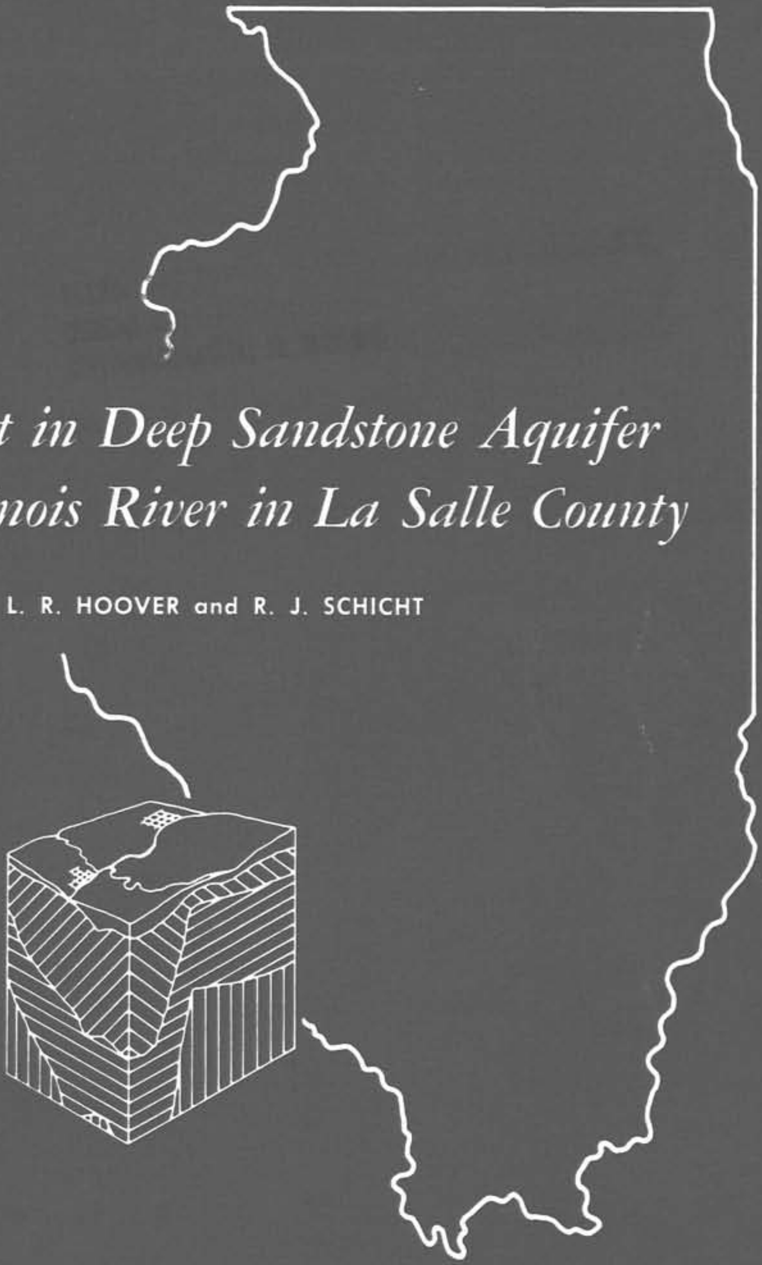
NVESTIGATION 59

INOIS

DEPARTMENT OF REGISTRATION AND EDUCATION

Development in Deep Sandstone Aquifer along the Illinois River in La Salle County

by L. R. HOOVER and R. J. SCHICHT



ILLINOIS STATE WATER SURVEY

URBANA

1967

REPORT OF INVESTIGATION 59

Development in Deep Sandstone Aquifer along the Illinois River in La Salle County

by L. R. HOOVER and R. J. SCHICHT

Title: Development in Deep Sandstone Aquifer along the Illinois River in La Salle County.

Abstract: Large supplies of groundwater are developed from the Cambrian-Ordovician aquifer in La Salle County for municipal and industrial use. Yields of wells normally exceed 500 gpm. Pumpage was 11.2 mgd in 1963. Municipal wells at Peru and Oglesby are among the deepest in the state producing potable water, over 2800 feet. As a result of heavy pumping the original slope of the piezometric surface has steepened, and water levels have declined more than 100 feet in pumping centers. Recharge from vertical leakage based on flow-net analysis was estimated to be 14,000 and 7200 gallons per day per square mile in the northern and southern parts of the area, respectively. Hydraulic properties of the aquifer and its confining bed were estimated from available data. Estimates of future nonpumping water-level declines in the aquifer were made from a model aquifer and mathematical model. Estimated declines by the year 2000 are 195 feet at Ottawa and 98 feet at Peru. Sufficient drawdown is available for further development. This study provides data for planning and development of groundwater resources for the area.

Reference: Hoover, L. R., and R. J. Schicht. Development in Deep Sandstone Aquifer along the Illinois River in La Salle County. Illinois State Water Survey, Urbana, Report of Investigation 59, 1967.

Indexing Terms: aquifer characteristics, aquifer development, Cambrian-Ordovician aquifer, groundwater, Illinois, water supply, water well yields.

STATE OF ILLINOIS
HON. OTTO KERNER, Governor

DEPARTMENT OF REGISTRATION AND EDUCATION
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STATE WATER SURVEY DIVISION
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URBANA

1967

Printed by authority of the State of Illinois—Ch. 127, IRS, Par. 58.29

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Development in Deep Sandstone Aquifer along the Illinois River in La Salle County

by L. R. HOOVER and R. J. SCHICHT

SUMMARY

Large supplies of groundwater are developed from the Cambrian-Ordovician aquifer along the Illinois River in La Salle County from Peru to Marseilles for municipal and industrial use. . The coefficient of transmissibility of the Cambrian-Ordovician aquifer ranges from 13,400 to 22,000 gallons per day per foot (gpd/ft). A coefficient of storage of 0.0006 applies for pumping periods of several years or more.

Wells uncased through most units of the Cambrian-Ordovician aquifer have observed specific capacities ranging from 5.3 to 19.8 gallons per minute per foot (gpm/ft) and averaging 10.5 gpm/ft. Yields of wells in the Cambrian-Ordovician aquifer normally exceed 500 gpm.

Pumpage from the Cambrian-Ordovician aquifer increased from 1.8 million gallons per day (mgd) in 1900 to 11.2 mgd in 1963. Of the 1963 pumpage, 44.6 percent was urban, 46.4 percent was industrial, and 9.0 percent was for rural and livestock use. Pumpage is largely concentrated in two pumping centers, at La Salle-Peru-Oglesby and at Ottawa. Pumpage in 1963 in the La Salle-Peru-Oglesby area was 2.7 mgd, and was 5.7 mgd at Ottawa.

West of the La Salle Anticline wells vary in depth from about 1000 to 2800 feet. Municipal wells at Peru and Oglesby are among the deepest in the state producing potable water. Well depths east of the La Salle Anticline range from about 400 to 1200 feet, penetrating either Ordovician or a combination of Cambrian and Ordovician Formations.

The piezometric surface under natural conditions was relatively featureless and sloped gently toward the Illinois River. There was some leakage from the Cambrian-Ordovician aquifer into parts of the Illinois River. As a result of heavy pumping, the slope of the piezometric surface has steepened, and water levels have declined more than 100 feet in pumping centers. Leakage into the river in 1963 was estimated to be negligible.

Recharge is from vertical leakage through confining beds in the glacial drift or overlying bedrock formations. Recharge to the Cambrian-Ordovician aquifer from vertical leakage based on flow-net analysis of the 1963 piezometric surface map was estimated to be 14,000 gallons per day per square mile (gpd/sq mi) in the northern one-half of the area and about 7200 gpd/sq mi in the southern one-half. The leakage coefficient of the confining bed in the northern one-half of the area was estimated to be 1.4×10^{-5} gallons per day per cubic foot (gpd/cu ft).

Estimates of future nonpumping water-level declines in the aquifer were made from a model aquifer and mathematical model. On the basis of extrapolated pumpage for the year 2000 (12 mgd at Ottawa and 6 mgd at La Salle-Peru-Oglesby) and the effects of dewatering a part of the aquifer at Ottawa, water-level declines by the year 2000 will be 195 feet at Ottawa and 98 feet at La Salle-Peru-Oglesby. Sufficient drawdown is available for further development of the resource after the year 2000.

The effects of expected increases in pumpage from the Cambrian-Ordovician aquifer in the Chicago region, at Morris, and in De Kalb County were not considered. It is recommended that an electric analog model of the Cambrian-Ordovician aquifer in northern Illinois be constructed to aid in forecasting the effects of further development on water levels not only in the Illinois Valley area but in other areas of heavy groundwater withdrawals from the aquifer.

South of the Illinois River the water from the Cambrian-Ordovician aquifer is highly mineralized. The southern limit of its potable water (1500 parts per million) lies several miles south of the study area.

INTRODUCTION

Large supplies of groundwater for municipal and industrial use are developed from the Cambrian-Ordovician aquifer along the Illinois River in La Salle County. This report evaluates the effects of further groundwater development in the Cambrian-Ordovician aquifer in the area. The geohydrologic characteristics of the Cambrian-Ordovician aquifer are reviewed and an analysis of past, present, and probable future development of the resource is presented. Basic geologic, hydrologic, and chemical data, maps, and interpretations pertinent to the area are included to aid in water resource planning.

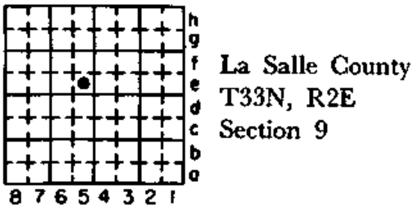
Groundwater development of the Cambrian-Ordovician aquifer in northeastern Illinois was studied in detail by Suter et al. (1959). Additional study is needed in northwestern Illinois and along other parts of the Illinois River where the aquifer is a source of supply for industries and several large municipalities.

Although this report summarizes present-day knowledge of the development of the Cambrian-Ordovician aquifer in the area, the information and conclusions may be modified and expanded from time to time as more data are obtained.

The geology of the area has received considerable study and many reports have been published. The major reports are listed in the references for this investigation. Information on the Cambrian-Ordovician aquifer in the Chicago region given in a cooperative report (Suter et al., 1959) issued by the State Water Survey and State Geological Survey and a study by Walton and Csallany (1962) was invaluable in interpreting geohydrologic data in the study area.

Well-Numbering System

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



The number of the well shown is: LAS 33N2E-9.5e. 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. Any number assigned to the well by the owner is shown in parentheses after the location well number. The abbreviations used for counties are:

BUR	Bureau	LAS	La Salle
DEK	De Kalb	LEE	Lee
PUT	Putnam		

Other abbreviations used in the tables are: (V) Village owned and (C) City owned.

Acknowledgments

This report was prepared under the general supervision of William C. Ackermann, Chief of the Illinois State Water Survey, and H. F. Smith, Head of the Hydrology Section. J. W. Brother, Jr., and William Motherway, Jr., prepared the illustrations. Many former and present members of the State Water Survey and State Geological Survey wrote earlier special reports which have been used as reference material, or aided the authors indirectly in preparing this report. Consulting engineers, well drillers, municipal officials, and many industrial firms and other well owners were most cooperative and helpful in making information on wells available.

GEOGRAPHY AND CLIMATE

Detailed study was confined to a rectangular area of about 432 square miles, hereafter referred to as the study area. The study area (figure 1) is in La Salle County about 80 miles west-southwest of Chicago. It extends about nine miles on either side of the Illinois River from the La Salle-Bureau County line to the city of Marseilles, a distance of about 24 miles. The study area encompasses the major municipalities of Peru, La Salle, Oglesby, Ottawa, and Marseilles. A general study area in north-central Illinois (figure 1) includes most of La Salle County, all of Putnam and Lee Counties, and parts of De Kalb and Bureau Counties.

The study area is located in the Bloomington Ridged Plain subdivision near the center of the Central Lowland Province, a glaciated lowland that stretches from the Appalachian Plateau on the east to the Great Plains of Kansas, Nebraska, and the Dakotas on the west.

The study area consists largely of gently rolling upland plains crossed occasionally by low, broad ridges. The Illinois River and its principal tributaries, the Vermilion and Fox Rivers, are cut well below the upland plains. Immediately adjacent to these streams the land surface is dissected by many small tributaries. The elevation of the land surface declines from about 700 feet a few miles north and south of the river valley to about 450 feet in the Illinois River floodplain. The Illinois River Valley varies from 1 to 2 miles wide. Drainage in the area is primarily toward the Illinois River and its principal tributaries.

Climate of the study area, which lies in the north temperate zone, is characterized by warm summers and moderately cold winters. Graphs of annual and mean monthly precipitation at Peru are given in figures 2 and 3, respectively.

According to U. S. Weather Bureau records at La Salle-

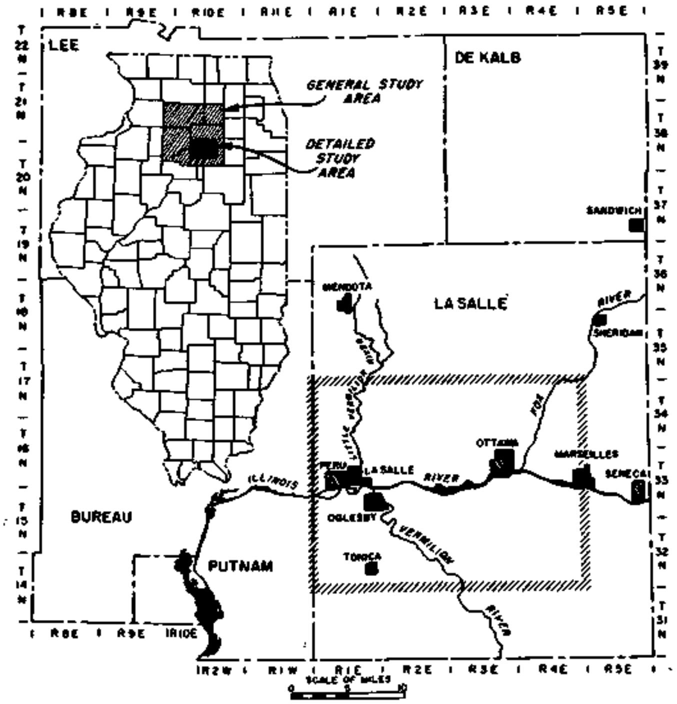


Figure 1. Location of study area

Peru the mean annual precipitation is 32.79 inches. On the average, the months of greatest precipitation are April, May, and June, each having more than 3.5 inches. February is the month of least precipitation, having slightly more than 1.5 inches.

The annual maximum precipitation amounts occurring on an average of once in 5 and once in 50 years are 38 and 48 inches, respectively; annual minimum amounts expected for the same intervals are 26 and 22 inches, respectively. Amounts are based on data given in the Atlas of Illinois Resources, section 1 (1958). The mean annual snowfall is 27 inches.

Based on U. S. Weather Bureau records at La Salle-Peru, the mean annual temperature is 52.2 F. June, July, and August are the hottest months with mean temperatures of 72.8, 77, and 75.3 F, respectively, January is the coldest month with a mean temperature of 26.5 F.

