GEOLOGY, HYDROLOGY, AND WATER QUALITY
OF THE CAMBRIAN AND ORDOVICIAN SYSTEMS
IN NORTHERN ILLINOIS

Adrian P. Visocky, Marvin G. Sherrill, and Keros Cartwright

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ABSTRACT

Cambrian and Ordovician strata provide much of the groundwater supply for approximately 250 municipalities and 150 industries in the northern half of Illinois. This report represents the cooperative effort of the Illinois State Water Survey, Illinois State Geological Survey, and U.S. Geological Survey to provide a current hydrogeologic evaluation of this water resource.

The Cambrian and Ordovician aquifers average approximately 1000 feet in thickness. Although numerous alternating layers of sandstones, limestone, and dolomites impart a heterogeneous character to them, these units are hydraulically interconnected and behave as a single aquifer. Hydraulic properties within the aquifers are generally affected by local or regional changes in thickness of the Ancell and Ironton-Galesville aquifers. Recharge occurs principally by vertical percolation of precipitation in areas where the Galena-Platteville Unit is the uppermost bedrock. Additional recharge in heavily pumped areas occurs through leakage across the Maquoketa Confining Unit.

This report introduces formal hydrostratigraphic names in describing major aquifers as divided into three aquisystems, each of which is subdivided into aquigroups. The three aquisystems and their aquigroups are: 1) Non-Indurated Rock Aquisystem, consisting of the Prairie Aquigroup - local and intermediate flow systems in alluvium, glacial drift, and Cretaceous and Tertiary sediments; 2) Indurated Rock Aquisystem, divided into a) Upper Bedrock Aquigroup - local and intermediate flow systems with connection to the Prairie Aquigroup, b) Mississippi Valley Bedrock Aquigroup - intermediate and regional flow systems in indurated rock that are always confined by indurated rock aquitards and whose base is the top of the Maquoketa Shale Group, c) Midwest Bedrock Aquigroup - intermediate and regional flow systems whose top is the top of the Maquoketa Shale Group or other confining units and whose bottom is at the top of the Eau Claire Formation or stratigraphically higher, and d) Basal Bedrock Aquigroup - intermediate and regional flow systems below the shale units of the Eau Claire Formation and above the crystalline basement rocks; and 3) Crystalline Rock Aquisystem, in which there are no significant aquifers in Illinois. The Midwest Bedrock Aquigroup
is basically the same as the "Cambrian-Ordovician Aquifer" in northeastern Illinois that has been previously described. It is the chief topic of concern in this report.

The practical sustained yield of the Midwest Bedrock Aquigroup was estimated to be 65 mgd (million gallons per day) in northeastern Illinois. Pumpage has exceeded this amount since about 1958. In north-central and northwestern Illinois, development has not exceeded the practical sustained yield, which is probably at least as great as that for northeastern Illinois. The practical sustained yield in western Illinois is limited by the amount of lateral inflow that can be induced and also by poor water quality.

Individual wells in the Midwest Bedrock Aquigroup in northern Illinois usually exceed 500 gpm (gallons per minute) in yield, but in western Illinois typical well yields are smaller. Total withdrawals from deep wells between 1971 and 1980 averaged 278.6 mgd. The largest withdrawals occur in Cook, DuPage, Kane, and Will Counties. Withdrawals have caused water levels to decline as much as 900 feet in parts of Cook, DuPage, and Will Counties. Dewatering of the upper aquifers in the Midwest Bedrock Aquigroup has begun in portions of the above four counties.

Groundwater in the "unconfined" area of the Midwest Bedrock Aquigroup is chemically homogeneous and low in total dissolved solids. However, significant vertical and areal changes in the chemical character of groundwater occur in the confined area. As water moves away from the recharge area to the east and south, it increases in total dissolved solids.
INTRODUCTION

Physical Setting

The Cambrian and Ordovician aquifers described in this report underlie most of the northern half of Illinois (fig. 1). The land surface configuration of most of this part of the state is the result of glaciation, and the physiographic features shown on figure 2 largely reflect this glaciation.

The study area is essentially a broad prairie plain, with the exception of the Rock River Hill Country and the Wisconsin Driftless Section in the northwest corner of the state (fig. 2). The soils are largely deep, black, and rich in organic content and lime, have good moisture-retaining capabilities, and form part of one of the richest agricultural belts in the world.

Relief in the study area ranges from a high of 1235 feet above sea level at Charles Mound in the northwest corner of the state (Jo Daviess County) to about 580 feet above sea level at Lake Michigan and about 420 feet above sea level at the juncture of the Illinois and Mississippi Rivers near Grafton (Jersey County). The greatest differences in local relief are near major valleys, particularly in the uplands of the northwest.

The climate in northern Illinois is continental, with warm summers and cold winters (fig. 3). The mean January temperatures range from about 20°F in the northwestern tip of the state (Jo Daviess County) to about 32°F near the confluence of the Illinois and Mississippi Rivers. Mean temperatures in July range from about 74°F to 80°F for the entire area. The length of the growing season for most of the area is in the 160- to 180-day range.

Average annual precipitation, like temperature, generally increases from north to south (fig. 4). The range of precipitation is from about 32 inches per year near Lake Michigan to about 38 inches per year in the southern part of the study area. February is normally the driest month, and June is the wettest.

A drainage map of Illinois is shown in figure 5. The major drainage ways are the Mississippi River and its tributaries along the western border of the study area, and the Illinois River and its tributaries in most of the central and eastern parts of the study area. In northeastern Illinois water
Figure 1. Location of study area
Figure 2. Physiographic divisions in Illinois
Figure 3. Mean January and July temperature for Illinois
Figure 4. Average annual Illinois precipitation, in inches, derived from 1901-1944 data
Figure 5. Drainage map of Illinois
drains into Lake Michigan; the drainage divide is only a few miles from the lake, so this drainage basin in Illinois is relatively small.

**Purpose and Scope**

Cambrian and Ordovician strata include many of the freshwater-bearing rocks in northern Illinois, and many cities, villages, industries, and individuals are dependent on these aquifers. Protection and management of this important groundwater resource is a major concern of state and local planning and management agencies, as well as water regulatory groups. Management decisions need to be based on a fundamental understanding of the aquifer system. The geologic, hydrologic, and chemical characteristics of the system need to be understood, as do the effects of past, present, and future pumpage.

This report represents the cooperative efforts of the U.S. Geological Survey, Illinois State Water Survey, and Illinois State Geological Survey to provide a current hydrogeologic evaluation of the Cambrian and Ordovician units in Illinois. The report presents information on the geology, hydrology, and water quality of the Cambrian and Ordovician units, and includes a history of groundwater development. Basic data are presented as maps, graphs, and tables to help those who formulate policy on water resource planning and development.

The investigation began in 1978 and has been conducted concurrently with the Northern Midwest Regional Aquifer System Analysis (RASA) study in Illinois and the nearby states of Wisconsin, Minnesota, Iowa, Missouri, and Indiana.

**Methodology**

The study utilized previously collected and reported data as well as data collected as a direct result of this investigation. Appendix A is a compilation of geologic, hydrologic, and water quality data for selected or key wells used during the course of this investigation. A description of the well numbering and location system is included. Although this appendix summarizes only a small part of the total data used in the study, it does show representative conditions on a county-by-county basis.

Much of the previously collected data used in this study is in the files of the Illinois State Geological Survey (ISGS) or the Illinois State Water
Survey (ISWS) or is contained in reports by these two agencies. Well drillers' logs and sample cutting analyses were obtained from the ISGS files and evaluated by ISGS and U.S. Geological Survey (USGS) personnel. Logs were utilized to determine stratigraphic contacts from which structural contour and isopach geologic maps were prepared or updated. Hydraulic data from ISWS files were summarized and evaluated, and interpretive maps and tables were prepared. Much of the data concerning water quality analyses, pumpage, and water level information also came from ISWS files or from published reports.

Considerable new data were collected during the course of this investigation. The most notable effort was the drilling, sampling, and testing of a 3460-foot well extending into Precambrian bedrock at Illinois Beach State Park, Lake County, in the extreme northeast corner of Illinois (Nicholas et al., 1984). This test well provided much insight into the geologic, hydrologic, and water quality properties of the aquifers, particularly the deeper Cambrian units, and the depth to and character of the Precambrian basement rock in an area which had not been explored. Select zones in the test well -- including the Galena-Platteville, St. Peter, Ironton-Galesville, and Mt. Simon units -- were tested (with packers used to seal off the selected zones) to provide information on hydraulic and water quality properties of individual units. A suite of geophysical borehole logs were run in the well. Similar packer-testing and logging were conducted at two deep wells in Rockford and Galena. Additionally, several other wells were logged to provide information on well construction design, physical properties of the rock units, and hydraulic characteristics of the aquifers. The logging and packer-testing are summarized in appendix B.

A water level and pumpage survey for the Cambrian and Ordovician aquifers was conducted during the fall of 1980 by ISWS personnel. These data, along with previously collected data, were used in preparing major sections of the report.

Groundwater samples from several wells drawing water from a single aquifer were collected and analyzed. These analyses, plus those obtained from the packer-testing and from other previously sampled wells, provided water quality information summarized on the interpretive maps and in the text of the "Groundwater Quality" section of this report. Representative water quality analyses are shown in appendix C.
Previous Reports and Related Work

The geology and water resources of the Cambrian and Ordovician rocks in northern Illinois (particularly in the Chicago metropolitan area) have been studied in some detail, and several reports have been published that have major sections concerning these rocks. A general discussion was presented by the Illinois Department for Business and Economic Development (Water for Illinois, A Plan for Action, 1967). Horberg (1950) reported on the bedrock topography; stratigraphic features are discussed in detail in the Handbook of Illinois Stratigraphy by Willman et al. (1975). Buschbach (1964) and Willman (1971) discuss the Cambrian and Ordovician strata in northeastern Illinois. Buschbach (1965) also discusses these strata in western Illinois. The Galena and Platteville strata have been reported on by Bristol and Buschbach (1973) and by Willman and Kolata (1978). Emrich (1966) reports on the Ironton and Galesville strata in Illinois and adjacent states.

Groundwater conditions in northeast Illinois are described by Bergstrom et al. (1955); Suter et al. (1959); Hughes and Kraatz (1966); Schicht and Moench (1971); ISWS and Hittman Associates (1973); Schicht and Adams (1977); and Schicht, Adams, and Stall (1976). Hackett and Bergstrom (1956) and Brueckmann and Bergstrom (1968) describe groundwater conditions in northwestern Illinois. Well yields and aquifer conditions are discussed by Walton (1960) and by Walton and Csallany (1962).

Public water supplies and water quality are described by Hanson (1950, 1958, 1961); by Woller et al. (1973-present); by Larson (1963); and by Visocky et al. (1978).

Water use, pumpage, and water level conditions have been described by Walton, Sasman, and Russell (1960); Sasman, Prickett, and Russell (1961); Sasman, Baker, and Patzer (1962); Russell (1963); Walton (1964); Sasman (1965); Sasman and Baker (1966); Sasman, McDonald, and Randall (1967); Sasman, Benson, Dzurisin, and Risk (1973, 1974); Sasman et al. (1977, 1982); and Kirk et al. (1979, 1982).

Water management studies have been described by the Northeastern Illinois Planning Commission (1966, 1974, 1976); Moench and Visocky (1971); Schicht, Adams, and Stall (1976); Keifer and Associates (1977a,b); Singh and Adams (1980); and Visocky (1982).
Steinhilber and Young (1979) presented a plan for a regional study of the Cambrian and Ordovician units. Kontis and Mandle (1980) developed a database for this same regional study.

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This investigation was supported in part by funds provided through the University of Illinois by the U.S. Geological Survey, Water Resources Division. Many people in addition to the principal authors were involved in the preparation of this report. Much of the basic geologic data was assembled and evaluated by Susan S. Wickham, Heidi O. Minc, and Robert W. Ringler of the Illinois State Geological Survey. Robert W. Gilkeson of ISGS provided data and consultation concerning the geochemistry of the Cambrian and Ordovician aquifers. Robert T. Sasman and his staff from the Northern Regional Office of the Illinois State Water Survey were very helpful in furnishing water level and pumpage data.

Dean M. Mades and James R. Nicholas of the U.S. Geological Survey prepared major portions of the sections on pumpage and groundwater quality, respectively. They were also much involved in the data collection phases of the project, including the test drilling, borehole logging, packer work, and water quality sampling.

USGS staff who are working on the Northern Midwest Regional Aquifer System Analysis (RASA) study in Wisconsin, Iowa, Indiana, and Missouri, as well as personnel of state agencies in these surrounding states, cooperated in developing "best fit" interpretations along state lines. Helpful suggestions and criticisms were given by many other individuals from USGS, ISGS, and ISWS.

Roger Selburg of the Permit Section, Public Water Supply Division, Illinois Environmental Protection Agency, and Robert Grosso, Park Superintendent of Illinois Beach State Park, were particularly cooperative during this investigation. Many municipal and industry officials, engineers, and water well contractors generously provided geologic, hydrologic, and Water quality data.

Illustrations were prepared by William Motherway, Jr., Linda J. Riggin, and Vicki S. Stewart under the supervision of John W. Brother, Jr. Pamela S. Lovett typed the manuscript and final copy, and Gail Taylor edited the manuscript.
GEOLOGY

Introduction

A set of 15 maps of the thickness and surface configuration of the bedrock units of the northern half of Illinois was prepared. The stratigraphic correlation was coordinated with the other states which are a part of the Northern Midwest Regional Aquifer System Analysis. Well records which provided the data base for the maps were selected on the basis of 1) spacing of at least one well per township; 2) wells penetrating at least the Galena Group and, if possible, into the Ancell Group or Cambrian System; and 3) wells with samples or geophysical logs. In areas of dense well control, key wells were designated by the following criteria:

1) The deepest wells possible
2) Wells with existing samples of well cuttings or geophysical logs which could be studied
3) The most recently drilled wells
4) Wells with previous studies of well cuttings

The maps were then compared to maps from the adjacent states to insure that transitions were smooth across state lines. Both published and unpublished maps from Iowa, Missouri, Wisconsin, and Indiana were used to make final adjustments along state lines.

All new data points selected for this study were field checked for location and elevation and are considered accurate. Points used from previous studies were checked in the office but were not field verified. Any seemingly anomalous points were double checked.

The maps of the Maquoketa and Galena surfaces are considered to be the most accurate, since more data were available for them. The accuracy of the maps diminishes as the Precambrian is approached, since fewer and fewer data points are available for the map preparation.

Precambrian Surface

The map of the top of the Precambrian surface (fig. 6) is based on the 21 control points from wells within Illinois; data from wells in the bordering states of Iowa, Indiana, and Wisconsin; and interpretation of known structural elements present within the state. The new map shows considerable refinement from the map by Bell et al. (1964).
Figure 6. Elevation (MSL) of the top of the Precambrian rocks
Local relief of about 800 feet on the Precambrian surface is shown by comparison of two granite test wells 8 miles apart in Pike County in western Illinois. One well penetrated 440 feet of Eau Claire Formation and 444 feet of Mt. Simon Sandstone before encountering the basement at 2488 feet below mean sea level. The second well encountered only 74 feet of Eau Claire and no Mt. Simon before encountering basement rocks at 1409 feet below mean sea level. The rugged topography of the top of the Precambrian is also revealed by outcrops in the St. Francois Mountains of Missouri. Relief away from these localities, of course, is uncertain; buried Precambrian hills may underlie some of the structural highs in overlying strata.

The Precambrian rocks in Illinois apparently do not have a zone of deep weathering. Most wells encounter fresh-looking igneous rock. Also, the feldspar grains in the arkose that commonly overlies the Precambrian have a fresh appearance. Thus, any weathered material that developed on the basement rocks in Illinois was apparently removed by erosion before deposition of the Paleozoic sediments.

The basement rocks encountered in borings in and immediately adjacent to Illinois are of granitic or closely related composition. Granite, encountered in 17 of the 22 Illinois wells and in the three Iowa wells, is by far the most common rock type. Granodiorite, the next most abundant type, was encountered in four wells, all in northern Illinois. Rhyolite and granophyre were encountered in wells in south-central and southern Illinois. Bradbury and Atherton (1965) describe the petrography of the Precambrian rocks penetrated by wells in Illinois.

Cambrian and Ordovician Systems

The Cambrian and Ordovician rocks can be grouped into seven units that have hydrogeologic significance. These units are: 1) the Mt. Simon Sandstone and the Elmhurst Sandstone Member of the Eau Claire Formation; 2) Proviso and Lombard Members of the Eau Claire Formation that form a major confining unit; 3) the Ironton and Galesville Sandstones; 4) Middle Confining Unit, consisting of the units between the top of the Ironton and Galesville Sandstones and the base of the Ancell Group (St. Peter Sandstone), which include the Cambrian Franconia Formation, Eminence Formation, and Potosi Dolomite, and the Ordovician Prairie du Chien Group; 5) the Ancell Group;
6) the Ottawa Limestone Megagroup, consisting of the Galena and Platteville Groups; and 7) the Maquoketa Shale Group. A discussion of these units follows.

