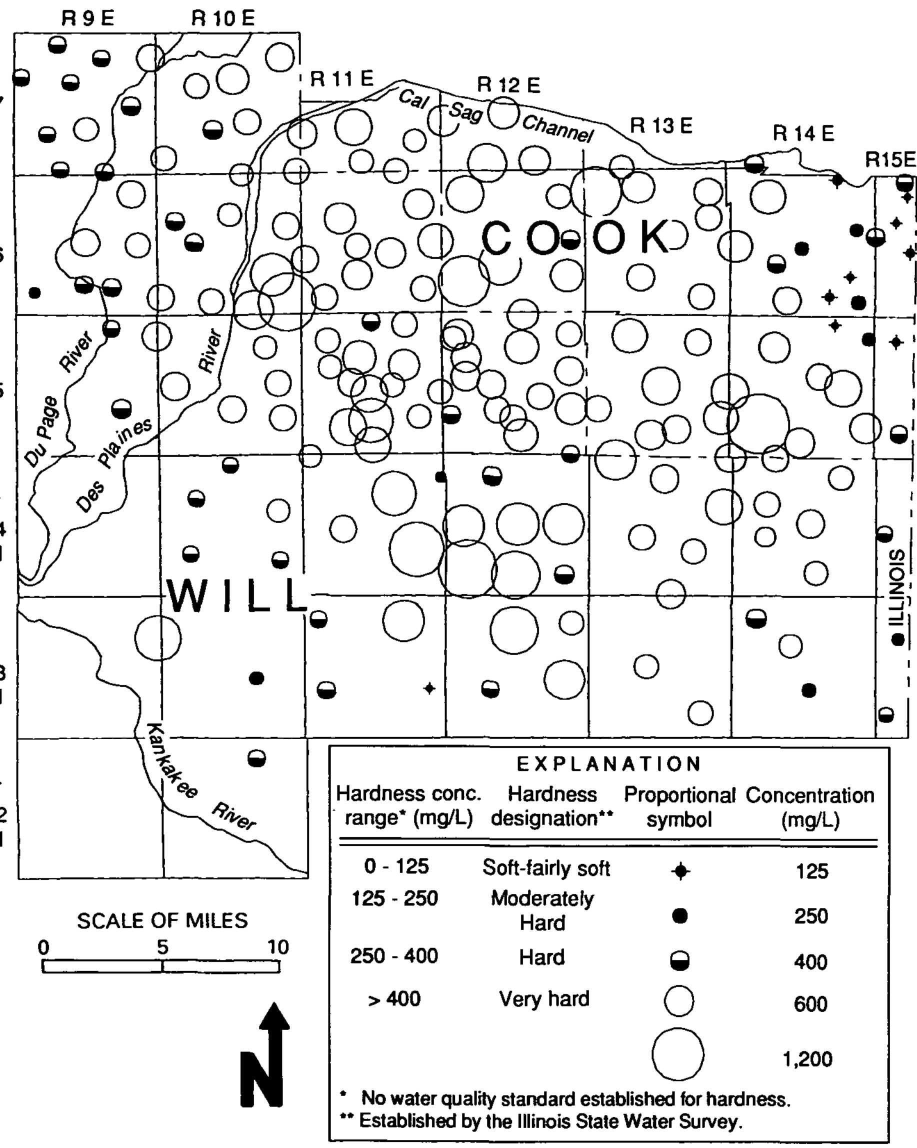


Figure 31. Hardness distribution in the Silurian dolomite aquifer

SUMMARY

The shallow aquifer system in Will and southern Cook Counties consists of Silurian-age dolomites overlain by Pleistocene-age glacial drift The dolomites form a large wedge-shaped unit more than 450 feet thick along the eastern edge of the study area with a gradual westward thinning to a complete disappearance west of the Kankakee River. The topography of the bedrock surface shows a general high running northwest to southeast through the center of the study area, which slopes off to the northeast and southwest A lot of relief occurs on this surface, reflecting the preglacial erosional surface highlighted by large valleys along the present-day Des Plaines River and the now-buried Hadley Valley. The formation of the bedrock surface was further complicated by karst processes that formed numerous closed depressions.

The unconsolidated glacial sediments overlying the bedrock are composed of tills, sands and gravels, lacustrine deposits from glacial lakes, and surficial eolian deposits of loess and sand. A series of moraines also trends northwest to southeast through the center of the study area, which may be a result of the advancing glaciers stalling on the bedrock high and forming thick deposits of drift. In the northeast and southwest portions of the study area, the drift is thinner with glacially-derived lacustrine or outwash deposits at the surface. A large expanse of basal sand occurs beneath the moraines, generally 10 to 50 feet thick, except in the buried Hadley Valley, where the sand occasionally exceeds 100 feet in thickness.

Ground water moves through the Silurian dolomite aquifer in cavities along horizontal bedding plains and vertical stress fractures that have been enhanced by chemical dissolution of the rock. Because the enlarged cavities are generally long and thin and somewhat randomly located, well productivities can vary tremendously even over a distance of several feet.

However, on a larger scale the aquifer conforms to the theories governing a porous medium. Aquifer transmissivity values calculated from specific-capacity tests displayed a log-normal distribution, with a median of 11,800 gpd/ft and a range of one standard deviation between 1,350 and 102,000 gpd/ft. The chances of constructing a well that will produce more the 500 gallons per minute are good for most of the study area. The only available data for the transmissivity of the sands is from the Hadley Valley, where Prickett et al. (1964) calculated a value of 186,000 gpd/ft.

Ground-water pumpage from the shallow aquifer system totaled 32.52 mgd in 1990 and came from 56 public and private water utilities located mainly along the Will-Cook County line, as well as several industrial wells and thousands of individual private wells throughout the study area. Since many communities switched to Lake Michigan water in the mid-1980s, total pumpage for the public water supplies in southern Cook County dropped dramatically from 18 mgd in 1974 to 5 mgd in 1990. This drop was mostly offset in Will County, where pumpage for the public water supplies increased from 8 to 17 mgd during the same period. Total ground-water use, including from the Cambrian-Ordovician aquifer, peaked in 1974 at 78 mgd and declined to 56 mgd in 1990.

The potentiometric surface measured in the Silurian dolomite aquifer is strongly influenced by the topography and the presence of major rivers. A major ground-water divide roughly follows the moraines and the bedrock high through the center of the study area and separates northeastward flow towards the Calumet River system from westward flow towards the Des Plaines and Kankakee Rivers. Another divide in the northwestern portion of the study area separates flow between the Des Plaines and Du Page Rivers. Ground-water pumping centers also influence the surface by creating cones of depression and areas of diversion in the regional flow field.