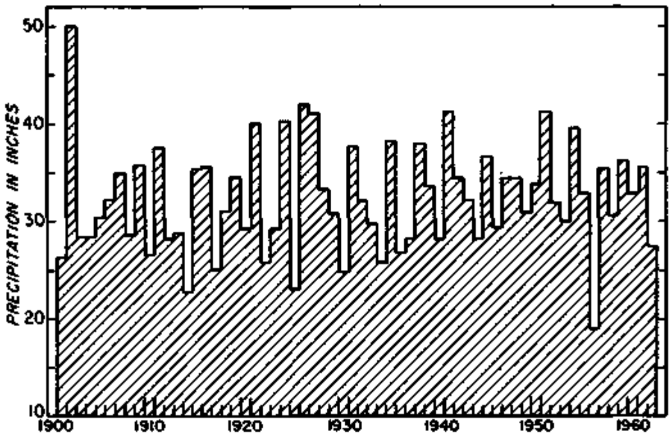


Figure 2. Annual precipitation at La Salle-Peru

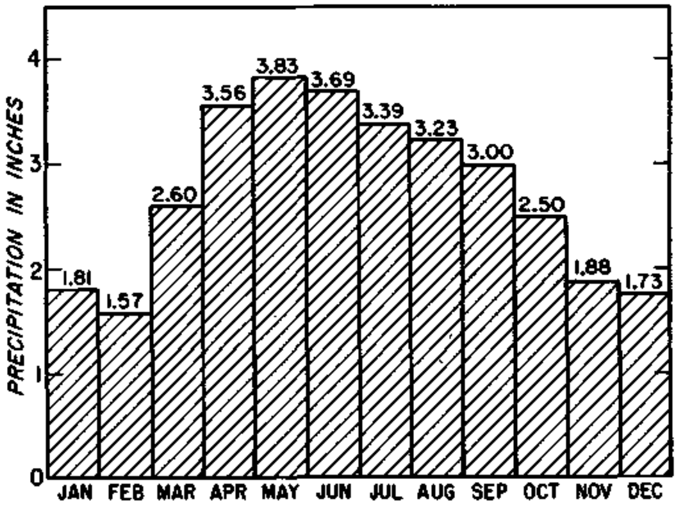


Figure 3. Mean monthly precipitation at La Salle-Peru

GEOLOGY AND HYDROLOGY

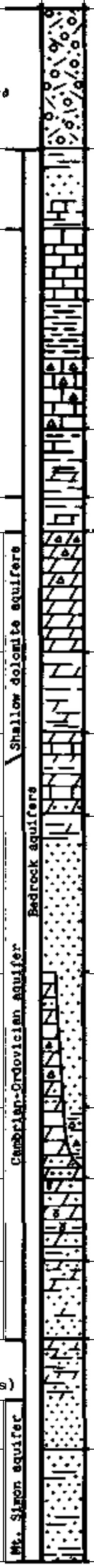
This report is concerned primarily with the development of groundwater resources from the Cambrian-Ordovician aquifer in the vicinity of La Salle, Peru, Oglesby, and Ottawa. Other rocks are considered only with respect to their relation to the geohydrologic conditions of the Cambrian-Ordovician aquifer.

The geologic nomenclature and characteristics, drilling and casing conditions, and water-yielding properties of the bedrock in northern Illinois are summarized in table 1. The sequence, structure, and general characteristics of the rocks are shown in the cross sections in figures 4, 5, and 6, and locations of the cross sections are shown in figure 7. The areal geological map of the bedrock surface is shown in figure 8. For further details of the geology the reader is referred to Sauer (1916), Cady (1920), Willman and Payne (1942), Horberg (1950), Randall (1955), and Suter et al. (1959). The following sections are based largely on these reports.

Cambrian Rocks

Rocks of Cambrian age overlie relatively impermeable crystalline Precambrian rocks which act as a barrier to the downward movement of groundwater. The Cambrian rocks have been divided into five geohydrologic units (Suter et al., 1959). In ascending order the units are Mt. Simon sandstone and sandstones of the lower Eau Claire

Table I. Generalized Stratigraphy and Water-Yielding Properties of Rocks in Northern Illinois

SYSTEM	SERIES	GROUP OR FORMATION	GEOHYDROLOGIC UNITS	LOG	APPROXIMATE RANGE IN THICKNESS (ft)	DESCRIPTION	DRILLING AND CASING CONDITIONS	WATER-YIELDING PROPERTIES
Quaternary	Pleistocene		Glacial drift aquifers		0-500	Unconsolidated clay, silt, sand, gravel, and boulders deposited as till, outwash, pond water deposits, and loess	Boulders, heaving sand locally; sand and gravel wells usually require screens and development; casing required in wells into bedrock	Probabilities for ground-water development range from poor to excellent; outwash sand and gravel yield more than 1000 gpm to walls at places; large supplies generally obtained from permeable outwash in major valleys; glacial aquifers used for many small water supplies because they are shallow
Pennsylvanian		McLeansboro Carbondale Tradewater Caseyville			0-600	Mainly shale with thin limestone, sandstone, and coal beds	May require casing because of shale caving and poor-quality water	Generally unfavorable as an aquifer; locally domestic and farm supplies obtained from thin limestone and sandstone beds
Mississippian	Valmeyer	St. Louis-Salem			0-100	Limestone		Water yielding where creviced; too thin to be important source of water in most of area
		Warsaw			0-100	Shale	Casing required	Not water yielding at most places
		Keokuk-Burlington			0-200	Cherty limestone		Generally creviced and water yielding; dependable aquifer for small supplies in western Illinois
	Kinderhook				0-300	Shale with limestone and dolomite	Casing required	Not water yielding at most places; locally limestones within shale are source of small farm supplies
Devonian					0-200	Thin limestone, shale, & sandstone beds		Not normally a source of water because of a lack of cracks or solution openings
Silurian	Niagaran	Port Byron Racine Waukesha Joliet	Silurian		0-500	Dolomite; silty at base, locally cherty	Upper part usually weathered and broken; extent of crevicing varies widely	Some wells yield more than 1000 gpm; not consistent; crevices and solution channels more abundant near surface
	Alexandrian	Kankakee Edgewood						
Ordovician	Cincinnatian	Maquoketa	Maquoketa		0-250	Shale, gray or brown; locally dolomite and/or limestone, argillaceous	Shale requires casing	Shales, generally not water yielding, act as confining beds between shallow and deep aquifers; crevices in dolomite yield small amounts of water
	Mohawkian	Galena Decorah Platteville	Galena-Platteville		220-350	Dolomite and/or limestone, cherty, sandy at base, shale partings	Crevicing common only where formations underlie drift; top of Galena usually selected for hole reduction and seating of casing	Where formation lies below shales, development and yields of crevices are small; where not capped by shales, dolomites are fairly permeable
		Glenwood	Glenwood-St. Peter		50-650	Sandstone, fine- and coarse-grained; little dolomite; shale at top Sandstone, fine- to medium-grained; locally cherty red shale at base	Lower cherty shales cave and are usually cased; friable sand may slough	Small to moderate quantities of water; coefficient of transmissibility probably averages about 15 percent of that of Cambrian-Ordovician aquifer
	Chazyan	St. Peter						
	Prairie du Chien	Shakopee New Richmond Oneota	Prairie du Chien		0-400	Dolomite, sandy, cherty; sandstone. Sandstone interbedded with dolomite, white to pink, coarse-grained, cherty, sandy	Crevices encountered locally in the dolomite, especially in Trempealeau; casing generally not required	Crevices in dolomite and sandstone generally yield small to moderate quantities of water; Trempealeau locally well creviced and partly responsible for exceptionally high yields of several deep wells; coefficient of transmissibility probably averages about 35 percent of that of Cambrian-Ordovician aquifer
Cambrian	St. Croixian	Trempealeau	Trempealeau		0-225	Dolomite, white, fine-grained, geodic quartz, sandy at base		
		Franconia	Franconia		45-175	Dolomite, sandstone, and shale, glauconitic, green to red, micaceous		
		Ironton	Ironton-Galesville		105-270	Sandstone, fine- to medium-grained, well sorted, upper part dolomitic	Amount of cementation variable; lower part more friable; sometimes sloughs	Most productive unit of Cambrian-Ordovician aquifer; coefficient of transmissibility probably averages about 50 percent of that of Cambrian-Ordovician aquifer
		Galesville						
		Eau Claire	Eau Claire (upper and middle beds)		235-450	Shale and siltstone, dolomitic, glauconitic; sandstone, dolomitic, glauconitic	Casing not usually necessary; locally weak shales may require casing	Shales generally not water yielding; act as confining bed between Ironton-Galesville and Mt. Simon
			lower beds					
		Mt. Simon	Mt. Simon		1000-2000+	Sandstone, coarse-grained, white, red in lower half; lenses of shale and siltstone, red, micaceous	Casing not required	Moderate amounts of water, permeability intermediate between that of Glenwood-St. Peter and Ironton-Galesville
Precambrian crystalline rocks								

After Sute et al.. 1959; and Selkregg and Kempton. 1958)

Formation, middle and upper beds of the Eau Claire Formation, Ironton-Galesville sandstone, Franconia Formation, and Trempealeau dolomite. In addition, in this study the Jordan Formation is discussed. The Jordan Formation is not listed in table 1. However, Willman and Payne (1942) believe it underlies all of the study area.

The Mt. Simon sandstone and the lower sandstones of the Eau Claire Formation are hydrologically interconnected in northern Illinois, and they collectively are called the Mt. Simon aquifer (Suter et al., 1959). Along the Illinois River Valley between Spring Valley and Peru, no wells have been drilled into the Mt. Simon aquifer. According to Willman and Payne (1942), the Mt. Simon may be an important aquifer in southern De Kalb, northern La Salle, and eastern Lee Counties where it lies at depths of only 600 to 1000 feet.

According to Walton and Csallany (1962), groundwater in the Mt. Simon aquifer occurs under leaky artesian conditions because the aquifer is overlain by confining beds of the Eau Claire Formation. Significant differences in hydrostatic head between the Mt. Simon aquifer and shallower bedrock aquifers have been reported in many areas. Data are not available on water levels in wells in the Mt. Simon aquifer; however, Walton and Csallany (1962) concluded that in the Chicago region during 1960 the hydrostatic head in the Mt. Simon aquifer was probably less than

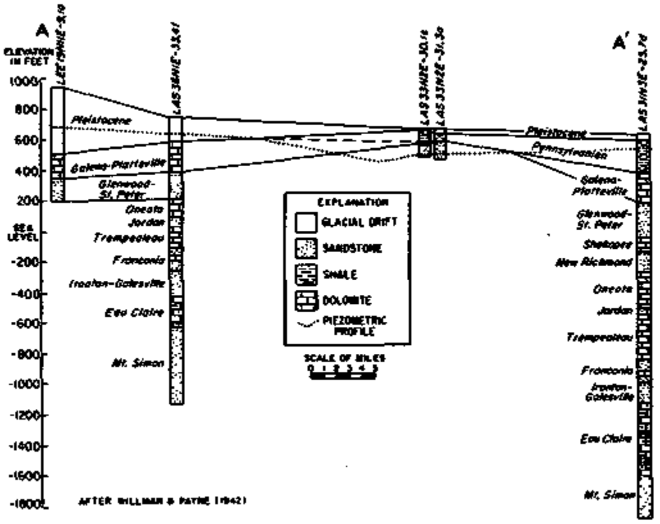


Figure 4. Geologic cross section A—A' and piezometric profile

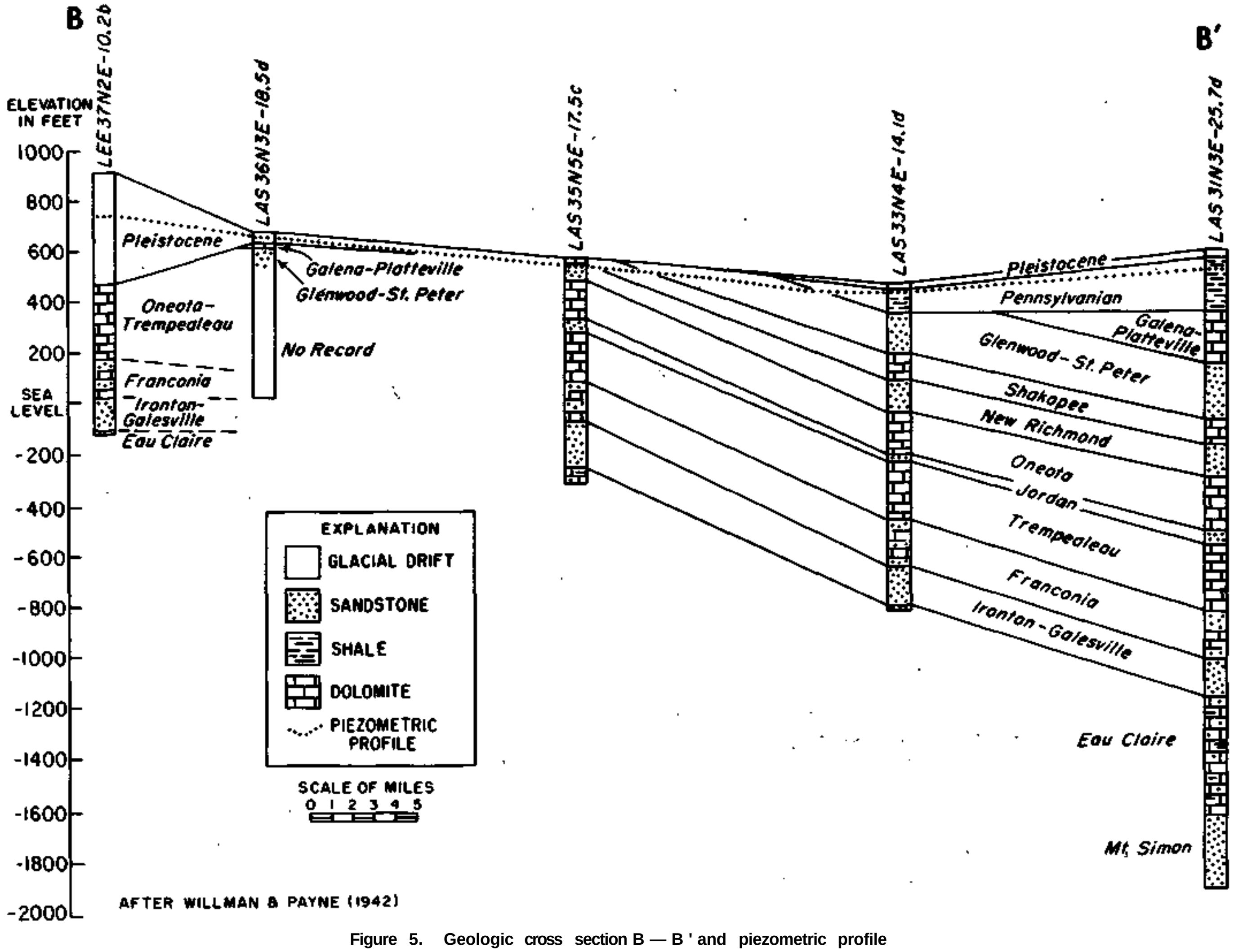


Figure 5. Geologic cross section B — B ' and piezometric profile

100 feet higher than hydrostatic heads in the overlying bedrock aquifers.

The middle and upper zones of the Eau Claire Formation form a unit which consists of shales, dolomites, and shaly dolomitic sandstones that grade laterally from one to another within short distances and have very low permeabilities. The unit acts as a confining bed between the overlying Ironton-Galesville sandstone and the Mt. Simon aquifer. Walton and Csallany (1962) stated that south of Chicago the Eau Claire Formation greatly retards the upward movement of highly mineralized water from the Mt. Simon aquifer.