Elmhurst-Mt. Simon Sandstone

The Mt. Simon Sandstone, although not exposed, underlies all of Illinois except in local areas where it failed to cover hills on the eroded Precambrian surface. It ranges in thickness from less than 500 feet in the southwest part of the study area to over 2600 feet in northeastern Illinois in Kendall, Grundy, eastern LaSalle, northeastern Livingston, western Kankakee, and northern Ford and Iroquois Counties (fig. 7). In general, the Mt. Simon consists of fine- to coarse-grained, partly pebbly, friable sandstone, most of which is coarser-grained, more angular, and more poorly sorted than younger Cambrian and Ordovician sandstones. It is dominantly white, but can be pink, red, yellow, or light greenish-gray. A basal zone as much as 350 feet thick is strongly arkosic, and beds of red and green micaceous shale occur locally in the upper 300 feet and lower 600 feet of the formation (Buschbach, 1975).

In the Rock Island region of western Illinois, the Mt. Simon is fine- to coarse-grained, poorly sorted, and generally friable, with some more compact zones which are cemented by silica or hematite. It is essentially non-dolomitic. The upper half contains interbedded red shale, and the lower half is pink and arkosic, with the amount of feldspar increasing downward (Buschbach, 1965).

In the vicinity of DeKalb County, the Mt. Simon contains zones of Well-developed cross-bedding in the coarser beds. Beds of red, green, and dark gray shale occur in the upper few hundred feet (Buschbach, 1970).

In the Chicago region, the sandstone is largely medium-grained, but some coarse-grained beds occur, especially in the upper part of the formation. The coarser beds are more abundant to the north, and granules up to 6 mm in diameter are common. The color may be pink, yellow, or white. Red, micaceous, hematitic beds also occur at some places in the northern counties. The sands are generally incoherent to friable and may be arkosic in places (Buschbach, 1964; Suter et al., 1959).

Near the Wisconsin border, the basal sand includes the basal member of the Eau Claire Formation, the Elmhurst Sandstone. The Elmhurst Sandstone is
Figure 7. Thickness of the Elmhurst–Mt. Simon Sandstone
widely distributed in the northern half of Illinois and is 10 to 200 feet thick. Most of it is fine- to medium-grained, fossiliferous gray sandstone that contains various amounts of gray shale. Near the Wisconsin border, the amount of shale greatly diminishes and the Elmhurst becomes a fairly Clean sandstone (Willman et al., 1975).

The map of the surface configuration of the combined sandstones (fig. 8) was compiled mainly by using projected points from overlying units. Only 122 wells which penetrated the top of the sand were available for compilation of the map. Therefore, the accuracy of this map is limited, especially with regard to the northernmost part of the area, where the overlying confining unit contains interbedded sandstones.

The map of the thickness of the combined units (fig. 7) is based on even more limited data; only 38 wells with reliable data were available for this map. Much of this map was constructed by interpolation between the Precambrian surface map (fig. 6) and the sandstone surface map (fig. 8). The sandstone is thickest in the eastern part of the study area and thins to the west and south.

**Lombard and Proviso Members of Eau Claire Formation**

*Basal Sandstone Confining Unit*

The Basal Sandstone Confining Unit consists of dolomite and dolomitic sandstone, siltstone, and shale of the upper two members (Lombard and Proviso) of the Eau Claire Formation. The confining unit overlies the relatively clean Mt. Simon and Elmhurst Sandstones, and underlies the clean Galesville Sandstone. The different lithologies grade laterally from one to another within short distances. In northern and western Illinois, the Eau Claire becomes predominantly a dolomitic, fine- to medium-grained, gray sandstone, but it includes shaly siltstone and silty, sandy, glauconitic, brownish-gray dolomite. The siltstone is grayish-orange, micaceous, and compact; and the shale, which is most abundant near the middle of the formation, is silty, green to red, micaceous, and brittle. The Eau Claire thickens and becomes more shaly to the southeast.

In central and eastern Illinois the Eau Claire is dominantly dolomitic, orange to pinkish-gray siltstone and green, gray or red shale; but it also includes light gray, glauconitic, partly oolitic limestone and dolomite (Willman et al., 1975). In the DeKalb area, the Eau Claire consists of light-gray, fine-grained sandstone, siltstone, shale, and dolomite. It
Figure 8. Elevation (MSL) of the top of the Elmhurst-Mt. Simon Sandstone
becomes sandier to the north, more shaly to the southeast, and more dolomitic to the southwest (Buschbach, 1970). Glauconite is abundant, especially in the Lombard Member.

In the Chicago region, the Lombard and Proviso Members are dolomitic, micaceous, fine- to medium-grained, compact sandstone with variable amounts of green to gray, sandy shale and siltstone and sandy brown dolomite. Cemented sandstone predominates in the Lombard member, and glauconite is common throughout the formation.

The thickness of the confining unit varies from less than 200 feet to 600 feet. The Eau Claire is much sandier in extreme northern Illinois, with finer grained sediments that are generally thinner; therefore, the basal sand confining unit is considerably thinner (fig. 9). Throughout the rest of the study area, the Eau Claire is a fairly uniform 200 to 400 feet thick, except for small areas in the southeastern and south-central parts of the study area, where the maximum thickness is over 600 feet.

The surface of the Eau Claire Formation dips to the southeast at about 11 feet per mile and reflects the general structural trend of the Illinois Basin and its surrounding positive features (fig. 10). The structurally highest part of the formation is north of the Plum River Fault Zone on the southern flank of the Wisconsin Arch. The Mississippi River Arch on the west is another positive structural element. The surface generally becomes lower to the south and southeast toward the deeper part of the basin. The major exception to this general trend is the structural high along the LaSalle Anticlinal Belt. This anticlinal belt is reflected as a structural high, trending southeastward through LaSalle, Livingston, and Ford Counties. The asymmetry of the belt is shown by the structural contours on the steep eastern flank and the much gentler western slope.

About 210 wells were available for development of figure 10, the surface of the Eau Claire Formation (the Basal Sandstone Confining Unit). Additional interpretation was possible by projecting down from the surface of the Ironton and Galesville Formations. Possible errors of a few feet up to a few hundred feet may exist on this map over short distances. The error increases where a facies change occurs from shale and dolomite to sandstone in northern Illinois; however, farther south the accuracy increases. Differentiation between the basal sandstone and the confining unit was based on the presence of significant shale content.
Figure 9. Thickness of the Basal Sandstone Confining Unit
Figure 10. Elevation (MSL) of the top of the Basal Sandstone Confining Unit
The thickness of the Basal Sandstone Confining Unit was derived from 116 data points, limiting the accuracy of this map. A few areas may exist where Precambrian hills are present and where units either were never deposited or were eroded.

**Ironton and Galesville Sandstones**

The Ironton and Galesville Sandstones are thick and form an important source of groundwater in northern Illinois. The sandstones are separated mainly on the basis of texture and dolomite content. The Galesville Sandstone (Willman et al., 1975) is fine-grained, well-sorted sandstone, essentially free from shale and glauconite, whereas the Ironton is medium-grained, generally poorly-sorted, dolomitic sandstone. The Galesville occurs throughout the northern half of Illinois but is not exposed. It is commonly 40 to 100 feet thick. At its southern margin, the Galesville grades laterally through a 50-mile-wide zone from dolomitic sandstone to a non-sandy dolomite. The name Galesville is applied as far south as the sandy zone can be identified. The Galesville Sandstone consists of white to light buff, clean to locally silty, fine-grained, moderately well-sorted, friable, and generally non-dolomitic sandstone (Buschbach, 1964). Locally, light buff to pink dolomite is a cementing material. The Galesville appears to be conformable with both the overlying and underlying formations.

The Ironton Sandstone is a relatively coarse-grained sandstone overlying the finer-grained Galesville Sandstone and underlying the glauconitic, argillaceous sandstone of the Franconia Formation. It occurs throughout the northern half of Illinois but is not exposed. The Ironton is commonly 50 to 100 feet thick, but it is thinner in northwestern Illinois. Near the Wisconsin boundary, it is a medium-grained, poorly sorted, white sandstone with coarse-grained beds near the top. It generally contains light pinkish-buff dolomite as cementing material and as pebbles in conglomeratic layers. Farther south it is more dolomitic and at its southern margin it grades into sandy dolomite.

The carbonate content (all dolomite) of the Ironton and Galesville Formations ranges from zero to over 80%. In northern Illinois, the amount of dolomite increases gradually southward to the area of maximum thickness. The increase is primarily in the Ironton, except in the southern part, where the basal beds of the Galesville are also dolomitic. South of the area of
maximum thickness, the dolomite content of both formations increases rapidly to a maximum at the southern limit of the formations. In eastern Illinois and Indiana, the dolomite content is much higher than in western Illinois and Iowa. Dolomite both cements sandstone and forms discrete beds in north, east, and east-central Illinois.

In the Chicago area and southward, lenses of fine to very finely crystalline, dark brown dolomite with minor amounts of very fine-grained sandstone are present at the base of the Galesville Sandstone. These coalesce to form one continuous unit with a maximum thickness of 50 feet in east-central Illinois.

Over 250 data points were used to compile the Ironton-Galesville thickness map (fig. 11). The Ironton-Galesville maintains a fairly uniform combined thickness of 150 to 200 feet over most of the study area. It ranges from a feather edge in the extreme southwest part to over 250 feet southwest of Chicago in southeastern Grundy County. The formation thins over the Wisconsin Arch, indicating that the arch actively influenced sedimentation during deposition of the Ironton and Galesville sands. During Ironton time, the inland sea over the Illinois Basin reached its farthest northward transgression (Emrich, 1966).

Over 280 wells were available to compile the map of the surface of the Ironton Formation (fig. 12). Additional points were also projected down from the Ancell Group surface. However, these data points were not sufficient to establish a 100-foot contour interval. The greatest accuracy exists in the northern part of the study area.

**Knox Megagroup (Middle Confining Unit)**

The dolomitic part of the Knox Megagroup (Swann and Willman, 1961) includes the strata between the base of the St. Peter Sandstone and the top of the Ironton Sandstone. It underlies all of Illinois except small areas in northern Illinois where an unconformity cuts entirely through the dolomitic formations and the St. Peter Sandstone rests on the Franconia Formation or, locally, on the Ironton Sandstone. Although dominantly dolomitic in the northern part of the state, the megagroup contains some relatively thin sandstones--the New Richmond and Gunter Sandstones, the Momence Sandstone Member of the Eminence Formation, the Jordan Sandstone, and numerous thin beds in the Shakopee Dolomite. The sandstones generally thin southward and
Figure 11. Thickness of the Ironton and Galesville Formations
Figure 12. Elevation (MSL) of the top of the Ironton Formation
disappear near the middle of the state. The megagroup itself thickens from 300 to 500 feet in much of northern Illinois (fig. 13) to over 6000 feet in extreme southern Illinois. The southward thickening of the Knox in the study area is related to northward truncation of the upper part of the Shakopee Dolomite. In addition, the Franconia Formation and the Ironton and Galesville Sandstones grade southward into dolomite, resulting in repeated lowering of the base of the Knox until it reaches the top of the Mt. Simon Sandstone.

Over 280 wells were available to compile the thickness map of the geologic units between the base of the Ancell and the top of the Ironton (fig. 13). The rock interval between the Ancell and Ironton aquifers is mainly a confining unit except for a few small aquifers, such as the Jordan Sandstone. In many cases these sandstones are absent; therefore, they are more a local than a regional source of water. Many of the wells do not penetrate the entire thickness of the confining unit, so some of the contours are estimated from the available data.

In northern Illinois the units between the top of the Ironton Sandstone and the base of the Ancell Group consist of the Cambrian Franconia Formation, Potosi Dolomite, Eminence Formation, and Jordan Sandstone, and the Ordovician Prairie du Chien Group.

**Franconia Formation.** The Franconia Formation consists of glauconitic, argillaceous sandstone and dolomite underlying the Potosi Dolomite. It underlies all of Illinois and thickens southward from about 50 feet near the northern border of Illinois to about 500 feet in the southern part of the state. In extreme northern Illinois, the Franconia consists largely of gray to pink, glauconitic, silty, argillaceous, fine-grained, dolomitic sandstone that contains various amounts of red and green shale. Southward from that area the lowermost part of the Franconia becomes increasingly shaly (Davis Member) and the uppermost part grades to silty and sandy dolomite (Derby-Doerun Member). In north-central Illinois these two units are separated by a wedge of fine-grained, dolomitic sandstone similar to that which composes the entire Franconia of extreme northern Illinois. In the central part of the state, the glauconitic sandstone is absent, and the silty, shaly sandstone of the Davis is overlain by the relatively pure dolomite of the Derby-Doerun. In Illinois, the Franconia is comformable with overlying formations.
Figure 13. Thickness of units between the base of the Ancell Group and the surface (top) of the Ironton Formation
**Potosi Dolomite.** The Potosi Dolomite is a relatively pure dolomite overlying the Franconia Formation and underlying the Eminence Formation. The Potosi underlies essentially all of Illinois except in parts of northern Illinois where it is truncated by pre-St. Peter erosion. It consists of finely crystalline, pure to slightly argillaceous, brown to pinkish-gray dolomite that is very slightly glauconitic at the top and glauconitic and sandy at the base. Drusy quartz covers the surfaces of small cavities in most areas and characterizes the formation in both outcrop and well samples. In wide areas of northern Illinois, it is unconformably overlain by the St. Peter, but it is otherwise conformable with the Franconia below and the Eminence above.

**Eminence Formation.** The Eminence Formation is a sandy dolomite overlying the Potosi Formation. It underlies most of Illinois except in the northern part where it is truncated by the unconformity at the base of the St. Peter Sandstone. The Eminence is normally 50 to 250 feet thick where it is overlain by the Gunter Sandstone or Oneota Dolomite of the Prairie du Chien Group. It consists of light gray to brown or pink, sandy, fine- to medium-grained dolomite that contains oolitic chert and thin sandstone strata. The formation is generally conformable with overlying units, and in extreme northwestern Illinois it grades laterally into the Jordan Sandstone.

**Jordan Sandstone.** The Jordan Sandstone is the uppermost Cambrian formation in the extreme northwestern part of Illinois. In Jo Daviess and Carroll Counties it is a few to 75 feet thick, and in Iowa it becomes an important aquifer. The formation is a white to yellowish-gray, partly iron stained sandstone that is medium- to fine-grained at its base. In some places the upper part is coarse to very coarse-grained. It varies from thin- to thick-bedded, and cross-bedding is common.

**Prairie du Chien Group.** The Prairie du Chien Group, the youngest unit of the Knox Megagroup, is present throughout much of Illinois. However, it is almost entirely absent in the northern two tiers of counties and is missing locally in the rest of the northern third of the state. It is also absent in areas where Cambrian rocks crop out near the Sandwich Fault Zone and structural highs. The group thickens southward, chiefly by the addition
of younger beds at the top. The group consists of cherty dolomite with some interbedded sandstone. It is subdivided into the Gunter Sandstone (basal), the Oneota Dolomite, the New Richmond Sandstone, and the Shakopee Dolomite.

**Ancell Group**

The Ancell Group (Templeton and Willman, 1963) is a predominantly elastic unit consisting of sandstone and argillaceous and sandy limestone and dolomite formations. It overlies the Prairie du Chien Group and older rocks and underlies the Platteville Group in northern Illinois (Willman et al., 1975). The Ancell is separated from the Platteville Group by a widespread unconformity of low relief, which is a useful structural horizon and can be recognized easily (Kolata et al., 1978). Ancell strata underlie most of the study area in northern Illinois and range in thickness from 100 to about 600 feet (fig. 14). The St. Peter Sandstone is the basal formation in the Group.

North of a line running diagonally across the center of the state from Chicago to Quincy, the St. Peter is overlain by members of the Glenwood Formation. The members have a facies relation with the upper part (Starved Rock Member) of the St. Peter Sandstone. The Joachim Dolomite has a similar facies relationship to the St. Peter south of the line.

The Ancell Group has a fairly smooth upper surface, and therefore the mapping of it is considered quite accurate, except where data are sparse (fig. 15). Over 515 wells were used to compile this map; most of the data points are concentrated in northeastern Illinois. South and west of the Sandwich Fault Zone the available data are more sparse, and contours are less accurate. Points were also projected down from the Galena surface by subtracting the Galena-Platteville thickness from the elevation of the Galena surface.

The Ancell thickness (fig. 14) is highly variable because the base of the Ancell rests on an eroded surface. In the northern portion of the state, the base is extremely irregular and truncates several formations. The thickness may vary from just a few feet to 200 feet over short distances. About 415 wells were used to make the Ancell thickness map.