The relationship of the potentiometric surface to the bedrock surface varies tremendously across the study area. A large area of naturally dewatered aquifers occurs along the Des Plaines River. And beneath the moraines, water levels generally run 40 to 100 feet higher than the bedrock, signifying leaky-artesian flow conditions. Several of the pumping centers, as well as the four bedrock quarries, have created their own areas of dolomite dewatering. Comparing 1990 water levels with historic measurements shows mat when Chicago Heights switched to Lake Michigan water, the aquifer quickly recovered more than 140 feet, and the existing dewatering problem was greatly reduced.

Calculated values for the amount of recharge entering the Silurian dolomite aquifer varied across the study area depending upon local hydraulic conditions. Where the regional flow gradients are low in south-central Will County, the calculated values of recharge are less than 50,000 gpd/mi^2. Conversely, along the Des Plaines River valley where the gradient is high and bedrock outcrops are present, the calculated recharge value can exceed 300,000 gpd/mi^2.

By delineating the areas of diversion around the pumping centers and computing recharge, the recharge value was found to increase by about 30,600 gpd/mi^2 per 1.0 mgd increase in total ground-water pumpage. By incorporating additional historic data, as well as data from Du Page County, it also was discovered that at high pumping rates this increase progressively diminishes and ultimately reaches a maximum value of about 230,000 gpd/mi^2.

The potential yield of the shallow aquifer system for a typical township in the study area is conservatively estimated to be 6.0 mgd, largely based on the calculated maximum recharge rate. Many townships deviate from this rate due to differences in township size, aquifer transmissivity, and the presence of aquifer outcrops. The potential aquifer yield throughout the entire study area is estimated to be 160.9 mgd, which is five times greater than the total pumpage for 1990. Individually, ground-water use did not exceed the potential yield in any of the townships. And only two townships, Du Page (T37N, R10E) and Rich (T35N, R13E), experienced use-to-yield ratios greater than 0.5.

Water quality within the study area can generally be termed acceptable based on the chemical analysis of samples from 186 wells completed in the Silurian dolomite. Although most constituent concentrations are within healthy limits, elevated concentrations of particular inorganic constituents occur in some areas. Constituents such as iron, sulfur, and hardness can give the ground water an unpleasant taste, odor, or color that may be undesirable to many consumers.

CONCLUSIONS AND RECOMMENDATIONS

The water resources of the shallow aquifer system in Will and southern Cook Counties adequately meet the needs of the communities that depend on it for their water supplies. The level of ground-water use in 1990 poses no major threat of aquifer over-utilization or dewatering. Proper planning and a thorough knowledge of the regional ground-water flow system should enable almost all of the communities within the study area to safely meet increased water demands well into the future. The general water quality of the aquifer is acceptable with regard to health concerns, although high levels of hardness, sulfate, and iron in some areas can give the water some very poor aesthetic qualities.

To evaluate how a community can effectively increase its total water usage from the shallow dolomite aquifer, several hydrogeologic conditions and relationships must be examined. If there is a strong regional gradient towards a well field, the wells should be placed in a line perpendicular to the flow direction in order to capture the regional flow most effectively. This will allow a well field to be more productive by maintaining higher water levels, allowing for more pumpage before the resulting drawdown reaches a critical stage. The presence of a regional gradient also reduces the amount of local recharge necessary to balance ground-water pumpage, thereby increasing the allowable amount of pumpage before the maximum recharge rate is exceeded. Along a major ground-water divide without a regional gradient, pumpage from a large well field must be more evenly distributed to match available recharge.

The height of the potentiometric surface over the bedrock surface is very important; the greater the height, the greater the allowable pumpage before the drawdown reaches the critical level at the bedrock surface. When the potentiometric surface falls below the bedrock surface, either naturally or through pumpage, the productivity of a well field begins to drop. This is a result of a drop in aquifer transmissivity due to a decreased saturated thickness and a dewatering of the more permeable upper portions of the Silurian dolomite. However, as the water level drops, the gradient across the confining glacial drift becomes greater, which in turn provides more recharge to the area around a well field. Once the water level drops below the bottom of the confining layer, the recharge rate reaches a maximum. In areas where the transmissivity and/or the amount of available drawdown are low, the productivity of a well field can be maintained or increased by using a larger number of wells spaced farther apart and pumping at lower individual rates.

The amount by which a community can increase its total pumpage depends on the ratio between ground-water use and potential yield within its diversion area and how much this area can expand. For most of the diversion areas in the study area, the use-to-yield ratios vary between 0.3 and 0.5 when the potential yield estimates are adjusted to the proper area size. This implies that pumpage within a diversion area could be increased 100 to 300 percent without increasing its size. However, as pumpage increases, the diversion area will expand by pushing back regional ground-water divides and smaller divides formed with adjacent diversion areas. As long as this expansion can continue, the potential yield will not be reached, although the use-to-yield ratio could likely increase in an adjacent diversion area affected by the expansion.

It is important to stress that the aquifer behaves as a single entity and that the activities of one community will affect surrounding communities. A new or expanded well field may have adverse effects on existing well fields nearby if the intricacies of the regional flow system are not taken into consideration.

For both new and existing well fields, it is also very important to consider variations in the vulnerability of the shallow aquifer to contamination and the location of potential contamination sources. For example, the well adjacent to Hickory Creek in downtown New Lenox is considerably more vulnerable than the wells south of town due to the absence of low-permeability till and the large number of potential sources of contamination in the downtown area. The recharge rate also affects an aquifer's vulnerability to contamination because the greater the recharge rate at a particular site, the greater the amount of vertical ground-water flow and the faster the contaminants can move downward into the aquifer.

The data collected and analyzed for this report could be used to construct a numerical computer model of the shallow aquifer system that could assess the impact of anticipated future ground-water use practices. As part of the need to protect the water quality of the aquifer, a computer model also could be used to delineate ground-water protection zones.

This evaluation of the shallow ground-water resources in Will and southern Cook Counties has provided insights into current hydrogeologic conditions and the future ground-water use potential of the aquifer system. Because the present conditions are not the same throughout the entire study area, separate conclusions and recommendations have been made for four major subareas.

Park Forest - Richton Park - Steger

With the conversion of Chicago Heights, Olympia Fields, and Matteson to Lake Michigan water, the potential of the shallow aquifer system has improved for the neighboring communities to the south. Recharge entering the aquifer in these former ground-water use areas now can be diverted into the pumping centers at Park Forest, Steger, and South Chicago Heights, where small dewatering problems still exist. Because water demands in these three towns are not increasing, these dewatering problems will probably not get worse.

Any future problem experienced by Park Forest could be alleviated by shifting some of the pumpage to the south, even as far as the forest preserves in Will County where the number of potential contamination sources would be lower. The aquifer likely will continue to supply ample amounts of water to the city wells in South Chicago Heights. However, in light of the organic contamination and the large number of potential contamination sources near the wells, it may be worthwhile for South Chicago Heights to consider switching to Lake Michigan water.