The Ironton-Galesville sandstone which overlies the Eau Claire Formation and is overlain by the Franconia Formation, is by far the most consistently permeable and productive unit of the bedrock of Cambrian and Ordovician age in Northern Illinois. Wells in the Peru area penetrate the Ironton-Galesville sandstone which is composed of fine- to coarse-grained sandstone, some of which is dolomitic. The thickness of the sandstone varies from less than 150 feet in northern La Salle County to more than 200 feet in an area from Peru to just north of Ottawa (figure 9). The thickness decreases to 125 feet a few miles south of Oglesby and Ottawa. The basal zone of the Ironton-Galesville sandstone is commonly the least cemented and most favorable water-producing zone. According to Walton and Csallany (1962), the friable zones in the lower part of the unit are often shot to increase the yields of deep sandstone wells. Figure 10 shows the elevation of the top of the Ironton-Galesville sandstone.

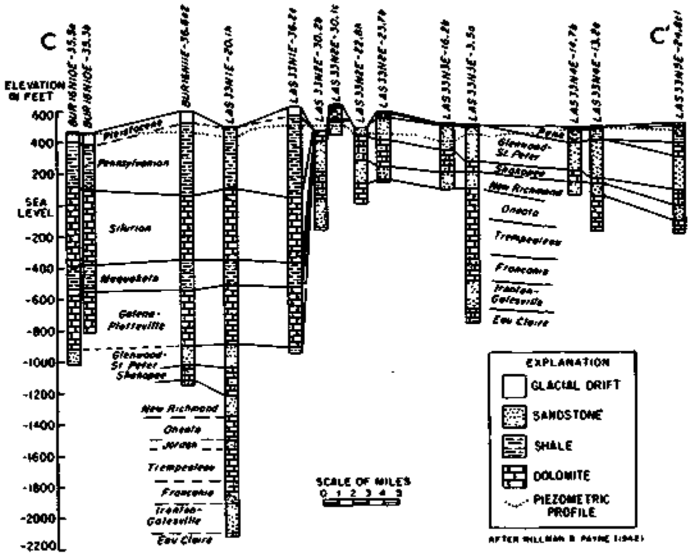


Figure 6. Geologic cross section C—C' and piezometric profile

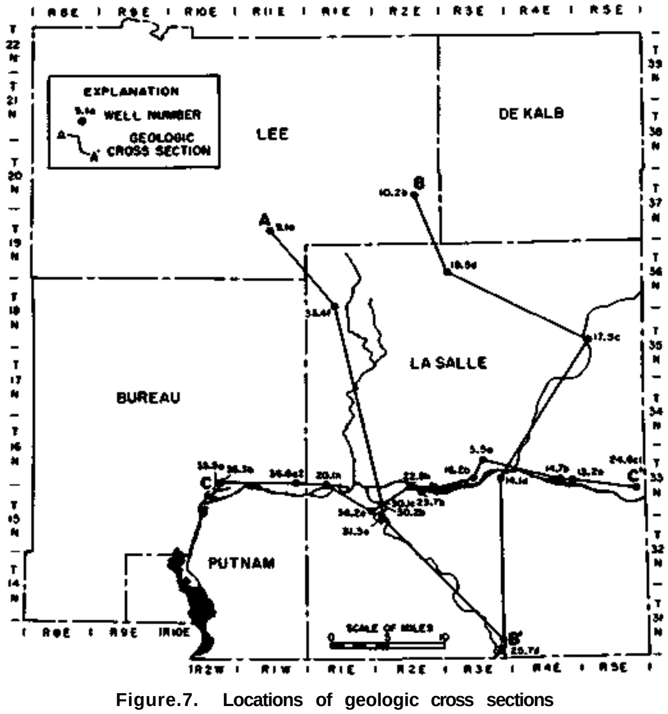


Figure.7. Locations of geologic cross sections

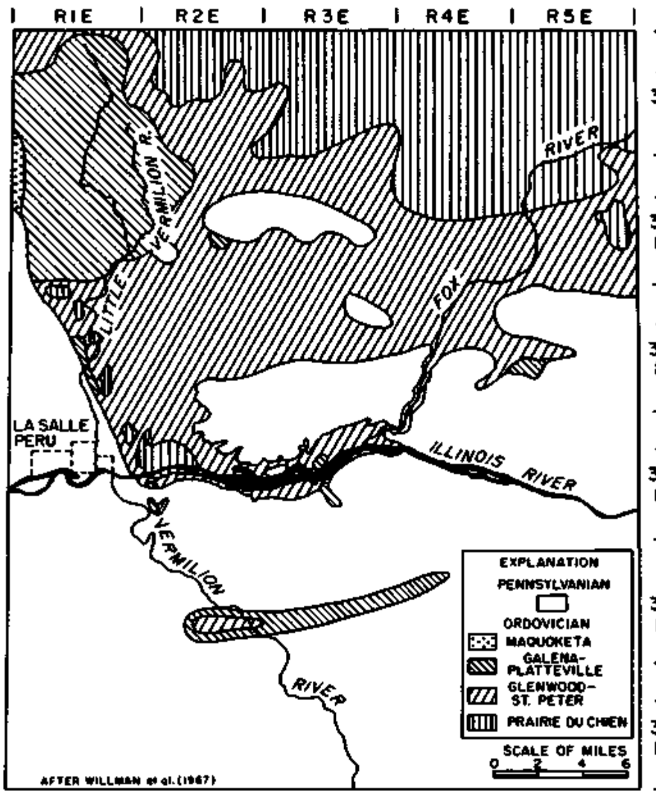


Figure 8. Areal geology of the bedrock surface

The Franconia Formation, consisting chiefly of interbedded sandstones, shales, and dolomites, is somewhat similar to the Eau Claire Formation. The shales and dolomites yield very little water; however, the sandy parts of the formation contribute moderate to small amounts of water to wells where it is not cased off by liners. The fine-grained sandstones are much less permeable than the Ironton-Galesville sandstone.

The Trempealeau dolomite contributes little water to deep sandstone wells except where secondary openings such as joints, fissures, and crevices have developed. The average thickness of the unit in the area is 200 feet.

The Jordan Formation consists dominantly of dolomite with some interbedded shale and sandstone, and it ranges in thickness from 0 to 60 feet. The formation probably contributes little water to wells.

Ordovician Rocks

The Ordovician rocks have been divided into four geohydrologic units (Suter et al., 1959). In ascending order the units are Prairie du Chien Series, Glenwood-St. Peter sandstone, Galena-Platteville dolomite, and Maquoketa Formation.

The Prairie du Chien Series, consisting of the Shakopee and Oneota dolomites and the New Richmond sandstone, is composed chiefly of dolomite with lenses of sandstone. The Prairie du Chien Series furnishes moderate to small quantities of water to wells uncased in the unit. Where the New Richmond sandstone is present in appreciable thickness it yields moderate quantities of water; its greatest thickness occurs near La Salle where a number of wells penetrate more than 160 feet of the formation. It crops out along the Fox River south of Sheridan, from about the center of section 5 to the northeast corner of section 18, T35N, R5E, La Salle County.

The Glenwood-St. Peter sandstone is widely used as an aquifer for municipal, industrial, and domestic supplies in the area. The unit also contributes moderate quantities of water to wells uncased to deeper bedrock aquifers. In northern Illinois, according to Walton and Csallany (1962), it ranks third after the Ironton-Galesville sandstone and Mt. Simon aquifer in consistency of permeability and production. The Glenwood-St. Peter sandstone is mostly fine- to medium-grained, and incoherent to friable. The thickness, cementation, and lithology of the unit vary greatly; the upper part is often shaly or dolomitic, and the lower part is commonly composed of shale and conglomerate.

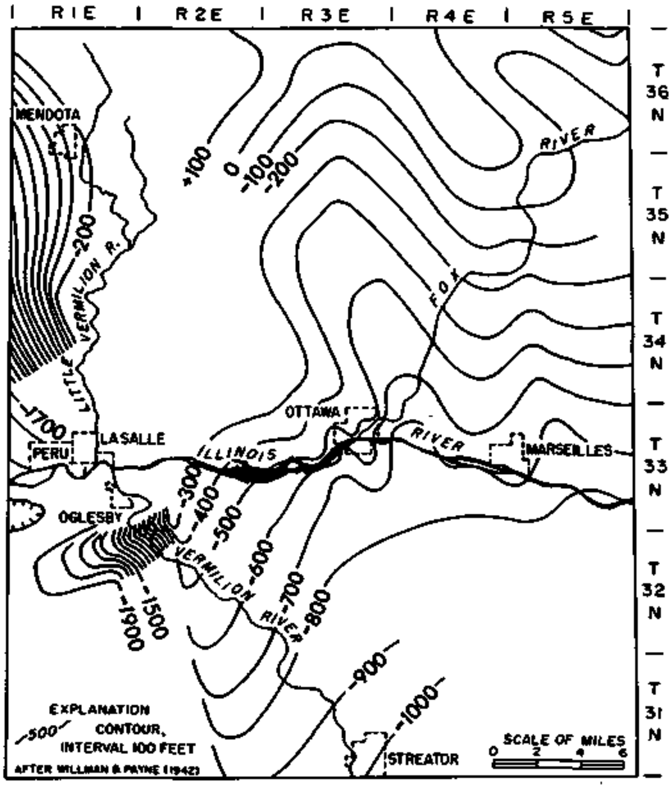


Figure 10. Elevation of the top of the Ironton-Galesville sandstone

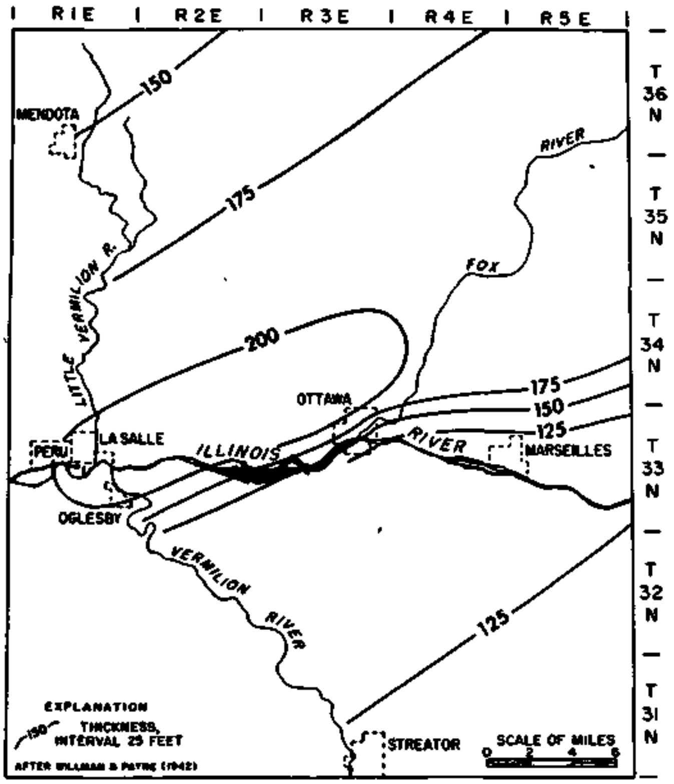


Figure 9. Thickness of the Ironton-Galesville sandstone

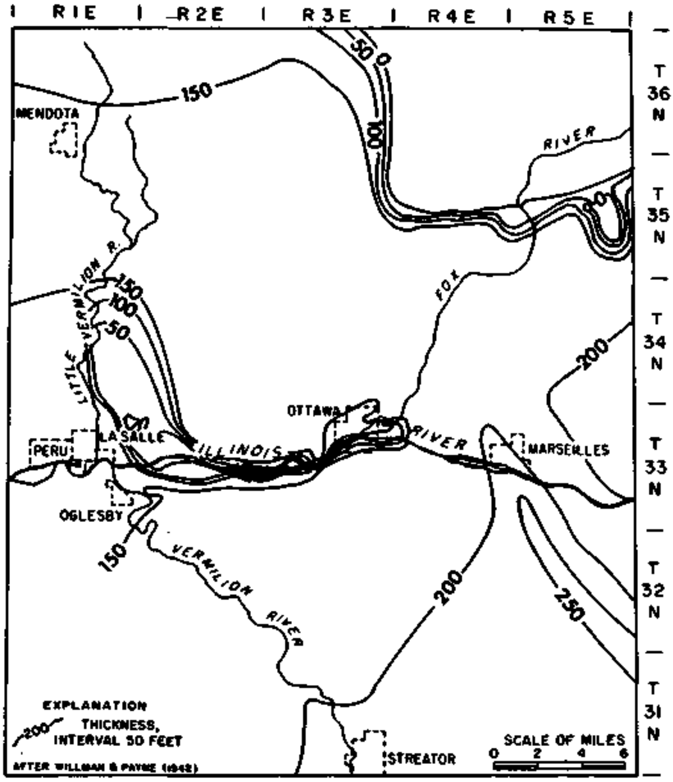


Figure 11. Thickness of the Glenwood-St. Peter sandstone

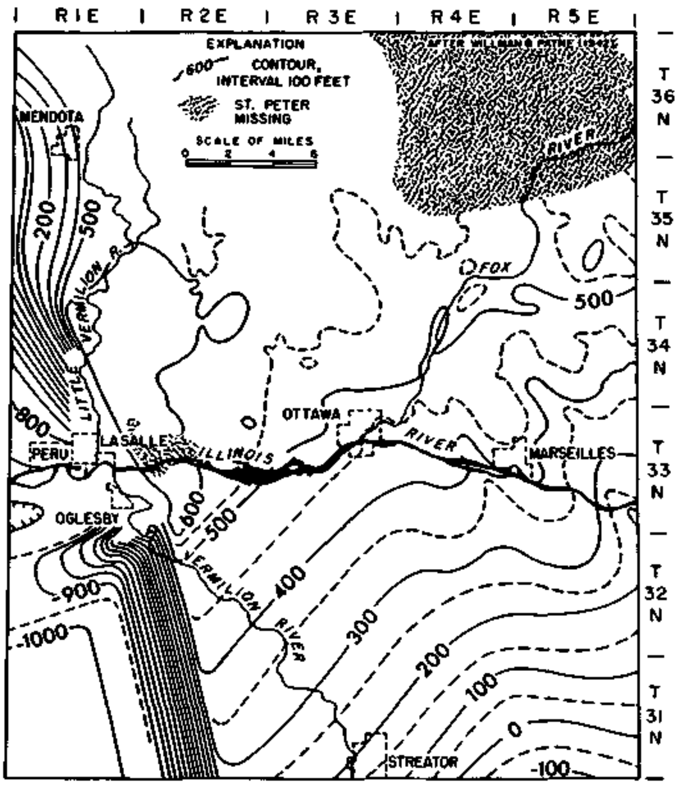


Figure 12. Elevation of the top of the Glenwood-St.Peter sandstone

The unit has been completely eroded in some areas, but is more than 250 feet thick in others (figure 11). The elevation of the top of the Glenwood-St. Peter sandstone is shown in figure 12.

The Galena-Platteville dolomite is dense to porous, partially argillaceous and cherty, and contains shale partings and sandy dolomite beds. Interbedded dolomitic limestone and calcareous dolomite grade into one another at places. The unit is missing in a large area of the northern part of La Salle County. In the northwest part of the county, west of the La Salle Anticline, the dolomite thickens and yields moderate quantities of water to wells where it lies directly beneath the glacial drift or is overlain by a thin layer of Pennsylvanian rocks or Maquoketa shale.

The Maquoketa Formation, although absent in a large part of the area, is present in the south and west parts where it usually is 150 to 170 feet thick. The unit consists mostly of shale, dolomitic shale, and argillaceous dolomite; it is not important as an aquifer.

Available data indicate that on a regional basis the entire sequence of strata, from the top of the Galena-Platteville dolomite to the top of the shale beds of the Eau Claire Formation, behaves hydraulically as one aquifer in northeastern Illinois and is called the Cambrian-Ordovician aquifer. In large parts of the Illinois River Valley area, the Galena-Platteville dolomite and Glenwood-St. Peter sandstone are missing. However, in this report the bedrock aquifer above the shale beds of the Eau Claire Formation in these areas will be referred to as the Cambrian-Ordovician aquifer.