About 340 wells were available to make the map of the base of the Ancell Group (fig. 16). Because of the irregularity of the underlying surface, it was difficult to determine the topography of the surface, and much of the map is interpretative.
Figure 14. Thickness of the Ancell Group
Figure 15. Elevation (MSL) of the top of the Ancell Group
Figure 16. Elevation (MSL) of the base of the Ancell Group
**St. Peter Sandstone.** The St. Peter Sandstone is restricted to the relatively pure sandstone present in most of Illinois below the Platteville Group carbonates and the Glenwood Formation elastics and overlying the carbonates of the Knox Megagroup. Because of a major unconformity at its base, the St. Peter truncates formations as old as the Franconia Formation (Templeton and Willman, 1963; Buschbach, 1964).

The St. Peter is composed mainly of quartz sand that is normally pure and very fine- to coarse-grained. It is chiefly fine- to medium-grained, very well sorted, friable, and thick to very thick-bedded, with cross-bedding common locally (Templeton and Willman, 1963; Buschbach, 1964). Its color is normally white, but it may be pink, buff, or reddish brown. Most sand grains are well rounded and frosted; the degree of rounding and frosting decreases with decreasing grain size so that very fine grains are generally angular and clear. The St. Peter commonly contains less than 2% silt and 1 to 3% disseminated clay, but it is locally very silty in western Illinois. Its heavy mineral suite is limited to the highly resistant minerals, tourmaline and zircon.

The St. Peter fills irregularities on a complex surface which includes both karst and erosional features. Where the sandstone is abnormally thick, the underlying carbonates are reciprocally thinned (Buschbach, 1961). The pattern of variation in thickness suggests deposition in previously eroded channels and adjacent uplands (Suter et al., 1959). The St. Peter is 100 to 200 feet thick over most of northern Illinois except in a band 40 to 50 miles wide north of the Sandwich Fault Zone, where thicknesses of 400 to 600 feet are encountered. Where abnormal thicknesses are found, the lower section (Kress Member) may consist of fine- to coarse-grained, pink to reddish-brown sandstone with varying amounts of shale, chert, and dolomite fragments (Suter et al., 1959).

From north-central Illinois to southeastern Missouri, the St. Peter consists of a lower, fine-grained unit, the Tonti Sandstone Member, and an upper, medium-grained unit, the Starved Rock Sandstone Member. The St. Peter sands were derived chiefly from erosion of pre-existing sandstones, of which the Cambrian Galesville Sandstone may be a chief source. From its area of maximum thickness in north-central Illinois, the Starved Rock Member grades northward into the Glenwood Formation and southward into the Joachim Dolomite.
Glenwood Formation. The Glenwood Formation, the upper part of the Ancell Group, is widely present in northern Illinois, with the same distribution as the St. Peter Sandstone. It underlies the Platteville Group, and is separated from it by a widespread and sharp unconformity of minor relief. The Glenwood is absent in some localities, especially near the Wisconsin state line (Willman et al., 1975). The formation is generally 25 to 50 feet thick and is characterized by abrupt and irregular variations in thickness. It is thickest along its southern margin just north of where it grades into the Starved Rock Member of the St. Peter Sandstone. Its maximum known thickness is 150 feet at Galesburg in Knox County.

The Glenwood is composed primarily of sandstone possessing a distinctive bimodal texture. Known as the Glenwood texture, it consists of medium to coarse, well-rounded quartz grains of the St. Peter type in a matrix of very fine sand and coarse silt. The sandstone is commonly dolomitic and has a high silt and clay content and abundant accessory garnets and other heavy minerals. The clay fraction contains illite and authigenic potassium feldspar. Fine-grained, impure dolomite and light green shale are found in the middle and upper portions of the formation. The northern distribution, variable lithology, and general absence of normal marine fauna suggest that the Glenwood sediments were derived from two different terrains and deposited in brackish, muddy water of a shallow marine basin (Templeton and Willman, 1963).

Ottawa Limestone Megagroup

The Ottawa Limestone Megagroup (Swann and Willman, 1961) consists of the dominantly carbonate rocks overlying the St. Peter Sandstone and underlying the dominantly elastic rocks of the Maquoketa Shale Group. In northern Illinois, it consists largely of the Galena and Platteville Groups, but locally it includes carbonate members of overlying and underlying formations. The Ottawa Megagroup underlies most of the state and thickens from about 300 feet in northern Illinois to 1300 feet in southern Illinois. In local areas where the St. Peter Sandstone is absent, the Ottawa Megagroup rests on the Knox Megagroup.

The Galena and Platteville Groups consist of a nearly continuous sequence of carbonate rocks that are generally 250 to 450 feet thick in northern and western Illinois, thickening southward into the Illinois Basin.
Over 470 data points were used to draw the Galena and Platteville thickness map. The map provides a fairly accurate portrayal of the Galena and Platteville thickness, except in the erosional areas where the thickness may vary greatly due to the topographic relief. These groups form the bedrock surface and are widely exposed in an area of about 2900 square miles (Willman and Kolata, 1978). Although largely dolomitic, both groups contain limestone in parts of the area. The carbonates are relatively pure and generally contain less than 10% impurities, mostly argillaceous material and chert. The siliceous detrital minerals are finely disseminated in the limestone and dolomite and consist largely of quartz in silt and sand-size grains and a variety of silicates, mostly clay minerals, feldspar, and heavy minerals.

**Platteville Group.** The Platteville Group (Templeton and Willman, 1963; Willman and Kolata, 1978) includes the dominantly limestone formations that overlie the Glenwood Formation of the Ancell Group and underlie the Spechts Ferry or Guttenberg Formations of the Galena Group. Across central Illinois it overlies the St. Peter Sandstone; farther south it overlies the Joachim Dolomite. The group is only about 30 to 45 feet thick in extreme western and northwestern Illinois, but it thickens to 135 feet in the Dixon area and southward to over 600 feet in the extreme southern part of the state (Willman et al., 1975).

In northern Illinois, the Platteville Group is largely blue-gray, lithographic, partly dolomite-mottled limestone, but in some areas it is gray, very fine-grained, cherty dolomite. It is divided into the Plattin Subgroup (stratigraphically above) which is dominated by the typical limestone facies, and the Pecatonica Formation, a persistent dolomite in the northern area.

**Galena Group.** The Galena Group (Templeton and Willman, 1963) consists of limestone and dolomite formations overlying the Platteville Group and underlying the Maquoketa Shale Group. The Galena Group is present in all of Illinois except in the areas where older rocks are exposed in central-northern Illinois, in Calhoun County, and in an area along the crest of the LaSalle Anticlinal Belt where the Galena strata were eroded before deposition of Pennsylvanian sediments. The Galena Group is 250 to 275 feet thick in the northern outcrop area, but the upper part is truncated by the Maquoketa Shale in central Illinois. The group is divided into two subgroups (Willman and
Figure 17. Thickness of the Galena and Platteville Groups
Kolata, 1978) -- the Decorah at the base is a shaly unit, and the Kimmswick above it is relatively pure limestone and dolomite.

A previously published structural contour map of the configuration of the surface of the Galena Group (Bristol and Buschbach, 1973) was used in this study. Some minor revisions have been made, especially near the borders of Illinois, to better match the maps of adjacent states (fig. 18). The map of the Galena surface probably is the most accurate of any in this report. It is an easily identified formation and has a uniform surface, and a large number of control wells were available.

Maquoketa Shale Group

The Maquoketa Shale Group is present throughout most of Illinois, except south of the Sandwich Fault Zone and in portions of northern and northwestern Illinois, where it has been removed by erosion. Unconformities separate it from the underlying Galena Group and the overlying Silurian dolomites and younger rocks. The sub-Silurian unconformity is erosional, and valleys up to 100 feet deep are cut into the top of the Maquoketa. In western Illinois, the sub-Kaskaskia unconformity at the base of the Middle Devonian rocks cuts through the Silurian System and into the Maquoketa. Farther west the Maquoketa is completely absent (Willman et al., 1975).

The Maquoketa Shale Group is normally about 200 feet thick in Illinois (fig. 19), with a maximum of 250 to 300 feet. The Maquoketa thickness map is quite accurate, with over 610 data points available. However, where the surface is eroded, the surfaces are not accurately portrayed, because the thickness in these areas may vary from a few feet to 200 feet within short distances.

There is an abundance of data for the map of the Maquoketa surface (fig. 20), with over 685 wells available. To provide the most nearly accurate portrayal of the Maquoketa surface in relation to its adjacent formations, additional points were projected by adding the Maquoketa thickness to the Galena-Platteville surface. The Maquoketa surface map is quite accurate except where pre-Silurian, pre-glacial, and modern erosion has occurred.

In most of Illinois, the Maquoketa consists of three formations: 1) the Scales Shale, a lower, dominantly shale unit; 2) the Fort Atkinson Limestone, a middle dolomite and/or limestone and shale; and 3) the Brainard Shale, an
Figure 18. Elevation (MSL) of the top of the Galena Group
Figure 19. Thickness of the Maquoketa Shale Group
Figure 20. Elevation (MSL) of the top of the Maquoketa Shale Group
upper dolomitic shale. In northern Illinois, the Neda Formation, a red and green shale and hematitic oolite, is locally present at the top of the group (Suter et al., 1959; Willman et al., 1975).

**Scales Shale.** The Scales Shale (Templeton and Willman, 1963), the lowermost unit of the Maquoketa Shale Group, is present throughout most of the state except in north-central and extreme western Illinois, where it has been removed by post-Ordovician erosion. Throughout the state, the Scales Shale has a range of 50 to 150 feet, but it is generally 75 to 100 feet thick. It is light olive gray to olive gray, weak to brittle, silty dolomitic shale interbedded with layers of fine-grained, silty dolomite. Locally, the shale is greenish-gray in its lower 5 to 10 feet (Buschbach, 1964).

**Fort Atkinson Limestone.** The middle unit of the Maquoketa Shale Group, the Fort Atkinson Limestone (Willman et al., 1975), is widely distributed in the subsurface of Illinois. It ranges from 15 to 20 feet thick near Rock Island (Rock Island County) to 5 to 50 feet thick in the Chicago area (Cook County). Its composition is highly variable. In northwestern Illinois it is very shaly and is inseparable from the shales above and below. In other areas it contains limestone that is laterally equivalent to shale elsewhere in the formation. It changes over short distances from white or pink, coarse-grained, crinoidal limestone to brown, fine-grained dolomite or gray, argillaceous limestone. In some areas, the upper portion is limestone and the lower is dolomite. The interbedded shale is generally green or brown and silty, and dolomitic or calcitic. Its amount varies greatly.

**Brainard Shale.** The Brainard Shale occurs throughout the area of the Maquoketa Group except where it has been truncated by unconformities. Where it has not been affected by post-Ordovician erosion, it is normally about 75 to 100 feet thick (Willman et al., 1975). It is a silty, dolomitic, weak, greenish-gray shale interbedded with varying amounts of silty, greenish-gray dolomite and, less commonly, limestone. In extreme northeastern Illinois it grades to partly silty dolomite that is light gray to light greenish-gray in color, partly black speckled, fine- to coarse-grained, and commonly interbedded with greenish-gray shale. The Brainard Shale is lighter colored and softer than the Scales Shale, and is commonly fossiliferous.

**Neda Formation.** The Neda Formation, the uppermost unit of the Maquoketa Shale Group, is present locally in northern Illinois, generally occurring
where the Maquoketa is thicker than 190 feet and the basal Silurian formations are thin or missing (Buschbach, 1964; Willman et al., 1975). It consists largely of weak red or green shale that contains flattened, hematitic, goethitic or limonitic oolites and interbedded pink or green dolomite. The Neda has a gradational contact with the underlying Brainard Shale and is unconformably overlain by the Silurian System and younger rocks.

Post-Ordovician Systems

Post-Ordovician deposits are not a detailed part of this study; they are described only briefly in the following sections.

Silurian System

The Silurian System underlies most of Illinois and makes up large portions of the bedrock surface in northeastern and northwestern Illinois (Willman et al., 1975). It is also exposed in the river bluffs at the confluence of the Illinois and Mississippi Rivers in western Illinois (fig. 21). The system has a maximum thickness of nearly 1000 feet at some pinnacle reefs in the area east of East St. Louis; however, the system is more commonly 400 to 600 feet thick. The Silurian thins and has been completely removed by erosion to the north and west. Preglacial erosion has produced deep valleys in the bedrock surface, and the thickness of the upper unit may change abruptly over short distances.

The Silurian rocks are almost entirely dolomite in the northern part of the state (Willman, 1943, 1973). In the lower third of the system, the formations maintain distinctive characteristics and lateral continuity over long distances. Where reefs are present in the upper part of the system, the sediments have abrupt lateral variations in lithology, and few units can be widely traced. The northern reefs, in the Racine Formation, are mainly pure dolomite. The interreef rocks are generally less pure, varying from cherty, silty dolomite to argillaceous dolomite. However, in northwestern Illinois, the interreef rocks, except in local areas, are nearly pure dolomite, similar in lithology to the reef rock.

The Silurian System is divided into three series: the Alexandrian Series (Zeizel et al., 1962; Willman, 1973), and the overlying Niagaran and Cayugan Series. Only the Alexandrian and Niagaran are present in northern and western Illinois. The Silurian System unconformably overlies the
Figure 21. Bedrock geology of Illinois
Maquoketa Group, generally the eroded surface of the Brainard Shale. Locally erosion has cut through the shale to the top of the Fort Atkinson Limestone. There is also a major unconformity between the Silurian System and the overlying Middle Devonian System and younger rocks.

**Devonian System**

The Devonian System (Willman et al., 1975) may originally have covered all of Illinois, but if so, it was eroded from the northern part of the state, largely before Pennsylvanian time. It occurs in parts of the southeastern and most of the western portions of the area covered by this report. The Devonian is less than 200 feet thick in large parts of central and western Illinois, but thickens slightly toward the northwest and dramatically toward the deep part of the basin to more than 1800 feet.

The Devonian System is divided into three series. The Lower Devonian Series occurs only in southern Illinois and is not present within the area of this report. The Middle Devonian Series is largely limestone and dolomite, and the Upper Devonian Series is dominantly black, gray, and green shale, although smaller amounts of limestone and siltstone are present.

**Carboniferous Systems**

The Carboniferous rocks in Illinois consist of two systems, the Mississippian and Pennsylvanian, separated by a major angular unconformity. The Mississippian System is dominantly carbonate, consisting of about 55% limestone and dolomite, 35% shale and siltstone, and about 10% sandstone. The Pennsylvanian System is dominated by shale, containing about 50% shale, 40% sandstone and siltstone, 5% limestone, 1 to 2% coal, and minor amounts of siderite and chert (Atherton and Palmer, 1979).

Mississippian rocks occur in the subsurface over the southern two-thirds of the state (Willman et al., 1975), where they are overlain mostly by Pennsylvanian rocks, except in the western part where they are overlain by glacial till (fig. 21).

In Illinois, the Mississippian System is divided into three series. The Kinderhookian Series at the base consists mainly of normal marine, fine-grained, elastic, sedimentary rocks. The relatively thick Valmeyeran Series in the middle includes biogenic limestone which outcrops along the outer edges of the basin in western and northwestern Illinois. The thick,
Chesterian Series, at the top, is confined to the deeper part of the basin and does not occur within the study area.

Strata of the Pennsylvanian System constitute the bedrock surface in about two-thirds of Illinois (Willman et al., 1975). Throughout most of the area in which they occur (fig. 21) they are covered by unconsolidated Pleistocene deposits, but in many areas they have been exposed by stream erosion. The maximum thickness of the Pennsylvanian in Illinois is about 2500 feet in the southeastern part of the state. The formations generally thicken from northern and western Illinois toward the south and southeast. In much of the Pennsylvanian area of western and northern Illinois, most of the members of the three lowest formations are relatively thin or missing, and in places along the LaSalle Anticlinal Belt, the base of the Carbondale Formation rests directly on the Ordovician St. Peter Sandstone. However, in the extreme northwest, in Rock Island and Mercer Counties, the three lowest formations are all present.

The Pennsylvanian System is characterized by many vertical changes in lithology, commonly abrupt, that produce more than 500 distinguishable units of sandstone, siltstone, shale, limestone, coal, and clay (Kosanke et al., 1960). Many of these units are laterally extensive, and even though they vary lithologically, they can be correlated widely because of their positions relative to continuous marker units, usually limestones, black fissile shales, or coals. Shale (dominantly gray with smaller amounts of red, green, and black) and underclay commonly form 65 to 70% of the sequence.

Cretaceous and Tertiary Systems

The Cretaceous System (Willman et al., 1975) is restricted to five counties in extreme southern Illinois, and to areas in Pike and Adams Counties in western Illinois (fig. 21). The Cretaceous rocks in western Illinois (Frye et al., 1964) are elastic rocks, largely sand, and as much as 100 feet thick. They are the easternmost outliers of Cretaceous sediments that formerly covered the region east of the Rocky Mountains and north of the Ozarks.