Substantial growth is expected for the outer suburban communities of Sauk Village, University Park, and Richton Park, while Crete is expected to double in population by the year 2010. The ensuing growth in water use can be safely accommodated if aquifer development is conducted efficiently. By combining diversion areas 9 through 12 (figure 10), the area can be examined as a whole. The 1990 pumpage was 8.012 mgd, and the average recharge rate was 69,000 gpd/mi^2. This is approximately 98,000 gpd/mi^2 below the conservatively estimated potential yield rate of 167,000 gpd/mi^2. Therefore an additional 11.4 mgd could be withdrawn from the 116-mi^2 area without increasing the size of the diversion. This is more than four times the 2.78 mgd that Sauk Village, University Park, Richton Park, and Crete collectively withdrew in 1990. For these four communities to use the aquifer most efficiently and to help improve the situation at the three other communities, pumpage should be shifted to the south, either in existing wells or in new well fields constructed to meet increasing demands.

Frankfort - Mokena - New Lenox - Homer Township Area

The population of north-central Will County grew by 35 percenter 17,585 people, between 1980 and 1990. By 2010 the cities of Mokena and New Lenox are expected to double in size, while Frankfort is expected to triple in size. In 1990, the pumpage from these thiree communities, along with the utilities in Homer Township (T36N, R11E), formed a group of five diversion areas (figure 10, areas 3-7) that collectively extended over 115 mi^2. The recharge rate calculated from the 6.417 mgd of pumpage was 56,000 gpd/mi^2, which is approximately 111 ,000 gpd/mi^2 below the conservatively estimated potential yield rate of 167,000 gpd/mi^2. Therefore, without increasing the size of the diversion area, an additional 12.7 mgd could be withdrawn from the aquifer for a total withdrawal potential of 19.1 mgd. Assuming the population projections hold true and assuming pumpage within the diversion area doubles (except in Frankfort where it will triple), the 2010 water use should be at about 14.5 mgd.

By expanding the size of the diversion area, an additional 5 to 10 mgd of recharge could be provided to the pumping centers. Assuming the same growth rate, this recharge would theoretically enable the aquifer to satisfy increased water demands for another 20 years to the year 2030. This additional recharge can most effectively be realized through a coordinated ground-water use strategy; that is, an increase in pumpage or the construction of a new well field by one community must be carefully planned out with respect to its effects on the regional flow field and the neighboring communities. Under such a strategy, New Lenox and Frankfort would place new pumping centers to the south and southwest to capture more of the regional flow field and less of the recharge presendy received by the communities to the north. The area along the soudiern boundary between New Lenox and Frankfort Townships may be a good area for expansion because of the thick deposits of saturated basal sand and better ground-water quality than in some of the surrounding areas. Because it lies in the center of the diversion area, Mokena has the fewest options and may consider spacing out any new wells enough to match the available recharge.

Although the regional gradient is very slight, the water utilities in Homer Township have several options that could enhance their use of the shallow aquifer system. One option would be to expand the diversion area by placing new wells to the west or south of the existing wells in the northeast corner of the township. If politically possible, new wells could be located in the surrounding Cook County townships of Lemont, Palos, and Orland, where water use is minimal and available drawdown isplentiful. Unfortunately, waterquality in Orland Township is generally poorer, with higher levels of total dissolved solids, sulfate, and iron, which could require extensive water treatment before the water would be acceptable to the public.

Another option for the utilities in Homer Township would be to utilize the Hadley Valley sand-and-gravel aquifer. Prickett et al. (1964) estimated the recharge for this aquifer at 300,000 gpd/mi^2 and proposed that a well field developed in eastern Homer Township would produce several million gallons per day. If the city of Joliet switches to Kankakee River water or Lake Michigan water, it may cease to pump from the Hadley Valley. In that case, its well field in western Homer Township could then supply water to the Homer Township utilities or New Lenox if needed.

The productivity of any new dolomite wells in the central part of the township could be affected by the natural dewatering that occurs in that area (figure 14). However, in the remaining fully saturated areas, the thick basal sands may help new wells be more productive than expected.

Bolingbrook - Romeoville - Crest Hill - Joliet

The portions of the study area probably facing the greatest water supply challenges in the future are the expanding urban areas between the Du Page and Des Plaines Rivers. The populations of Romeoville, Plainfield, and Lockport are expected to triple by the year 2010, while significant gains also are expected in Bolingbrook and Joliet. In the past, large water supply systems were developed from the deep Cambrian-Ordovician aquifer, while smaller systems used the shallow aquifer. The communities of Romeoville, Shorewood, Rockdale, and Naperville used water from both aquifers in 1990.

With the large-scale depletion of the deep aquifer, many communities are looking for alternative water supplies, which would include more development of the shallow aquifer system. However, if the public water supply systems of Joliet and Lockport were switched to Kankakee River or Lake Michigan water, the deep aquifer withdrawals would drop by 50 percent and the condition of the aquifer would greatly improve for the remaining water users such as Plainfield.

The ability of the shallow aquifer to meet the demands of the increasing population along this western slice of Will County varies with changes in both the present water-use patterns and the surficial geology. The 1990 pumpage from the shallow aquifer in Bolingbrook appears to have been distributed well enough along the regional ground-water divide between the two rivers to sufficiently match the available recharge without dewatering the aquifer. The conversion of the adjacent towns of Woodridge and Naperville to Lake Michigan water will provide additional regional flow and recharge to the Bolingbrook well fields.

To keep up with the expected increase in the demand for water, the general pattern of placing new wells a half-mile to a mile west and southwest of existing wells will have to continue to prevent aquifer over-utilization. However, as urban expansion moves into Wheatland Township (T37N, R9E), new production wells may start to experience a drop in aquifer transmissivity as the dolomite thins and shaley zones are encountered in the lower units. Thus an impractical, large number of wells may be required to withdraw the same amount of water.

In some areas along the Du Page River, the overlying glacial materials are composed of outwash sands and gravels that may increase the transmissivity and the amount of recharge from precipitation, while inducing the flow of additional water into the aquifer from the river. In the absence of glacial till, the aquifer is much more susceptible to contamination. As a result, it may be necessary to delineate ground-water protection zones and institute the proper land-use controls.

Romeoville is in a situation similar to that of Bolingbrook, except that it faces two additional problems with adding more wells to the west:

1. Large areas of naturally dewatered aquifer exist in the Romeoville area, so new production wells must be spaced carefully to avoid exacerbating the problem and causing large decreases in aquifer productivity.
2. A nitrate contamination problem also exists in the area, which may make the water from any proposed wells or even existing wells unsuitable for human consumption without additional water treatment.