Silurian, Devonian, Mississippian, and Pennsylvanian Rocks

Rocks of Silurian age are absent in most of the area. East of the La Salle Anticline they lie directly beneath Pennsylvanian rocks; in a small part of the northwest section they are directly beneath glacial drift. Devonian and Mississippian rocks are missing in the study area. Pennsylvanian rocks occur over the southern part of the area; their thickness increases irregularly and reaches 450 feet in the southwest corner of the area on the west slope of the La Salle Anticline. The rocks of Pennsylvanian age yield only small quantities of water to wells.

Bedrock Structure and Topography

Through western La Salle, the extreme southwest corner of De Kalb, and the northeast corner of Lee Counties, the rocks have been warped upward into an arch-like structure, or anticline (figure 13). This structure, the La Salle anticlinal belt which is the most prominent structural feature in the area, extends from Ogle County in northern Illinois to Wabash County in southeastern Illinois. In La Salle County, beds on the western side dip westward as much as 2000 feet per mile, so that any given formation is encountered at a greater depth west of La Salle than east of La Salle. The St. Peter sandstone is at the surface at Starved Rock State Park, but in wells at Peru it is en-

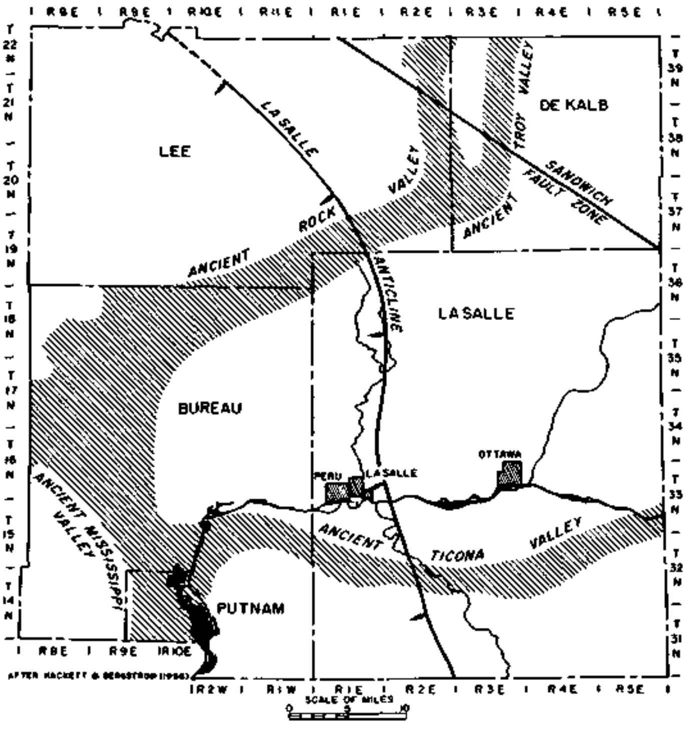
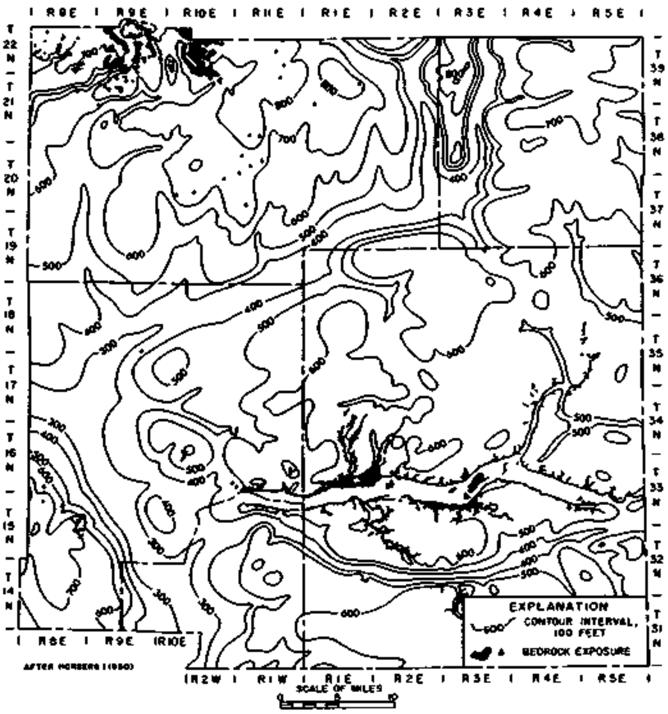


Figure 13. Location of major structures and buried bedrock valleys

countered at depths of some 1400 feet. Beds east of the anticline dip eastward from less than 25 to 50 feet. The La Salle Anticline is evident in the contours of the surface of the Galesville and St. Peter sandstones, shown in figures 10 and 12, respectively, and in the cross sections in figures 4, 5, and 6. The long Sandwich Fault Zone extends southeastward through Ogle, northeastern Lee, and De Kalb Counties (figure 13). Because of movements along the fault, rocks are displaced vertically as much as 900 feet.

A contour map showing the topography of the bedrock surface in the area is shown in figure 14. Most features of the bedrock topography were previously delineated and named by Willman and Payne (1942), Horberg (1950), and Randall (1955). Four major bedrock valleys are shown in figure 13. The buried portion of the Ancient Rock and Troy Valleys extends from the north-central part of the area southwest to join the Ancient Mississippi Valley in the southwestern part of the area. The Ancient Ticona Valley extends from east to west south of the Illinois Valley area and joins the Ancient Mississippi Valley in northern Putnam County. Bedrock uplands cut by minor bedrock valleys cover a large portion of the remaining area. The present valleys of the Illinois, Fox, and Vermilion Rivers are deeply entrenched in the bedrock (figure 14).

Most of the area is covered with glacial drift which varies in thickness from a razor's edge along the Illinois River Valley to more than 300 feet in buried bedrock valleys. Numerous bedrock exposures are found along the Illinois River and its main tributaries, the Fox and Vermilion Rivers.



AFTER HORBERG (1950)

Figure 14. Bedrock topography

HYDRAULIC PROPERTIES

The principal hydraulic properties of an aquifer and its confining bed influencing water-level decline and the yields of wells are the coefficients of permeability or transmissibility, storage, and vertical permeability.

The capacity of a formation to transmit water is expressed by the coefficient of transmissibility *T* which is defined as the rate of flow of water in gallons per day through a vertical strip of the aquifer 1 foot wide and extending the full saturated thickness of the aquifer under a hydraulic gradient of 100 percent (1 foot per foot) at the prevailing temperature of the water. The coefficient of transmissibility is the product of the saturated thickness of the aquifer *m* and the coefficient of permeability *P* which is defined as the rate of flow of water in gallons per day, through a cross-sectional area of 1 square foot of the aquifer under a hydraulic gradient of 100 percent at the prevailing temperature of the water. The storage properties of an aquifer are expressed by the coefficient of storage, which is defined as the volume of water in cubic feet released from or taken into storage per square foot of surface area of the aquifer per foot change in the component of head normal to that surface.

The rate of vertical leakage of groundwater through a confining bed in response to a given vertical hydraulic gradient is dependent upon the vertical permeability of the confining bed. The coefficient of vertical permeability *P'* is defined as the rate of vertical flow of water, in gallons

Table 2. Coefficients of Transmissibility of the Cambrian-Ordovician Aquifer

Owner	Depth of well *(ft)*	Year of test	l'umping rate *(gpm)*	Coefficient of transmissibility *(gpd/jt)*
Cedar Point (V)	1750	1922	57	13,950
Mendota(C)	990	1949	350	15,300
Oglesby(C)	2784	1947	350	13,500
Oglesby(C)	2812	1949	786	19,500
Ottawa(C)	1180	1945	1260	16,600
Libby-Owens-Ford Glass (Ottawa)	1168	1948	800	18,250
Illinois State School for Boys (Sheridan)	885	1940	170	16,100

(after Suter et al., 1959)

per day, through a horizontal cross-sectional area of 1 square foot of the confining bed under a hydraulic gradient of 1 foot per foot at the prevailing temperature of the water.

Suter et al. (1959) summarized 63 pumping tests made in northeastern Illinois from 1922 through 1954 to determine the hydraulic properties of the Cambrian-Ordovician aquifer in northeastern Illinois. Seven of the tests made in La Salle County are summarized in table 2. Suter et al. (1959) estimated the coefficient of storage, computed from the results of relatively short-term tests, to be 0.00035. A larger coefficient of storage, 0.0006, was believed to be more realistic for periods of pumping involving several years or more.

Six additional pumping tests were made after 1954. Leakage was not measurable during the tests, and the data collected were analyzed by the modified nonleaky artesian formula (Cooper and Jacob, 1946). The results of the tests are given in table 3.

Table 3. Coefficients of Transmissibility of the Cambrian-Ordovician Aquifer from Pumping Tests Conducted after 1954

Well number and owner	Depth *(ft)*	Year of test	Length of test *(min)*	Pumping rate *(gpm)*	Coefficient of transmissibility *(gpd/ft)*
LAS—					
35N5E-17.7h(3) State cf Illinois Industrial School for Boys	900	1965	60	500	22,000
36NlE-32.1a(4) Mendota(C)	1360	1957	234	480	16,300
»33NlE-36.3b(4) Oglesby(C)	2795	1959	330	1000	15,300
33N5E-21.5c(l) National Phosphate Corp.	583	1961	490	760	13,400
34N5E-2.3h(3) AT&T	1353	1961	210	1020	15,800
33N3E-3.2b(l) Union Carbide Corp.	1225	1964	28 (days)	1710	17,000

* *Coefficient of storage=0.0002, estimated from observation-well data*

YIELDS OF WELLS

The yield of a well may be expressed in terms of its specific capacity which is- the yield of the well in gallons per minute per foot of drawdown (gpm/ft) for a stated pumping period and rate. Walton (1962) gave an equation which can be used to compute the theoretical specific capacity of a well discharging at a constant rate in a homogeneous, isotropic, artesian aquifer that is infinite in areal extent.

The theoretical specific capacity of a well depends in part upon the radius of the well and the pumping period. A 30-inch diameter well has a specific capacity about 13 percent greater than that of a 12-inch diameter well. It is evident that large increases in the radius of a well are accompanied by comparatively small increases in specific capacity. The theoretical specific capacity decreases with the length of the pumping period because the drawdown continually increases with time as the cone of depression of the well expands.

Table 4. Specific Capacity Data for Bedrock Wells

Well number	Owner	Units or aquifers contributing to yield of well*	Diameter of inner casing *(in)*	Year of test	Length of test (hr)	Pumping rate *(gpm)*	Observed specific capacity *(gpm/ft)*	Adjusted specific capacity *(gpm/ft)*
BUR—								
16N11E-								
10.8e	Phillips Joanna Co.		10	1963	10	300	3.3	3.4
LAS—								
31N1E-								
24.6e	Lostant (V)	G-P, G-SP	10	1953	24	59	0.3	0.3
31N3E-								
22.8h	Kangley (V)	G-SP	10	1958	8	100	1.1	1.1
32N2E-								
19.4a	Charles Pool	G-P, G-SP	4		8	10	0.9	1.1
33N1E-								
14.8g	Carus Chemical Co.	G-SP	8	1940		255	2.8	
14.8g	Carus Chemical Co.	G-SP	8	1931		150	1.5	
14.8g	Carus Chemical Co.	G-SP	8	1938		165	2.7	
15.lh	M&H Zinc Co.	G-SP	8	1944		407	4.4	
15.lh	M&H Zinc Co.	G-SP	8	1963		325	4.3	
16.8a3(6)	Peru (C)	C-O	16	1952	3-5	1075	16.5	16.1
16.8a3(6)	Peru (C)	C-O	16	1960		1000	21.0	
20.2h2(5)	Peru (C)	C-O	12	1960		850	17.0	
20.3g	Star Union Products	C-O	8	1963	3	150	10.7	10.2
20.8h	Amer. Nickeloid Co.	G-SP	10	1957	11	240	1.3	1.3
21.8h(7)	Peru (C)	C-O	12	1963	12	1000	7.7	7.7
36.3b(3)	Oglesby (C)	C-O	16	1949	12	764	5.0	5.9

Table 4 (Concluded)

Well number	Owner	Units or aquifers contributing to yield of well*	Diameter of inner casing *(in)*	Tear of test	Length of test (Ar)	Pumping rate *(gpm)*	Observed specific capacity (gpm/ft)	Adjusted specific capacity *(gpm/ft)*
36.6hl(l)	Oglesby (C)	G-P, G-SP				350	2.0	2.1
36.6hl(l)	Oglesby (C)	C-O				362	5.4	6.0
36.6hl(l)	Oglesby (C)	G-SP	8	1963	2	140	1.0	1.0
36.6h2(2)	Oglesby (C)	C-O	8	1933		362	5.4	
36.6h2(2)	Oglesby (C)	C-O	8	1947		350	8.4	
36.6h3(4)	Oglesby (C)	C-O	10	1959	8	700	12.7	13.3
33N2E-								
21.2g(2)	Starved Rock Park			1960	1			
21.3g(3)	Starved Rock Park			1953	1	405	4.5	
33N3E-								
1.6b(7)	Ottawa(C)**	C-O		1945	9	990	11.2	11.6
1.7a(8)	Ottawa (C)	C-O	16	1959	24	1280	14.4	15.9
3.2bl(l)	Inland Rubber Co.	G-SP	24	1945	24	340	3.2	3.2
3.2b2(l)	Bakelite Corp.	C-O	18	1946	24	1440	6.3	7.9
3.2b2(l)	BakeliteCorp.**	C-O	18	1947	4	1850	13.0	12.7
3.2b2(l)	Bakelite Corp.	C-O	18	1963	12	1840	16.4	16.1
3.5al(2)	Inland Rubber Co.	C-O	18	1945	24	1050	7.4	7.6
3.5al(2)	Inland Rubber Co.	G-SP	24	1945	24	290	4.8	5.0
3.5a2(2)	Bakelite Corp.	C-O	18	1963	12	1540	8.6	8.4
12.2g	Chicago Retort & Fire Brick Co.	G-SP		1954	6	200	1.9	1.8
14.1d(8)	Ottawa (C)	C-O	10	1932	9.5	922	6.5	6.7
14.4a(9)	Ottawa (C)	G-SP	12	1946	22	455	3.3	3.7
14.4b(9)	Ottawa (C)	C-O	12	1963	3	1000	18.5	19.8
16.2a(3)	Libby-Owens-Ford Co.	G-SP		1953	7.5	490	3.6	
16.2b(5)	Libby-Owens-Ford Co.	G-SP	15	1960		970	5.9	
(10)	Ottawa (C)	C-O	15	1950	18	1620	15.1	15.1
33N4E-								
13.3c(2)	Marseilles (C)		12	1931		406	11.6	
13.3c(2)	Marseilles (C)		12	1962		400	3.3	
33N5E-								
24.8c(2)	Seneca (V)	G-SP	10	1943	3	407	2.7	2.7
25.4d(3)	Seneca Shipyards	G-SP	10	1943	3	414	2.6	2.5
25. (1)	Navy Indust. Reserve Shipyards			1942		230	1.9	
25. (2)	Navy Indust. Reserve Shipyards			1942		265	1.7	
25. (2)	Navy Indust. Reserve Shipyards			1954		210	2.2	
34N4E-								
9.4d	Wedron Silica Co.	G-SP	6			75	1.1	
9.4d(2)	Wedron Silica Co.	G-SP	6	1949	2	207	2.2	2.0
34N5E-								
2.21(1)	AT&T (Norway)	C-O	12	1960	8	1285	8.9	8.7
2.3h(3)	AT&T (Norway)	C-O	12	1961	8	1288	9.4	9.2
2.31(2)	AT&T (Norway)	C-O	12	1960	8	825	11.8	11.4
8.6b(l)	Illinois State Industrial School for Boys	C-O	10	1963	0.5	225	12.0	11.4
21.8h(2)	Illinois State Industrial School for Boys	G-SP	8	1951	24	109	1.5	1.7
36N1E-								
27.3a(l)	California Packing Co.**	C-O		1949	21	660	4.6	5.5
32.1a(4)	Mendota (C)	C-O	20	1957	4	475	5.5	5.3
32.1a(4)	Mendota (C)	C-O	20	1947	24	1000	7.0	8.3
33.3g(3)	Mendota (C)	C-O	12	1952	12	690	6.8	6.9
33.3g(3)	Mendota (C)	G-P, G-SP	16	1945	24	550	2.6	2.9
36N3E-								
18.4d	Earlville (C)	G-SP		1959		100	1.1	1.1
PUT—								
32N1W-								
9.1e(2)	Granville (V)	G-P, G-SP	8	1948	10.5	234	2.5	2.7
9.4g(l)	Granville (V)	G-P, G-SP	4	1946	6.5	100	1.2	1.2
9.4g(l)	Granville (V)	G-P, G-SP	4	1958		125	1.5	
ll.lc(l)	Standard (V)	G-P, G-SP	6	1963	0.5	70	1.6	
11.1c	Standard (V) -	G-P, G-SP	6	1958	6	25	2.5	2.6
21.5d	L. W. Hartman	G-SP	6	1958		50	1.0	

• *G-P=Galena-Platteville; G-SP=Glenwood-St. Peter; 0-0 = Cambrian-Ordomcitm*

** *Shot well*

There is generally a head loss or drawdown (well loss) in a production well due to the turbulent flow of water as it enters the well itself and flows upward through the bore hole. Well loss and the well-loss coefficient may be computed by equations given by Jacob (1946).