The Tertiary System (Willman et al., 1975) is extensive in extreme southern Illinois and also occurs in small, widely scattered areas in western and northern Illinois (fig. 21). Tertiary deposits in northern and

The existence of these scattered Cretaceous and Tertiary deposits has little or no influence on groundwater conditions in the northern two-thirds of Illinois. However, widespread erosion that took place during the long interval between the end of the Pennsylvanian and into and during the Quaternary has produced a bedrock surface that at least locally influences groundwater movement and recharge to the bedrock aquifers.

**Quaternary System**

Surficial deposits assigned to the Quaternary System, Pleistocene Series, blanket nearly all of Illinois. The thickness, lithology, and physical and mineralogical properties of these deposits, predominantly glacial in origin, may have a significant effect on the chemistry, rate, and amount of water entering the bedrock aquifers. There is evidence that continental glaciation caused regional changes in the groundwater flow systems and altered the chemistry of the groundwater in the bedrock (Gilkeson et al., 1981).

Extensive studies have been conducted on these deposits; therefore, this section will only briefly summarize the most pertinent aspects which must be considered in relationship to the bedrock aquifers. Additional details on these deposits may be obtained from published reports (e.g., Frye et al., 1962, 1963, 1969; Willman et al., 1963; Willman and Frye, 1970; Willman, 1971; and Piskin and Bergstrom, 1975) and many unpublished reports, manuscripts, and data sources in the files of ISGS.

The principal Pleistocene surficial deposits are glacial materials deposited during numerous ice advances and retreats which occurred over most portions of the state. In some areas thick loess or valley fill sand and gravel are the principal deposits. Only northwestern Illinois (mainly Carroll and central Jo Daviess Counties), a small area of western Illinois (Calhoun County and portions of Pike and Adams Counties), and the extreme southern portion of the state have not been covered by glaciers. The thickness of these deposits (Piskin and Bergstrom, 1975) ranges from zero to about 600 feet (fig. 22). Although these deposits, both glacial and interglacial, have been assigned to the Nebraskan, Aftonian, Kansan, Yarmouthian,
Figure 22. Thickness of the Pleistocene deposits
Illinoian, Sangamonian, Wisconsinan, and Holocene Stages, they have also been included in numerous formations and members on the basis of their lithologic characteristics and stratigraphic position.

The topography of the bedrock surface (Horberg, 1950; Willman and Frye, 1970) is characterized by a number of long, relatively wide and deep valleys, significant portions of which are now completely or partially buried by Quaternary glacial deposits. It is also characterized by extensive, relatively flat upland surfaces developed on the Pennsylvanian rocks of the central part of the state, and by relatively hilly, irregular topography developed mainly on the older Paleozoic rocks in northern and western Illinois. In these latter two areas, the bedrock valleys have locally been eroded into and through two or more of the aquifer or nonaquifer systems. Since the overlying Quaternary sediments blanket most of the state, covering the bedrock uplands and at least partially filling the bedrock valleys, the relationship between the bedrock topography and the distribution and thickness of Quaternary materials is often both locally and regionally quite obvious (fig. 22).

The distribution of the principal surficial Pleistocene deposits is shown on figure 23. While pre-Illinoian deposits form the principal surface materials in only a small portion of western Illinois (western Hancock, Adams, and Pike Counties), they occur extensively in the subsurface in sizable areas of western Illinois (Enion, Wolf Creek and Alburnett Formations) and central and east-central Illinois (Banner Formation). Scattered pre-Illinoian deposits have also been reported in the subsurface of parts of northern and south-central Illinois.

Two of the largest areas of surficial outwash, the Green River-Lower Rock River Basin (Leighton, Ekblaw, and Horberg, 1948) and the Havana region of the Illinois River (Walker et al., 1965), in northern and western Illinois, respectively, contain sand and gravel deposits that are locally continuous from land surface to bedrock; fine-grained Holocene alluvium (Cahokia Alluvium) is also present along streams. Surficial glacial outwash sand and gravel (Henry Formation) is present extensively in the form of outwash plains, valley trains, and kames in McHenry and Kane Counties in northeastern Illinois (Masters, 1978).
Figure 23. Quaternary deposits of Illinois
HYDROGEOLOGY

Introduction

Formal names of hydrostratigraphic units in Illinois are in the process of change to reduce confusion with rock stratigraphic terminology. The interim revised terminology for hydrostratigraphic units will be used in this report. This terminology (Cartwright, 1983) divides the hydrogeologic units into three major aquisystems, each of which is subdivided into aquigroups. The aquigroups, also shown on figure 24, are defined and then described in more detail in the following sections.

All aquisystems and aquigroups are present in the northern part of the state. The Cambrian and Ordovician aquifers studied comprise the Basal Bedrock and Midwest Bedrock Aquigroups, and in some areas are classified as the Upper Bedrock Aquigroup. Detailed descriptions of all the geologic units are given in the "Geology" section of this report.

Aquisystems and Aquigroups

Crystalline Rock Aquisystem

There are no significant aquifers within this aquisystem in Illinois.

Indurated Rock Aquisystem

Basal Bedrock Aquigroup. The Basal Bedrock Aquigroup is characterized by intermediate and regional groundwater flow systems in indurated rocks and is always overlain by indurated rock confining units. This aquigroup includes productive sandstone aquifers below thick, regionally extensive shale of the Eau Claire Formation. This aquigroup is basically the same as the "Mt. Simon Aquifer" previously defined in northeastern Illinois (Suter et al., 1959).

The Basal Bedrock Aquigroup is comprised of the rocks of the Mt. Simon Formation and the Elmhurst Sandstone Member of the Eau Claire Formation. The sandstones lie on the Precambrian granite (fig. 6).

The aquigroup is more than 2500 feet thick in east-central Illinois and northward and westward (fig. 7). The aquigroup varies from fine- to coarse-grained sandstone. Shale beds, a few feet to several tens of feet thick, are found throughout the aquigroup. The shale probably is lenticular in nature and not continuous over large areas. Much of the sandstone is moderately
Figure 24. Stratigraphy and water-yielding properties of the rocks and character of the groundwater in the study area
<table>
<thead>
<tr>
<th>DRILLING AND CASING CONDITIONS</th>
<th>WATER-YIELDING PROPERTIES</th>
<th>CHEMICAL QUALITY OF WATER</th>
<th>WATER TEMPERATURE °F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boulder, heaving sand locally; sand and gravel walls usually require screens and development; casing in wells into bedrock.</td>
<td>Sand and gravel, permeable. Locally, wells yield as much as 3000 gpm. Specific capacities vary from about 0.1 to 5600 gpm/ft.</td>
<td>TDS generally between 400 and 600 mg/L. Hardness 300–400 mg/L. Iron generally 1–8 mg/L.</td>
<td>50 – 64</td>
</tr>
<tr>
<td>Shale requires casing.</td>
<td>Extremely variable. Sandstone and limestone units generally yield less than 10 gpm.</td>
<td>TDS extremely variable regionally with depth. North-central Illinois, 500–1000 mg/L; southern, 500–3000 mg/L. Hardness: 150–400 mg/L north, 160–1000 mg/L south. Iron generally 1–5 mg/L.</td>
<td>53 – 57</td>
</tr>
<tr>
<td></td>
<td>In southern two-thirds of state yields generally less than 25 gpm.</td>
<td>TDS ranges between 400 and 1000 mg/L. Hardness is generally between 200 and 400 mg/L. Iron: 0.3–1.0 mg/L.</td>
<td>53 – 59</td>
</tr>
<tr>
<td>Upper part usually weathered and broken; crevicing varies widely.</td>
<td>Yields inconsistent. Major aquifer in NE and NW Illinois. Yields in fractured zones more than 1000 gpm.</td>
<td>TDS: 350–1000 mg/L; Hardness: 200–400 mg/L; Iron: 0.3–1.0 mg/L.</td>
<td>52 – 54</td>
</tr>
<tr>
<td>Shale requires casing.</td>
<td>Shales generally not water yielding. Crevices in dolomite units yield small local supplies.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Crevice commonly where formations underlie drift, Top of Galena usually selected for hole location and sealing of casing.</td>
<td>Where overlain by shale, crevicing and well yield small yields. Where overlain by drift wells yield moderate quantities of water.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lower cherty shales cave and are usually caved. Frangible sand may slough.</td>
<td>Small to moderate quantities of water. Transmissivity approximately 15 percent of that of the Midwest Bedrock Aquifer.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Crevice encountered locally in the dolomite, especially in the Eminence–Potosi. Casing not required.</td>
<td>Crevices in dolomite and sandstone yield small to moderate quantities of water. Transmissivity approximately 35 percent of that of the Midwest Bedrock Aquifer.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Amount of cementation variable. Lower part more friable. Sometimes sloughs.</td>
<td>Most productive unit of the Midwest Bedrock Aquifer. Yields over 500 gpm common in northern Illinois. Transmissivity approximately 50 percent of that of the Midwest Bedrock Aquifer.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Casing not usually necessary. Locally weak shales may require casing.</td>
<td>Shales generally not water yielding.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Casing not required.</td>
<td>Moderate quantities of water in upper units. Compareable in permeability to the Ginkwood–St. Peter Sandstone.</td>
<td>Varies northwest to southeast and with depth. At shallower depths, TDS: 225–400 mg/L. Hardness: 220–400 mg/L; Iron: 0.1–30 mg/L. High chloride concentrations with depth.</td>
<td>51 – 62</td>
</tr>
</tbody>
</table>

Figure 24. Concluded
well cemented and therefore has a relatively low hydraulic conductivity. The upper 300 to 600 feet is generally friable, and several friable zones are found in the unit. The degree of cementation decreases to the north toward the Wisconsin state line and increases southward toward the Illinois Basin.

The sandy lower zones of the Eau Claire Formation increase in thickness in relation to the total thickness of the formation. The shales become thinner and probably become lenticular in character. When sandstone becomes the predominant lithology, it yields significant water.

The Basal Bedrock Aquigroup is separated from the production zones of the Midwest Bedrock Aquigroup by the shales of the Eau Claire Formation. The confining unit is formed by the predominantly shaly upper part of the Eau Claire Formation (fig. 9). The Eau Claire Formation gradually becomes sandier to the north and west. However, the shale of the Proviso Siltstone Member is quite persistent and forms a barrier between the aquifers of the Basal Bedrock Aquigroup and the Ironton-Galesville aquifer of the Midwest Bedrock Aquigroup above.

Wells near the Wisconsin border penetrate increasing amounts of sandstone interbedded with the shales. Detailed studies of wells in the northern tier of counties show that 50 to 60% of the upper Eau Claire is sandstone. Thus, wells which penetrate the confining unit may obtain moderate yields of water from this zone. Nevertheless, the shales are laterally continuous, in contrast to shales in the Elmhurst-Mt. Simon aquifer which are lenticular in character. The sandstones in the Eau Claire confining unit may or may not be continuous. Thus, despite the sandy character of the Eau Claire Formation, the shales are persistent throughout the state and form a major aquitard.

Less is known about the confining unit in western Illinois. It appears to become quite sandy, as in northern Illinois.

**Midwest Bedrock Aquigroup.** The Midwest Bedrock Aquigroup is characterized by intermediate and regional groundwater flow systems in indurated rock that are overlain by indurated rock confining units. The top of the aquigroup is defined as the top of the Maquoketa Shale Group or other confining units where the Maquoketa is absent. The base of the aquigroup is at the top of the Eau Claire Formation or stratigraphically higher where the Ironton and Galesville Sandstones are absent. This aquigroup is basically the same as the "Cambrian-Ordovician Aquifer" previously defined in northeastern Illinois (Suter et al., 1959).
In northern Illinois the Midwest Bedrock Aquigroup consists of rock from the base of the Galesville Sandstone up through the top of the Maquoketa Shale Group. The Ironton-Calesville and Glenwood-St. Peter Sandstones are the principal water-producing zonea in this region and are of principal concern in this report. The lower boundary of the Midwest Bedrock Aquigroup is at the base of the Galesville Sandstone in northern Illinois. Where the Ironton-Galesville feathers out, the boundary rises along vertical cutoffs to either the porous sandstone of the St. Peter or to the lowest productive aquifer in the Knox Megagroup.

**Ironton-Galesville Aquifer.** The Ironton-Galesville aquifer is described in detail in the "Geology" section. This sandstone (fig. 11) is the moat uniform and productive zone in the Cambrian and Ordovician Systems in Illinois north of the Illinois River.

South of the Illinois River the sandstone becomes finer, gradually changing to a shale and then dolomite (in this same stratigraphic position) in the deeper parts of the Illinois Basin. This change is also reflected in the water quality trends in the aquifer.

**Middle Confining Unit.** The strata between the top of the Ironton-Galesville and St. Peter Sandstone (Ancell) are highly variable in thickness (fig. 13) as a result of the erosion which took place before the deposition of the St. Peter. This surface has been described both as a karat surface and as one with deep valleys (Buschbach, 1961). While there is evidence to support both hypotheses, it is clear that if karat did develop, there is no remnant of the high permeability which must have existed.

The confining unit is mainly dolomite and shale with some sandstone. The dolomite and sandstone contribute considerable quantities of water to wells. Two of the sandstones are major aquifers in some regions. The Jordan Sandstone, which is extensively used in Iowa, is present along the western edge of the state in sufficient thickness to be productive; some wells in the Rock Island-Moline area penetrate to the Jordan.

The New Richmond Sandstone is tapped by wells in parts of LaSalle and Grundy Counties where it is relatively thick. In much of this area the St. Peter is near the land surface and partly eroded, while the New Richmond is confined and has considerable artesian head.
Ancell Aquifer. The St. Peter Sandstone, along with the overlying Glenwood Sandstone when present (see "Geology" section), forms the second principal aquifer of the Midwest Bedrock Aquigroup. This sandstone is widespread in the north-central United States and is present under the entire state, except where it has been eroded (fig. 15).

The thickness (fig. 14) averages about 200 feet; however, the thickness varies greatly from less than 100 feet to over 600 feet. The thickening reflects the irregular base of the formation; the surface is fairly regular. The lower Kress member, which accounts for much of the increase in thickness, frequently adds little to the yield of wells, being a rubble-like deposit in a clay or shale matrix. Thus, the yield does not increase proportionally to increases in thickness.

Galena-Platteville Unit. The Galena-Platteville Unit is found throughout most of Illinois. It overlies the Ancell aquifer and sometimes forms part of the confining unit for that aquifer, although it is locally productive. In northeastern Illinois and south of the Illinois River, the Galena-Platteville Unit is overlain by the Maquoketa Shale Group or younger shales. Although it yields some water in this situation, the yield generally is only a small portion of the total water yielded to wells penetrating the deeper sandstones as part of the Midwest Bedrock Aquigroup. Locally, larger supplies are obtained from the Galena-Platteville. In northwestern Illinois the Galena-Platteville Unit immediately underlies glacial deposits or is exposed at the surface (fig. 17). The Maquoketa Shale Group is present above the Galena-Platteville in small areas. In this region, the Galena-Platteville dolomites become part of the Upper Bedrock Aquigroup.

Maquoketa Confining Unit. The Maquoketa Shale Group (fig. 19), where present, forms the principal confining bed for the Midwest Bedrock Aquigroup in northern and western Illinois. The Maquoketa Shale Group is described in some detail in the "Geology" section of this report. Little water, if any, is obtained from the shale. Where the Maquoketa directly underlies the glacial deposits, limited amounts of water are obtained from joints and fractures. Some dissolution has occurred in the Middle Fort Atkinson Limestone, where it is overlain by Silurian and Quaternary deposits, and has increased yields somewhat.
Mississippi Valley Bedrock Aquigroup. The Mississippi Valley Bedrock Aquigroup is characterized by intermediate and regional groundwater flow systems in indurated rock that are overlain by indurated rock confining units. The base of this system is at the top of the Maquoketa Shale Group (this is the only aquigroup boundary which cannot move stratigraphically). The aquigroup consists of rocks from the Pennsylvanian System through the Silurian System in the southern three-fourths of Illinois; the aquigroup is not present in northern Illinois.

In the southwestern part of the region studied, where Mississippian and Pennsylvanian rock are present, the shales confine several moderately productive aquifers. The primary water-yielding zones are dolomites of the Devonian and Silurian Systems and sandstones and carbonates of the Mississippian System. Some sandstones are also present in the Pennsylvanian, but these generally have very low productivity.

Devonian and Pennsylvanian shales are present throughout most of the area south of the Illinois River, and form the principal confining units within the aquigroup. The upper boundary of the Mississippi Valley Bedrock Aquigroup rises stratigraphically to include the uppermost aquifer confined by indurated rocks and all the confining units below the Upper Bedrock Aquigroup.

Upper Bedrock Aquigroup. This aquigroup consists of local and intermediate flow systems in indurated sediments with open connection to the Prairie Aquigroup so that water quality is related to that in the Prairie Aquigroup. This aquigroup is basically the same as the "Shallow Dolomite Aquifer" as previously defined in northern Illinois (Suter et al., 1959).