If substantial population growth occurs west of Romeoville and in Wheatland (T37N, R09E) and Plainfield (T37N, R09E) Townships, the shallow aquifer system may eventually be exhausted and an alternate source of water would have to be located. If the water from this alternative source were limited, it might be prudent to reserve it for growth in areas not presendy served by public water supplies that are based on the shallow aquifer system.

The remaining shallow aquifer users in Crest Hill, Shorewood, and the many small water supply systems in the Joliet and Lockport area collectively used 2.46 mgd in 1990. Pumpage came from 36 wells distributed widely enough over the area to avoid any over use problems. Based on the potential yield estimates, it is likely that this pumpage could safely double or even triple, as long this large number of wells is maintained. Any additional pumpage in Crest Hill may require the location of new wells north of town and west of the Stateville Correctional Center. The biggest problem facing these water users is the threat of contamination because many of their production wells are located either in established urban areas with many potential contamination sources, or in areas where the surficial geology makes the aquifer very susceptible to contamination.

Beecher - Peotone - Manhattan

The shallow aquifer system will be able to meet the water supply demands of the small communities in southern Will County well into the future. The 1990 level of ground-water use in the rural townships of soudiern Will County was less than 10 percent of the estimated potential yield.

If a proposed third regional airport is built near Peotone or Beecher, demands for water will increase dramatically. If the locations and pumping rates of any new well fields are carefully planned out, possibly with the aid of a computer model, then it would be reasonable to expect the aquifer to supply at least 10 mgd for the airport and its associated growth. Careful planning will keep the disturbance of existing wells to a minimum, although some domestic wells may require redlining or deepening. If the proposed airport is located at the Joliet Arsenal or ata site in Kankakee County that overlaps into Wilton Township (T33N, R11E), any new well fields will have to be constructed on the east sides of these sites because the aquifer thins towards the Kankakee River.

REFERENCES

Berg, R.C., and J.P. Kempton. 1988. *Stack-Unit Mapping of* ***Geologic Materials in Illinois to a Depth of 15 Meters.*** Illinois State Geological Survey Circular 542, Champaign, 23p.

Bergeron, MP. 1981. *Effect of Irrigation Pumping on the Ground-Water System in Newton and Jasper Counties,* *Indiana.* U.S. Geological Survey Water Resources Investigations Report 81-38, Indianapolis, 170p.

Bergstrom, R.E., J.W. Foster, L.F. Selkregg, and W.A. Pryor. **1955. *Ground-Water Possibilities in Northeastern*** *Illinois.* Illinois State Geological Survey Circular 198, Champaign, 23p.

Bogner, J.E. 1976. Geology for Planning in Northeastern Illinois V, Cook County. Illinois State Geological Survey Open File Report, Champaign, 29p.

Borland International. 1991. QUATTRO PRO - Version 3. Scotts Valley, CA.

Bowman, J.A. 1991. *Illinois State Water Plan Task Force Special Report on Ground-Water Supply and Demand* *in Illinois.* Illinois State Water Survey Report of Investigation 116, Champaign, 93p.

Bradbury, Kit., and E.R. Rothschild. 1985. A Computerized Technique for Estimating the Hydraulic Conductivity of Aquifers from Specific Capacity Data. *Groundwater,* 23(2):240-246.

Bretz, J.H. 1955. *Geology of the Chicago Region, Part II-The* *Pleistocene.* Illinois State Geological Survey Bulletin 65, Champaign, 132p.

Brown,R.H. 1963. Estimating the Transmissibility of an Artesian Aquifer from the Specific Capacity of a Well. In *Methods* ***of Determining Permeability, Transmissibility, and*** *Drawdown,* R. Bentall, compiler. U.S. Geological Survey Water Supply Paper 1536-I, Reston, VA: 336-338.

Bruvold, W.H. 1970. Mineral Taste and the Potability of **Domestic Water. *Water Research,* 4(5):331-340.**

Burch,S.L. *l991.The New Chicago Model: A Reassessment of the Impacts of Lake Michigan Allocations on the Cambrian-Ordovician Aquifer System in Northeastern* *Illinois.* Illinois State Water Survey Research Report 119, Champaign, 52p.

Buschbach, T.C., and G.E. Heim. 1972. *Preliminary Geologic* ***Investigations of Rock Tunnel Sites for Flood and Pollution Control in the Greater Chicago Area.* Illinois** State Geological Survey Environmental Geology Notes 52, Champaign, 35p.

Cedergren, H.R. 1967. *Seepage, Drainage, and Flow Nets.* John Wiley & Sons, Inc., New York, 489p.

Cravens, S.J., S.D. Wilson, and R.C. Barry. 1990. *Regional* ***Assessment of the Ground-Water Resources in Eastern Kankakee and Northern Iroquois Counties.* Illinois** State Water Survey Report of Investigation 111, Champaign, 86p.

Cravens, S.J., and A.L.Zahn. 1990. *Ground-Water Quality* ***Investigation and Monitoring Program Design for the Lake Calumet Area of Southeast Chicago.* Illinois** State Water Survey Contract Report 496, Champaign, 112p.

Csallany, S.C., and W.C. Walton. 1963. *Yields of Shallow* ***Dolomite Wells in Northern Illinois.* Illinois State Water** Survey Report of Investigation 46, Champaign.

Ekblaw, G.E. 1938. *Kankakee Arch in Illinois.* Illinois State Geological Survey Circular 40, Champaign, 6p.

Englund,E., and A. Sparks. 1988. *Geostatistical Environmental* ***Assessment Software, User's Guide.* Environmental** Monitoring Systems Laboratory, Office of Research and Development, U.S. Environmental Protection Agency, Las Vegas, 172p.

Environmental Systems Research Institute. 1991. ARC/INFO - Version 6. Redlands, CA.

Fetter, C.W. 1988. *Applied Hydrogeology.* Merrill Publishing Company, Columbus, OH, 592p.

Fischer, D.J. l925. Geology and Mineral Resources of the Joliet *Quadrangle.* Illinois State Geological Survey Bulletin 51, Champaign, 160p.

Foote, G.R. 1982. Fracture Analysis in Northeastern Illinois and Northern Indiana. Unpublished M.S. thesis, University of Illinois at Urbana-Champaign, 192p.

Golden Software. 1988. GRAPHER - Version 1.75. Golden, CO.

Golden Software. 1989. SURFER - Version 4. Golden, CO.

Gross, D.L., and R.C. Berg. 1981. *Geology of the Kankakee* ***River System in Kankakee County, Illinois.* Illinois State** Geological Survey Environmental Geology Notes 92, Champaign, 80p.

Hansel, A.K., and W.H. Johnson. 1987. Ice Marginal Sedimentation in a Late Wisconsinan End Moraine Complex, Northeastern Illinois, USA, In *Tills and Glaciotec tonics,* J.J.M. van der Meer, ed. Proceedings of an INQUA Symposium on Genesis and Lithology of Glacial Deposits: 97-104.