Production wells often do not completely penetrate aquifers, or they are open only to part of an aquifer. The drawdown in a production well partially penetrating an aquifer is greater than the drawdown in a fully penetrating production well. An equation given by Butler (1957) may be used to estimate the drawdown in a partially penetrating production well.

Data on well-production tests made from 1931 through 1963 on 46 deep sandstone wells in the Illinois River Valley area are given in table 4. The tests consisted of pumping a well at a constant rate and frequently measuring the drawdown in the pumped well. Drawdowns were commonly measured with an airline or electric dropline. The discharge rates were usually measured by a circular orifice at the end of the pump discharge pipe.

Each test is identified by the number of the pumped well. The units or aquifers contributing to the yields of wells and the diameters of inner casings, which coincide largely with the diameters of well bores through contributing formations, are given.

The lengths of tests range from less than 1 hour to 24 hours. Pumping rates range from 10 to 1850 gpm and average about 560 gpm; diameters of inner casings range from 4 to 24 inches, and average about 12 inches. Observed specific capacities and specific capacities adjusted to a common radius (0.5 feet) and a common pumping period (12 hours) are given in table 4.

Walton and Csallany (1962) investigated the yields of deep sandstone wells in northern Illinois. They concluded that the yields of the 1) Galena-Platteville dolomite and Glenwood-St. Peter sandstone, 2) Prairie du Chien Series, Trempealeau dolomite, and Franconia Formation, and 3) Ironton-Galesville sandstone constitute about 15, 35, and 50 percent, respectively, of the total yield of the rocks above the Mt. Simon sandstone. In addition, they estimated that the average increase in the yields of deep sandstone wells as the result of shooting is about 28 percent.

Observed specific capacities of wells penetrating primarily the Glenwood-St. Peter sandstone range from 1.0 to 5.9 gpm/ft and average 2.7 gpm/ft. In places where the sandstone is not the uppermost bedrock formation, specific capacities range from 1.0 to 4.4 gpm/ft and average 2.1 gpm/ft. In places east of the La Salle Anticline, where the sandstone is the uppermost bedrock formation below the glacial deposits or crops out, specific capacities range from 1.0 to 5.9 gpm/ft and average 3.5 gpm/ft. Data given by Walton and Csallany (1962) suggest that in areas where the Glenwood-St. Peter sandstone is the uppermost bedrock formation yields of wells penetrating the sandstone are higher.

Wells open primarily to the Galena-Platteville dolomite and Glenwood-St. Peter sandstone are located west of the La Salle Anticline where the Galena-Platteville is overlain by the Maquoketa Formation. Observed specific capacities are low, ranging from 0.3 to 2.6 gpm/ft and averaging 1.7 gpm/ft. According to Walton and Csallany (1962) the estimated average yield of wells uncased in the Galena-Platteville dolomite is low (0.2 gpm/ft) in areas where the Maquoketa Formation is present. They show that yields of wells uncased in the Glenwood-St. Peter sandstone are comparable to the range of yields of wells in the Galena-Platteville dolomite and Glenwood-St. Peter sandstone in this area assuming the primary contribution is from the sandstone.

In the study area, observed specific capacities of wells uncased in the Cambrian-Ordovician aquifer (table 4) range from 5.3 to 19.8 gpm/ft and average 10.5 gpm/ft.

GROUNDWATER WITHDRAWALS

Cambrian-Ordovician Aquifer

The first significant withdrawal of groundwater in the area began in the late 1800s. Prior to the drilling of wells, springs were a chief source of supply. Along the Illinois River Valley flowing wells were in common use during the late 1800s. Flowing wells are still in evidence at several industries and municipalities although they are not in wide use.

Groundwater pumpage from the Cambrian-Ordovician aquifer within the area of diversion (see figure 24 in section on piezometric surface) is shown in figure 15. During 1900 to 1963, total pumpage increased from 1.8 to 11.2 mgd, at an average rate of about 150,000 gpd/yr. Pumpage increased at a relatively uniform rate of 70,000 gpd/yr from 1900 to 1937, but increased to about 260,000 gpd/yr after 1937.

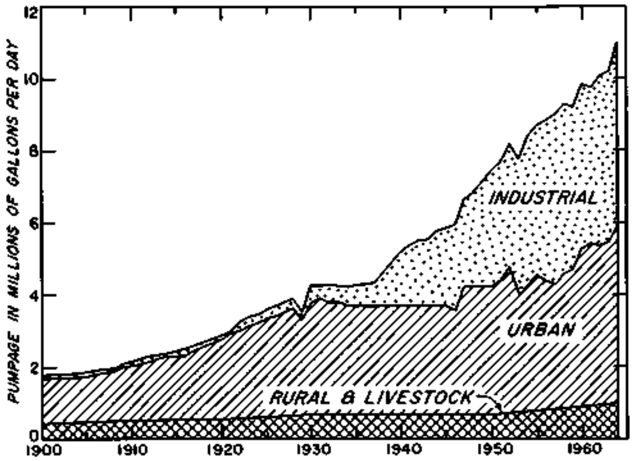


Figure 15. Pumpage from the Cambrian-Ordovician aquifer, 1900-1963, subdivided by use

In 1963 withdrawals for urban water-supply systems amounted to about 44.6 percent of the total pumpage, industrial pumpage was about 46.4 percent, and rural and livestock pumpage 9.0 percent.

Records of pumpage since the 1940s are fairly complete, but very few pumpage records for the years prior to World War II are available. The graphs in figure 15 were constructed by considering population growth, percent population served and per capita consumption, number of wells and their yields, and reported or estimated pumpage. The growth of industrial pumpage was greatest after 1940.

Pumpage-use data in this report are classified according to three main categories: 1) *urban,* including pumpage for municipalities, subdivisions, institutions, and from private sources within incorporated areas; 2) *industrial,* including commercial business; and 3) *rural,* including farms and nonfarms outside incorporated areas, and livestock. Most public water-supply systems furnish water for several types of use. Any water pumped by a public water-supply system is called an urban supply, regardless of its use.

The reliability of pumpage data varies greatly. Municipal pumpage is often metered in cities and larger villages, but not in most smaller villages. Total groundwater withdrawals from farm and residential wells were estimated from data on per capita consumption, and U. S. Bureau of Census reports. Pumpage for livestock use is based on accepted water consumption rates per head.

Within the area of diversion, groundwater for rural and livestock use is withdrawn primarily from wells finished in the Cambrian-Ordovician aquifer and in the glacial drift. Groundwater withdrawals from the Cambrian-Ordovician aquifer for rural and livestock use were estimated by determining the percent of wells, based on data in the State Water Survey and State Geological Survey files.

Industrial pumpage was less than 200,000 gpd until 1929. It increased gradually from about 400,000 gpd in 1930 to 5.2 mgd in 1964. From 1930 to 1963 the average rate of pumpage increase was about 145,000 gpd/yr.

Urban pumpage increased from about 1.2 mgd in 1900 to about 5.0 mgd in 1963. Between 1900 and 1930 urban pumpage increased at a relatively uniform rate of 0.07 mgd/yr. During the period 1946 to 1957 it fluctuated between 2.9 and 4.0 mgd. After 1957 urban pumpage increased sharply from 4.0 mgd to 5.0 mgd in 1963.

Rural and livestock pumpage increased gradually from about 450,000 gpd in 1900 to about 1.0 mgd in 1963.

Pumpage from wells in the Cambrian-Ordovician aquifer is concentrated primarily in two pumping centers located along the Illinois River Valley, the Ottawa and the La Salle-Peru-Oglesby areas.

The locations of production wells within the La Salle-Peru-Oglesby area and the Ottawa area are shown in figures 16 and 17, respectively. Since the majority of production wells in the La Salle-Peru-Oglesby area are located at Peru, hereafter the La Salle-Peru-Oglesby area will be referred to as the Peru area.

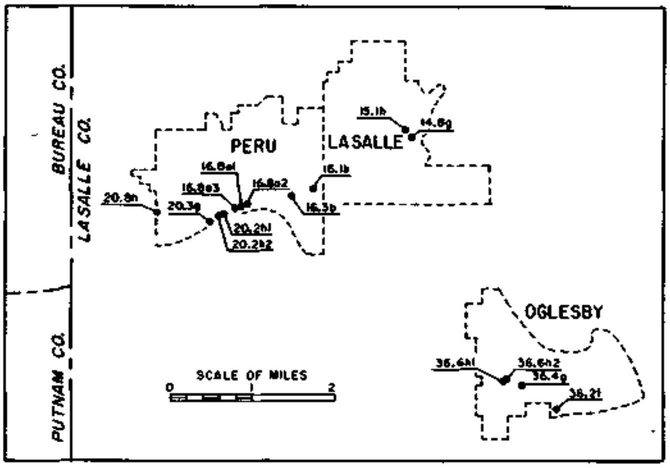


Figure 16. Location of production wells. La Salle-Peru-Oglesby area

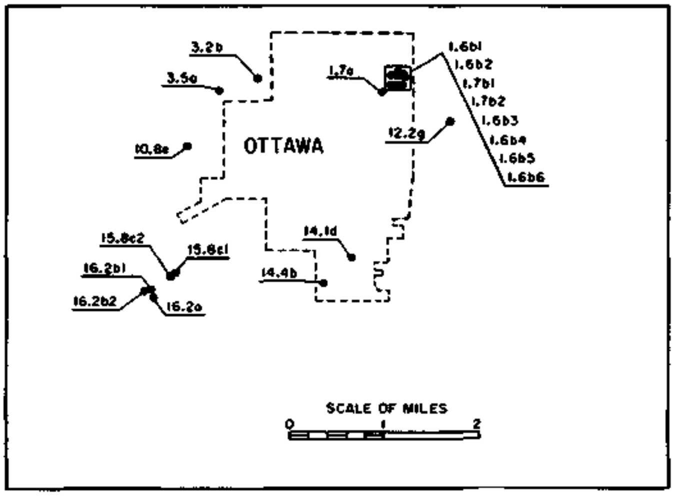


Figure 17. location of production wells, Ottawa area

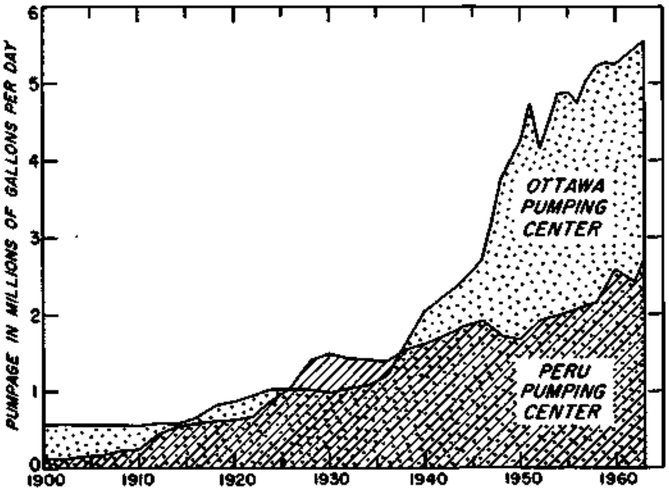


Figure 18. Estimated pumpage from the Cambrian-Ordovician aquifer, Peru and Ottawa areas, 1900-1963

Pumpage in the Ottawa area increased from about 0.5 mgd in 1900 to about 5.7 mgd in 1963 (figure 18). The rate of pumpage growth was greatest from 1935 to 1963, averaging about 0.17 mgd/yr.

Groundwater pumpage in the Peru area (figure 18) increased at a fairly uniform rate from about 0.10 mgd in 1900 to about 2.7 mgd in 1963.

Sand and Gravel Aquifers

The city of La Salle withdraws water for municipal use from a sand and gravel aquifer southeast of the city along the Illinois River. Estimated pumpage from wells in the sand and gravel aquifer from 1900 through 1963 is shown in figure 19. Pumpage in 1963 was 1.82 mgd.