The Galena-Platteville Unit, the Maquoketa Confining Unit, and, locally, the Ancell aquifer become part of the Upper Bedrock Aquigroup in north-central Illinois, where they are exposed at the surface or overlain by glacial deposits. These aquifers are moderately productive. In this region dissolution of the rock by groundwater has occurred, enlarging the joints and fractures in the rock and increasing its permeability. The degree of jointing and fracturing and dissolution decreases with increasing depth of penetration in the rock. Most of the water is obtained in the uppermost 100 feet of rock.

The most significant and productive aquifer of the aquigroup is the Silurian Dolomite aquifer, which underlies northeastern Illinois and a small
part of northwestern Illinois (fig. 21). In these areas, large yields are sometimes obtained, reducing the dependence on the Cambrian- and Ordovician-age aquifers.

The only other significant aquifers which make up the Upper Bedrock Aquigroup in the region studied are the Mississippian carbonate rocks in the southwestern part of the region (fig. 21).

Non-Indurated Rock Aquisystem

Prairie Aquigroup. This aquigroup consists of local and intermediate flow systems in nonindurated geologic materials consisting of alluvium, glacial drift, and Cretaceous and Tertiary sediments. The major component of recharge to the system is local precipitation. The aquigroup is confined locally by fine-grained nonindurated sediments (referred to as confining units or aquitards). In some regions the Prairie Aquigroup is 400 to 500 feet thick, while in others it is 0 to 50 feet thick.
Hydrologic Properties

The principal hydraulic properties which influence well yields and water-level response to pumpage in the Cambrian and Ordovician aquifers are transmissivity and storage coefficient. Regionally, the leakage coefficient also plays an important role in influencing water levels. The capacity of an aquifer to transmit groundwater is expressed by the transmissivity, which is defined as the rate of flow of water through a unit width of the aquifer under a unit hydraulic gradient. The storage properties of an aquifer are expressed by the storage coefficient, which is defined as the volume of water released from or taken into storage per unit surface area of the aquifer per unit change in head normal to that surface.

For confined (artesian) conditions, in which water levels rise above the top of the aquifer in wells penetrating the aquifer, water released from or taken into storage is attributed solely to compressibility properties of the aquifer and water. Such coefficients are usually very small. On the other hand, where unconfined conditions (water table) prevail, in which water levels in wells represent the top of the saturated thickness of the aquifer, water released from or taken into storage is attributed almost entirely to gravity drainage or refilling of the zone through which the change of the water table takes place. A small portion of the water volume change comes from the compressibility of the aquifer and water, as in the artesian case, but this volume is proportionately nearly insignificant.

Most of the available data on hydraulic properties are from the Midwest Aquigroup. The storage coefficients for the confined aquifer are generally $10^{-5}$ to $10^{-3}$. Water-table storage coefficient data for the Midwest Aquigroup have never been obtained from tests, because until recently the aquifers have remained under artesian conditions. Typical values of water-table storage coefficients in unconsolidated material range from 0.01 to 0.3.

The rate of vertical leakage of groundwater through a confining bed in response to a given vertical head gradient is dependent upon the vertical hydraulic conductivity of the confining bed. In cases where the confining bed is not well defined or is unknown, Hantush (1956) suggested the use of the term leakage coefficient, which is the ratio of the vertical hydraulic conductivity of the confining bed to its thickness. It is defined as the
quantity of water that crosses a unit area of the interface between an aquifer and its confining bed divided by the head loss across the confining bed.

Aquifer Tests

The hydraulic properties of aquifers and confining beds may be determined by means of aquifer tests wherein the effect of pumping a well at a known constant rate is measured in the pumped well and in observation wells penetrating the aquifer. Graphs of drawdown versus time or drawdown versus distance from the pumped well are used to solve formulas which express the relationship between the hydraulic properties of an aquifer and its confining bed, if present, and the lowering of water levels (drawdown) in the vicinity of a pumping well. Graphical analyses may utilize the leaky artesian formula (Hantush and Jacob, 1955), the nonequilibrium formula (Theis, 1935), or the modified nonequilibrium formula (Cooper and Jacob, 1946). Type-curve and straight-line methods for graphical analysis were described by Walton (1962). Test data collected under water-table conditions may be analyzed by methods devised by Boulton (1963) and described by Prickett (1965). Where geohydrologic boundaries are known to exist, their effect on drawdown can be determined by means of image-well theory, described by Ferris (1959).

Basal Bedrock Aquigroup. Aquifer test data from the Basal Bedrock Aquigroup were available from three long-term tests at gas storage project sites (Illinois State Water Survey and Hittman Associates, 1973). The tests were conducted at pumping rates of 80, 45, and 56 gpm for periods of 48, 40, and 18 days, respectively. At least five observation wells were available at each site; however, because of the partial penetration effects caused by the great thickness of this aquifer system, data from distant (greater than 1.5 times the aquifer thickness) observation wells were given preference over data from wells closer to the pumped well, in order to minimize distortions caused by partial penetration of wells.

Data from the distant observation wells were analyzed by graphical techniques described in the above references. The results are summarized in table 1.
Table 1. Hydraulic Properties in the Basal Bedrock Aquigroup

<table>
<thead>
<tr>
<th>Gas storage site</th>
<th>General location</th>
<th>Average transmissivity (gpd/ft)</th>
<th>Average storage coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ancona</td>
<td>NW LaSalle Co.</td>
<td>10,600</td>
<td>$1.8 \times 10^{-4}$</td>
</tr>
<tr>
<td>Pontiac</td>
<td>Central Livingston Co.</td>
<td>1,635</td>
<td>$1.3 \times 10^{-4}$</td>
</tr>
<tr>
<td>Hudson</td>
<td>NW McLean Co.</td>
<td>980</td>
<td>$5.2 \times 10^{-4}$</td>
</tr>
</tbody>
</table>

Table 2. Storage Coefficients of the Midwest Bedrock Aquigroup

<table>
<thead>
<tr>
<th>Location</th>
<th>Well owner</th>
<th>Date of test</th>
<th>Storage coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cook County</td>
<td>Corn Products Corp., Argo</td>
<td>10/43</td>
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</tr>
<tr>
<td>Kane County</td>
<td>City of Elgin</td>
<td>4/44</td>
<td>0.00068*</td>
</tr>
<tr>
<td>Knox County</td>
<td>City of Knoxville</td>
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<td>0.00057</td>
</tr>
<tr>
<td>Will County</td>
<td>Blockson Chemical Co., Joliet</td>
<td>3151</td>
<td>0.00037</td>
</tr>
<tr>
<td>Will County</td>
<td>Kankakee Ordinance Works, Joliet</td>
<td>3143</td>
<td>0.00018</td>
</tr>
</tbody>
</table>

Average 0.00039

*Well also open to Basal Bedrock Aquigroup

**Midwest Bedrock Aquigroup.** Because most wells tapping the Midwest Bedrock Aquigroup are open to several aquifers as well as to the Middle Confining Unit, the aquigroup behaves more or less as a single hydraulic system. Hydraulic properties determined from aquifer tests, therefore, represent the combined properties of all units beneath the Maquoketa Confining Unit. Pumping tests in the Midwest Bedrock Aquigroup have been made at approximately 220 sites within the study area. Tests involving observation wells were made at only five of these sites. The effects of leakage were negligible during the tests, and analysis was limited to the use of nonleaky or modified nonequilibrium formulas. The storage coefficient was not determined from pumped well data, since the effective radius of the well cannot normally be estimated with sufficient accuracy. Storage coefficients determined at five sites are presented in table 2. Transmissivity values determined from the controlled tests are included in Appendix A and were used to prepare figure 25.
AREA: Regional transmissivity values generally are between 10,000 and 20,000 gpd/ft.

AREA B: Regional transmissivity values generally are greater than 20,000 gpd/ft.

AREA C: Area of highly variable transmissivities. Values may be less than 10,000 to greater than 20,000 gpd/ft.

AREA D: Limited data. Transmissivities tend to be greater than 20,000 gpd/ft in areas where Ancell aquifer thickens, but may be much less elsewhere.

Figure 25. Regional transmissivities in the Midwest Bedrock Aquigroup
Lithologic changes within the Ancell and Ironton-Galesville aquifers appear to have an effect on transmissivities of the Midwest Bedrock Aquigroup. The thickness of the Ironton-Galesville aquifer generally increases from the northwest to the southeast (see fig. 11), while that of the Ancell aquifer is highly variable locally (fig. 14). Transmissivities are generally increased by local or regional thickening of these two formations. In addition, the transmissivity of the Midwest Bedrock Aquigroup increases significantly where the overlying Maquoketa Confining Unit is absent.

In Area A of figure 25, the aquifers of the Midwest Bedrock Aquigroup are overlain by the Maquoketa Confining Unit, and regional values of transmissivity may vary from 10,000 to 20,000 gpd/ft. Locally, however, where the Ancell aquifer thickens at the expense of underlying, less permeable, carbonate rocks, transmissivities may exceed 20,000 gpd/ft. In Areas B and C, wells in the Midwest Aquigroup are often open to shallower aquifers which may affect the transmissivities measured. In the recharge area to the west of the Maquoketa Confining Unit border (Area B), transmissivities generally exceed 20,000 gpd/ft. In Area C the Maquoketa and the Galena-Platteville Unit are highly dissected by streams, and as a result, transmissivities vary in this region from fewer than 10,000 to more than 20,000 gpd/ft. Another factor which probably contributes regionally to the lower transmissivity values is the thinner Ironton-Galesville section in this area. The higher values of transmissivity are usually accounted for by the locally thicker Ancell aquifer, as well as a local absence of the Maquoketa. Area D is a region where transmissivity data are sparse and variable. The Midwest Bedrock Aquigroup is confined under the Maquoketa Confining Unit and other overlying rocks, as in northeastern Illinois. Transmissivities in this region are as low as 5,000 gpd/ft, but may exceed 20,000 gpd/ft.

**Upper Bedrock Aquigroup.** Six aquifer tests were made at five sites in DuPage County between 1955 and 1980. At this location the Upper Bedrock Aquigroup is composed of dolomites of Silurian age. According to Zeizel et al. (1962) the Upper Bedrock Aquigroup is highly fractured and in many places is under leaky artesian conditions. Transmissivities and storage coefficients are highly variable both regionally and among the various observation wells in aquifer tests. Values of transmissivity and storage coefficient ranged from 10,500 to 85,400 gpd/ft and from $9.0 \times 10^{-5}$ to $3.5 \times 10^{-4}$,
respectively. Data from other areas in Illinois are not available for the Upper Bedrock Aquigroup.

Specific Capacity Analyses

One means of expressing the yield of a well is by use of the specific capacity, which is defined as the yield of the well in gallons per minute per foot of drawdown for a given pumping period and discharge rate. Walton (1962) showed that the Theis nonequilibrium formula can be expressed in terms of the theoretical specific capacity of a well discharging at a constant rate in a homogeneous, isotropic, areally infinite, nonleaky aquifer.

The theoretical specific capacity of a well varies with the radius of the well and the pumping period. For instance, a 30-inch diameter well has a specific capacity about 13% greater than that of a 12-inch diameter well. The theoretical specific capacity decreases with the length of the pumping period, since drawdown continuously increases with time.

Head losses within the well, known as well losses, must be accounted for before drawdown data can be used in the specific capacity formula to estimate hydraulic properties. Jacob (1947) and Rorabaugh (1953) described graphical methods to compute the well loss coefficient from data collected during a step-drawdown test in which the well pump is operated during several successive and equal time periods at constant fractions of the final pumping rate.

Where applicable, additional corrections must be made to drawdown data for the effects of partial penetration and for decreases in saturated thickness under water-table conditions. None of the specific capacity data for the Midwest Bedrock Aquigroup were affected by water-table conditions. The effects of partial penetration within the Midwest Bedrock Aquigroup could not be assessed because of the heterogeneous character of the various hydrogeologic units within the aquigroup. It is believed, however, that the majority of wells penetrating the Midwest Bedrock Aquigroup generally receive groundwater flow from the most productive units within the system and that the effects of partial penetration are not significantly large. Partial penetration effects, likewise, are not considered significant in the Upper Bedrock Aquigroup, since wells in that system generally penetrate its most productive upper zones, which are more creviced than are those at depth. Data from the Basal Bedrock Aquigroup are extremely limited. There is evidence that the
units within this system are stratified, and the effect of such stratification in such a thick aquifer system cannot be evaluated at present.

All specific capacity data were corrected for well losses and adjusted to a common well radius (0.5 foot) and a common pumping period (12 hours) for purposes of comparison. From these data, values of aquifer transmissivity were derived from the relationship between transmissivity and specific capacity given by the modified nonequilibrium formula (Walton, 1962). To solve this formula the storage coefficient must be assumed, based upon whether aquifer conditions are water table or artesian.

**Basal Bedrock Aquigroup.** Specific capacity data are available for just one well open only to the Basal Bedrock Aquigroup. The well, located in northern Cook County, had an adjusted specific capacity of 0.6 gpm/ft. The effects of partial penetration in this well could be large, since the ratio of vertical to horizontal hydraulic conductivity is believed to be about 0.3 to 0.4 (Illinois State Water Survey and Hittman Associates, 1973) and the thickness of the aquigroup is approximately 2000 feet in northern Cook County.

**Midwest Bedrock Aquigroup.** Specific capacity data were collected during well production tests at approximately 570 sites. The transmissivity for each data value was then obtained from the relationship between transmissivity and specific capacity described above. Transmissivity values obtained from specific capacity were used to help prepare figure 25.

**Upper Bedrock Aquigroup.** Csallany and Walton (1963) studied yields of wells in the Upper Bedrock Aquigroup in northern Illinois. The massive amounts of data (approximately 1000 production tests) available, however, yielded specific capacity values which were extremely variable and interpretatively intractable. Csallany and Walton solved this problem by treating the data statistically, whereby adjusted specific capacities were divided by the depths of penetration of the wells and plotted as frequency graphs. It had been known that crevicing and depth of well strongly influence well yields. Csallany and Walton’s study, however, also indicated a correlation between well yields and bedrock upland areas and areas where sand and gravel were present in the glacial drift immediately above the bedrock. The 50% frequency value of unit specific capacity (yield per foot of penetration) for bedrock upland areas, for example, was 0.24 gpm/ft/ft, whereas in bedrock valleys the 50% frequency value was only 0.065 gpm/ft/ft. Where sand and
gravel in the drift overlaid the bedrock, the 50% value of unit specific
capacity was 0.26 gpm/ft/ft, whereas if the glacial drift material was till,
the 50% value was 0.06 gpm/tt/ft.

**Leakage Coefficient**

Values of the leakage coefficient of a confining layer are normally
determined by analysis of long period (24 hours or more) aquifer tests,
involving time-drawdown data from one or more observation wells. Such was
the case with the Upper Bedrock Aquigroup. Within the Basal and Midwest
Bedrock Aquigroups, however, leakage due to pumpage from a single well is too
small to be observed in a typical well test, and a regional analysis must be
made using flow-net and mass balance analyses.

**Basal Bedrock Aquigroup Confining Unit.** Schicht, Adams, and Stall
(1976) used flow-net analysis of earlier work by Walton (1960) to estimate
the average coefficient of vertical hydraulic conductivity for the confining
unit of the Basal Bedrock Aquigroup as $3.0 \times 10^{-5}$ gpd/ft². The leakage
coefficient for this confining unit can be estimated, therefore, by dividing
the vertical hydraulic conductivity at a given location by the thickness of
the confining unit. Figure 9 shows that the thickness of the confining unit
in the study area varies from 0 to 600 feet but is generally from 200 to 400
feet thick. The leakage coefficient, therefore, is estimated to be between
$7.5 \times 10^{-8}$ and $1.5 \times 10^{-7}$ gpd/ft³ throughout much of the study area.

**Midwest Bedrock Aquigroup Confining Unit.** The Maquoketa Shale Group
forms the confining unit of the Midwest Aquigroup in large parts of north-
eastern Illinois and also in portions of northwestern Illinois. As shown in
figure 19, the Maquoketa Shale Group has a maximum thickness of about 200
feet in the Chicago area and thins to the north and west. The changes in
artesian pressure produced by pumping in the Midwest Aquigroup have been
pronounced and widespread and have caused large differentials in head above
and below the Maquoketa. As a result, appreciable quantities of water have
moved downward through the Maquoketa as leakage, as will be discussed in the
section, "Recharge and Movement of Groundwater."

Walton (1960) made a regional flow-net analysis of the Chicago area and
determined a leakage coefficient for the confining unit of $2.5 \times 10^{-7}$.
gpd/ft$^3$, which is comparable to that of the Basal Bedrock Aquigroup confining unit.