Horberg, L. 1950. Bedrock Topography in Illinois. Illmois Slate Geological Survey Bulletin 73, Champaign, 111p.

Horberg, L. 1953. *Pleistocene Deposits below the Wisconsinan Drift in Northeastern Illinois.* Illinois State Geological Survey Report of Investigations 165, Champaign, 61p.

***Horberg, L., and K.O. Emery. 1943. Buried Bedrock Valleys East of Joliet and Their Relation to Water Supply.* Illinois State** Geological Survey Circular 95, Champaign, 6p.

Hughes, G.M., P. Kraatz, and R.A. Landon. 1966. *Bedrock* ***Aquifers of Northeastern Illinois.* Illinois State** Geological Survey Circular 406, Champaign, 15p.

Illinois Environmental Protection Agency (IEPA). 1989. ***Groundwater Quality Protection Program: New Lenox Facility Number 1970700 Well Site Survey Report.*** IEPA Report 89-097, Springfield.

Illinois Environmental Protection Agency (IEPA). *l992.Illinois* ***Water Quality Report 1990-1991.* IEPA Report 92-055,** Springfield.

Illinois Pollution Control Board. 1984a. *State of Illinois Rules* ***and Regulations, Title 35: Environmental Protection,*** Subtitle C: Water Pollution.Chapter I. Springfield, 44p.

Illinois Pollution Control Board. 1984b. *State of Illinois Rules* ***and Regulations, Title 35: Environmental Protection,*** Subtitle F: Water Pollution, Chapter I. Springfield, 19p.

Johnson, W.H., and A.K. Hansel. 1985. The Lemont Section, In ***Depositional Environments and Correlation Problems of the Wedron Formation (Wisconsinan) in Northeastern*** *Illinois,* by Johnson, W.H., A.K. Hansel, B.J. Socha, L.R. Follmer, and J.M. Masters. Illinois State Geological Survey Guidebook 16, Champaign, 91p.

Kamin, B. 1990. Job Bloom by 2010 May Be Traffic Bust. *Chicago Tribune,* No. 339, December 6.

Kirk, J.R. 1987. *Water Withdrawals in Illinois, 1986.* Illinois State Water Survey Circular 167, Champaign.

Kirk, *JR.,* K.J. Hlinka, R.T. Sasman, and E.W. Sanderson. **1985. *Water Withdrawalsm Illinois,1984. Illinois* State** Water Survey Circular 163, Champaign.

Kirk, J.R., J. Jarboe, E.W. Sanderson, R.T. Sasman, and C. **Lonnquist. 1982. *Water Withdrawals in Illinois, 1980.*** Illinois State Water Survey Circular 152, Champaign.

Kirk, J.R., E.W. Sanderson, R.T. Sasman. 1984. *Water* ***Withdrawals in Illinois, 1982.* Illinois State Water Survey** Circular 161, Champaign.

Knowles, D.B., W J. Drescher,and E.F. LeRoux. 1963. *Ground-water* ***Conditions at Argonne National Laboratory,*** *Illinois, 1948-1960.* U.S. Geological Survey Water Supply Paper 1669-0, Washington, DC, 40p.

Kolata, D.R., T.C. Buschbach, and J.D. Treworgy. 1978. *The* ***Sandwich Fault Zone of Northern Illinois.* Illinois State** Geological Survey Circular 500, Champaign, 26p.

Kolata, D.R., and A.M. Graese. 1983. *Lithostratigraphy and* ***Depositional Environments of the Masquoketa Group (Ordovician) in Northern Illinois.* Illinois State** Geological Survey Circular 528, Champaign, 49p.

Larsen, J.I. 1976. *Geology for Planning in Northeastern lllinois:* *VI, Will County.* Illinois State Geological Survey Open File Report, Champaign, 32p.

Lowenstam, H.A. 1957. Niagran Reefs in the Great Lakes Area, **In *Treatise on Marine Ecology and Paleoecology,* GSA** Mem. 67, 2:215-248.

Masters, J.M. 1978. Sand and Gravel Resources in Northeastern *Illinois.* Illinois State Geological Survey Circular 503, Champaign, llp.

McConnel, D.R. 1972. Bedrock Topography and Paleogeomorphology Northeast of Joliet, Illinois. Unpublished M.S. thesis, University of Illinois at Urbana-Champaign, 33p.

Northeast Illinois Planning Commission (NIPC). 1991. 7990 ***Census Housing Units and Population by Race and Spanish Origin for Northeastern Illinois Municiplities, Counties, Townships, and Chicago Community Areas, with Selected 1980 Statistics.* Research Services** Department, NIPC, Data Bulletin 91-1, Chicago.

O'Hearn, M., and J.P. Gibb. 1980. *Ground-Water Discharge to Illinois Streams.* Illinois State Water Survey Contract Report 246, Champaign, 31p.

Peters, J.G. 1987. *Description and Comparison of Selected Models for Hydrologic Analysis of Ground-Water Flow, St.Joseph* River Basin, Indiana. U.S. Geological Survey Water Resources Investigations Report 86-4199, Indianapolis, 125p.

Piskin, K., and R.E. Bergstrom. 1975. *Glacial Drift in Illinois - Thickness and Character.* Illinois State Geological Survey Circular 490, Champaign, 35p.

Prickett, T.A., L.R. Hoover, W.H. Baker, and R.T. Sasman. **1964. *Ground-Water Developments in Several Areas of*** *Northeasternlllinois.* Illinois State Water Survey Report of Investigation 47, Champaign.

Richards, T.E., P.D. Hayes, and D.J. Sullivan. 1992. *Water* ***Resources Data, Illinois, Water Year 1990.* U.S.** Geological Survey Water Data Report IL-90-2, Washington, DC, 530p.

Rosenshein, J.S. 1961. *Ground-Water Resources of Northwestern Indiana, Preliminary Report, Lake* *County.* Indiana Department of Conservation, Division of Water Resources, Bulletin 10, Indianapolis, 229p.

Rosenshein, J.S. 1963. Recharge Rates of Principal Aquifers in Lake County, Indiana. *Ground Water,* Journal of the National Water Well Association, 1 (4): 13-20.

Rosenshein, J.S., and J.D. Hunn. 1968. *Geohydrology and **Ground Water Potential of Lake County, Indiana.*** **U.S.** Geological Survey in cooperation with the Division of Water, Indiana Department of Natural Resources, Bulletin 31, Indianapolis, 36p.

Sasman, R.T. 1965. *Ground-Water Pumpage in Northeastern* *Illinois through 1962.* Illinois State Water Survey Report of Investigation SO, Champaign, 31p.

Sasman, R.T., C.R. Benson, G.L. Dzurisin, and N.E. Risk. **1974. *Ground-Water Pumpage in Northern Illinois,*** *1960-1970.* Illinois State Water Survey Report of Investigation 73, Champaign, 46p.