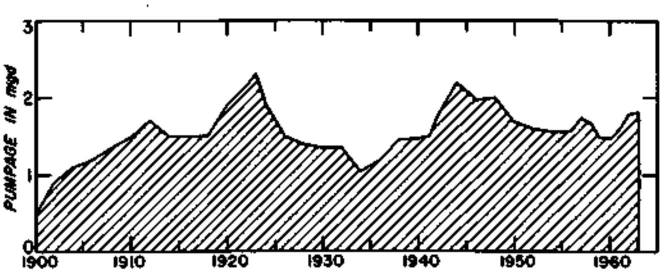


Figure 19. Estimated pumpage from sand and gravel wells, city of La Salle. 1900-1963

CONSTRUCTION FEATURES OF WELLS AND PUMPS

West of the La Salle Anticline wells penetrating deep sandstone aquifers range in depth from about 1000 to over 2800 feet. Municipal wells at Peru and Oglesby are among the deepest in the state which produce potable water. These wells are drilled by the cable-tool method employing techniques of telescoping casing and liners. Final well diameters usually range from 8 to 12 inches. From 3 to 6 or more casing liners ranging in diameter from 6 to 38 inches are used to aid in drilling through caving formations and to exclude water of poor quality from shallow forma-

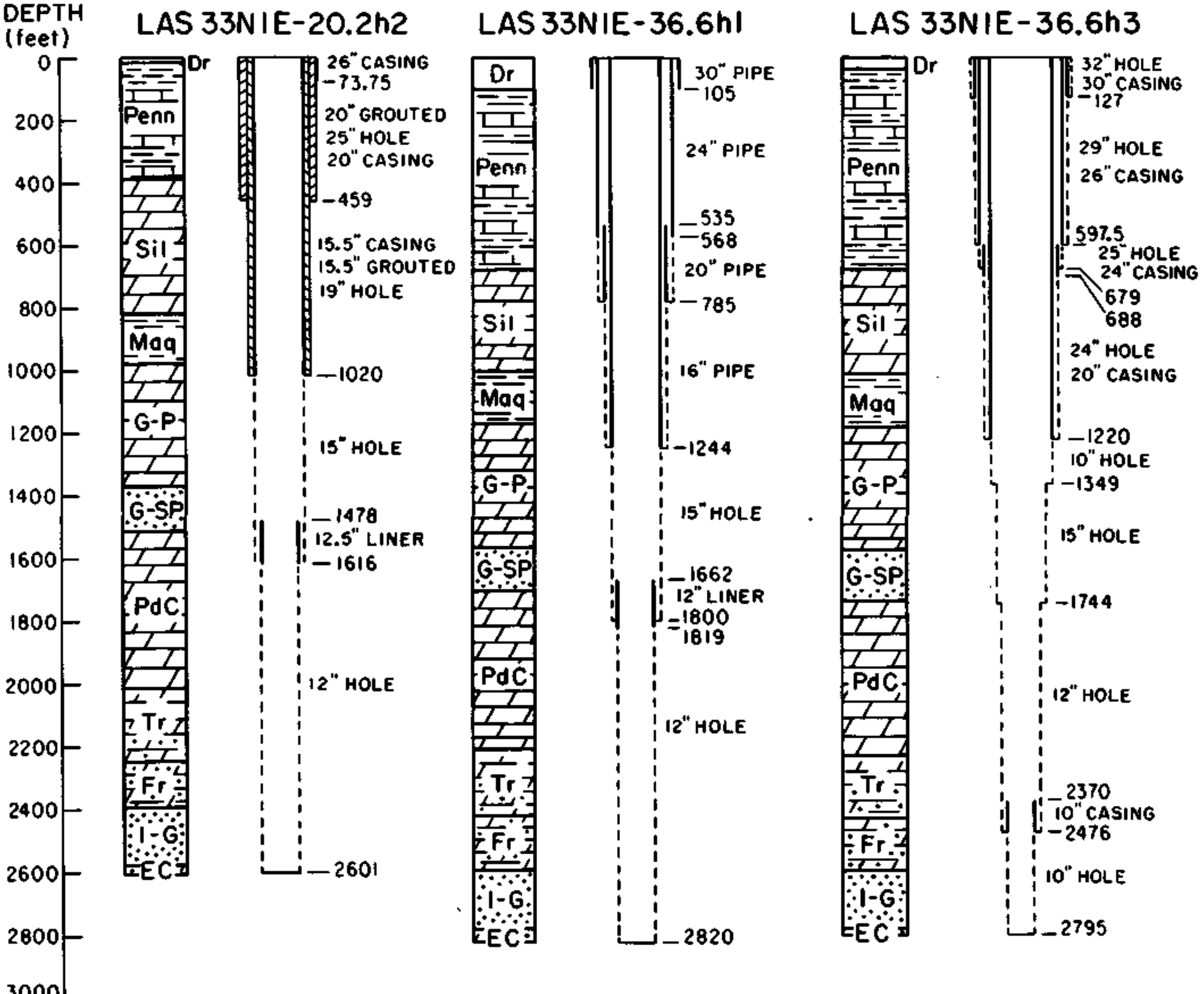


Figure 20. Construction features of wells in the Cambrian-Ordovician aquifer west of the La Salle Anticline

tions. Cement grout is commonly used with liner pipe in the Pennsylvanian rock. A final casing generally extends through the Maquoketa Formation and is seated in the Galena-Platteville dolomite. Liners are seldom required below the Galena-Platteville dolomite, but they may be used to aid drilling through particularly difficult formations. Liners also are used to protect wells in which lower units are subject to caving. Construction features and generalized graphic logs of typical wells west of the La Salle Anticline are given in figure 20.

Construction features of wells penetrating the Cambrian-Ordovician aquifer east of the La Salle Anticline are less complex. Depths of wells and casing requirements are reduced because of the higher elevation of units of the Cambrian-Ordovician aquifer. Usually one or two casings are used to penetrate drift deposits and Pennsylvanian rock where it is present. The final casing is usually seated in the Galena-Platteville dolomite and the remainder of the bore hole drilled without casing. Well depths in this area range from about 400 to 1200 feet, penetrating either Ordovician or a combination of Cambrian and Ordovician Formations. The completed diameters of wells in this area range from 6 to about 17 inches.

Construction features and generalized graphic logs of typical wells east of the La Salle Anticline are given in figure 21.

Pumps in wells in the Cambrian-Ordovician aquifer in the area are powered by 7.5- to 200-horsepower electric motors. The number of bowl stages ranges from 4 to 26. Column pipes have lengths ranging from 50 to 416 feet and diameters ranging from 2 to 8 inches. Details on pump installations are given in table 5.

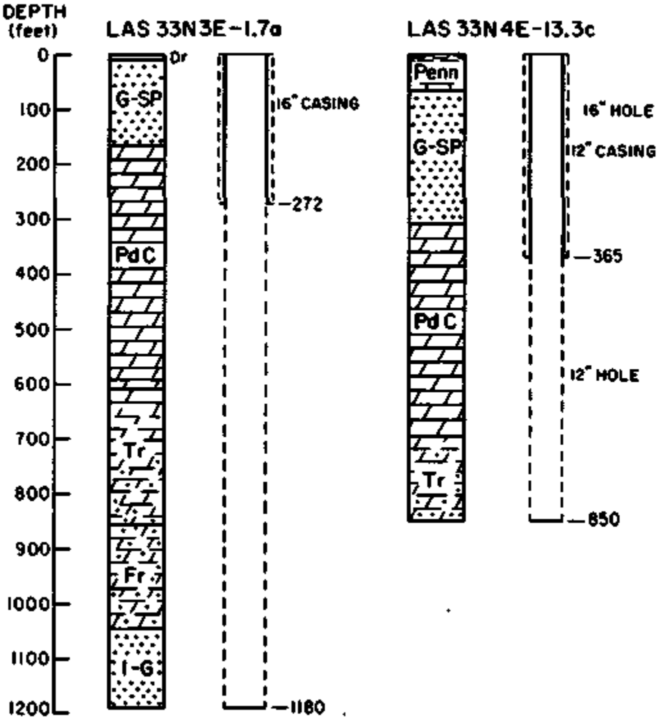


Figure 21. Construction features of welts in the Cambrian-Ordovician aquifer east of the la Salle Anticline

Table 5. Description of Pumps in Wells

Well number	Pump rating capacity/head *(gpm/ft)*	Number of bowl stages	Column pipe length* *(ft)*	Column pipe diameter *(in)*	Motor horsepower	Pump type**
BUR—						
16N11E-10.8e	260/300		360		75	LT
16N11E-15.6hl	200/300	13	247	5	25	LT
PUT—						
32NlW-9.4f	125/360	8	400	3	15	SUB
32NlW21.5d	60/380	26	300	2	$7/_2$	SUB
32N1W-1l.lc	60/380	26	250	2	$7/_2$	SUB
LAS—						
32NlE-4.7b			416	2		CA
33N1E-14.8g	350/400		400		75	SUB
33N1E-15.1h		17	210	6	40	LT
33N1E-16.8a3			160	8	50	LT
33NlE-20.2h2	1000/130	4	124	8	50	LT
33NlE-20.3g	1000/140		70	6	50	LT
33NlE-20.8h	160/300	8	303	4	20	SUB
33NlE-36.6hl	250/330		340		30	LT
33NlE-36.6h2	350/205		175		50	LT
33NlE-36.2f	600/237				60	LT
33NlE-36.2e				2		CA
33N2E-21.2g	235/237		75		20	LT
33N2E-21.3g	300/75					LT
33N3E-1.6b	800/	4	150		60	LT
33N3E-3.2b	1500/250		250		200	LT
33N3E-3.5a	1500/250		250		200	LT
33N4E-13.3c			250		40	LT
33N5E-24.8cl	300/200				25	LT
33N5E-24.8c2	500/188				30	LT
33N5E-25.4gl	250/225		115		20	LT
33N5E-25.4e	500/220		230		40	LT
35N5E-8.6b	350/55		50			LT
35N5E-21.8h	80/200					LT
36N3E-18.4d2	250/250		140		25	LT
36N3E-18.4d3			150		40	LT

** Includes length of bowl assembly and suction pipe*
*** LT=Lineshaft Turbine, SVB=Submersible Pump, and CA = Compressed Air*

PIEZOMETRIC SURFACE OF CAMBRIAN-ORDOVICIAN AQUIFER

The exact shape of the piezometric surface of the aquifer before extensive groundwater development occurred in the Illinois Valley area is not known. However, Suter et al. (1959) interpreted water-level data given by Anderson (1919) and by Weidman and.Schultz (1915) in northeastern Illinois and indicated, as shown in figure 22, that under natural conditions the piezometric surface was relatively featureless and sloped gently toward the southeast. According to Suter et al. (1959) the isopiestic lines in the Illinois Valley area bent in an upstream direction around the Illinois River in Grundy and La Salle Counties west of the border of the Maquoketa Formation, indicating leakage from the Cambrian-Ordovician aquifer into parts of the Illinois River Valley. A groundwater ridge existed north of the Illinois Valley (figure 22). Groundwater moved south under natural conditions toward the valley from the groundwater ridge.

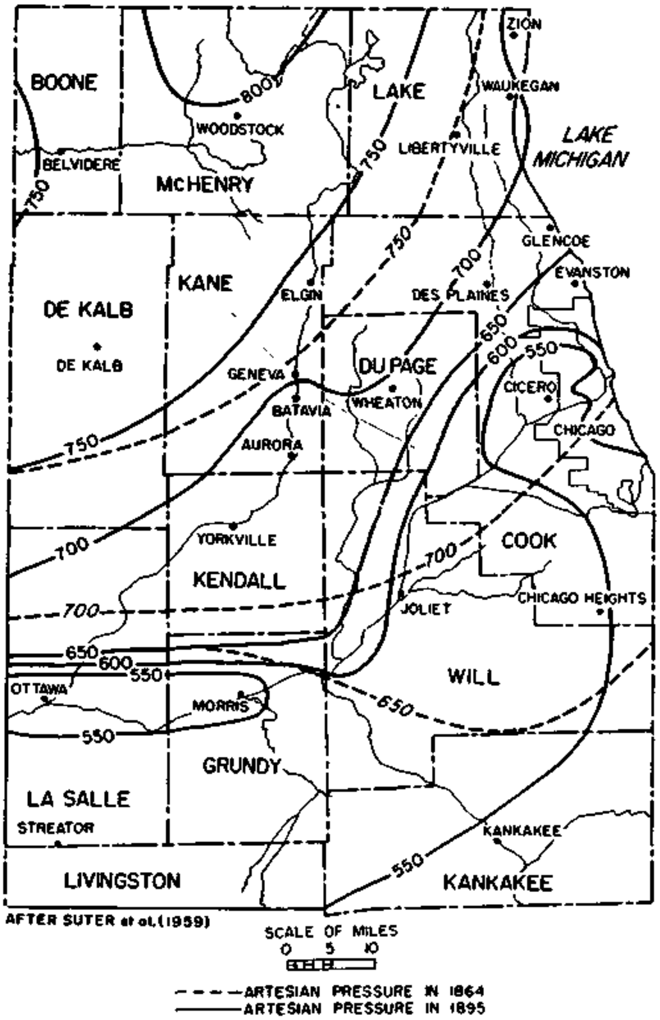


Figure 22. Piezometric surface of Cambrian-Ordovician aquifer about 1864 and 1895

Based largely on water-level data given by Suter et al. (1959), the estimated piezometric surface in 1895 (figure 22) was from slightly more than 500 feet to more than 550 feet along the Illinois River Valley. By 1915 (figure 23) the piezometric surface was modified by moderate withdrawals of water. Records of water levels in the area (table 6) indicate a decline from 21 to 75 feet.

For a more detailed study of recharge and discharge areas and directions of groundwater movement in the aquifer, a piezometric surface map was made (figure 24) from water-level data collected during the latter part of 1963

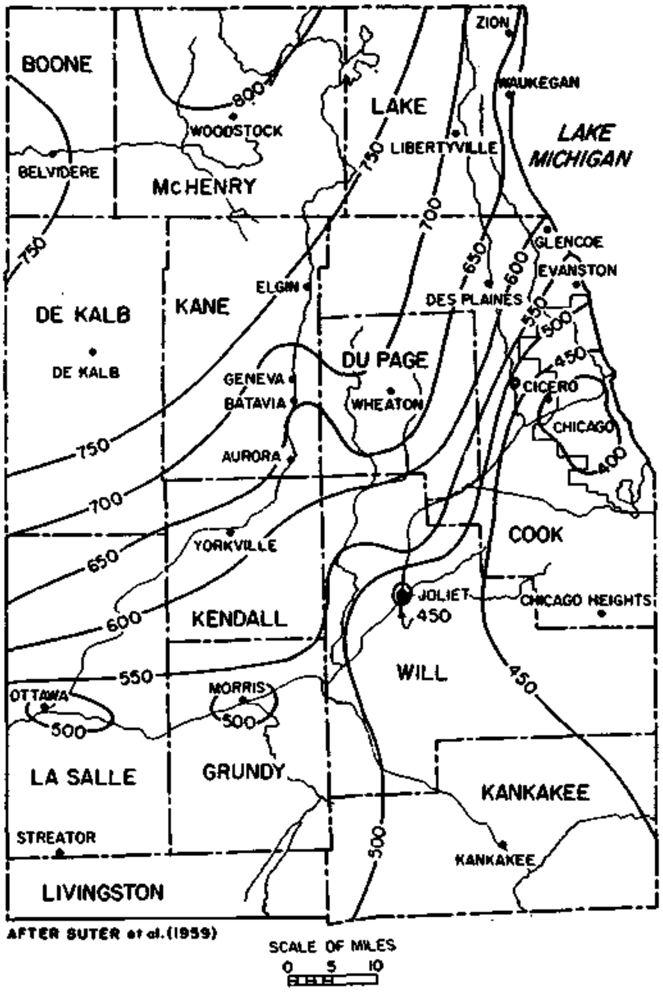


Figure 23. Piezometric surface of Cambrian-Ordovician aquifer about 1915

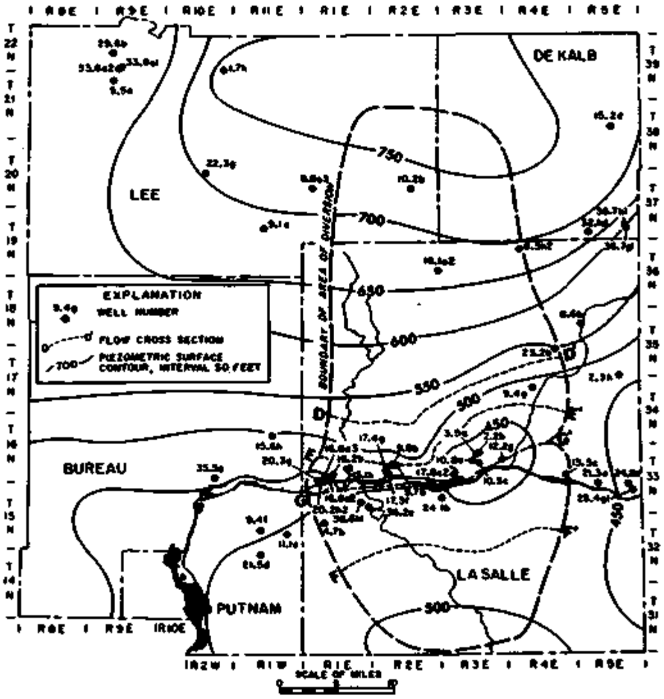


Figure 24. Piezometric surface of the Cambrian-Ordovician aquifer during the fail of 1963

and the early part of 1964. Data on nonpumping levels used to prepare the map are given in table 7.