**Piezometric Surface of Midwest Bedrock Aquigroup**

The piezometric surface of an aquifer is an imaginary surface which marks the height to which water will rise in artesian wells penetrating the aquifer. If the water level elevations in such wells are plotted on a map and contoured, it is called a piezometric surface map. The piezometric surface map is actually a map of the hydraulic head in the aquifer. The water table is a particular piezometric surface for unconfined aquifers. Under isotropic conditions (aquifer hydraulic properties independent of direction) groundwater travels downgradient at right angles to the water level contours (isopiestic lines), and, therefore, a piezometric surface map is useful in indicating directions of groundwater flow. The literature also often refers to these maps as potentiometric surface maps whose contours are called isopotential lines. Under anisotropic conditions (aquifer Properties dependent upon direction) orthogonality is not maintained, and other procedures are required to draw flow nets (Freeze and Cherry, 1979).

It is to be understood that water levels in wells penetrating individual units of the Midwest Bedrock Aquigroup represent the piezometric levels for those units, whereas water levels in multi-unit wells represent composite levels for the aquigroup as a collective unit. In constructing the piezometric maps shown in figures 26-29, these limitations were recognized and taken into consideration. In northeastern Illinois, for example, the piezometric surface map is a composite, whereas in western Illinois the predominance of data was from wells tapping the Calena-Platteville Unit and Ancell aquifer only. Elsewhere in the study area, the data were from both single- and multi-unit wells.

The exact configuration of the piezometric surface of the Midwest Bedrock Aquigroup at the time of initial development is not known. Suter et al. (1959) interpreted water level data presented by Anderson (1919) and Wiedman and Schultz (1915) in northeastern Illinois (see fig. 26). According to Suter et al., a groundwater ridge existed in parts of McHenry, Kane, and DeKalb Counties, and groundwater moved southeastward toward Chicago. Westward flow from the ridge moved toward the Rock River. Water level contours
Figure 26. Approximate piezometric surface (MSL) of the Midwest Bedrock Aquigroup at the time of initial development
Figure 27. Piezometric surface (MSL) of the Midwest Bedrock Aquigroup in October 1971
Figure 28. Piezometric surface (MSL) of the Midwest Bedrock Aquigroup in October 1980
Figure 29. Piezometric surface (MSL) of the Midwest Bedrock Aquigroup, October 1980, northeastern Illinois
also indicate that groundwater moved toward discharge along the Illinois River in Grundy and LaSalle Counties.

Water level measurements on file at the State Water Survey for the northwestern, western, and southwestern portions of the study area in Illinois (taken prior to any significant effects of deep groundwater development) were used, along with geologic information, to construct water level contours in those areas and, in effect, extend Suter’s piezometric surface map (with minor modification) over the entire study area (fig. 26). The contours indicate a groundwater ridge in portions of Jo Daviess, Stephenson, Carroll, and Ogle Counties in northwestern Illinois, an area which topographically is the highest in the state. Stream incisionment, which is pronounced in the area, has exposed the Midwest Bedrock Aquigroup. Groundwater movement toward the Mississippi and Pecatonica Rivers can be inferred from the contours. Flow toward the other incised streams, such as the Galena and Apple Rivers, cannot be inferred from the historical data. It is evident in the 1980 data, however, and it is assumed to have occurred prior to significant pumpage.

Water level data from western Illinois and eastern Iowa (Norton, 1897) indicate that water flowed southeastward from Iowa under the Mississippi and Illinois Rivers toward the Illinois Basin. There is some evidence of a low, discontinuous groundwater ridge between the Mississippi and Illinois Rivers; hydrologic and stratigraphic information suggest that no discharge to these rivers occurs in western Illinois, except in the extreme southern portion of the Illinois River in Calhoun and Jersey Counties. Here, erosion has brought the aquifer close to the surface, and discharge takes place.

Suter et al. (1959) reported that hundreds of deep wells were drilled in Chicago and Joliet after 1864, and, as a result of heavy pumpage, considerable changes in the piezometric surface were noted as early as 1895. The 700-foot isopiestic line had migrated in a northwesterly direction about 22 miles since 1864, while the 550-foot contour had moved northwestward from northern Indiana and south of Kankakee, Illinois, to a position west of the Chicago centers of pumpage. No such early data are available elsewhere, but it is reported that the first high-capacity deep well in northwestern Illinois was drilled in 1875 (Sasman and Baker, 1966). The rate of growth in pumpage was not as rapid in northwestern Illinois, however, as in northeastern Illinois.
Although several piezometric surface maps were prepared for northeastern Illinois (Suter et al., 1959; Sasman et al., 1961, 1962, and 1967), it was not until 1971 that a comprehensive study was made of water levels in deep aquifers across northern Illinois. Sasman et al. (1973) summarized deep pumpage and prepared a 1971 piezometric surface map for a 20-county area (fig. 27). The general pattern of groundwater flow in 1971 was toward the deep cones of depression, primarily centered at Des Plaines, Elmhurst, Bellwood, and Joliet. Other large pumping centers west of the Chicago region, at Belvidere, Rockford, Rochelle, and DeKalb, were also diverting flow. In the Chicago region the average water level decline since 1864 was about 800 feet.

In the fall of 1980 water levels were measured in approximately 800 wells tapping the Midwest Bedrock Aquigroup. The area covered was northern Illinois and western Illinois south to Calhoun County. This is the largest area ever covered by a set of water level measurements in Illinois. Sasman et al. (1982) prepared a piezometric surface map from the data points (figs. 28 and 29). In the northeastern portion of the study area the cones of depression had deepened and grown considerably since 1971, as can be observed from a comparison of figures 27 and 29. Major growth of pumping centers can be observed in eastern DuPage County, west-central and northern Cook County, the Joliet area of Will County, and the Fox River valley centers in eastern Kane County. Declines of water levels since 1971 were as much as 183 feet in the Joliet area, 220 feet in the upper Cook County suburbs, 200 feet in eastern DuPage County, and 190 feet in the Fox Valley. As a result of the rapid growth and deepening of the major pumping cones, large areas of dewatering have occurred in the upper permeable units of the Midwest Bedrock Aquigroup. The 1980 map was compared with the elevation of the tops of the Galena-Platteville Unit and the Ancell aquifer (from Suter et al., 1959) at several selected pumping centers to determine the amount of dewatering. The results are shown in table 3. For the most part, the groundwater divide for northeastern Illinois remained much the same as in 1971, moving slightly westward in Boone county and nearly out of Grundy County into LaSalle County.
Table 3. Units of Midwest Bedrock Aquigroup
Dewatered in Major Pumping Centers, Fall 1980

<table>
<thead>
<tr>
<th>Pumping Center</th>
<th>Units Dewatered</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aurora</td>
<td>More than 2/3 of the Galena-Platteville</td>
</tr>
<tr>
<td>Elgin</td>
<td>More than 2/3 of the Galena-Platteville</td>
</tr>
<tr>
<td>E. DuPage-W. Cook Co.</td>
<td>All of Galena-Platteville and less thah 1/4 of Ancell</td>
</tr>
<tr>
<td>Joliet</td>
<td>All of Galena-Platteville and nearly 1/4 of Ancell</td>
</tr>
<tr>
<td>N. Cook Co.</td>
<td>All of Galena-Platteville and more than 1/3 of Ancell</td>
</tr>
</tbody>
</table>

Recharge and Movement of Groundwater

The predominant feature of the 1980 piezometric surface map of the Midwest Bedrock Aquigroup is the major pumping cones in the Chicago area. A second area of interest, however, is the recharge area of north-central and northwestern Illinois. Sasman et al. (1982) superposed on the 1980 piezometric surface map the major streams as well as the outline of the Maquoketa and Pennsylvanian shales which rim the recharge area and act as confining beds to the Midwest and Mississippi Valley Aquigroups. In the west, the Mississippi Valley Aquigroup overlies the Midwest Bedrock Aquigroup. A groundwater ridge along the major flow divide in north-central Illinois roughly marks the center of the recharge area of the Midwest Bedrock Aquigroup, with flow moving from the ridge principally to the east and south and, to a lesser extent to the west, toward the Rock River.

Flow from a smaller groundwater high in Stephenson and Jo Daviess Counties divides into a southwesterly direction toward the Mississippi River and an east-southeasterly direction toward the Rock River. Water level contours also indicate flow toward the Fox, Apple, Galena, and Pecatonica Rivers. In areas where these major streams are underlain by drift and shale, the streams are not incised into the productive units of the Midwest Bedrock Aquigroup. Where the shales are missing, however, streams have cut into the upper permeable units (Galena-Platteville Unit or Ancell aquifer), and in these reaches of the streams groundwater discharge takes place.

In the southwestern part of the study area, the Midwest Bedrock Aquigroup is buried beneath the Mississippi Valley Aquigroup. Because it is not
exposed at the surface, except in the extreme southern portion of the Illinois River Valley, no discharge to streams can be inferred from the map contours. Hydraulic gradients are quite low, and flow is sluggish. Slight remnants of a low groundwater ridge apparently are still present between the Illinois and Mississippi Rivers. In this area, the regional flow is generally southeastward toward the Illinois Basin.

Using flow-net analysis of the piezometric surface map for 1864, Walton (1960) determined that the recharge rate through the Maquoketa Confining Unit to the aquifers of the Midwest Bedrock Aquigroup in northeastern Illinois was about 1330 gpd/sq mi. He also calculated that by 1958 this recharge rate had increased to about 2100 gpd/sq mi under the influence of large head differentials created by pumpage. In a 1964 report, Walton estimated that the maximum amount of leakage that could take place through the Maquoketa would be about 12 mgd. Based on the area through which such leakage could occur (4000 sq mi), the maximum rate of leakage through the Maquoketa is about 3000 gpd/sq mi. There is also evidence that head differentials across the Basal Bedrock Aquitard have been produced by pumping in the Midwest Bedrock Aquigroup and that upward leakage of water from below the aquitard has resulted. Walton estimated that the maximum amount of upward leakage to the Midwest Aquigroup from the Basal Bedrock Aquigroup would be about 3 mgd.

Walton (1962) computed a recharge rate of 21,000 gpd/sq mi to the Midwest Bedrock Aquigroup in 1958 in an area west of the border of the Maquoketa Confining Unit. Hoover and Schicht (1967) calculated an average recharge rate in LaSalle County of 10,800 gpd/sq mi. As part of this study a flow-net analysis was made in the area west of the Maquoketa Confining Unit in north-central Illinois. Using the 1971 piezometric surface map (fig. 30), five flow channels were investigated. These flow channels were selected because they were not believed to be significantly influenced by groundwater pumpage. Recharge rates for each flow channel were determined by solving Darcy’s Law for the flow through each channel cross section and dividing this amount by the area within the flow channel. An average transmissivity of 20,000 gpd/ft was assumed in calculating flow through sections 1, 2, 3, and 5. Based on local data, a value of 17,000 gpd/ft was assumed for section 4. The results are summarized in table 4. An average recharge rate in 1971 for the area west of the Maquoketa boundary was 20,400 gpd/sq mi, close to the value Walton had determined earlier. In 1964 Walton estimated
Figure 30. Flow-net analysis using 1971 piezometric surface map
that the maximum rate of recharge in the area west of the Maquoketa would be about 42,000 gpd/sq mi.

Table 4. Recharge Rates in North-Central Illinois in 1971

<table>
<thead>
<tr>
<th>Flow Channel</th>
<th>Recharge Rate (gpd/sq mi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>22,000</td>
</tr>
<tr>
<td>2</td>
<td>22,400</td>
</tr>
<tr>
<td>3</td>
<td>19,000</td>
</tr>
<tr>
<td>4</td>
<td>11,300</td>
</tr>
<tr>
<td>5</td>
<td>27,400</td>
</tr>
<tr>
<td>Average</td>
<td>20,400</td>
</tr>
</tbody>
</table>

Attempts at computing recharge rates in northwestern Illinois using the 1971 piezometric surface maps have been unsuccessful. Water level declines there have resulted in storage changes which are difficult to account for in a flow channel analysis due to the uncertainty in estimating a regional storage coefficient. Flow analysis on the piezometric map for the time of initial development (fig. 31) was reasonably successful, however. Three flow channels in portions of Stevenson, Carroll, Ogle, and Whiteside Counties were analyzed. Transmissivity values of 12,000, 10,000, and 12,000 gpd/ft were assumed for channels A, B, and C, respectively. Recharge rates for channels A, B, and C in figure 31 were calculated to be 16,900, 16,500, and 18,200 gpd/sq mi, respectively. The average rate was 17,200 gpd/sq mi, about 16% lower than the 1971 rate for north-central Illinois but nearly 13 times as large as the pre-development rate for northeastern Illinois.

Hydraulic gradients in western Illinois are very small and result in uncertainties in flow-net analysis. Recharge rates are probably extremely low, however, because of the thick sequence of strata overlying the Midwest Bedrock Aquifer (the Maquoketa Confining Unit as well as the Mississippi Valley Aquifer). On the basis of pre-development water level and transmissivity maps presented by Horick and Steinhilber (1978), recharge rates to the Jordan Aquifer in eastern Iowa were estimated. The results indicate that recharge to the Jordan is of the same order of magnitude as determined by Walton (1960) for the Chicago area (1330 gpd/sq mi).
Figure 31. Flow-net analysis using piezometric surface map for the time of initial development
Historical Pumpage

Table 5 shows average groundwater pumpage from the Midwest Bedrock Aquigroup by county for 10-year periods beginning in 1861 and ending with 1980. Figure 32 shows the average pumpage for the entire area for the same 10-year periods. It also presents three regional pumpage-time distributions, aggregated from the data in table 5. All of the recorded pumpage from 1861 through 1880 was in Cook County. From 1881 through 1940 the 10-year average pumpage increased 1.57 million gallons per day (mgd) per year. Average pumpage continued to increase, at a rate of 2.90 mgd per year, from 1941 through 1960. The largest increase in pumpage was during 1961 through 1980 when average pumpage increased 6.15 mgd/yr. Total withdrawals from Cambrian and Ordovician aquifers averaged 278.6 mgd between 1971 and 1980. By 1980, however, the total had declined to 258.4 mgd, of which the largest withdrawals—67.2 mgd, 28.4 mgd, 27.7 mgd, and 23.7 mgd—occurred in Cook, DuPage, Kane, and Will Counties, respectively.

It should be noted that in the past, and to a lesser extent at present, pumpage from deep wells in northern (especially northeastern) Illinois has included pumpage from wells known to be open to both the Midwest Bedrock Aquigroup and the Basal Bedrock Aquigroup (Schicht et al., 1976). Some wells were also known to be open to both the Upper Bedrock Aquigroup and the Midwest Bedrock Aquigroup. In addition, many deep wells were improperly cased through the Upper Bedrock Aquigroup, and leakage down the well bore may have been significant. Suter et al. (1959) estimated the contributions to deep pumpage from these outside sources in northeastern Illinois to be as much as 43% of the total in 1958. There is evidence to indicate that this contribution declined to about 14% of the total in northeastern Illinois by 1975 (Visocky, 1982).

Most of the pumpage occurs in the northeast region, consisting of Cook, DuPage, Grundy, Kane, Kendall, Lake, McHenry, and Will Counties. Average pumpage has increased from 0.381 mgd during 1861 through 1870 to 165 mgd during 1971 through 1980. Pumpage in the northeast region has averaged 59% of the total groundwater pumped from the Midwest Bedrock Aquigroup since 1881.

The data used in table 5 and figure 32 were compiled from several sources. Suter et al. (1959) presented a detailed discussion of the areal distribution of pumpage within the northeast region from 1864 through 1957.
Table 5. Average Pumpage from the Cambrian and Ordovician aquifers from 1861 through 1980 in mgd

<table>
<thead>
<tr>
<th></th>
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Figure 32. Pumpage growth in the Midwest Bedrock Aquigroup
They also classified pumpage in 1957 according to usage categories (public, industrial, rural, and irrigation). Sasman (1965) also summarized historical pumpages through 1962 for public, industrial, and domestic water supplies. Annual pumpage data for 1960 through 1975 were summarized by Sasman et al. (1967, 1973, 1974, 1977) and Schicht et al. (1976). The data are presented on an areal basis and by water use. Pumpage data for 1978 and 1980 were estimated from results of the Illinois Water Use Inventory presented by Kirk et al. (1979 and 1982).

The first deep well in northern Illinois was drilled in Chicago in 1864. The well was probably finished in the Galena and Platteville Groups (Suter et al., 1959) and had an artesian flow estimated at 0.2 mgd. Cook County pumpage was more than 60% of the total pumpage in the northeast region for the period 1861 through 1930. Since 1930, the Cook County portion has declined to 38% or 62.88 mgd during 1971 through 1980.

Pumpage in DuPage, Kane and Will Counties has increased at a considerable rate since 1891. The combined three-county pumpage averaged 3.19 mgd or 17% of the regional total from 1891 through 1900. During 1971 through 1980 the pumpage in this same area totaled 77.95 mgd or 47% of the northeast region’s total.

Boone, Carroll, DeKalb, Jo Daviess, La Salle, Lee, Ogle, Rock Island, Stephenson, Whiteside, and Winnebago Counties compose the northwest region. As shown in table 5, average pumpage has increased from 8.10 mgd during 1881 through 1890 to 103 mgd during 1971 through 1980. Pumpage in the northwest region has averaged 37% of the total pumpage from the Midwest Bedrock Aquigroup since 1881. Historic pumpage from 1881 through 1971 has been categorized on a county basis by water use in publications by Sasman and Baker (1966) and Sasman et al. (1973 and 1974). More detailed historical pumpage data for Winnebago and La Salle Counties have been published by Smith and Larson (1948) and Hoover and Schicht (1967), respectively.