Sasman, R.T., R.J. Schicht, J.P. Gibb, M. O'Hearn, C.R. Benson, and R.S. Ludwigs. 1981. *Verification of the **Potential Yield and Chemical Quality of the Shallow Dolomite Aquifer in DuPage County, Illinois.*** **Illinois** State Water Survey Circular 149, Champaign, 46p.

Schicht,RJ., *J.R..* Adams, and J.B. Stall. 1976. *Water Resources **Availability, Quality, and Cost in Northeastern Illinois.*** Illinois State Water Survey Report of Investigation 83, Champaign, 90p.

Shafer, J.M. 1990. GWPATH - Version 4.0. Champaign, IL.

Singh, K.P., and J.R. Adams. 1980. *Adequacy and Economics **of Water Supply in Northeastern Illinois, 1985-2010.*** Illinois State Water Survey Report of Investigation 97, Champaign, 205p.

Smith, W.M. 1968. *Strippable Coal Reserves of Illinois: Part 6 -La Salle, Livingston, Grundy, Kankakee, Will, Putnam, and Parts of Bureau and Marshall Counties.* Illinois State Geological Survey Circular 419, Champaign, 29p.

Smith, E.C., and MM. McLean. 1992. *Geology of Will and **Southern Cook Counties, Illinois.*** **Illinois State Geological** Survey Open File Report, Champaign, in preparation.

Suter, M., *RE.* Bergstrom, HP. Smith, G.H. Emrich, W.C. Walton, and T.E. Larson. 1959. *Preliminary Report on **Ground-Water Resources of the Chicago Region, Illinois.*** Illinois State Water Survey and Geological Survey Cooperative Ground-Water Report 1, Champaign.

Theis, C.V. 1963. Estimating the Transmissibility of a Water-Table Aquifer from the Specific Capacity of a Well. In *Methods **of Determining Permeability, Transmissibility, and*** *Drawdown,* R. Bentall, compiler. U.S. Geological Survey Water Supply Paper 1536-I, Washington, DC:332-336.

Thwaites, F.T. 1927. *Stratigraphy and Geologic Structure of* *Northern Illinois.* Illinois State Geological Survey Report of Investigations 13, Champaign, 49p.

U. S. Environmental Protection Agency (USEPA). 1982. ***Secondary Maximum Contaminant Levels* (Section** 143.3 of Part 143, National Secondary Drinking Water Regulations). U.S. Code of Federal Regulations, Title 40, parts 100-149, revised July 1, 1987. Washington, DC.

Visocky, A.P., and M.K. Schulmeister. 1988. *Ground-Water **Investigations for Siting the Superconducting Super Collider in Northeastern Illinois.*** **Illinois State Water** Survey Circular 170, Champaign, 80p.

Visocky, A.P., M.G. Sherrill, and K. Cartwright. 1985. ***Geology, Hydrology, and Water Quality of the Cambrian and Ordovician Systems in Northern*** *Illinois.* Illinois Department of Energy and Natural Resources Cooperative Groundwater Report 10, Springfield, 136p.

Walton, W.C. 1965. *Ground-Water Recharge and Runoff in* *Illinois.* Illinois State Water Survey Report of Investigation 48, Champaign.

Willman, H.B. 1971. *Summary of the Geology of the Chicago* *Area.* Illinois State Geological Survey Circular 460, Champaign, 77p.

Willman, H.B. 1973. *Rock Stratigraphy of the Silurian System in Northeastern and Northwestern Illinois.* Illinois State Geological Survey Circular 479, Champaign, 55p.

Willman, H.B., and J.A. Lineback. 1970. Map of the Surficial Geology of the Chicago Region. In *Summary of the **Geology of the Chicago Area*** **by H.B. Willman (1971).** Illinois State Geological Survey Circular 460, Champaign, 77p.

Willman, H.B., E. Atherton, T.C. Buschbach, C. Collinson, J.C. Frye, M.E. Hopkins, J.A. Lineback, and J.A. **Simon. 1975. *Handbook of Illinois Stratigraphy.*** Illinois State Geological Survey Bulletin 95, Champaign, 261p.

Woller, D.M., and E.W. Sanderson. 1983. *Public Ground-**Water Supplies in Will County.*** **Illinois State Water** Survey Bulletin 60-29, Champaign, 127p.

Zeizel, A.J., W.C. Walton, R.T. Sasman, and T.A. Prickett. **1962. *Ground-Water Resources of Du Page County,*** *Illinois.* Illinois State Water Survey and Geological Survey Cooperative Report 2, Champaign.