The general pattern of flow in the Cambrian-Ordovician aquifer (figure 24) is slow movement from the north and south toward the Illinois River and the cones of depression along this river. A groundwater ridge occurs in the northeastern part of Lee County, the southern part of De Kalb County, and the southern part of La Salle County. A trough of water levels occurs along the Illinois River Valley, and associated with it is a pronounced cone of depression centered at Ottawa.

Water levels slope from an elevation of greater than 750 feet above mean sea level in southern De Kalb County to less than 450 feet in Ottawa. The average slope of the piezometric surface from De Kalb County south to the Illinois River Valley is about 10 feet per mile. South of the Illinois River Valley the slope of the piezometric surface is about 4 feet per mile. North of the Illinois River Valley the slope of the piezometric surface is 12.5 feet per mile south of the 650 piezometric surface contour. North of the 650 piezometric surface contour the slope is 7.5 feet per mile.

Table 6. Water Levels in Deep Wells about 1895 and 1915

County and owner	Depth ot well *(ft)*	Land surface elevation *(ft above msl)*	Depth to water *(ft)*	Date measured	Water level elevation *(ft above msl)*
1895					
La Salle					
Mendota(C)	500	752	47	1895	705
Ottawa(G)	1450	484	+22	1894	506
Peru(C)	1250	475	+85	1895	560
1915					
De Kalb					
Hinckley(V)	708	740	4	1913	736
Sandwich(C)	600	667	17	1914	650
La Salle					
La Salle Co. Carbon Coal Co. (Cedar Point)	1749	653	90	1912	563
M&H Zinc Co. (La Salle)	1619	585	62	1913	523
Marseilles(C)	800	500	+5	1915	505
Mendota(C)	500	752	73	1915	679
Oglesby(C)	1645	642	103	1915	539
Ottawa(C)	1450	484	+1	1915	485
Peru(C)	1250	475	+10	1915	485
Private wells (Utica)				1915	520

(after Suter et at., 1959)

Table 7. Water-Level Data for Wells in Cambrian-Ordovician Aquifer

Well number	Owner	Depth of well *(ft)*	Land surface elevation *(ft above msl)*	Depth to water *(ft)*	Date measured	Water level elevation* *(ft above msl)*
BUR—						
15N11E-2.8g1	Spring Valley(C)	1480	450	F**	8/63	450+
16N10E-35.5a(1)	Depue(V)	1278	465	F**	1/64	465+
16N11E-10.8e	Phillips Joanna Co.	1643	635	110	11/63	525
15.6h	Ladd(V)	1860	650	158	9/63	492
DEK—						
37N5E-32.1c1(1)	Somonauk(V)	190	685	21	11/63	664
36.7g1(1)	Oatman Dairy Co.	300	655	85	11/63	570
36.7h1(1)	Sandwich(C)	600	661	22	11/63	639
38N5E-15.2d(1)	Hinckley(V)	708	740	22	12/63	718
LAS—						
32N1E-4.7b	Cedar Point(V)	1750	653	165	9/63	488
33N1E-15.1h	M&H Zinc Co.	1619	577	115	11/63	462
33N1E-16.2b	Ill. Zinc Co.	1250	465	F**	11/63	465+
33N1E-16.8a2(4)	Peru(C)	1505	460	F**	11/63	460+
33N1E-16.8a3	Peru(C)	2665	540	100	10/63	440
33N1E-20.2h2(5)	Peru(C)	2601	465	38	10/63	427
33N1E-20.3g	Star Union Brewery	2600	470	35	10/63	435
33N1E-21.8h(7)	Peru(C)	2591	460	F**	11/63	460+
33N1E-36.2e	Marquette Cement Mfg. Co.	1565	480	F**	8/63	480+
33N1E-36.6h1	Oglesby(C)	1645	630	147	8/63	483
31N3E-22.7g	Kangley(V)	600	632	150	10/63	482
33N2E—9.5e	Belrose Silica Co.	80	550	50	8/63	500
33N2E-9.7b	Philadelphia Quartz Co.	200	460	F**	8/63	460+
33N2E-9.8b	Utica(V)	618	480	F**	11/63	480+
33N2E-17.3f	Amer. Silica Co.		460	F**	11/63	460+
33N2E-17.4g	Amer. Silica Co.		460	F**	11/63	460+
33N2E-21.2g(2)	Starved Rock St. Pk.	475	470	27	11/63	443
33N2E-24.1h	Starved Rock St. Pk.		462	F**	11/63	462+
33N3E-3.2b	Union Carbide Plastics Co.	1225	491	90	11/63	401
33N3E-3.5a	Union Carbide Plastics Co.	1225	510	65	10/63	445
33N3E-10.5c	La Salle Ready Mix Co.	100	481	68	11/63	413
33N3E-12.2g	Chicago Retort and Firebrick Co.	450	480	42	11/63	438
33N3E-17.6c2	Buffalo Rock St. Pk.	480	542	86	11/63	456
33N4E-13.3c	Marseilles(C)	850	498	11	9/63	487
33N5E-21.3e	Spicer Sand and Gravel Co.		520	30	10/63	490
33N5E-24.8c1	Seneca(V)	700	510	67	11/63	443
33N5E-25.4g1(1)	U.S. Gov't	451	505	63	9/63	442
33N5E-25.4g2(2)	U.S. Gov't	1447	505	63	9/63	442
34N4E-9.4g(1)	Wedron Silica Co.	261	545	50	11/63	495
34N5E-2.3b(3)	AT&T	1353	770	290	11/63	480
35N4E-23.2b	Serena School	270	632	83	9/63	549
36N3E-18.1a2	Marathon Electric Mfg. Corp.	257	700	30	11/63	670
36N4E-8.5h2	Leland(V)	220	700	18	11/63	682
LEE—						
19N11E-9.1a	Sublette(V)	752	920	241	1/64	679
20N10E-22.3g	Amboy(C)	1100	750	49	1/64	701
21N9E-5.5a(7)	Dixon(C)				1/64	660
21N10E-1.7h	Franklin Grove(V)	298	810	42	1/64	768
22N9E-29.6b	Dixon(C)		755	120	1/64	635
22N9E-33.8a1	Dixon(C)		660	80	1/64	626
33.8a2	Dixon(C)		660	30	1/64	630
37N1E-8.8e3(3)	West Brooklyn(V)	650	945	233	11/63	712
37N2E-10.2b	Paw Paw(V)	1018	928	198	1/64	730
PUT—						
32N1W-9.4f	Granville(V)	1790	685	280	11/63	405
32N1W-11.1c	Standard(V)	1768	683	188	9/63	495
32N1W-21.5d	L. W. Hartman	1852	733	234	11/63	499

* *Nonpumping levels*
** *F=flowing*

Recharge to the Cambrian-Ordovician aquifer is primarily from vertical leakage of water through confining beds in the glacial drift or overlying bedrock formations. Recharge is directly from precipitation in areas where units of the Cambrian-Ordovician aquifer crop out. Water levels have declined below the elevation of the water surface of the Illinois River in pumping centers, and there is probably some recharge into the aquifer from the river.

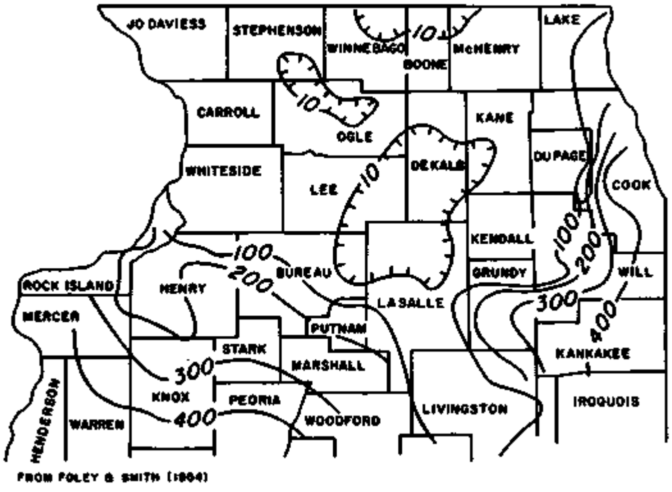
Flow lines, paths followed by particles of water as they move through the aquifer in the direction of decreasing head, were drawn at right angles to the piezometric surface contours to define the area of diversion. As determined from figure 24, the area of diversion is 862 square miles. The part of the area of diversion north of the Illinois River, 580 square miles, is greater than the area of diversion south of the river, 282 square miles.

Continuous records of water levels in the area have not been kept except in very recent times. Indications are, however, that water-level declines in the area of diversion can be explained by pumpage increases. Within a relatively short time after an increase in pumpage, recharge from vertical leakage through the glacial drift or overlying bedrock formations increases in proportion to pumpage because vertical hydraulic gradients become greater and areas of influence expand. The average recharge rate, computed as the quotient of pumpage (11.2 mgd in 1963) and area of diversion (862 sq mi in 1963), is 13,000 gpd/sq mi.

In the northern one-half of the area of diversion (464 sq mi) glacial drift deposits overlie either the Jordan-Franconia Formation, the Galena-Platteville dolomite, the Prairie du Chien Series, or the Glenwood-St. Peter sandstone. In a small area near the center of T35N, R3E, and T35N, R2E, the drift overlies bedrock of Pennsylvanian age. Recharge to these deposits occurs locally, mostly as vertical leakage of water through the unconsolidated deposits. Vertical movement is possible because of differentials in head between the water table in the unconsolidated deposits and the piezometric surface of the deep sandstone aquifers. The quantity of water moving through the section of the aquifer D—D' at the southern limit of the above area was computed from Darcy's equation (see Walton, 1962, page 22). The coefficient of transmissibility at section D—D' was estimated to be 17,000 gpd/ft, based on the average for the Cambrian-Ordovician aquifer given by Suter et al. (1959) and data in tables 2 and 3. The average hydraulic gradient and width-of-flow cross section were determined from figure 24. Based on Darcy's equation the flow through cross section D—D' was estimated to be about 5.2 mgd in 1963. It was estimated that in 1963 the average groundwater withdrawal in the northern one-half of the area from wells in the deep sandstone aquifer was 1.3 mgd. Thus, recharge to the deep sandstone aquifer in the northern one-half of the area was 6.5 mgd, or about 14,000 gpd/sq mi. Walton (1962) estimated the recharge rate by flow-net analysis for the Cambrian-Ordovician aquifer in areas where the Galena-Platteville dolomite immediately underlies the glacial drift in southwestern De Kalb and northeastern Kendall Counties. He computed the recharge rate to be 18,000 gpd/sq mi, or in close agreement with the recharge rate for the area in La Salle County.

South of the Illinois River Valley and east of the La Salle Anticline, rocks of Pennsylvanian age overlie either the Glenwood-St. Peter sandstone or the Galena-Platteville dolomite except along the Ancient Ticona Valley where the Pennsylvanian rocks have been eroded and the Galena-Platteville dolomite and (in a small area) the St. Peter sandstone lie directly beneath glacial drift deposits. West of the La Salle Anticline the Cambrian-Ordovician aquifer is overlain in ascending order by Maquoketa shale, Silurian rocks, Pennsylvanian rocks, and glacial-drift deposits. The quantity of water moving through the section of the aquifer F—F' is 0.9 mgd, computed from Darcy's equation, assuming a coefficient of transmissibility of 12,000 gpd/ft and using the average hydraulic gradient and width-of-flow cross section determined from figure 24. Total withdrawals in the area were estimated to be 0.1 mgd. Recharge to the deep sandstone aquifer south of the flow cross section (an area of 139 sq mi) was 1.0 mgd, or about 7200 gpd/sq mi.

It was estimated that 8.9 mgd was withdrawn from wells in the deep sandstone aquifer between cross-sections D—D' and F—F'. A total of 6.1 mgd is moving into the area through sections D—D' and F—F'; thus, 2.8 mgd is replenished either by recharge from precipitation or from the Illinois River. Assuming all the recharge is from precipitation, the recharge rate computed as the quotient of 2.8 mgd and the area between cross sections D—D' and F—F' (259 sq mi) is 10,800 gpd/sq mi. On the basis of recharge rates in the northern and southern parts of the area of di-



FROM FOLEY & SMITH (1964)

Figure 25. Sulfate content (ppm) of waters from the Cambrian-Ordovician aquifer in northern Illinois

version given above, a recharge rate of 10,800 gpd/sq mi from precipitation is reasonable; thus, it can be assumed that recharge from the river is not appreciable.

In northern Illinois, waters from glacial sand and gravel deposits immediately overlying bedrock contain less than 10 ppm sulfates, whereas the sulfate content of water from the Cambrian-Ordovician aquifer is usually higher. Thus, Foley and Smith (1954) concluded that waters from the Cambrian-Ordovician aquifer which contain less than 10 ppm sulfates have been recharged through the overlying strata. The distribution of sulfates in water from the Cambrian-Ordovician aquifer is shown for northern Illinois in figure 25. The southern limit of the area where waters from the Cambrian-Ordovician aquifer contain less than 10 ppm sulfates corresponds roughly with cross section D—D'.

VERTICAL PERMEABILITY OF THE CONFINING BED

Although the thickness of the confining bed is not known, the ratio of the vertical permeability to the thickness of the confining bed P'/m' can be estimated from the following form of Darcy's equation:

$$Q_c = (P'/m')\,\Delta h\, A_c \qquad (1)$$

where

Q_c = leakage through confining bed, in gpd

P' = vertical permeability of confining bed, in gpd/sq ft

m' = thickness of confining bed through which leakage occurs, in ft

A_c = area of confining bed through which leakage occurs, in sq ft

Δh = difference between the head in the aquifer and in the source bed-above the confining bed, in ft

The quantity P'/m' termed the leakage coefficient by Hantush (1956) may be determined by rewriting equation 1 as:

$$P'/m' = Q_c/(\Delta h\, A_c) \qquad (2)$$

The magnitude of the leakage coefficient was studied in the area north of cross section D—D'. The area A_c of the confining bed through which leakage occurs is enclosed by the flow lines, the groundwater divide, and section D—D'. The area is about 464 square miles (figure 24). The leakage Q_c through the confining bed, estimated from the flow through section D—D' and groundwater withdrawal in the area, was 6.5 mgd. The average Δh over the area was determined to be about 35 feet. Substitution of these data in equation 2 indicates the average leakage coefficient of the confining bed in the area is 1.4×10^{-5} gpd/cu ft.

MODEL AQUIFER AND MATHEMATICAL MODEL

To simulate the aquifer conditions in the Illinois Valley area the Cambrian-Ordovician aquifer was modeled with an effective barrier boundary oriented east and west and located about 20 miles south of the Illinois River Valley. The position of the effective barrier boundary was based upon geologic and hydrologic data interpreted by Suter et al. (1959) and specific capacity data in tables 3 and 4 that indicate permeabilities decrease south and east of Chicago and that the changes in the water-bearing properties are great enough to approximate the effects of a barrier boundary 20 miles south of the Illinois River Valley. Based on aquifer-test data, specific-capacity data, and assumptions made by Suter et al. (1959), the average coefficient of transmissibility and long-term coefficient of storage were estimated to be 17,000 gpd/ft and 0.0006, respectively. To introduce the effects of Pennsylvanian rocks in the southern part of the area and the Maquoketa shale west of the La Salle Anticline, the coefficient of leakage of the confining bed was estimated to be 0.00001 gpd/cu ft.