Pumpage in Winnebago County is concentrated in the Rockford area and has been greater than twice the pumpage for any other county in the region except Jo Daviess County since 1891. During 1931 through 1950, Winnebago County accounted for more than 40% of the total regional pumpage. During the period 1971 through 1980, however, this amount decreased to 29% of the total.

Historically, pumpage has been distributed uniformly among the other counties except Winnebago and Jo Daviess Counties. In Jo Daviess County,
more than 50% of the pre-1960 pumpage was for dewatering lead and zinc mines in the Galena and Platteville Groups.

The total pumpage in the 16 counties that comprise the central region (table 5) has averaged 3% of the total pumpage from the Cambrian and Ordovician aquifers since 1881. Total pumpage in the central region has increased uniformly from 0.014 mgd during 1881 through 1890 to 10.3 mgd during 1971 through 1980. Historical pumpages were estimated from data presented by Hanson (1950, 1958, and 1961) and Visocky et al. (1978). Additional information was obtained from publications by Woller et al. (1973 to date).

Prior to 1961, more than 68% of the central region pumpage was concentrated in Henry, Knox, and Warren Counties. All counties except Knox County have increased pumpages from the aquifers. Since 1961, Knox County has increased pumpage from sand and gravel sources (the Prairie Aquigroup) and decreased pumpage from the bedrock aquifers.

Potential Development of Midwest Bedrock Aquigroup

**Practical Sustained Yield**

Recharge to the Midwest Bedrock Aquigroup in northeastern Illinois, while due in part to downward leakage through the Maquoketa Confining Unit and upward leakage from the Basal Bedrock Aquigroup, comes primarily from lateral flow eastward from the major recharge area toward large pumping centers in Cook, DuPage, and Will Counties. Walton (1964) estimated that the maximum amount of water which could be safely pumped from the aquifers in northeastern Illinois (the practical sustained yield) consisted of three elements: 1) the rate at which groundwater could be induced to move laterally under maximum head gradients (estimated to be 50 mgd); 2) downward leakage from the Upper Bedrock Aquigroup (12 mgd); and 3) upward leakage from the Basal Bedrock Aquigroup (3 mgd). Maximum hydraulic gradients would occur when pumping levels reached the top of the Ironton-Galesville aquifer. The practical sustained yield could reach a maximum of 65 mgd if the number of pumping centers were increased, pumping centers were shifted westward, and wells were spaced at greater distances to minimize interference.

The practical sustained yield in north-central and northwestern Illinois is not as dependent on the establishment of large hydraulic gradients as is the case in the Chicago area where vertical recharge is limited. Thus, even
if existing or new pumping centers in these areas were unable to develop hydraulic gradients as large as those suggested by Walton (1964) for the Chicago area, the substantially higher recharge rates west of the Maquoketa Confining Unit border should allow pumpage of comparably large quantities of water from the aquifers.

The practical sustained yield in western Illinois is limited by the same constraints as in the Chicago area, i.e., by the amount of lateral groundwater flow that can be induced toward pumping centers. Also, the Ironton-Galesville is thinner or absent in western Illinois. Currently there are no major pumping centers. In order to maximize the sustained yield in this area, controlled development will be necessary, including judicious placement of pumping centers in proximity to the recharge areas to the north and spacing of wells to minimize interference.

Well Yields

Yields of wells developed in the Midwest Bedrock Aquigroup vary considerably throughout the study area and depend upon the units penetrated as well as the geographic location. Several hundred deep wells in northern Illinois tap several units within the aquigroup. Walton (1962) concluded that the yields of the Ancell aquifer; the Prairie du Chien, Eminence-Potosi, and Franconia Formations; and the Ironton-Galesville aquifer constitute about 15, 35, and 50%, respectively, of the total yield of the Midwest Bedrock Aquigroup. The Ironton-Galesville aquifer is the principal source of groundwater for many municipal and industrial supplies because of its consistently high yield. Figure 33 shows observed well yields for the Midwest Bedrock Aquigroup in northern and western Illinois. Yields in northern Illinois usually exceed 500 gpm and, depending on the depth of penetration, may exceed 1000 gpm. In western Illinois, typical well yields are smaller, because wells in that area generally avoid the more mineralized units of the aquigroup and produce mainly from the Ancell aquifer.
Figure 33. Observed yields of water wells in the Midwest Bedrock Aquigroup
GROUNDWATER QUALITY

Introduction

The water quality of the Cambrian and Ordovician aquifers was evaluated relative to the groundwater flow and geologic units. Geologic and well construction information for about 400 wells was obtained from ISGS and USGS files. Water quality analyses for about 300 wells were obtained from Illinois Environmental Protection Agency (IEPA) and ISWS files and from published reports. USGS additionally collected about 25 single-aquifer-unit water samples from individual wells or packer tests during the study. Four geological cross sections were constructed and water quality data were overlaid. (Cross sections are not necessarily oriented along present or past flow paths.) Concentrations of chemical constituents in water from wells on the cross sections were converted from milligrams per liter (mg/L) to percent milliequivalents per liter (% meq/L) and then plotted on trilinear diagrams (Hem, 1970) to show water types and changes (fig. 34).

It had become apparent during the study that groundwater quality within the aquifers of the Cambrian and Ordovician Systems had both similarities and differences that were related to regional flow systems. Therefore, the intent of this portion of the study was to characterize the water quality of individual aquifers (rather than of aquigroups) where possible. This approach would also provide data that is essential to the regional modeling of the Northern Midwest RASA, which is being carried out by the U.S. Geological Survey as part of its overall RASA report. As a result, it was decided that the most efficacious manner of summarizing groundwater quality was to divide the study area into two general subareas: 1) the portion of north-central and northwestern Illinois in which the upper bedrock aquifers (within the Cambrian and Ordovician Systems) are not confined by shales and in which they become part of the Upper Bedrock Aquigroup (the stippled area of figure 28), which will be designated the "unconfined" area; and 2) the portions of northern and western Illinois that are confined by rocks of the Maquoketa Shale Group and/or rocks of Pennsylvanian or Devonian age. In these areas the upper aquifers of the Ordovician System are part of the Midwest Bedrock Aquigroup. These areas will collectively be called the confined area for purposes of this discussion.
Figure 34. General changes in water type with increasing length of groundwater flow path.
Water Quality of the "Unconfined" Area

The "unconfined" area of the Cambrian and Ordovician aquifers includes a large area of northern Illinois and represents a part of the recharge area of both shallow and deep flow systems (fig. 34). Local confining conditions, caused by fine-grained glacial deposits or dense strata of the Galena-Platteville Unit, are present in the regional "unconfined" area. Principal upper bedrock units are the Galena-Platteville Unit and the Ancell aquifer, with some older Cambrian rocks occurring locally in uplifted areas such as the Sandwich Fault Zone. The quality of groundwater in the "unconfined" area is influenced by local, intermediate, and regional flow systems; strong vertical gradients; and relatively rapid movement of groundwater. Faster movement of groundwater reduces the contact time between rocks and water and results in water with generally low concentrations of dissolved solids, indicating that only moderate changes in water quality occur from points of recharge. Flow systems contain water which is well-mixed vertically because of the strong vertical components of flow. Groundwater from individual rock Units in most of the "unconfined" area cannot be differentiated on the basis of major ion chemistry. A relatively homogeneous chemical system, dominated by calcium, magnesium, and bicarbonate ions, is present from the Basal Bedrock Aquigroup up through the Galena-Platteville Unit. An example of this vertical homogeneity in major ion chemistry is provided by a suite of analyses from packer tests in a deep well in Galena, Illinois (table 6). This well is a flowing well, situated in or near a discharge zone for a deep, intermediate, or regional flow system.

In the "unconfined" area, concentrations of dissolved solids usually range from 250 to 400 mg/L. The water is a calcium/magnesium bicarbonate type (fig. 34 and Creston sample, appendix C). Calcium is the dominant cation, representing greater than 50% meq/L (milliequivalents per liter). Magnesium represents 30-50% meq/L and sodium represents less than 5% meq/L. Bicarbonate is the dominant anion, representing 90% meq/L. Sulfate is generally less than 10% meq/L, and chloride represents less than 2% meq/L. The horizontal and vertical variations in water types are depicted on four cross sections (figs. 35 to 38).
Table 6. Water-Quality Data from the Packer Tests in Limback Well in Galena, Illinois

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Total depth 1489 feet
Flowing well

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*GPAN - Galena-Platteville/Ancell
PEPF - Prairie du Chien/Eminence-Potosi/Franconia
IG - Ironton-Galesville
EMS - Elmhurst/Mt. Simon

Although there is little vertical or areal variation in the water quality of the "unconfined" area, there are two exceptions. The first occurs along the eastern and southern edges of the "unconfined" area on sections B-B' and C-C' (figs. 36 and 37). This area contains water with low concentrations of dissolved solids, usually less than 300 mg/L (appendix C). Calcium is the dominant cation, ranging between 33 and 49% meq/L, but sodium increases to about 33% meq/L as shown in figure 34. Bicarbonate is the dominant anion and represents greater than 90% meq/L. Most significant is a reduction in the concentration of sulfate. This anion does not exceed 2% meq/L, with frequent zero values reported. On section B-B' (fig. 36) this area in Ogle and DeKalb Counties corresponds to a local reducing zone. The second exception to the general vertical and areal homogeneity of the "unconfined" area is found along the southern edge of the "unconfined" area as shown on section C-C' (fig. 37). Here, concentrations of dissolved solids increase from younger to older units. The Ironton-Galesville and Elmhurst-Mt. Simon aquifers contain water of higher dissolved solids concentrations than do the waters of the younger aquifers. Faults which appear on cross
Figure 35. Cross section A-A' from Dubuque, Iowa, to Zion, Illinois, showing geology, dominant anions, and dissolved solids concentration.
Figure 36. Cross section B-B' from Fulton, Illinois, to Chicago, Illinois, showing geology, dominant anions, and dissolved solids concentration.
Figure 37. Cross section C-C' from South Beloit, Illinois, to Minonk, Illinois, showing geology, dominant anions, and dissolved solids concentration
Figure 38. Cross section D-D' from Dubuque, Iowa, to Raritan, Illinois, showing geology, dominant anions, and dissolved solids concentration.
sections B-B', C-C', and D-D' (Pigs. 36-38, respectively) are not of major extent but are included for accuracy and completeness.

Water Quality of the Confined Area

In contrast to the "unconfined" area, significant vertical and areal changes in the chemical character of groundwater occur within the confined area of the Cambrian and Ordovician aquifers. Prior to heavy pumpage in northeastern Illinois, groundwater in the confined area traveled relatively longer flow paths at slower travel rates. The resultant longer time of contact between groundwater and rock units increased the dissolved solids concentration and more directly affected water types.

There are several water types between the calcium-magnesium bicarbonate water of the recharge area and the sodium chloride brines of the deep basin (Fig. 34). The cation evolution is from calcium-magnesium to calcium to sodium, with mixed waters occurring between dominant types. Anion evolution is from bicarbonate to sulfate to chloride, with mixed waters occurring between dominant types.

The pattern of evolution of water type from calcium magnesium bicarbonate to sodium chloride may be modified by geologic structures. Changes of water type across relatively short horizontal distances are associated with the steeply dipping bedrock near La Salle/Peru (fig. 37). Dissolved solids, sodium, and chloride increase significantly; however, there is no sulfate-dominant water type.

Within certain limitations, the general water quality and hydrology of the four units within the confined area of the Cambrian and Ordovician aquifers can be differentiated and discussed separately (fig. 39). The four units are the 1) Maquoketa Confining Unit (not shown in fig. 39), 2) Galena-Platteville and Ancell aquifers, 3) Ironton-Galesville aquifer, and 4) Basal Bedrock Aquigroup (Elmhurst-Mt. Simon aquifer). The limitations that affect area-wide characterization of units are:

1. Water-type changes occur down-dip within aquifer units.
2. Vertical components of flow cause mixing to occur between aquifer units.
3. Composite wells produce water from two or more aquifer units.
4. Data are non-uniformly distributed areally and vertically.
Figure 39. Map of 500 mg/L isocons of dissolved solids for major producing units
Unless otherwise noted, the following discussion is based on data from wells used in the preparation of cross sections A-A’ and B-B’ (figs. 35 and 36), where data are most abundant.

**Maquoketa Confining Unit**

The Maquoketa Confining Unit is the major confining unit of the Midwest Bedrock Aquigroup in northern Illinois but may yield small to moderate supplies of water where the unit is at the bedrock surface (fig. 19). Water from the few available single unit Maquoketa wells generally contains concentrations of dissolved solids of less than 500 mg/L. Calcium and magnesium are usually less than 10% meq/L, and chloride and sulfate are usually insignificant (figs. 34 and 35 and appendix C). Sodium and bicarbonate are both usually greater than 90% meq/L. Higher chloride and sulfate concentrations in some samples are caused by mixing with groundwater from overlying strata such as the glacial drift or Silurian dolomite.

**Galena-Platteville and Ancell Aquifers**

In the northeastern part of the confined area, water in the Galena-Platteville and Ancell (GP-AN) aquifers has a relatively low concentration of dissolved solids as shown in the Illinois Beach State Park test well (appendix C). Southeastward from the "unconfined" area there is a gradual increase in the concentration of dissolved solids (figs. 40 and 41), which is accompanied by a progression from calcium and magnesium to sodium as the dominant cation, and a progression from a bicarbonate to sulfate as the dominant anion.

South of the unconfined area, changes in the water quality occur rapidly over a short distance as the strata dip steeply toward the Illinois basin. In La Salle County, dissolved solids concentrations increase from 500 to 1500 mg/L in fewer than 20 miles (figs. 40 and 41). As shown on cross section C-C’ (fig. 37) the water type across a similar distance changes from a calcium-magnesium bicarbonate type to a sodium chloride type with no evidence of an intermediate sulfate type.

In western Illinois, no significant changes in water quality occur where the GP-AN aquifers are confined by only the Maquoketa Confining Unit. However, when the GP-AN aquifers are confined by the Pennsylvanian-age rocks as well, the water type changes from a calcium-magnesium bicarbonate to a sodium sulfate (cross section D-D’, fig. 38). Associated with the water-type...
Figure 40. Generalized concentrations of dissolved solids in the Galena-Platteville aquifer

Figure 41. Generalized concentrations of dissolved solids in the Ancell aquifer
change is an increase in the dissolved solids concentrations. North of the Pennsylvanian outcrop, concentrations are less than 400 mg/L; under the Pennsylvanian concentrations exceed 1000 mg/L.

**Ironton-Galesville Aquifer**

In northeastern Illinois, the Ironton-Galesville aquifer is regionally the most permeable and most heavily pumped aquifer. High transmissivity reduces the travel time of water in this aquifer relative to travel times in aquifers above and below. In general, water in the Ironton-Galesville has the lowest concentrations of dissolved solids (fig. 42) in the Cambrian and Ordovician aquifers in northeastern Illinois. This may be seen by comparing figs. 40 to 43; it is also shown on cross section B-B’ (fig. 36) and in the water analysis for city well no. 8 in Bloomingdale (appendix C). The water type is calcium bicarbonate, with calcium exceeding 50% meq/L and bicarbonate exceeding 90% meq/L. Changes in water quality of the Ironton-Galesville occur in the easternmost portion of northeastern Illinois, as the bedrock units dip into the Michigan Basin (cross section B-B’; fig. 36). As water moves into the basin from the recharge area, the water type changes from calcium bicarbonate to sodium bicarbonate to sodium sulfate.

Very little water quality data is available to describe the Ironton-Galesville in central and west-central Illinois, although changes in water quality are probably similar to those in the other aquifers in the Midwest Bedrock Aquigroup in central Illinois.

**Basal Bedrock Aquigroup**

The water quality of the Basal Bedrock Aquigroup (Elmhurst-Mt. Simon aquifer) is highly variable; all water types present in the Cambrian and Ordovician aquifers are also present in this single aquifer. Water quality changes from a calcium-magnesium bicarbonate to a sodium-chloride type. The change in water type is associated with increasing depth of penetration into the Elmhurst-Mt. Simon and with southward and eastward movement from the unconfined area. Samples of water from the USGS test well near Zion, which penetrates the entire Mt. Simon, show that water quality changes with depth from sodium-sulfate to sodium chloride type (appendices A, B, and C).