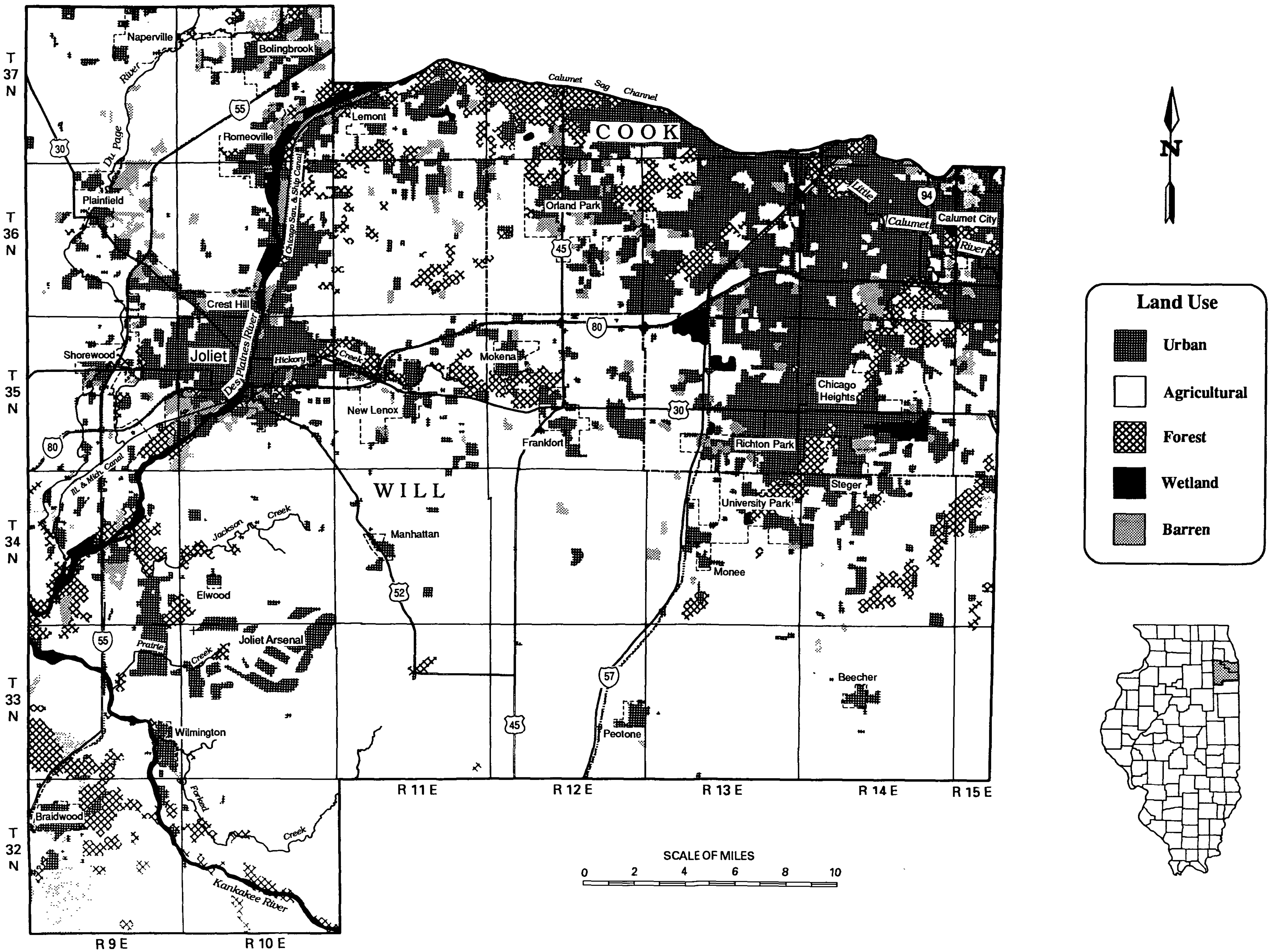


Plate 1. Geography and land use of the study area

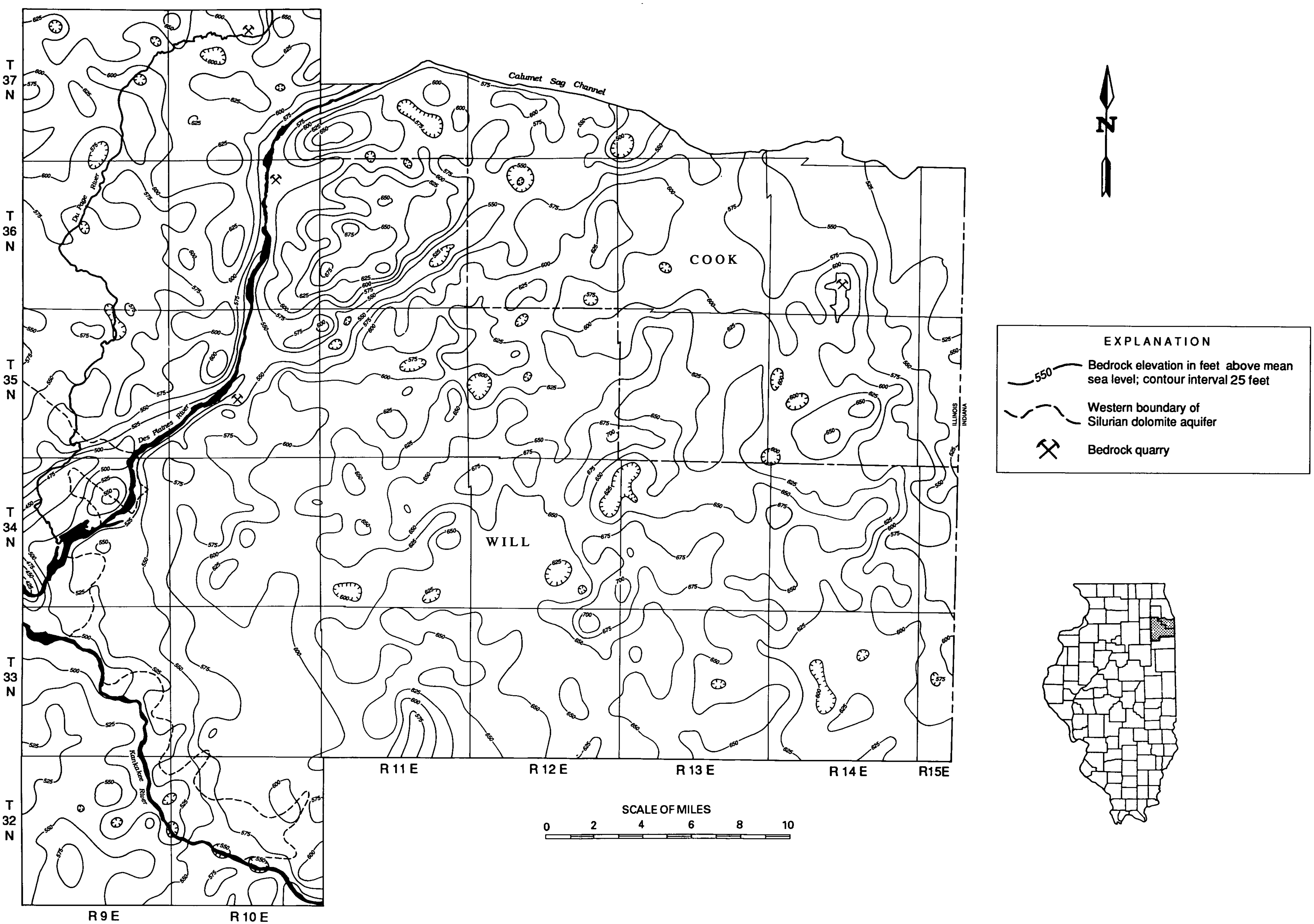


Plate II. Topography of the bedrock surface in the study area

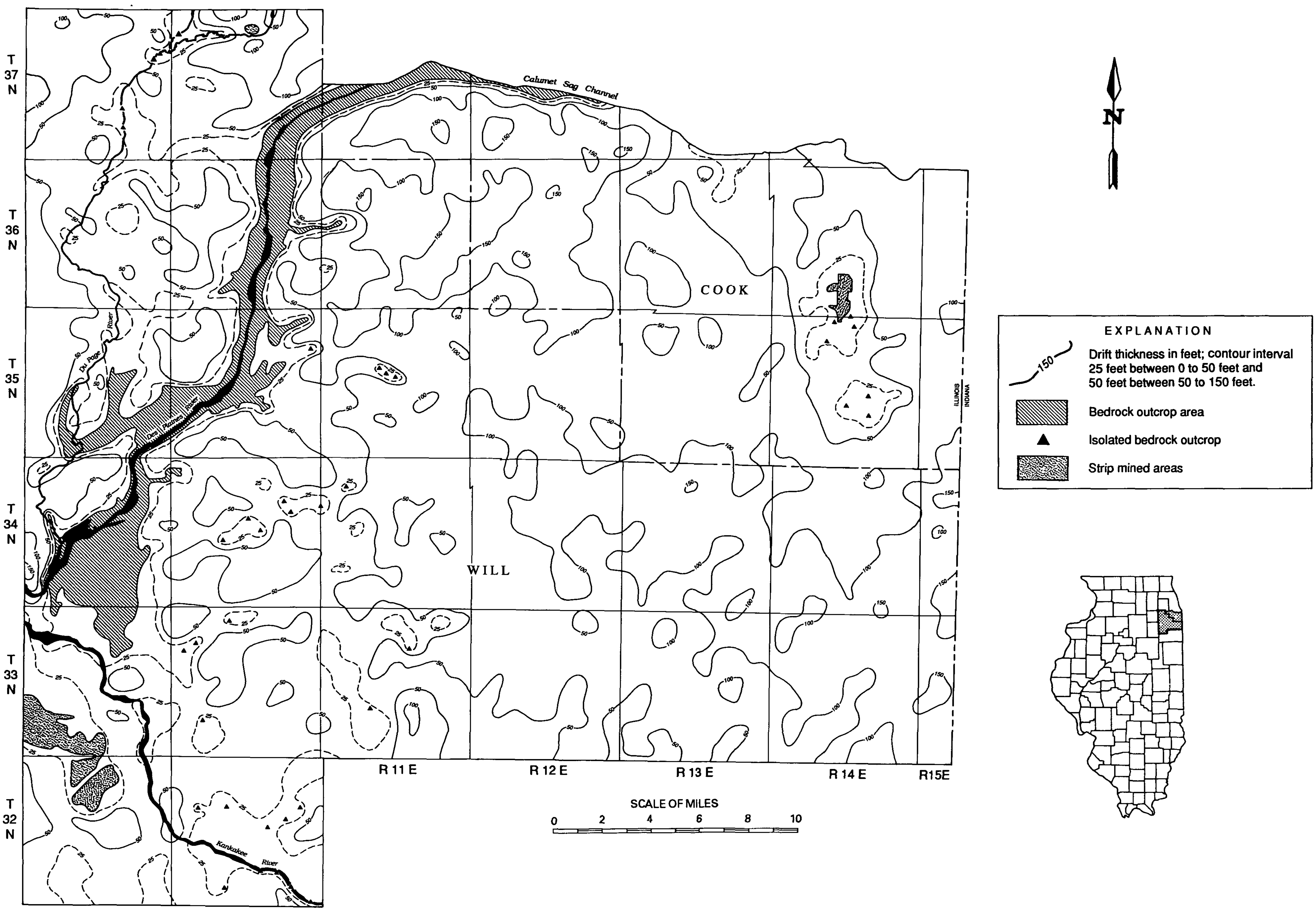