The nonpumping water-level declines were computed for well LAS 33N1E-I5.1h near the Peru center of pumpage and at a point on the piezometric surface about 5 miles west-northwest of the Ottawa center of pumpage and about 8 miles east-northeast of the Peru center of pumpage. These computations were made by using the model aquifer, estimated hydraulic properties of the aquifer, the image-well theory, estimated pumpage data, and the steady-state leaky artesian formula (see Walton 1962, page 6). The computed water-level decline in well LAS 33N1E-15.1h was 53 feet, which compares favorably with the actual decline of 61 feet measured between 1912 and 1963. The computed water-level decline at the point on the piezometric surface was 47 feet, which compares favorably with the actual decline of 55 feet measured between 1895 and 1963. It should be emphasized that the declines in water levels cited are nonpumping water levels. Pumping levels will decline about the same amount as the nonpumping water levels if the present rates of pumping from individual wells are maintained.

The differences in computed and actual declines are probably due to the effects of withdrawals from the Cambrian-Ordovician aquifer in the Chicago region and at Morris along the Illinois River in Grundy County. Although differences exist between the computed and actual declines, the model aquifer and mathematical model can be used to predict with reasonable accuracy the effects of increased pumpage on water levels at Peru and Ottawa.

ESTIMATED WATER LEVELS BY YEAR 2000

If pumpage continues to increase in the area at the present rate, by the year 2000 about 12 mgd will be withdrawn from the vicinity of the Ottawa pumping center and about 6 mgd will be withdrawn from the Peru center. The water-level declines due to the increased pumpage estimated from the model aquifer and mathematical model are about 163 feet in the Ottawa center and about 98 feet in the Peru center. Water levels in the Ottawa pumping center are already in the St. Peter sandstone (see cross sections in figures 4, 5, and 6). Continued declines in the pumping center will dewater a part of the aquifer with a resultant decrease in the coefficient of transmissibility of approximately 20 percent (Walton and Csallany, 1962). As estimated from an equation derived by Jacob (1946), an additional 32 feet of drawdown will occur in the Ottawa pumping center or a total of 195 feet.

WATER QUALITY

The results of chemical analyses of water from bedrock wells in the study area are given in tables 8, 9, and 10. The constituents listed in the tables are given in ionic form in parts per million. The results of partial analyses of water from bedrock wells west of the La Salle Anticline are given in table 8. In this area, water samples were collected from 12 wells ranging in depth from 1330 to 2821 feet.

Table 8. Partial Chemical Analyses of Water from Bedrock Wells West of the La Salle Anticline

(Chemical constituents in parts per million)

Well number	Depth *(ft)*	Iron (Fe)	Ohlo-ride (01)	Sul-fate ($S0_4$)	Alka-linity (as $CaC0_3$)	Hard-ness fas $Ca00_3$)	Total dis-solved min-erals	Tem-pera-ture ***(deg F)***
LAS—33N1E-								
15.lh	1619	1.6	255	88	300	245	911	69.0
16.8a2	2665	1.9	220		316	295	779	72.0
16.8a3	1505	0.2	267	90	308	226	824	
20.2h2	2601	0.9	236	50	320	341	792	74.5
20.3h	2600	2.6	199	58	312	282	729	
21.8h	2591	0.7	290		332	344	905	73.2
28.2a	1330	6.5	174	65	288	238	685	
36.2e	1565	1.5	225	88	280	255	795	
36.3b	2821	0.8	290	95	284	286	897	73.5
36.6hl	1645	1.6	572	85	274	233	1369	
36.6h2	2784	0.8	272	75	304	320	878	75.0
36.6h3	2795	0.9	265	79	308	282	859	74.0

The iron content of waters in the 12 wells ranges from 0.2 to 6.5 ppm and averages 1.6 ppm. The chloride content ranges from 174 to 572 ppm and averages 272 ppm. The hardness of waters ranges from 226 to 344 ppm and averages 279 ppm. The temperature of water from 7 wells ranges from 69.0 to 75.0 F and averages 73.0 F.

The results of partial analyses of water from bedrock wells east of the La Salle Anticline are given in table 9. Water samples were collected from 43 wells ranging in depth from 40 to 1447 feet.

The iron content of waters east of the La Salle Anticline ranges from 0.0 to 12.0 ppm and averages 1.8 ppm. South of the Illinois River and in some areas where Pennsylvanian rocks are present the chloride content (an indication of high total mineral content) is high. In T33N, R2E and T33N, R3E, where Pennsylvanian rocks are present, the chloride content ranges from 450 to 2425 ppm and averages 1260 ppm. In the above-mentioned areas where the Pennsylvanian rocks are not present, the chloride content ranges from 3 to 402 ppm and averages 92 ppm. The hardness of waters in areas where the Pennsylvanian rocks are present ranges from 391 to 1485 ppm and averages 882 ppm. Where the Pennsylvanian rocks are not present, the hardness of waters ranges from 220 to 533 ppm and averages 357 ppm. In T33N, R4E and T33N, R5E where the Pennsylvanian rocks are present, the chloride content and the hardness of water are in the same order of magnitude as in T33N, R2E, and T33N, R3E where the rocks are not present.

The temperature of water in 21 wells ranges from 50.5 to 58.0 F and averages 54.6 F.

Eighteen selected chemical analyses of water from deep sandstone wells are given in table 10. These analyses are more complete than the analyses in tables 8 and 9 and list the units, or aquifers, contributing to the well yields. Fluoride content listed in the table ranges from 0,7 to 5.0 ppm. Nitrate content ranges from 0.0 to 4.6 ppm.

Water from the sandstones south of the Illinois River is highly mineralized. The southern limit of potable water (1500 ppm total solids) in the Cambrian-Ordovician aquifer lies several miles south of the study area. For lack of more suitable water, supplies are developed from the Cambrian-Ordovician aquifer to an approximate line 30 to 35 miles south of the Illinois River.

Table 9. Partial Chemical Analyses of Water from Bedrock Wells East of the La Salle Anticline

(Chemical constituents in parts per million)

Well number	Penn. rock present	Depth *(ft)*	Iron (Fe)	Chloride (CI)	Sulfate (SO.)	Alkalinity (as CaCO$_3$)	Hardness (as OaCO$_3$)	Total dissolved minerals	Temperature *(deg F)*
LAS—									
33N1E-									
1.8a	No	236	0.9	9	166	290	454	502	
33N2E-									
3.8a	No	115	0.9	3	83	196	284	328	
9.7e	No	163	0.9.	12	137	276	410	467	
21. lg	No	637	0.6	402	34	332	469	1104	
21.2gl	No	475	10.4	93	26	334	333	533	52.3
21.2g2	No	401	0.3	116	35	336	352	576	52.3
23.7b	Yes	445	0.0	1223	270	260	737	2581	
24.1a	Yes	220	0.2	1855	208	256	1258	3641	
25.2h	Yes	500	0.2	2425	274	228	1485	5912	53.3
32.1a	Yes	200	10.0	572	214	216	391	1472	
33N3E-									
1.6b	No	1138	0.3	54		312	276	446	56.0
1.7a	No	1178	0.4	126	6	302	283	531	
2.	No	40	1.0	41		12	347	585	55.5
3.2a	No	1225	0.3	47	7	312	299	392	56.0
3.2b	No	275	2.9	14	36	348	358	448	53.0
3.5a	No	1230	0.3	65	6	280	270	404	56.4
10.8g	No	402	7.0	82	208	328	519	638	57.5
12.	No	60	3.7	74		266	533	783	53.9
33N3E-									
14. 1d	Yes	380	0.2	963	118	274	877	2163	
14.2d	Yes	1290	0.6	1936	226	246	1315	4104	
14.4a	Yes	427	0.6	950	119	272	732	1968	54.4
14.4b	Yes	315	7.9	470	66	308	450	1178	
15.4d	No	80	7.2	70		140	220	1080	
15.4h	No	837	7.5	96	12	322	298	506	50.5
15.5h	No	837	2.4	98	13	320	284	536	53.5
15.8d	No	1168	0.0	261	30	296	370	753	
16.	No	500	1.0	94	16	320	308	527	57.6
16.	No	1100	0.3	300	73	280	444	846	58.0
17.2d	No	600	0.7	57	27	314	355	481	55.6
17.6c	No	420	0.4	61	7	346	323	426	
17.7c	No	480	0.7	70	23	328	373	487	52.3
26.6c	Yes	276	0.7	450	58	344	428	1212	
29.8e	Yes	510	2.5	1260		280	1080	2644	
33N4E-									
13.6b	Yes	800	0.2	92	100	290	314	568	
15.4cl	Yes	220	0.1	41		272	464	936	54.0
24.2f	Yes	600	0.6	94	92	296	345	581	55.0
24.7f	Yes	440	0.6	66	44	300	328	486	
33N5E-									
11.1a	Yes	143	1.4	8	403	190	643	792	
21.5b1	Yes	165	0.9	165		268	402	827	
24.8cl	Yes	700	0.2	109	125	296	312	640	
24.8c2	Yes	704	0.1	118	133	292	336	678	54.5
25.4g	Yes	1447	0.3	158	174	292	371	783	57.8
30.7g	Yes	201	0.1	230	225	290	446	1009	

Table 10. Selected Chemical Analyses of Water from Deep Sandstone Wells

(Chemical constituents in parts per million)

Well number	Owner	Analysis number	Units or aquifers oontributing to yield of well*	Depth *(ft)*	Iron (Fe)	Manganese (Mn)	Ammonium (NH_4)	Sodium potassium (Na+K)	Calcium (Ca)	+ Magnesium (Mg)	Silica ($Si0_2$)	Fluoride (F)	Nitrate (NOs)	Ohioride (CI)	Sulfate (SO.)	Alkalinity (as $CaCo_3$)	Hardness (as $CaCo_3$)	Total dissolved minerals	Temperature *(deg F)*
LAS—33N1E-																			
15.1h	M&H Zinc Oo.	66362	C-0	1619	2.0	0.0	0.9	179	62.0	26.5			1.80	17.5	81	322	264	735	
16 8a2(6)	Peru(C)	153214	0-0	2665	0.2	0.0	0.3	190	82.8	22.4	10	0.9	3.4	245	65	300	299	816	74
20'.3g	Star Union Prod.	81529	0-0	2600	2.8		1.1	170	74.6	23.3	10		1.5	199	58	312	282	729	
2o.8h	Amer. Nickeloid Oo.	144561	G-SP	1632	1.0	Tr	1.2	161	63.0	23.9	10	0.8	2.4	160	68	312	256	711	67
36 3b(3)	Oglesby(O)	721168	C-0	2820	1.1	0.0	1.6	231	68.0	22.0	13	0.9	1.8	572	85	274	233	1369	
36 6hl(l)	Oglesby(O)	111049	C-0	1645	0.1	0.0	0.5	458	56.9	21.0	15	1.2	3.5	580	57	344	229	1422	67.5
36.6h2(2)	Oglesby(O)	88490	C-0	2784	0.0	0.0	0.3	224	71.1	25.7	14		4.6	281	71	283	283	902	
36.6h3(4)	Oglesby(O)	721169	C-0	2795	1.6	0.0	1.6	227	68.0	24.0	13	0.9	0.0	270	75	304	270	880	
33N3E-																			
1.6b(7)	Ottawa(C)	111050	C-O	1138	0.1	Tr	Tr	42	72.9	28.1	13	0.7	2.9	76	11.3	268	298	429	59.0
1.7a(8)	Ottawa(O)	82438	C-O	1178	0.4	0.0	Tr	95	73.6	24.0	13		3.6	126	6	302	283	531	
3.2a(l)	Bakelite Corp.	108676	C-O	1225	0.3	Tr	0.7	40	71.5	29.2	11		1.8	47	7.2	312	299	392	56
3.5al(2)	Inland Rubber Oo.	104306	O-O	1230	0.3	0.0	0.3	43	64.3	30.6	10		3.1	65	6	280	270	404	56.4
14.4a(9)	Ottawa(O)	108298	G-SP	427	0.6	0.1	1.8	460	190.7	61.9	11.4		0.8	950	119	272	732	1968	
33N5E-																			
24.8c(2)	Seneca(V)	715728	G-SP	700	0.2	0.0	Tr	124	67.0	35.0	9	5.0	0.0	109	125	296	312	640	53.8
25.4d(8)	Seneca Shipyards	96077	G-SP	1447	0.3	0.0	8.0	149	85.6	38.3	8		0.9	158	174	292	371	783	57.8
34N4E-																			
1.2d	Int. Harvester Oo.	151488	G-SP	398	1.6	Tr								4		260	368	514	
9.4d	Wedron Silica Oo.	147469	G-SP	242	0.5	0.0						1.0	2.5	3		360	340	368	
16.1e	St. Joseph Health Resort	150561	G-SP	338	0.1	Tr								10		320	300	344	

** C-0 = Cambrian-Ordovieian; G-SP = Glenwood-St. Peter*

REFERENCES

Anderson, G. B. 1919. Artesian waters of northeastern Illinois. Illinois State Geological Survey Bulletin 34.

Atlas of Illinois resources, section 1: water resources and climate. 1958. Illinois Department of Registration and Education, Division of Industrial Planning and Development, Springfield.

Butler, S. S. 1957. Engineering hydrology. Prentice-Hall, Englewood Cliffs, New Jersey.

Cady, Gilbert H. 1920. Structure of the La Salle Anticline. Illinois State Geological Survey Bulletin 36.

Cooper, H. H., Jr., and C. E. Jacob. 1946. A generalized graphical method for evaluating formation constants and summarizing well-field history. Transactions American Geophysical Union v. 27(4).

Foley, F., and H. Smith. 1954. Groundwater recharge of a deeply buried artesian aquifer in Illinois and Wisconsin, U.S.A. International Association Scientific Hydrology, General Assembly of Rome, (Gentlerugge) Belgium, Publication 37, Book II.

Hackett, James E., and Robert E. Bergstrom. 1956. Groundwater in northwestern Illinois. Illinois State Geological Survey Circular 207.

Han tush, M. S. 1956. Analysis of data from pumping tests in leaky aquifers. Transactions American Geophysical Union v. 37(6).

Horberg, Leland. 1950. Bedrock topography of Illinois. Illinois State Geological Survey Bulletin 73.

Jacob, C. E. 1946. Drawdown test to determine effective radius of an artesian well. Proceedings American Society Civil Engineers v. 72(5).

Randall, A. D. 1955. Glacial geology and groundwater possibilities in southern La Salle and eastern Putnam Counties, Illinois. University of Illinois Masters Thesis.

Sauer, Carl Ortwin. 1916. Geography of the Upper Illinois Valley and history of development. Illinois State Geological Survey Bulletin 27.

Selkregg, L. F., and J. P. Kempton. 1958. Ground-water geology in east-central Illinois. Illinois.Geological Survey Circular 248.

Suter, Max, R. E. Bergstrom, H. F. Smith, G. H. Emrich, W. C. Walton, and T. E. Larson. 1959. Preliminary report on ground-water resources of the Chicago region, Illinois. State Water Survey and Geological Survey Cooperative Ground-Water Report 1.

Walton, William C. 1962. Selected analytical methods for well and aquifer evaluation. Illinois State Water Survey Bulletin 49.

Walton, W. C, and Sandor Csallany. 1962. Yields of deep sandstone wells in northern Illinois. Illinois State Water Survey Report of Investigation 43.

Weidman, S., and A. R. Schultz. 1915. The underground and surface water supplies of Wisconsin. Wisconsin Geological and Natural History Survey Bulletin 35.

Willman, H. B., and J. Norman Payne. 1942. Geology and mineral resources of the Marseilles, Ottawa, and Streator quadrangles. Illinois State Geological Survey Bulletin 66.