High concentrations of dissolved solids and sodium chloride at depth restrict the use of water from the Basal Bedrock Aquigroup (figs. 43 and 44) for such uses as public and industrial water supplies. Concentrations of
Figure 42. Generalized concentrations of dissolved solids in the Ironton-Galesville aquifer

Figure 43. Generalized concentrations of dissolved solids in the upper part 1200–300 feet) of the Basal Bedrock Aquigroup
Figure 44. Concentration of chloride and dissolved solids versus altitude in the Basal Bedrock Aquigroup
chloride below an elevation of approximately -1600 feet MSL increase at a
rate of about 1000 mg/L per 25 feet of penetration (fig. 44). Dissolved
solids increase about 1400 mg/L per 25 feet of penetration (fig. 44).
Temperature also increases with depth. Temperature logs from the Common-
wealth Edison test well in Stephenson County (STE 28N6E-7.4d) and the U.S.
Geological Survey test well in Lake County (LKE 46N12E-14.6g) (appendix A),
both of which fully penetrate the Elmhurst-Mt. Simon, show an increase from
0.7 to 1.68 degrees Fahrenheit per 100 feet of penetration (fig. 45).

In the upper part of the Mt. Simon Sandstone, shale is interbedded with
sandstone. These shale beds are important in confining highly mineralized
water to the lower part of the Mt. Simon. At the USGS test well, chloride
concentrations are two orders of magnitude higher beneath the shales than
above them.
Figure 45. Temperature logs of two wells in northern Illinois
SUMMARY AND CONCLUSIONS

The Cambrian and Ordovician rocks include major aquifers throughout all of northern Illinois and are also tapped by wells as far south and west as Fulton and McDonough Counties. In northern Illinois approximately 250 municipalities as well as 150 industries derive at least a portion of their water requirements from these sources. This report incorporates both previously collected and reported data as well as data collected during the study. The updated information was used in the preparation of fifteen maps showing the thickness and surface configuration of geologic units. The report reflects the current state of understanding of the geologic, hydrologic, and water quality character of the aquifers. The scope of this understanding can be summarized by the following key conclusions:

1. Storage coefficients of the Midwest Bedrock Aquigroup under artesian conditions range from 1.6x10⁻⁴ to 6.8x10⁻⁴ and average 3.9x10⁻⁴. Storage coefficients have not been evaluated where the system is now dewatered by pumpage. Storage coefficients in the Basal Bedrock Aquigroup range from 1.3x10⁻⁴ to 5.2x10⁻⁴.

2. Transmissivities in the Midwest Bedrock Aquigroup range from 10,000 to 20,000 gpd/ft in northeastern Illinois and are generally increased by local or regional thickening of the Ancell and Ironton-Galesville aquifers. In north-central Illinois, where the Maquoketa Confining Unit is absent, the Galena-Platteville Unit contributes significantly to the transmissivity, and regional values generally exceed 20,000 gpd/ft. Transmissivities in the Basal Bedrock Aquigroup range from 980 to 10,600 gpd/ft.

3. Total withdrawals from wells finished in Cambrian and Ordovician rocks averaged 278.6 mgd between 1971 and 1980 but declined to 258.4 mgd in 1980. The largest withdrawals occur in Cook, DuPage, Kane, and Will Counties, where 1980 deep pumpages averaged 67.2 mgd, 28.4 mgd, 27.7 mgd, and 23.7 mgd, respectively.

4. Water level data suggest that, prior to development of the Midwest Aquigroup, a groundwater ridge existed in parts of McHenry, Kane, and DeKalb Counties, and groundwater moved southeastward toward Chicago and westward toward the Rock River. A second groundwater ridge existed in
portions of Jo Daviess, Stephenson, Carroll, and Ogle Counties. Ground-
water discharge is believed to have occurred along portions of the Rock 
River; along the Illinois River in Grundy, LaSalle, Calhoun, and Jersey 
Counties; along the Mississippi River above Clinton, Iowa; and along the 
Pecatonica, Galena, -and Apple Rivers.

5. Groundwater withdrawals have caused water levels to decline as much as 
900 feet in parts of Cook, DuPage, and Will Counties. Dewatering of the 
Galena-Platteville Unit is occurring at Aurora and Elgin, while at 
pumping centers at Joliet and in northern Cook County and eastern 
DuPage-western Cook Counties, all of the Galena-Platteville Unit and the 
upper part of the Ancell aquifer have been dewatered.

6. Maximum recharge rates, through the Maquoketa Confining Unit in north-
eastern Illinois and outside the area where the Maquoketa is present, 
have been estimated to be 3060 gpd/sq mi and 42,000 gpd/sq mi, respec-
tively. Maximum recharge has probably- been reached in areas of heavy 
pumpage in the northeast, while in areas to the west of the Maquoketa, 
recharge is at about half of the maximum estimated rate.

7. The practical sustained yield of the Midwest Aquigroup, estimated by 
Walton (1964) to be 65 mgd for the eight-county northeastern Illinois 
areas, has been exceeded every year since about 1958. In north-central 
and northwestern Illinois, development has not exceeded the practical 
sustained yield, which is probably at least as great as that for north-
eastern Illinois. The potential for groundwater development in western 
Illinois is limited by the amount of lateral inflow which can be induced 
and also by poor water quality.

8. Wells in northern Illinois usually exceed 500 gpm in yield and may 
 exceed 1000 gpm. In western Illinois, typical well yields are smaller 
because wells generally do not penetrate the more mineralized deeper 
units and tap only the Ancell aquifer.

9. Groundwater in the "unconfined" area of the Cambrian and Ordovician 
aquifers is chemically homogeneous and low in total dissolved solids. 
Concentrations of dissolved solids are generally between 250 and 400 
 milligrams per liter (mg/L). Water is a calcium-magnesium bicarbonate 
type, with calcium greater than 50% milliequivalents per liter (meq/L), 
magnesium between 30 and 50% meq/L, and bicarbonate about 90% meq/L.
10. In contrast to the "unconfined" area, significant vertical and areal changes in the chemical character of groundwater occur in the confined area of the Cambrian and Ordovician aquifers. These changes are related to the longer Plow paths and travel times in the confined area. Cation evolution is from calcium-magnesium to calcium to sodium, and anion evolution is from bicarbonate to sulfate to chloride.

11. Hydraulic stress imposed by heavy pumpage of an aquifer modifies the pattern of chemical change evolution. For example, increased concentrations of sodium and chloride in the Ironton-Galesville aquifer are due at least in part to increasing head differences between this aquifer and the underlying, more saline, Elmhurst-Mt. Simon aquifer.

12. In northeastern Illinois the Ironton-Galesville aquifer generally has the lowest dissolved solids concentrations in the confined part of the Cambrian and Ordovician aquifers. The better quality of water from the Ironton-Galesville is probably attributable to its greater permeability and larger production, which result in reduced travel time for water moving from the recharge area.

13. In northeastern Illinois water from the upper 300 or 400 feet of the Basal Bedrock Aquigroup is normally of sufficient quality to be used for public or industrial supplies. Below an elevation of about -1600 feet MSL, concentrations of chlorides increase about 1000 mg/L per 25 feet of penetration. Concentrations of dissolved solids similarly increase about 1400 mg/L per 25 feet of penetration.

14. Temperature of groundwater also increases with depth in the Basal Aquigroup. Temperature logs from two wells fully penetrating this aquifer show increases of 0.7 and 1.68 degrees Fahrenheit per 100 feet of penetration.
SELECTED BIBLIOGRAPHY


APPENDIX A

DATA FROM KEY WELLS

Wells listed below are key or essential wells used in preparing various parts of the text and/or illustrations or wells which are representative of the counties in which they are located. The well listing is by no means comprehensive and represents only a small portion of the Cambrian and Ordovician wells in the study area.

The well-numbering system used in the appendix is based on the location of the well, and uses the county, township, range, and section for identification. The well number consists of five parts: a three-letter county abbreviation, township, range, section, and coordinates within the section. Sections are divided into rows of one-eighth mile squares. Each one-eighth mile square contains 10 acres and corresponds to a quarter of a quarter of a quarter section. A normal section of one square mile contains eight rows of one-eighth-mile squares; an odd-size section contains more or fewer rows. Rows are numbered from east to west and lettered from south to north as shown below. Where there is more than one well in a 10-acre square, they are identified by arabic numbers after the lower case letter in the well number.

The number of the well shown is WIL 35N10E–5.4c
County abbreviations used are:

ADM = Adams  IRO = Iroquois  OGL = Ogle
BNE = Boone  JDV = Jo Daviess  PEO = Peoria
BRN = Brown  KNE = Kane  PKE = Pike
BUR = Bureau  KNK = Kankakee  PUT = Putnam
CAL = Calhoun  KEN = Kendall  RIS = Rock Island
CAR = Carroll  KNX = Knox  SCH = Schuyler
COK = Cook  LKE = Lake  STK = Stark
DEK = DeKalb  LAS = LaSalle  STE = Stephenson
DUP = DuPage  LEE = Lee  TAZ = Tazewell
FRD = Ford  LIV = Livingston  VER = Vermillion
FUL = Fulton  LMD = McDonough  WAR = Warren
GRY = Grundy  MCH = McHenry  WIS = Whiteside
HAN = Hancock  MCL = McLean  WIL = Will
HND = Henderson  MRS = Marshall  WIN = Winnebago
HRY = Henry  MER = Mercer  WDF = Woodford

Other abbreviations used in the report are:

P = Public Supply  PEPF = Prairie du Chien, Eminence-Potosi, Franconia
I = Industrial Supply  IG = Ironton-Galesville
R = Rural (non-irrigation)  EC = Eau Claire
A = Abandoned  MS = Mt. Simon
T = Test Well  PC = Precambrian
QUAT = Pleistocene (Quaternary)  DL = Driller's Log
PENN = Pennsylvanian  SS = State Geological Survey, Sample Set Number
MISS = Mississippian  GP = Galena-Platteville
DEV = Devonian  AN = Ancell (Glenwood-St. Peter)
SIL = Silurian  PDC = Prairie du Chien
MAQ = Maquoketa  EP = Eminence-Potosi
CO = Cambrian-Ordovician  FR = Franconia
(Midwest Bedrock Aquigroup)  CTY WELL = SGS designated county well number
GP = Galena-Platteville  W = State Water Survey, water quality analysis
AN = Ancell (Glenwood-St. Peter)  E = Illinois EPA, water quality analysis
PDC = Prairie du Chien  U = U.S. Geological Survey, water quality analysis
EP = Eminence-Potosi  FR = Franconia

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**SOLIDS (MG/L)**

**REMARKS**

Dry and Aband.

Single Unit

Backfilled to 1400'

Borehole logged

Single Unit AN

Power

Single Unit IG

City #2 AN, MS

City #6
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<th>PRINC EQUIP</th>
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<th>TRANS-MISSIVITY (GPD/FT)</th>
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**Remarks:**

- **Well Drilled:** Indicates the type of drilling method used.
- **Depth:** The total depth of the well, measured from the ground surface to the point where the casing is extended.
- **Casing Diameter:** The diameter of the casing used to protect the well from external damage.
- **Water Level:** The depth below the ground surface where the water is present.
- **Mineral Analyses:** The number of mineral analyses performed on the well water.
- **Total Solids:** The total dissolved solids present in the well water, measured in mg/L.
APPENDIX B

DRILLING AND TESTING

New data collected for this report include data from the drilling of a deep test well to Precambrian bedrock in Lake County, select packer tests in this test well plus two other deep wells, and borehole logging of the three packed wells plus several other representative Cambrian and Ordovician wells.

Illinois Beach Park Test Well (LKE 46N12E-14.6f)

This is a 10-inch well, located in the Camp Logan part of Illinois Beach State Park, and was drilled to a depth of 3460 feet into Precambrian bedrock as a part of this study (Nicholas et al., 1984). The Ancell, Ironton-Galesville, and Elmhurst-Mt. Simon aquifers were packed off, tested, and sampled during the period December 1980 to September 1981 (see appendix A). The following borehole logs were run in this well: spontaneous potential, resistivity, natural gamma, caliper, fluid conductivity, temperature, density, and porosity. Upon completion, piezometers were installed in the lower and upper Elmhurst-Mt. Simon and Ironton-Galesville aquifers, with open-hole completion into the Galena-Platteville unit and Ancell aquifer.

See appendices A and C for additional information on this well.

City of Rockford Unit Well #4 (WIN 44N1E-34.6h)

This 20-inch diameter, 1219-foot deep well is part of Rockford’s municipal water supply system and was tested during a down period in September, 1980. Six packer tests in five different zones were conducted and water samples were taken (appendix A). Natural gamma, spontaneous potential, resistivity, caliper, and fluid conductivity borehole logs were run.
Limback Well in the City of Galena (JDV 28N1W-13.78)
This is a privately-owned, 12-inch diameter, flowing well, 1491 feet deep. Four zones were packed and tested (appendices A and C). Several geophysical borehole logs were also run: natural gamma, spontaneous potential, resistivity, caliper, fluid conductivity, temperature, and flow meter tests.

Additional Borehole Geophysical Logging
The following Cambrian-Ordovician wells were borehole logged during this investigation:

Aledo City Well #2 (MER 14N3W-17.4a): gamma, spontaneous potential, resistivity

Bensenville City Well #6 (DUP 40N11E-26.3h1): gamma, spontaneous potential, resistivity, caliper, fluid conductivity, temperature

Carol Stream City Well #4 (DUP 40N10E-32.1c): gamma, spontaneous potential, resistivity, caliper, fluid conductivity, temperature

Elgin-Schuler St. Well (KNE 41N8E-14.8b): gamma, spontaneous potential, resistivity, caliper, fluid conductivity, temperature, flow meter

Mt. Prospect City Well #17 (COK 42N11E-27.1h): gamma, spontaneous potential, caliper, temperature

Rochelle City Well #10 (OGL 40N1E-36.2h): gamma, spontaneous potential, resistivity, caliper, fluid conductivity, temperature

Sterling City Well #2 (WTS 21N5E-22.1e): gamma, spontaneous potential, resistivity, caliper, fluid conductivity

Silvis City, Well #6 (RIS 17N1E-5.6dl): gamma, spontaneous potential, resistivity, caliper, fluid conductivity, temperature, flow meter
APPENDIX C

SELECTED CHEMICAL ANALYSES

Seven analyses are shown. Five of these are representative of water from single aquifer units and two are representative of a mixture of water from the aquifer units. The Maquoketa Shale Group, although generally considered an aquitard rather than an aquifer, does yield small supplies, so a typical sample from this unit is included.

"Unconfined" Area - Elmhurst-Mt. Simon Aquifer

An Elmhurst-Mt. Simon aquifer water sample was collected from the Limback well in the Village of Galena in Jo Daviess County (JDV 28N1W-24.2b). This is a 1491-foot flowing well. The well was packer-tested and sampled in four zones with this analysis representing the Elmhurst-Mt Simon aquifer between 981 feet and the bottom of the hole. This analysis is generally representative of the recharge area and, as such, is similar to the analyses for overlying aquifers.

USGS Lab Number 299087

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Reducing Zone - Galena-Platteville and Ancell Aquifers

A water sample was collected from a well in the Village of Creston in Ogle County (OGL4ON2E-23.1f). This is a 585-foot well cased to 417 feet and open to the Galena-Platteville and Ancell aquifers. The sample is typical of the reducing zone mentioned in the water quality section.
Maquoketa "Aquifer"

A water sample was collected from a well in the Turnberry Subdivision about 1-1/2 miles south of Lakewood in McHenry County (MCH 43N7E-11.4f). This is a 12-inch well, 395 feet deep with a surface elevation of 920 feet. The well is cased to the dolomitic part of the Maquoketa. The well is located in the outer edge of the confined area where the Maquoketa yields small supplies of water.

Discharge Area - Ancell Aquifer

A water sample was collected from the Ancell aquifer in the USGS test well in Illinois Beach State Park (Camp Logan Campground) in northeastern Lake County (LKE 46N2E-14.6g). This is a 3460-foot deep test well penetrating Precambrian bedrock. The land surface is 586 feet and the well is cased.
with 600 feet of steel casing down to the top of the Calena Group. This well was packer-tested and sampled in several zones. This analysis is from the Ancell aquifer between 896 feet and 1046 feet in depth.

**USGS Lab No. 246077**

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**Discharge Area - Ironton-Galesville Aquifer**

A water sample was collected from the Ironton-Galesville aquifer from Bloomingdale Well No. 8 in DuPage County (DUP 40N10E-20.4g1). This is a 1,400-foot well drilled to the top of the Eau Claire confining unit. It is cased with 16-inch steel casing to 1174 feet down to the Franconia Formation. For practical purposes the well can be considered to be single-unit Ironton-Galesville.

**IEPA Lab No. B42608**

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**Discharge Area - Elmhurst - Upper Mt. Simon Aquifer**

This water sample is from a packer test in the upper Mt. Simon aquifer from 1355 feet to 1920 feet in the USGS test well (LKE 46N12E-14.6g) described above.

**USGS Lab No. 351038**

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**Discharge Area - Lower Mt. Simon Aquifer**

This is a point sample from the lower Mt. Simon aquifer at a depth of 3120 feet in the USGS test well (LKE 46N12E-14.6g) described above.

**USGS Lab No. 19041**

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