Plate III. Thickness of the glacial drift in the study area.
Bedrock outcrop information after Piskin et al. (1975) and Berg and Kempton (1988).

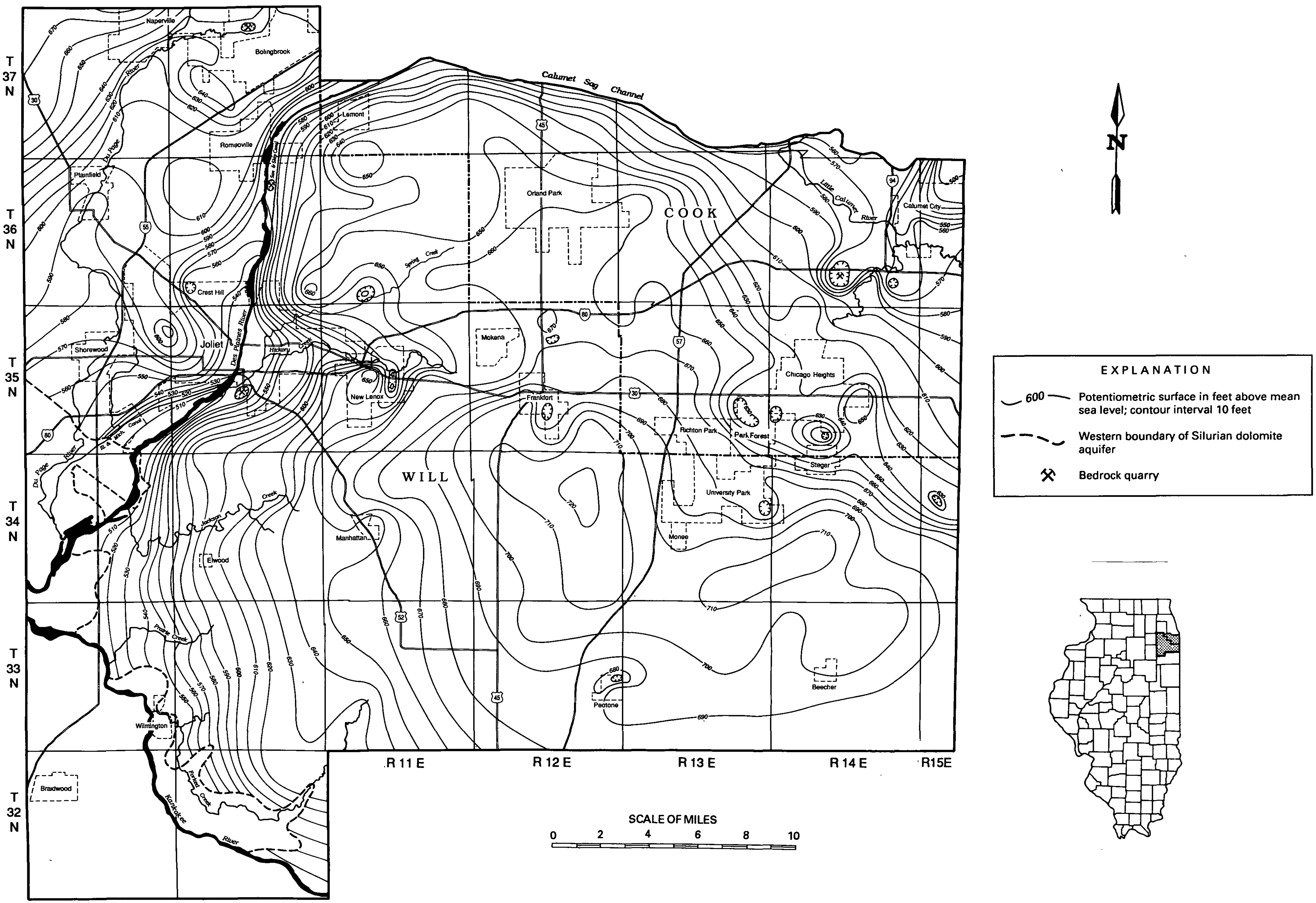


Plate IV. Potentiometric surface of the Silurian dolomite aquifer in the study area, September 1990